

**ECOLOGY AND CONSERVATION OF PRAIRIE RATTLESNAKES
(*CROTALUS VIRIDIS VIRIDIS*) IN RELATION TO MOVEMENT
IN A FRAGMENTED URBAN ENVIRONMENT**

WONNITA ANDRUS
BACHELOR OF ENVIRONMENTAL SCIENCE, UNIVERSITY OF LETHBRIDGE, 2002

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Department of Biology
University of Lethbridge
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ABSTRACT

Eighteen prairie rattlesnakes (*Crotalus viridis viridis*) were tracked using radio-telemetry and 82 snakes were PIT-tagged over a 2-year period in Lethbridge, AB to determine population size, movement patterns, and habitat utilization, and to predict fragmentation effects on the species within an urban locale. Population size was estimated using closed population models at 374 snakes (295 adults) and open population models at 204 snakes (161 adults), greater than an estimate of <50 adults in 2003 (Ernst, 2003) and 2006 (Ernst & Quinlan, 2006).

Mean home range sizes, based on 95% minimum convex polygon analysis, differed significantly between years (31.51 ha in 2005, 3.72 ha in 2006). Calculated movement parameters, such as mean distance moved per day, total distance moved over the course of the active season, and frequency of movement varied between years and individuals. Greater-than-expected (under hypotheses of even habitat choice) utilization was observed in habitat types located within coulee and flood plain areas, with apparent preference towards unbroken parcels of grassland or cottonwoods, whereas less-than-predicted utilization of agricultural habitat type was observed. Fragmentation effects on prairie rattlesnake movement and occurrence were examined through modeling and were found to coincide with observed species' locations, suggesting that prairie rattlesnakes are undergoing modification of movement patterns to avoid highly concentrated human density or use. Influence of weather on the use of vegetative ground cover was observed, as it was accessed more by prairie rattlesnakes at higher temperatures.

Recommendations towards future management of the prairie rattlesnake population in Lethbridge are given, including protection of the Bridge View Drive site and inclusion of varied habitat types and terrain when planning habitat and wildlife corridors. Management decisions that ensure remaining habitat parcels and connective areas near rattlesnake foraging or movement corridors are also advocated. Identification of future research focuses include studies on juvenile survivorship, genetic structure, and vehicle-related mortality.

EXECUTIVE SUMMARY

My study on the ecology and conservation of prairie rattlesnakes (*Crotalus viridis viridis*) in relation to movement in a fragment urban environment resulted in:

- 1) adjustment of the previous population estimate (< 50 adult snakes; Ernst & Quinlan, 2006) for prairie rattlesnakes in Lethbridge, AB based on both closed (P=374 snakes [295 adults]) and open (P=204 snakes [161 adults]) population models.
- 2) discovery and documentation of previously unverified hibernacula and rookeries in Lethbridge, AB.
- 3) evidence of successful movement by transmitter-implanted prairie rattlesnakes between Popson Park and the Cottonwood Nature Reserve, and from Cottonwood Nature Reserve to hibernacula adjacent and across the river, providing evidence that immigration or emigration is occurring amongst sub-populations within Lethbridge, AB and surrounding areas.
- 4) evidence that the life-history requirements of prairie rattlesnakes (i.e., availability of appropriate hibernacula and cover sites) are being fulfilled at the Bridge View Drive site.
- 5) documentation of the use of anthropogenic structures as hibernacula and cover sites by prairie rattlesnakes in Lethbridge, AB.
- 6) documentation of home range size and movement lengths of prairie rattlesnake in Lethbridge, AB.
- 7) indication that prairie rattlesnakes in Lethbridge, AB display preferential use of flood plain habitat at multiple levels of analysis.
- 8) indication of the importance of coulee/grassland habitat in the provision of hibernacula for prairie rattlesnakes in Lethbridge, AB.

- 9) evidence of avoidance of urban residential areas by prairie rattlesnakes in Lethbridge, AB.
- 10) indication that movement patterns of prairie rattlesnakes in Lethbridge, AB are being modified in response to habitat fragmentation and alteration.

Recommendations of my study include:

- 1) future and immediate research focused on better inclusion of the juvenile cohort into population assessments (including survivorship) for prairie rattlesnakes in Lethbridge, AB.
- 2) immediate development of habitat protection initiatives for the Bridge View Drive site, with restrictions on future development in the area if possible.
- 3) unbiased assessment of education- and conservation-directed initiatives aimed at alleviating human/snake conflicts to ensure they are effective, with consideration of alternative ways to reduce accidental interactions (e.g., fencing regimes, mowing, commercial deterrents, restrictions to development in areas where prairie rattlesnakes are known to occur).
- 4) incorporation of a wide variety of geographical locations and terrain features (varied slopes, elevations, aspects, soil types, vegetative components, ground cover options, subterranean features, etc.) into habitat and wildlife corridors to ensure species' requirements are being met.
- 5) management decisions that have an effect on potential foraging areas or movement corridors should aim towards maximum retention of remaining habitat parcels and connective areas.

- 6) requisite pre-site assessments and surveys of all developments within the coulees and river valley to establish species' presence/absence, with consideration of long-term impacts of proposed projects on prairie rattlesnake populations and recommendations towards appropriate mitigation when necessitated.
- 7) immediate and continuing investigation into prairie rattlesnake mortality in relation to roads, recreational, residential, and industrial expansions; the effects of these factors on dispersal and movement patterns of prairie rattlesnakes in Lethbridge, AB; and potential mitigation opportunities (e.g., culverts, fencing, signage, seasonal road closures, etc.).
- 8) immediate and continuing examination into habitat quality, use, modification effects, and association with life-history and behavioural patterns of prairie rattlesnakes in Lethbridge, AB.
- 9) immediate and continuing examination of prey abundance, inter-patch connectivity, and activity allocation in relation to prairie rattlesnake ecology in Lethbridge, AB.
- 10) immediate and continuing assessment of the genetic structure of the Lethbridge, AB prairie rattlesnake population, with restrictions to snake translocations beyond individual home ranges, movement of sub-populations or approval of alterations to parcels of remaining habitat until assessment is completed.

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1.0 INTRODUCTION

The six major threats to the long-term success of reptile populations on a global scale are: introduced invasive species, environmental pollution, disease and parasitism, unsustainable use (e.g., supply for exotic pet trade and/or medicinal markets), climate change and habitat loss/degradation (Gibbons *et al.*, 2000). Further understanding of the vulnerability of reptile populations to such threats is important for identifying the unique challenges facing management programs for reptiles, including snake species, across the world (Gibbons *et al.*, 2000). As early as the 1990's, over 180 rare, declining or data-deficient snake species or populations had been identified, with the importance of species' assessments and appropriate management strategies being emphasized as key considerations in snake species' conservation initiatives (Dodd, 1993).

The first step in creating an effective species' recovery is having a sound understanding of the biological, demographical, habitat and human-related factors affecting the species in question. This is particularly true if such factors are suspected of contributing to species' decline (Dodd & Seigel, 1991; Dodd, 1993).

1.1 Factors Contributing to Global Snake Species' Decline: One of the most extensively studied snake families is the viperids (vipers), which are characterized morphologically by a shortened upper jaw bone, a thickened venom gland wall and hollowed fangs (Campbell & Brodie, 1992; McDowell, 2001). Snakes of the subfamily Crotalinae (pit vipers) are identified by the presence of heat-sensory pits on each side of the head, and comprise ~6% of snake species in the world across 3 continents, including Canada (Klauber, 1982; Campbell & Brodie, 1992; Greene, 1992). Examination of population trends in pit vipers has identified 6 potential characteristics that make a snake species more prone to extinction (Greene & Campbell, 1992). These include 1) confinement to islands or other small areas of remaining habitat, 2) specialized habitat requirements, 3) high mortality rates, 4) past or currently low fluctuating population size, 5) low reproductive rates, and 6) large physical size (Greene & Campbell, 1992). The tendency

towards slow growth and maturation of individual snakes in northern locations, as in populations of black rat snakes (*Elaphe obsoleta obsoleta*) in Ontario and Maryland, hampers population growth and recovery once decline had been experienced (Blouin-Demers *et al.*, 2002).

Comparisons of sympatric populations of the broadheaded snake (*Hoplocephalus bungaroides*) and the common small-eyed snake (*Cryptophis nigrescens*) in Australia suggest that species with delayed maturation, slower growth and small litter sizes are more susceptible to extinction (Webb *et al.*, 2002). Similarly, recuperation of great basin rattlesnake (*Crotalus oreganus lutosus*) populations is limited by 1) late female maturity, 2) biennial reproduction, 3) vulnerability to mass kills during winter aggregations, and 4) conspicuous behaviour such as rattling, which may reveal the animal's location making it vulnerable to potential assault (Parker & Brown, 1974).

Canadian studies of snake populations have identified anthropogenic interference and conversion, loss, and fragmentation of habitat as factors contributing to decline in snake species. Habitat fragmentation is a combination of habitat loss and habitat insularization, with both components potentially leading to long-term declines in biodiversity (Wilcox & Murphy, 1985). Fragmentation implies habitat loss, increased inter-patch distance, and decreased patch size (Andrén, 1994), and both loss and fragmentation are critical threats to the long-term viability of populations of many species (Wilcox & Murphy, 1985; Lande, 1987; Boyce, 1992). Habitat loss is likely more detrimental to a population's continuance than habitat fragmentation; however, fragmentation is a process that may result in habitat loss (Yahner, 1996; Fahrig, 1997; Harrison & Bruna, 1999). Reductions in habitat loss and restoration of existing habitats are critical components of a population's conservation (Fahrig, 1997).

Assessment of critical extinction thresholds indicates that species with limited demographic potential are most vulnerable to habitat loss and fragmentation effects (With & King, 1999). Patch occupancy and population persistence are typically lower in areas of fragmented landscape than in those where habitat patches were more clumped (With & King, 1999). The negative effects of increased inter-patch distance caused by fragmentation on future population growth include

genetic isolation, changes in gene variability due to genetic drift, and inbreeding depression (Templeton *et al.*, 1990; Smith & Smith, 1998; Keller & Largiadér, 2003; Wilson & Provan, 2003). Movement of animals between distant populations becomes further restricted with loss of appropriate foraging areas and biophysical limitations of inter-patch routes, such as inadequate cover sites, which causes recolonization and access to habitat patches to be extremely difficult (Taylor *et al.*, 1993). This is particularly true when species mobility is already limited or competition from species with greater rates of dispersal occurs (Smith & Smith, 1998).

1.2 Status and Influences on Prairie Rattlesnake (*C. viridis viridis*) Populations in Canada:

Concerns regarding prairie rattlesnake (Figure 1) population decline in Canada have been expressed by landowners, herpetologists, private consultants, and government organizations such as Alberta Fish and Wildlife.



Figure 1: Adult prairie rattlesnake (*C. v. viridis*) in Lethbridge, AB.

Anecdotal evidence and historical records suggest prairie rattlesnake populations are undergoing reductions in size and distribution throughout the province of Alberta, with similar findings in Saskatchewan (Kissner *et al.*, 1996; Watson & Russell, 1997; Powell *et al.*, 1998; Didiuk, 1999; Nicholson & Rose, 2001; Rose, 2001; Kissner & Nicholson, 2003). In 2000, the Alberta

Endangered Species Conservation Committee classified the prairie rattlesnake as *Data Deficient*, recommending year-round protection for the species and their hibernacula (Nicholson & Rose, 2001). Such recommendations have led to inclusion of the prairie rattlesnake under provincial regulations in 2000, with current protection through the Alberta Wildlife Act (ASRD, 2010). Under the General Status of Alberta Wild Species 2005, the prairie rattlesnake was listed as a species that “May be at Risk” with status reassessment currently being completed (Jorgenson & Nicholson, 2007; ASRD, 2010).

Many factors make the prairie rattlesnake particularly vulnerable to decline including dependency on hibernacula, which limits species’ distribution and creates potential for mass mortalities during aggregations (e.g., deliberate destruction of hibernacula by humans or collapse of hibernacula; Kissner *et al.*, 1996; Kissner, 2004). High fidelity to summer home ranges and winter hibernacula makes recolonization or occupation of new habitat patches difficult, limiting species’ range expansion (Kissner, 2004). Slower growth rates and delayed maturity for individual western rattlesnakes (*C. viridis*) in northern regions than in the species’ southern range potentially limit species’ success (Gannon & Secoy, 1984; Macartney *et al.*, 1990; Ashton, 2001; Jorgenson & Nicholson, 2007).

A review of maturity and growth in 4 sub-species of western rattlesnakes, including the prairie rattlesnake, across the species’ geographical range supports the theory that growth in juvenile western rattlesnakes is delayed with increasing latitude (Macartney *et al.*, 1990). Comparison of northern populations of western rattlesnakes to those at lower latitudes reveals that the snout-vent length (SVL) of a 1-year-old western rattlesnake from California is equivalent to that of a 3-year-old western rattlesnake from British Columbia (Macartney *et al.*, 1990). Maturity also occurs at a later age for western rattlesnakes in British Columbia than that recorded for other *C. viridis* populations and the shorter, cooler active season found at northern latitudes is considered a primary factor contributing to observed variations amongst western rattlesnake clades (Macartney *et al.*, 1990).

Female prairie rattlesnakes are typically biennial breeders (though annual and triennial breeding cycles have been noted) and undergo lengthy gestation periods of ~1 year in Canada, compounding reproductive limitations (Gannon & Secoy, 1984; Duvall *et al.*, 1985; Gannon & Secoy, 1985; Charland, 1989; Macartney *et al.*, 1990; Kissner *et al.*, 1996; Macartney & Weichel, 1993; Jorgensen & Nicholson, 2007). Litter sizes range from 4 to 18 with a mean litter size of 10.2 (8-16) for gravid females in Saskatchewan (Gannon & Secoy, 1984; Duvall *et al.*, 1985; Macartney & Weichel, 1993; Jorgensen & Nicholson, 2007). Survivorship in western rattlesnakes is limited, especially during the winter months, for younger cohorts and was as low as 54% and 56% at 2 locations for neonates in Okanagan Valley of British Columbia (Charland, 1989).

Limited growth rates, delayed maturation, biennial or triennial reproductive cycles, low survivorship of younger cohorts, relatively small litter sizes, and conspicuous defensive behaviour are biological attributes threatening the long-term viability of sub-species of the western rattlesnake, including the prairie rattlesnake (Macartney & Weichel, 1993).

Conversions of native prairie, extermination by humans, and hibernaculum disturbance or destruction are contributing factors leading to prairie rattlesnake decline in Canada (Kissner *et al.*, 1996; Macartney & Weichel, 1993). In addition to a higher probability of hibernaculum disturbance, urban populations also face increased risk of roadside mortality and extreme habitat fragmentation that results from inner city recreational areas (e.g., parks, golf courses, archery ranges, dog runs), as well as continuing residential development of native grassland and riparian areas.

Habitat alteration and anthropogenic structures such as roads enhance vulnerability to migration mortality, and there is evidence of greater mortality in relation to increased species vagility (Fahrig *et al.*, 1995; Bonnet *et al.*, 1999; Carr & Fahrig, 2001; Hels & Buchwald, 2001; Gibbs & Shriver, 2002; Aresco, 2004). Declines in population, as well as behavioural modifications in movement patterns in response to barriers, occur in several snake species in Arizona (Rosen &

Lowe, 1994) and South Carolina (Andrews & Gibbons, 2005), as well as garter snakes in Manitoba (*Thamnophis sirtalis parietalis*; Shine *et al.*, 2004), and eastern massasaugas in Illinois (*Sistrurus catenatus*; Shepard *et al.*, 2008). Examinations of these types of habitat fragmentation and predictions or observations of alteration in animal movement in response to this fragmentation are therefore crucial components in determining long-term species viability.

2.0 REVIEW OF MOVEMENT, DISPERSAL, AND HOME RANGE USE BY SNAKE SPECIES

Movement, dispersal, and home range use are important considerations when examining factors leading to population declines in snake species; however, information is limited for most snake species (McCartney *et al.*, 1988; Gregory *et al.*, 2001; Pough *et al.*, 2001). Movement and activity patterns were therefore a major focal point of my study on prairie rattlesnakes. Movement events are costly due to the energetic requirements involved, as well as increased predation risks, and theoretically should only be undertaken by an individual out of necessity (Gregory *et al.*, 2001; Pough *et al.*, 2001). Movement should therefore be limited to that required to maintain individual fitness.

Despite high fidelity to home ranges in some species, territorial behaviour is infrequent in snakes and is unlikely to influence dispersal patterns of any cohorts (Gregory *et al.*, 2001). Rather dispersal and movement events by snake species often relate to the availability of resources including prey, basking sites or mates (Gregory *et al.*, 2001). Avoidance of areas occupied by conspecifics may be the result of resource depression caused by the occurrence of other individuals at a site. Dispersal in all cohorts may reflect such avoidance tendencies with aggregations only occurring where resource availability is extremely high or concentrated, as part of mating and courtship behaviour, for physiological purposes (e.g., energy conservation) or where a resource is limited to such an extent that aggregation must occur to gain resource access (Graves & Duvall, 1995; Gregory *et al.*, 2001).

Erratic movement patterns in snake species are predicted when resources are unevenly distributed or unreliable, compared to a more sedentary approach when resources are evenly distributed or dependable (Gregory *et al.*, 2001). Minimization of movement occurs in the majority of vipers with relocations within habitat patches being infrequent and sit-and-wait foraging tactics being employed (Pough *et al.*, 2001). Individuals often occupy an area for long stretches of time, up to a few months, until resources have been exhausted (Pough *et al.*, 2001). The majority of movements undertaken by viper species are between habitat patches, as occurs in sidewinders (*C. cerastes*) (Secor, 1995) and coachwhips (*Masticophis flagellum*) (Pough *et al.*, 2001) in California and prairie rattlesnakes in Wyoming (King & Duvall, 1990). When resource patch size is in decline, attraction to areas of conspecific occurrence leads to short-term fitness gains for individuals when compared to random search strategies (Fletcher, 2006). In areas experiencing habitat loss or fragmentation, conspecific attraction and aggregation behaviour occur because they minimize the amount of movement an individual must engage in to find resources (Fletcher, 2006). However, the short-term fitness gained by individuals through these movement strategies sacrifices long-term survival of the population due to risks associated with inbreeding depression and competition for resources (Fletcher, 2006).

Occasional long-distance migrations along a consistent angle by western rattlesnakes may relate to either mate or prey patch-searching strategies (Duvall *et al.*, 1985/1990; Duvall & Schuett, 1997; Didiuk, 1999). Prairie rattlesnakes in Alberta may engage in this type of movement, with records of 1 female travelling 52 km round trip during a single active season (Didiuk, 1999). Individual variance in movement by western rattlesnake sub-species also takes place, with both short- and long-distance migrations occurring within the same populations of prairie rattlesnakes in Alberta (Powell *et al.*, 1998) and midget-faded rattlesnakes (*C. o. concolor*; Parker & Anderson, 2007) in Wyoming and may be due to behavioural polymorphism (Jorgensen, 2009). In other cases, this variance relates to reproductive status, such as in non-gravid female timber rattlesnakes (*C. horridus horridus*) in Arkansas, which move more extensive distances than gravid females (Gardner-Santana & Beaupre, 2009). A large amount of individual variation in

movement distance and activity range estimates between Australian blacksnakes (*Pseudechis porphyriacus*) also exists, even amongst those of similar size monitored during the same time period and area (Shine, 1987).

Differences in movement distances between age cohorts occur in sidewinders in the Mojave Desert (Secor, 1992) but not between age or sex cohorts in brown water snakes (*Nerodia taxispilota*; Mills *et al.*, 1995) in South Carolina. Rather, movement type varies with body size in brown water snakes as larger snakes engage frequently in river crossings whereas smaller individuals do not. Studies examining the movement patterns of neonatal or juvenile snakes versus those of adults are limited; however, movement distances for juveniles can be as immense and erratic as adult conspecifics in western ribbon snakes (*Thamnophis proximus*; Clark, 1974) in Texas and other snake species (Gregory *et al.*, 2001). Variation in movement between individuals within the same cohort also occurs with differences in movement patterns and distances between adult, non-gravid prairie rattlesnakes in Alberta existing (Jorgenson, 2009). Annual changes in individual snake movement distances may in some cases be reflective of climatic trends as male and female black pinesnakes (*Pituophis melanoleucus lodingi*) in Mississippi partake in shorter distance movements in response to drought (Baxley & Qualls, 2009).

Intersexual differences in home-range size and/or movement distance or activity occurs in many species of snakes. Male bull snakes (*P. catenifer sayi*) in Wisconsin have larger home ranges and daily movement rates than females (Kapfer *et al.*, 2008), male Australian black snakes have larger activity ranges than females during the breeding season (Shine, 1987), and male sidewinders in the Mojave Desert travel farther than females (Secor, 1992). Activity ranges are smaller for females in black rat snake in Kansas than males (Fitch, 1963), the eastern massasauga (Weatherhead & Prior, 1992) in Ontario, and brown snakes (*Pseudonaja textilis*; Whitaker & Shine, 2003) in Australia. Conversely, home ranges of female grass snakes in Sweden are larger than those of males (*Natrix natrix*; Madsen, 1984). Greater distance per move

by male versus female Grand Canyon rattlesnakes (*C. o. abyssus*) occurs in Arizona, but frequency of movement events does not significantly differ between sexes (Reed & Douglas, 2002). Temporal variation in movement between female and male snakes occurs in grass snakes (Madsen, 1984) in Sweden, timber rattlesnakes in Virginia (Martin, 1992), and black rat snakes in Maryland (Durner & Gates, 1993).

Variation in movement and habitat use between female and male *Crotalus* species does not necessarily relate to reproductive status. Both sexes of canebrake rattlesnakes (*C. h. atricaudatus*) in South Carolina exhibit distinctive behavioural-based seasons, with partitioning of available habitat occurring between the sexes during foraging and shared habitat use during breeding or hibernation (Waldron *et al.*, 2006). Partitioning during foraging activity likely indicates differences in prey preference, but may reflect foraging-strategy variation between the sexes (Waldron *et al.*, 2006). Intersexual differences in movement patterns and activity ranges do not occur in eastern kingsnakes (*Lampropeltis getula getula*) in New Jersey (Wund *et al.*, 2007).

The extensive variation in movement activities and patterns between and within species of snakes exemplifies the importance of understanding population-specific movements as generalizations amongst populations are difficult to make. Since movement behaviour is often strongly related to habitat availability and occurrence, species and population-specific information on habitat requirements and occupancy are crucial to understanding movement trends over time, as well as for identifying changes to them.

3.0 DISTRIBUTION AND HABITAT REQUIREMENTS OF PRAIRIE RATTLESNAKES IN CANADA

Two of 8 known sub-species of the western rattlesnake are native to Canada (Ashton & Queiroz, 2001). The northern Pacific rattlesnake (*C. v. oregonus*) occurs in British Columbia, whereas the

prairie rattlesnake occurs east of the Rocky Mountains in Alberta and Saskatchewan (Figure 2; Watson & Russell, 1997; Cook, 1984; Russell & Bauer, 1993).

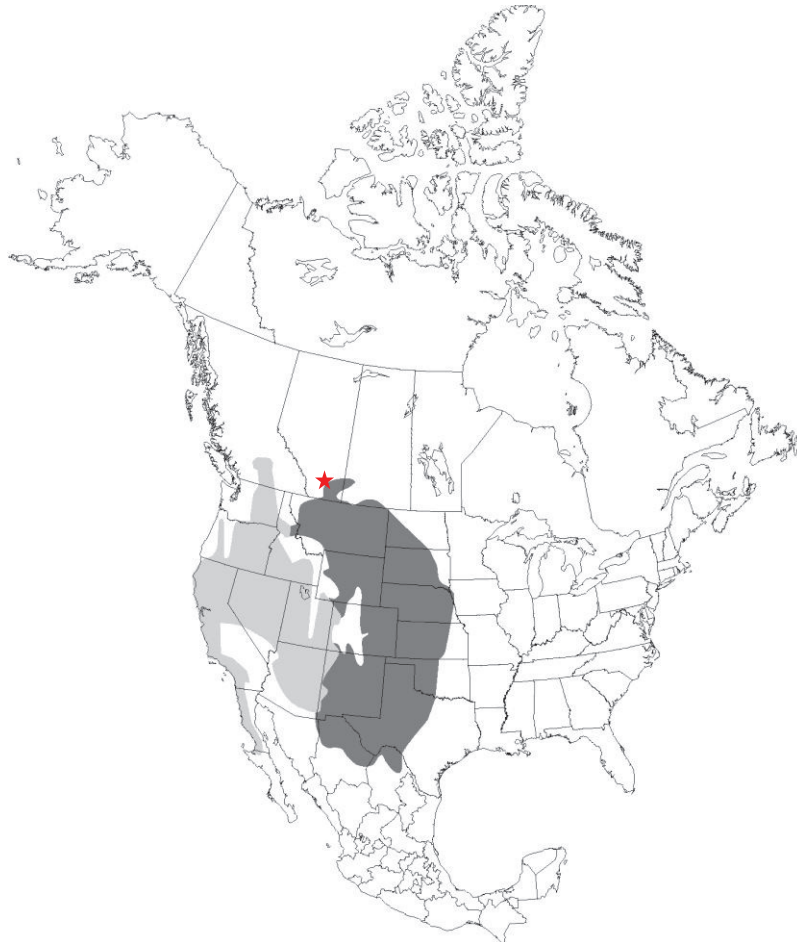


Figure 2: Distribution of the western rattlesnake (*Crotalus viridis*) in North America (modified from Stebbin, 1985, by Watson & Russell, 1997, used with permission). The dark region represents the distribution of the subspecies *C. v. viridis*, the prairie rattlesnake, and the light region represents the subspecies *C. v. oregonus*, the Northern Pacific rattlesnake. The location of Lethbridge is indicated by the red star.

Prairie rattlesnakes in Alberta occur at the most northerly extent of the species' range, often along major river drainages such as the South Saskatchewan River drainage (Red Deer, South Saskatchewan, Bow, and Oldman Rivers) and the Missouri River drainage (in Canada this includes mainly the Milk River; Watson & Russell, 1997). Historic range of the prairie rattlesnake in Alberta extended north along the Red Deer River basin to Trochu and along the Bow River,

almost to Calgary (Watson & Russell, 1997). Prairie rattlesnake observations have been primarily concentrated in south-eastern Alberta since the late 1970's (Watson & Russell, 1997), with Lethbridge occurring in the north-westerly region of the sub-species' range. Prairie rattlesnake distribution in the province is more restricted than suggested by habitat suitability models produced by Kissner (2004), which indicate appropriate patches of habitat continue to exist throughout the south half of Alberta, excluding mountain regions.

Populations of prairie rattlesnakes in Canada are strongly associated with dry grasslands such as the mixed-grass prairie region in Alberta (Cook, 1984; Powell *et al.*, 1998). These semi-arid regions have low annual precipitation, high temperatures throughout the summer months, and a relatively short growing season limited by cold winters (Watson & Russell, 1997).

Thermoregulation is important for prairie rattlesnakes both during the summer and winter months and is linked to life-history and activity responses (Wills & Beupre, 2000; Peterson *et al.*, 2001).

Female prairie rattlesnakes in Wyoming participate in cover-seeking activity when air temperatures become too low or too high, with basking occurring between 15°C and 25°C, and go underground if temperatures are excessive (Graves & Duvall, 1993). Maximum daily temperature and solar radiation intensity may be limiting factors to daily activities in eastern brownsnakes in Australia (Whitaker & Shine, 2002). In Alberta, the prairie rattlesnake usually occurs in areas dominated by coulee systems near riparian zones where slumping allows creation of hibernacula, necessary for meeting the species' ectothermic requirements during winter months (Watson & Russell, 1997; Kissner & Nicholson, 2003).

Hibernation for prairie rattlesnakes in Alberta lasts 6-8 months so dependency on appropriate hibernacula is inherent for survival (Kissner & Nicholson, 2003; Kissner, 2004). Naturally occurring hibernacula sites include those created by burrowing mammals, subterranean water channels, fissures, sinkholes, and rock outcroppings (Watson & Russell, 1997; Kissner & Nicholson, 2003). Appropriate hibernacula locations have stable slope material with southern exposure and dissected slopes, allowing access to the bedrock layer below the frost line (Didiuk,

1999). Hibernaculum site fidelity is relatively high for the prairie rattlesnake so areas appropriate for hunting and basking must occur within reasonable proximity of a hibernaculum's location (Watson & Russell, 1997). Mammal burrows function as daytime shelters for prairie rattlesnakes; in areas void of such burrows, such as badland slopes, locations sheltered by rim rock edges are preferred (Powell *et al.*, 1998). Rookery requirements of the prairie rattlesnake may be associated with large rocks close to mammal burrows (Gannon & Secoy, 1985; Watson & Russell, 1997).

4.0 STUDY SPECIFIC DETAILS

4.1 Objectives: Movement patterns, home range use, and habitat utilization of prairie rattlesnake in relation to anthropogenic factors such as habitat alteration and/or fragmentation are under-examined in Canada. In order to assess the influence of these factors on long-term viability of this species within a city boundary, at the most north-westerly portion of its range, I initiated a 2-year study through cooperation with the City of Lethbridge, Alberta Fish and Wildlife Division, and the University of Lethbridge. The primary objectives of my study was to quantify movement patterns and home ranges of prairie rattlesnakes in Lethbridge, AB through tracking selected individuals using radio-telemetry and to determine if anthropogenic factors such as habitat fragmentation and/or alteration and human activity in remaining habitat parcels are influencing movement patterns in relation to habitat use and selection. Secondary objectives included collection of information regarding hibernacula and rookery locations, measurement of physical characteristics (mass, length, sex, age) of snakes, and assessment of demographics (sex ratio, age classes and distribution over study sites). This information was considered crucial for resource managers who are attempting to assess the long-term viability of prairie rattlesnakes and make informed decisions regarding management and conservation initiatives for the species in Alberta.

4.2 Study Setting: My study on prairie rattlesnakes was conducted over 2 field seasons in 2005 and 2006, within the city boundaries of Lethbridge, AB, Canada (49° 41' 39" N and 112° 50' 27"

W). The city encompasses an area of 124.3 km² and has a human population of 85,492 (City of Lethbridge, 2009). The climate of the region is moderate continental, with average daily air temperature of -7.8°C in January and 18.0°C in July. Lethbridge represents the most north-westerly location of the prairie rattlesnake's current range (Watson & Russell, 1997). The city sits along the Oldman River Valley (Figure 3), and slump zones associated with post-glacial drainage channels (coulees) provide prairie rattlesnakes with naturally occurring hibernacula, protective cover during summer months and varied foraging habitat.

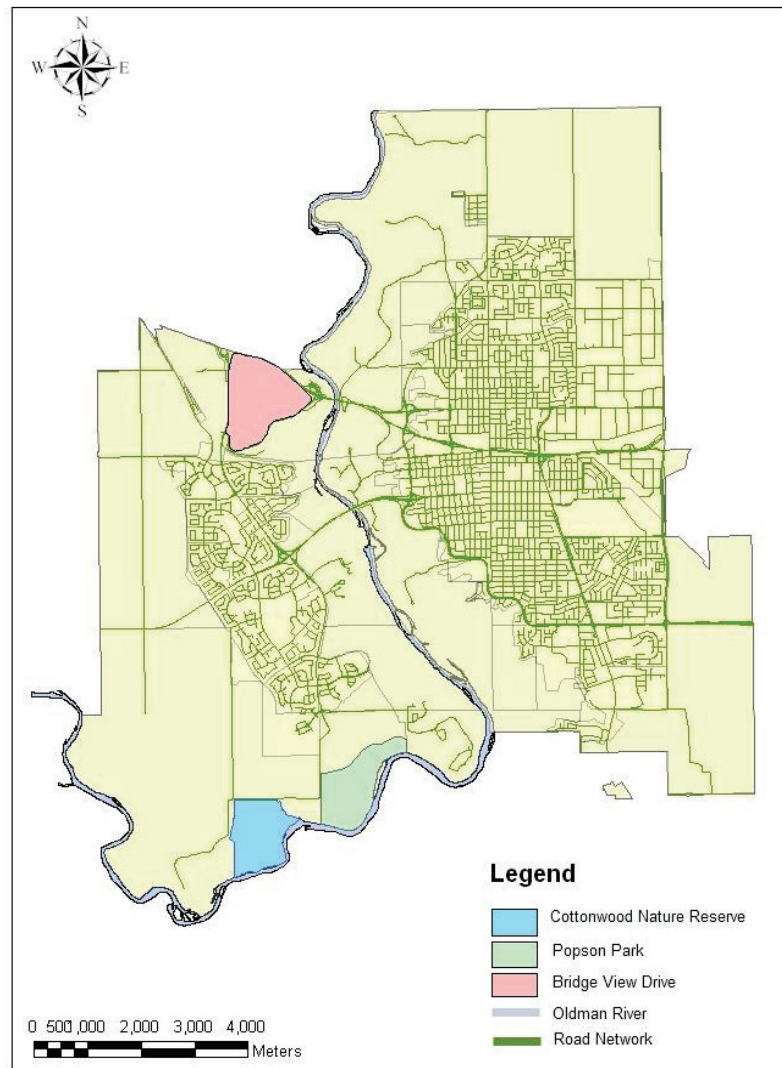


Figure 3: Locations of the 3 study sites (Cottonwood Nature Reserve, Popson Park, and Bridge View Drive) near the Oldman River in Lethbridge, AB. The river flows west then north through Lethbridge. Shape file provided by City of Lethbridge, 2009.

Following some preliminary work assessing the status of prairie rattlesnakes in Lethbridge, AB (1997-1999), a Lethbridge Rattlesnake Conservation Program (LRCP) was initiated in 2001 (Ernst & Quinlan, 2006). This research suggested that prairie rattlesnake populations in Lethbridge were restricted to small parcels of fragmented habitat, with population estimates of <50 adult snakes (Ernst & Quinlan, 2006). Between 1991 and 2006 about 75% of available habitat for prairie rattlesnakes in south-west Lethbridge (primarily pasture land) was urbanized, eliminating a substantial amount of foraging area for the species (Ernst & Quinlan, 2006). Much of the remaining grassland was set aside for recreational use through the creation of campgrounds, dog runs, hiking trails, and golf courses (Ernst & Quinlan, 2006).

On-going residential development and urbanization of coulee systems in southwest Lethbridge may be leading to the destruction of suitable habitat patches and act as barriers to rattlesnake movement, with many newer community developments being located directly adjacent to known prairie rattlesnake hibernacula and migratory routes (Ernst, 2002). Roads associated with such developments, as well as access roads created for recreational-area use, and the subsequent increase in traffic volume may be impeding natural rattlesnake movement patterns in the city and potentially leading to increased prairie rattlesnake mortalities (Ernst, 2002; Ernst & Quinlan, 2006). Additional fragmentation throughout the city has occurred through the placement of high traffic roads, which may make immigration or emigration between sub-populations difficult or even deadly. Prairie rattlesnake mortalities have occurred on the roads intersecting parks located in the Oldman River valley (Ernst, 2002; Ernst & Quinlan, 2006).

Areas of advanced coulee slumping in Lethbridge, either resulting from natural or agricultural-related activities, are also of concern. Hibernaculum collapse would make an area unsuitable for inhabitation of prairie rattlesnakes, leading to the modification of home ranges and movement patterns, and may result in the mortality of multiple animals (Ernst, 2002). Agricultural land use has transformed native grassland into a homogenous landscape with more limited resources and prey. Natural barriers to snake movement and population expansion include the Oldman River

and areas of advanced coulee slumping, where movement opportunities are limited by the terrain. As available habitat for prairie rattlesnakes continues to decrease and become more disjointed, increasing human and rattlesnake interactions may result in injuries to either party or persecution of the snake. Such altercations could lead to increased fear and animosity towards prairie rattlesnakes, putting them at further risk for deliberate human destruction and reducing citizen support for conservation initiative aimed at the species in Lethbridge. Continuing development also brings into question how the increasing fragmentation of the Oldman River Valley will affect the city rattlesnake population, which may already be at a critical level (Ernst, 2004).

Cooperative efforts between the City of Lethbridge and Alberta Fish and Wildlife Division to monitor rattlesnake populations within Lethbridge and mitigate human-snake conflicts have been in place since the late 1990's. Through the LRCP, 55 prairie rattlesnakes were permanently marked in 2002-2004 using Passive Integrative Transponders (PIT-tags) and the locations of ~5 naturally occurring hibernacula throughout Lethbridge were identified (Ernst, 2002/2003; Ernst & Quinlan, 2006). Ernst & Quinlan (2006) estimate that ~10 prairie rattlesnakes were lost from the Lethbridge population annually from 1997-2000 due to human/snake interactions. Examples of such interactions include human and rattlesnake conflicts on golf courses, subdivisions, and recreational areas, and have resulted in non-fatal bites to humans: 1 in 2001 (Ernst, 2002) and 1 reported to me in 2005 (W. Andrus, unpublished data). Such events could potentially escalate citizen fears and/or concerns regarding the species and lead to increased persecution and harassment, regardless of the fact that prairie rattlesnake bites have never resulted in a human fatality in Alberta (ASRD, 2010).

Communications with 6 veterinarian clinics engaged in small animal practice in Lethbridge, AB (Chinook Pet Clinic, Green Acres Animal Hospital, Highlands Pet Hospital, Northside Veterinarian Clinic, Park Pet Hospital, and Uplands Pet Hospital) reveal 4 clinics do not treat rattlesnake inflicted bites of dogs on an annual basis and estimated <1 rattlesnake bite treated/year, with no reported fatalities. Of these 4 clinics, only 2 reported treating any bites in 2008 and 2009 (1

treated by Chinook Pet Clinic in 2008, 1 treated by Park Pet Hospital in 2009). The remaining 2 clinics, Uplands Pet Hospital and Highlands Pet Hospital, treat rattlesnake bites annually in dogs from the Lethbridge area. Veterinarians at Uplands Pet Hospital estimate they treat between 6-12 rattlesnake bites in dogs/year, none of which have been fatal. Veterinarians at Highlands Pet Hospital estimate that they treat ~2-3 rattlesnake bites in dogs/year and verify that 1 bite has been fatal in the past, due to the unique placement of the bite. Occurrence of these incidences is primarily limited to areas of river valley, often in off-leash parks, where human/snake conflicts are also relatively frequent.

Other examples of conflict include deliberate killing of several rattlesnakes on the Bridge View Drive property by a sports club in 1997, along with 3-4 deliberate killings of rattlesnakes in 2001, and 1 in 2002 (Ernst, 2002/2003). At least 15 prairie rattlesnake deaths occurred in 2001-2004, mostly due to accidental or deliberate human-induced mortality (Ernst & Quinlan, 2006).

Educational resources aimed towards increasing citizen understanding and decreasing ambivalence towards the species, as well as translocations of "problem" prairie rattlesnakes, have been the primary management strategies implemented to mitigate these types of conflicts (Ernst, 2003). The network of conservation initiatives, obvious development pressures, and its geographic location make Lethbridge a well-suited area to study anthropogenic influences on the movement patterns and habitat utilization of prairie rattlesnakes in Canada.

5.0 METHODS

5.1 Study Sites: I selected 3 main sites (Figure 3) for the study of the prairie rattlesnakes in Lethbridge based on their identification as primary activity centres for rattlesnakes (i.e., highest previous snake densities) by Ernst (2003). One study site was in the Cottonwood Nature Reserve, located at the most south-western tip of the city's area. The study site area encompasses the entire reserve, including 133 ha of grassland, with some shale walking trail development, a lookout, and a parking lot (City of Lethbridge, 2009). Residential acreages and the Oldman River border this site (City of Lethbridge, 2009). The second location was Popson Park, located adjacent to the suburban communities of Riverstone and Paradise Canyon, Paradise Canyon Golf Course, agricultural fields, and the Oldman River. The park is composed of 133 ha of grassland, with numerous gravel roads, a group picnic and campground area, an off-leash dog run, and a boat launch (City of Lethbridge, 2009). Also located on this site are the Oldman River Observatory and several abandoned buildings. The total area of the study site was ~140 ha, inclusive of the agricultural fields adjacent to the park boundaries where a large hibernaculum is situated. The final site I selected was an area of private land situated between the Bridge View RV Resort, Earth Wind Sand and Gravel Company, Bridge View Golf Course, the Elizabeth Hall Wetland, numerous acreages, and 3 main transport routes (Highway 3, Highway 3A and University Drive). The remains of concrete foundations, intersecting dirt roads, and an archery range make this site the most altered of the study sites. The total area of the Bridge View Drive study site was ~182 ha.

5.2 Prairie Rattlesnake Distribution, Population Estimates, and Demographics: I carried out concentrated visual surveys in areas of species-appropriate habitat from April to October of 2005 and 2006 to establish where prairie rattlesnakes were occurring at the study sites and to gain a better estimation of how many snakes were present. Drift-net fencing and pit-fall traps aided capture of 2 snakes during May of 2005, primarily for a period of 3 days. The drift-net fencing was constructed from fine mesh page wire and was placed along the perimeter of a

hibernaculum, with 2 pit-fall traps set along it. The traps were specially designed for the purpose of capturing snakes (provided by Alberta Fish and Wildlife) and were monitored every 3 hours throughout the day before exclusion of these collection methods due to concerns of an advisor that fencing would expose hibernacula locations and lead to deliberate destruction of hibernacula or snakes (Macartney *et al.*, 1990; Kissner *et al.*, 1996; Powell *et al.*, 1998; Jorgenson & Nicholson, 2007). Thereafter, I captured snakes opportunistically (an additional 103 individuals) during ground surveys, radio-telemetry monitoring (i.e., those animals occurring in aggregations with radio transmitter-implanted snakes) or in response to citizen reports. Deliberate searches to locate both marked and unmarked prairie rattlesnakes in Lethbridge were made by me on 145 days in 2005 and 153 days in 2006.

I handled all captured individuals using 42" (1.07 m) Whitco Whitney professional snake tongs and placed animals in professional snake containment tubes, ranging from 3/8" (0.95 cm) to 2" (5.08 cm) in diameter, for physical measurements as required. Long-term containment (> 72 hours) was minimized. When necessary, animals were kept in a secure terrarium that had areas appropriate for shading and basking and provisioned with water, as suggested by advisors (Dr. Dan Johnson & Reg Ernst). Containment times varied from a few hours to up to 1 week, with the majority (16 of 18) held for less than 3 days. Individual snakes were marked using PIT-tags (AVID microchips, 125 kHz) and tags were read with an AVID portable PIT-tag scanner (AVID Mini-Tracker). In accordance with accepted standards, only snakes over 42 cm SVL were PIT-tagged (Powell *et al.*, 1998). I implanted PIT-tags subcutaneously on the right side of the animal, approximately 30 cm cranial to the cloaca, using a bulk syringe and 12-gauge Luer Lock needle tips. The majority of rattlesnakes I captured (40 of 48 in 2005 and 42 of 57 in 2006) received PIT-tags.

Locations of all captured individuals were recorded using a Garmin Etrex GPS unit and coordinates were verified using a Geographic Information System (GIS), with in-field correction based on field notes and knowledge of site characteristics. I compared distributions of all

captured prairie rattlesnakes on study sites using χ^2 analysis to assess variation in snake occurrence over study-site locations or yearly variations (Pontes *et al.*, 2009). Because the degree of isolation for the prairie rattlesnake sub-populations in Lethbridge is unknown, I used both closed (Schnabel) and open (Jolly-Seber) population estimate models to make predictions of population size based on my recapture success methods. Both methods were chosen due to their use in predicting population size for prairie rattlesnakes in Grassland National Park, Saskatchewan (Kissner *et al.*, 1996).

Body size, body mass, sex and age were measured in accordance with accepted standards for most captured individuals, excluding neonate and juvenile cohorts in 2005 and neonates in 2006 (Klauber, 1982; Fitch, 2001). However, some exceptions did occur where minimized handling of an animal was necessary such that measurements were not taken, thus, sample sizes for measurements or demographic estimates vary. Excluded individuals were those considered to be in an overly fragile state (extremely stressed, particularly small in size, suspected of pregnancy, engaged in courtship, etc.). I immediately released all prairie rattlesnakes at their original location following data collection unless kept for transmitter-implantation. Among the methods used for estimating age and maturity in prairie rattlesnakes in Canadian studies (Table 1), I used the age-at-maturity criteria of Macartney *et al.* (1990).

Table 1: Overview of aging protocols used for prairie rattlesnakes.

Protocol Author	Measure	Neonate	Juvenile	Sub-Adult	Adult
Didiuk (2007), Macartney <i>et al.</i> (1990)	SVL (cm)	N/A	<75 for females, <65 for males	N/A	> 75 for females, > 65 for males
	colour		N/A		N/A
	rattle count	button only			
Gannon & Secoy (1984)	SVL (cm)	<30	30-80	N/A	>80
	colour	dark brown/defined blotches	colour transitional between young and adults		light yellow to yellow brown
	rattle count	button or button + rattle	2-7 rattles		7 + rattles
Kissner <i>et al.</i> (1990)	SVL (cm)	20-30	40-50	50-70	70-130

*SVL = snout-vent length

During my study, I consistently took SVL and tail length (TL) measurements with the same meter stick, with 2 measurements per snake. I measured SVL to the nearest mm from the tip of the snake's head to the cloacal opening and TL from the posterior tip of the anal plate to the beginning of the rattle segment (Fitch, 2001). I measured mass to the nearest gram twice for each individual using a calibrated Rapala digital hanging scale. Sex was determined through gentle probing of the cloaca, using size-appropriate, disinfected professional stainless-steel sexing probes to establish the presence (male) or absence (female) of hemipenes ventral to the cloacal opening (Figure 4; Fitch, 2001).



Figure 4: Sexing of a prairie rattlesnake by inserting a sexing probe into the cloaca to determine the presence (male) or absence (female) of hemipenes ventral to the cloacal opening.

In some cases natural eversion of the hemipenes (also known as popping) occurred, allowing verification of the snake as a male (Fitch, 2001). The number of rattle segments was counted and I clipped a small piece (~5 mm) of 1 ventral scale for each snake, which I kept in a 10% ethanol solution as a voucher DNA tissue sample (Klauber, 1982).

I determined if either sex was disproportionately represented in the population amongst age cohorts using χ^2 analysis (Nishimura & Kamura, 1994; Dyer, 1996; Zar, 1999; Stevenson *et al.*, 2009; Karns *et al.*, 2010). I determined whether sex, age, year of capture or study site location had significant effect on body-size measurements and rattle count of prairie rattlesnakes using ANOVA (French & Poulsen, 2002; Zar, 1999). Pearson's product moment correlation coefficients were used to examine the relationship of body measures to each other and to rattle count to verify predictions that SVL, TL, and mass are correlated, as individuals should, theoretically, increase in all measures simultaneously as they grow (Beaupre *et al.*, 1998). I expected rattle count to correspond to SVL and TL as the process of ecdysis (shedding of the outer skin) is related to yearly growth and results in rattle addition.

5.3 Assessing Cause of Mortality: The cause of mortality for individuals was established using visual examination of the remains, citizen reports, and inspection of the area where the animal's body was located. Because exact dates of mortalities could not be confirmed, mortalities were recorded as the day when the body of the animal was recovered.

5.4 Radio-Transmitter Implantation: I used internal whip-antenna transmitters throughout my 2-year study, though transmitter type differed between 2005 and 2006. In 2005, refurbished transmitters were provided by Alberta Fish and Wildlife Division, with an average battery life expectancy of 5 months (Holohil Systems Ltd., SB-2; 3.55 g). In 2006, funding for transmitters was provided by Dr. Dan Johnson (University of Lethbridge) and Alberta Fish and Wildlife, with transmitters having an average battery life of 10 months (Holohil Systems, Ltd., SB-2T; 5.50 g).

A single female and 17 male snakes were implanted. Female snakes were not generally chosen for transmitter-implantation due to an early advisor's (Reg Ernst) objection to their inclusion. Specifically the advisor suggested exposing females to the risks associated with surgery could lead to long-term detrimental effects on the population, as population growth is already limited by the reproductive capacity of females (i.e., biennial-breeding cycle) and the loss of any female snakes could further amplify such restrictions. The single selected female was permitted due to her close proximity to an acreage which prompted the advisor to suggest monitoring of her movements was important for preventing human-conflict. Neonatal, juvenile, and gravid females were excluded from transmitter-implantation due to the potential detrimental effects of surgery and additionally to ensure that transmitter weight did not exceed 5% of the total body mass of any snake (Reinert, 1992; Weatherhead & Prior, 1992; Hardy & Greene, 1999). Minimum eligible mass to receive a 3.55 g transmitter in 2005 was 71 g and a 5.5 g transmitter in 2006 was 110 g. Nine of 43 confirmed eligible snakes in 2005 and 9 of 48 confirmed eligible snakes in 2006 were implanted with a radio-transmitter. Transmitters were implanted between 19 May and 5 July in 2005 and on 18 May in 2006 on first capture of the selected individuals for that year.

Dr. Rod McFarlane (DVM) carried out the transmitter-implantation and monitored levels of anesthetic and painkillers, using methodologies modified from Reinert & Cundall (1982) and Reinert (1992). Surgery took place at the Highland's Pet Hospital in Lethbridge, AB. Six mg/kg of propofol was administered by insertion of a small needle into the ventral tail vein to induce anesthesia, which was then maintained using isoflurane (2-2.5%) through a modified plastic tube (Figure 5). Surgical incision was made approximately 6 cm cranial to the vent and was about 2 cm in length (located where the ventral scutes and dorsal scutes join). Before insertion, the transmitter was cold-sterilized. It was then inserted into the coelomic cavity of the snake and secured to a rib using suture material (4-O PDS) so that it was unable to move within the cavity (Figure 5). The antenna was positioned directly underneath the skin towards the head after a 10-gauge nylon catheter was used to create a space between the skin and muscle. The incision was then closed using 4-O PDS suture material (Figure 5).

Post-operatively, prairie rattlesnakes were given Butophanol (1 mg/kg I.M.) and Meloxicam (0.1 mg/kg I.M.) for pain and the antibiotic Tribissen (30 mg/kg I.M.). Snakes were monitored for signs of infection, and allowed to recover in a controlled environment for 24 hours after surgery, as recommended by the supervising veterinarian. After the snake had regained full mobility it was released at the original capture site.



Figure 5: Transmitter-implantation surgery on a prairie rattlesnake included anesthetic maintenance with isoflurane inhalant (top), transmitter implantation into the peritoneum (middle), and closure of the incision site (bottom).

I tracked radio-implanted prairie rattlesnakes using radio-telemetry from the time of their capture during egress from the hibernaculum until mortality, hibernation or signal loss occurred. I located animals every other day when possible with a telemetry receiver and scanner (Reinert, 1992; 2005-Wildlife Materials Inc. TRX-2000S PLL Synthesized Tracking Receiver, 2006-Telonics TR2 Receiver). No discernable problems related to transmitter-implantation were observed. Observation of courtship activities for transmitter-implanted snakes was noted in both years of the study and 1 episode of mating was verified in August, 2006. Participation in these activities by implanted snakes suggests that transmitters did not adversely affect these individuals' ability to breed. Transmitters were not removed when the batteries failed/at the conclusion of the study as advisors were concerned additional surgery associated with transmitter removal would be potentially more detrimental to the long-term health of implanted-individuals than leaving the transmitter in place.

5.5 Analysis of Tracking Data: I recorded the number of tracking events and occurrences of other prairie rattlesnakes with each transmitter-equipped individual. Continued presence of a transmitter-equipped snake in 1 location until radio signals were no longer obtained was considered indicative of hibernation having taken place, and thereby evidence that a location was a hibernaculum. The definitive date marking the start of hibernation for the population was considered to be the day following the last date when a transmitter signal was received from any transmitter-equipped snake in a given year.

While all efforts were made to avoid interference with the natural movements of rattlesnakes, due to urban location of the study and cooperative association with Alberta Fish and Wildlife and the Lethbridge Rattlesnake Conservation Program, 2 transmitter-implanted snakes were translocated from areas of high human activity and traffic near the peripheries of study sites to a more centralized location that they might not normally have frequented. Decisions regarding relocation were made in conjunction with Richard Quinlan (Endangered Species Biologist) and Reg Ernst (Lethbridge Rattlesnake Conservation Program Coordinator) and were carried out at their

request. Translocation distances of the 2 transmitter-implanted snakes were not included in calculation of home range or activity areas, movement parameters or habitat use assessments.

Efforts to standardize the reporting of movement parameters, to increase comparability between studies, required the inclusion of at least 2 or more types of movement parameters (Reinert, 1992). I included number of days tracked, maximum relative distance of movement events between consecutive locations, directionality of movement, movement frequency, movement per day, range length, mean distance per move, and cumulative distance moved as movement parameters in my study (King & Duvall, 1990; White & Garrott, 1990; Reinert, 1992; Zar, 1999; Kingsbury *et al.*, 2003; Gerald *et al.*, 2006; Marshall *et al.*, 2006). I determined whether each parameter was significantly affected by study year, study site location or an individual's size (SVL) using ANOVA (Zar, 1999; Webb & Shine, 1997; Jenkins & Peterson, 2005; Wund *et al.*, 2007). I examined directionality of movement using Raleigh's z to establish if fixed-directional movement occurred, as reported elsewhere for prairie rattlesnakes. In 3 cases, I could not obtain a critical value because the number of relocation events exceeding 5 m was limited.

5.6 Examination of Site Fidelity, Home Ranges, and Core Activity Areas: I examined site fidelity (100% inclusive of individual locations), home range (95% inclusive of individual locations), and core activity (50% inclusive of individual locations) area for transmitter-implanted snakes using minimum convex polygon analysis (MCP) and kernel density (KD) analyses. Benefits of calculating the core activity area include a better understanding of which part of the home range is most utilized by the individual and a more accurate measure of activity range size (Secor, 1994; Johnson, 1995).

Home ranges are created using MCP analysis by the linking the most peripheral locations occupied by an individual and calculating the resulting area (White & Garrott, 1990; Kingsbury *et al.*, 2003). A MCP is inclusive of every movement event for the 100% analysis, with outliers being removed for the 95% analysis. Analysis of home range estimators by White & Garrott (1990)

identified benefits of the MCP approach including simplicity, flexibility of the calculated shape and the ease of which the calculations can be made. Drawbacks include over estimation of home range size when large sample sizes exist and inclusion of locations in the home range area that were not representative of normal movements made by an individual (Worton, 1989; White & Garrott, 1990; Kingsbury *et al.*, 2003; Gerald *et al.*, 2006). White & Garrott (1990) recommended the elimination of outliers to help alleviate the amplification of the resulting home range area.

Kernel-based estimators of home range are generally defined as the minimal area that is inclusive of a percentage of points where the probability of an individual occurring at each point has been established (Kernohan *et al.*, 2001). That is to say for each location a probability density (kernel) is placed over that point and a rectangular grid is superimposed (Seaman & Powell, 1996). At each intersection created by the grid an estimate of density (an average of the degree of overlap with other kernels at that position) is calculated, based on the whole sample of observations (Seaman & Powell, 1996). Any locations that are close together will contribute more to the estimation of density for that point, than those distributed further away, resulting in high density estimates where many observations occur and low density estimates where few are located (Seaman & Powell, 1996). Benefits of home range estimation using KD analysis include freedom from assumptions of bivariate normality of the data set and identification of areas of concentrated activities, in some cases allowing a better understanding of specific resource use (Kernohan *et al.*, 2001; Kingsbury *et al.*, 2003). Weaknesses of kernel estimation include the assumption of independence amongst observations and inclusion of areas never utilized by an individual (Kernohan *et al.*, 2001). To counteract this affect 95% probability isopleths are often used (Kingsbury *et al.*, 2003).

MCPs have been found to more accurately predict maximum home range size for reptiles and amphibians than KD analyses and their use is recommended even when comparisons between groups or across time are the goal of the research (Row & Blouin-Demers, 2006; Langory *et al.*, 2009). Fixed KD analyses are reported in my study to allow for comparison with future studies

where this type of analysis may be used. All other use of home range or core activity area estimates was completed using MCP analyses. I calculated MCP and KD areas using the Home Range Tools extension for ArcGIS (Rodgers *et al.*, 2005) for all but 1 implanted individual, which died shortly (20 days) after implantation. As only 1 snake was tracked in multiple years, comparison of differences in home range sizes among years or between sexes was not possible.

5.7 Examination of Site Utilization and Habitat Availability: I used movement and home range observations to generate information on site use by prairie rattlesnakes. I considered a site to be a rookery if neonatal clutches and female snakes were observed at the location (Figure 6) and a hibernaculum if the time of prairie rattlesnake occupation coincided with emergence (late March to early May) or return of snakes to hibernacula (mid-September to mid-October) and multiple snakes were seen, indicating seasonal aggregations (Figure 6). I recorded locations of hibernacula or rookery sites using a Garmin Etrex GPS unit and I verified coordinates using a GIS, with in-field correction based on field notes and knowledge of site characteristics. I collected information on site composition and used it to establish whether hibernacula originated from mammal burrows, coulee slumping or human activity (Powell *et al.*, 1998; Nicholson & Rose, 2001). I also used site compositions to determine whether adequate and useable cover still occurred throughout the 3 study sites, a basic requirement for long-term species viability, and to gain some insights into prairie rattlesnake activity and adaptability.



Figure 6: Aggregation of adult and neonatal prairie rattlesnakes at a confirmed rookery location (top) and seasonal aggregation of adult prairie rattlesnakes at a confirmed hibernaculum location (bottom).

Because resource use by hognose snakes in New Hampshire varies between the home range and landscape level (*Heterodon platirhinos*; Lagory *et al.*, 2009), I examined habitat availability and utilization at the home range, study area, and at maximum movement distance levels using ArcGIS 9.1 (Erickson *et al.*, 2001; Brito, 2003; Kingsbury *et al.*, 2003; Moore & Gillingham, 2006; Dodd & Barichivich, 2007).

Shape files and digitization of the Lethbridge, AB LANDSAT image (15 m resolution-2005; image and shape files provided by the City of Lethbridge, made accessible through the Department of Geography at the University of Lethbridge) allowed me to differentiate habitat types and use (White & Garrott, 1990). I first classified habitat types as occurring either on the floodplain, in the coulee, or in the upland areas of the city by considering elevation, proximity to the river and topography. I then used the shape files and LANDSAT image to further classify habitat type based on vegetation type (e.g., cottonwood stands, native (original or recovered) grassland) and land use including agriculture (including farms), urban residential areas, acreages and recreational areas (e.g., golf courses, campgrounds, dog runs). Bodies of water (mainly community lakes and the Oldman River), university property, and areas that were otherwise classified as a city landscape but did not fit into the above categories (i.e., ditches, land cleared for development, airports, etc.) were also identified.

I calculated habitat availability for home ranges by identifying habitat types and proportions occurring within the generated 100% MCPs (Langory *et al.*, 2009). Habitat availability was examined at the maximum movement distance level based on the distance travelled by the farthest moving transmitter-implanted prairie rattlesnake in my study, as an identifier of how far an animal could potentially travel in 1 active season (Moore & Gillingham, 2006). I delineated the maximum movement potential as a circular area around all individual locations, removing overlap to produce a single area representative of potential habitat available to that individual. I determined habitat availability at the study site level by identifying habitat types and proportions occurring within the boundaries of each of the 3 primary study sites. Habitat availability was defined for the study site area when using logistic regression approaches for analysis of resource selection (Erickson *et al.*, 2001; Brito, 2003). I similarly measured habitat utilization at the 100% MCP, maximum range of movement, and study site levels (Slip & Shine, 1988; White & Garrott, 1990; Weatherhead & Prior, 1992; Moore & Gillingham, 2006). I used Bonferroni statistics in the identification and comparison of which habitat types were preferred (Kapfer *et al.*, 2008).

5.8 Examination of Habitat Fragmentation and Weather Effects on Prairie Rattlesnakes:

5.8.1 Habitat Fragmentation Effects: I created explanatory models using ArcGIS 9.1 (including geoprocessing, analysis, spatial analyst, hydrology and raster calculator tools) that incorporated current knowledge of species' habitat use, life-history requirements, and movement limitations (Kissner, 2004). These models were used to represent prairie rattlesnake habitat preferences, as well as provide insights into the effect of habitat fragmentation on species' movement and presence throughout Lethbridge, AB. A 15-m digital elevation model (DEM) of Lethbridge, AB was provided to me by the Department of Geography (University of Lethbridge, 2005; interpolated using inverse distance weighting from the city point file). I used the DEM and ArcMap to create surface grids representing slope, aspect, flow accumulation, soil type, topographical wetness, road type, and road density (Santos *et al.*, 2006; Lagory *et al.*, 2009). Such factors were incorporated based on their inclusion during previous habitat suitability modeling for prairie rattlesnake in Alberta (Kissner, 2004).

Soil type over the study area was represented through the creation of a topographical wetness index (TWI) model, using the 15m DEM as an input source. Slope was calculated using the spatial analyst>surface>slope function. Aspect was calculated using the spatial analyst>surface>aspect tool for comparison purposes to the TWI grid. A flow accumulation grid was then created from the DEM by calculating a flow direction grid using the hydrology>flow and model builder tools. The resulting grid was then used as input for creating the flow accumulation grid using the hydrology>flow accumulation tool. The final topographical wetness grid was calculated using the raster calculator.

Due to the ectothermic nature of rattlesnakes, location of animals is strongly affected by an area's appropriateness for basking activity. For this reason I created monthly insolation grids, representative of varying seasonal differences in the amount of direct radiation a surface receives, for the field season. Zeniths and azimuths were calculated using the MIDC Solar

Position Calculator for each hour of one day of the week, for each week of every month, from April to October (Reda & Andres, 2003). Results were input into the spatial analyst>surface>hill shade tool and hourly hill shade grids were calculated. I created an average daily grid by adding the hourly grids together in raster calculator, after which maximum daily resolutions were calculated then averaged to obtain monthly maximum resolution grids. All derived land-use, surface-feature, and insolation grids were reclassified to account for no data values, which were assigned a zero, and limited to the spatial extent of the city boundaries. I combined the grids with created shape files to represent land classification within the city boundaries.

Intersected MCP shape files of prairie rattlesnake home ranges were considered indicative of optimized location sites due to species presence and were applied to the final surface grids to extract features occurring with the home range boundaries (Santos *et al.*, 2006). These characteristics then provided model parameters for identifying other areas of the surface grids that were appropriate for occurrence and movements of prairie rattlesnake throughout Lethbridge, as well as identifying accessible corridors between remaining habitat patches (Santos *et al.*, 2006). Once model parameters were established through home range analysis they were directly applied to the previously extracted city grids using the spatial analyst>reclassify and raster calculator tools. Produced output grids were added together to generate a predictive habitat suitability grid for the entire city that took into account habitat fragmentation factors such as concentrated urban residential areas and road density (Santos *et al.*, 2006).

Although presence/absence data can be used to generate an understanding of optimal habitat for a species, it is not necessarily representative of how that species' will respond to barriers or land features. For example, while none of the transmitter-implanted rattlesnakes were observed to cross roads it is evident from previous status reports (Ernst, 2003; Ernst & Quinlan, 2006) and investigation of reported road kills (W. Andrus, unpublished data) that movement attempts occur, though crossing success may be impeded. To better represent risk or impedance to prairie rattlesnake occurrence/movement throughout Lethbridge, AB, I reclassified the habitat suitability

grid through assignment of “costs” to surface features (Clark *et al.*, 2008). Features that were not known to impede prairie rattlesnake occurrence/movement, and were represented in my literature review as having very little associated risk to the species, were given the lowest “cost” values. Features that were known to impede prairie rattlesnake occurrence/movement, and were represented as having substantial associated risks in my literature review, were assigned the highest “cost” values. This allowed me to examine which areas would be optimal for movement events (i.e., appropriate movement corridors) between confirmed prairie rattlesnake occurrence sites and identify areas where habitat fragmentation would likely interfere with movement or species’ occurrence (Clark *et al.*, 2008). Additional prairie rattlesnake observation locations were plotted on the resulting grids to examine if they coincided with areas identified through the modeling to be appropriate for species occurrence and movement, validating the accuracy of the models (Santos *et al.*, 2006).

5.8.2 Weather Effects: I acquired maximum mean, minimum mean, and mean temperatures, as well as total precipitation values for Lethbridge, AB (airport station) from Environment Canada and used these to understand generalities in monthly changes over the field seasons (Environment Canada, 2009). I classified snake activity as basking, shading, in ground, under vegetative cover, under anthropogenic cover, moving, hunting, and mating/courtship activity. I determined whether monthly variation in activity frequency was influenced by weather and investigated potential influences on prairie rattlesnake activity and movement occurrence in Lethbridge, AB using ANOVA (Wund *et al.*, 2007).

6.0 RESULTS

6.1 Limitations and Considerations to the Study of Prairie Rattlesnakes in Lethbridge, AB:

The secretive nature and cryptic colouration of rattlesnake species make location, monitoring and collection of demographic data difficult, even in the most secluded and opportune settings (Sweet, 1985; Vitt, 2001). Amplification of such difficulties is due to characteristics that make prairie rattlesnakes inherently hard to observe such as propensity towards infrequent feeding activity, short activity seasons further limited in northern climates, and use of underground or hidden hibernacula (Gannon & Secoy, 1985; Macartney *et al.*, 1990; Diller & Wallace, 1996; Vitt, 2001). Small size, lowered motility, and more evasive behaviour of younger cohorts further limits the ability of a researcher to represent these groups when sampling the population.

Scientific study of prairie rattlesnakes in an urban environment faces many additional challenges, mainly related to the possibility of negative human perceptions and reactions. Most population and life-history studies of prairie rattlesnakes rely on data obtained through mark-and-recapture studies at or near hibernacula due to the strong fidelity of the species towards their hibernacula. This often involves using drift-nets and pit-fall traps in the region of the hibernacula, which may alert humans and predators to these locations. Discoveries of hibernacula could potentially result in deliberate destruction of hibernacula and animals at a much higher proportion on urban land than on privately owned or government land. In response to this threat, additional security measures are required to avoid harm to prairie rattlesnakes within the city boundaries and use of drift-net fences and pit-fall traps was limited in my study despite their proven field record (Macartney *et al.*, 1990; Kissner *et al.*, 1996; Powell *et al.*, 1998; Jorgenson & Nicholson, 2007).

Restrictions on these commonly used sampling methodologies exaggerate the challenges of sampling prairie rattlesnakes in Lethbridge, leading to theoretically low estimation and misrepresentation of population size for all cohorts. Additionally, in 2005 capturing and handling of younger cohorts was advised against due to concerns about their fragility, limiting

representation of neonatal and juvenile prairie rattlesnakes during my study. Although greater vulnerability of neonates to sub-cutaneous water loss, predation, and temperature fluctuations may lead to higher mortality rates, no definitive examination of increased neonatal or juvenile mortality rates due to researcher handling is available (Price, 1988; Reiserer *et al.*, 2008). Subsequent review of methodologies by both Alberta Fish and Wildlife Division and the University of Lethbridge Animal Care Committee allowed for late-season capture and handling of juvenile cohorts in 2006, allowing better representation of this group in that year.

6.2 Prairie Rattlesnake Distribution, Population Estimates, and Demographics: I captured 48 prairie rattlesnakes in 2005 and 57 in 2006, with 9 individuals captured in both years. Overall, more snakes (47) were captured at the Popson Park study site than Cottonwood Nature Reserve (22) or Bridge View Drive (30). The distribution among sites did not differ significantly in 2005, though it did differ significantly in 2006 ($\chi^2=11.019$; DF=2; P=0.0040) (Figure 7). An additional 7 snakes were reported as occurring outside my study site locations by Alberta Fish and Wildlife or citizens (Figure 7).

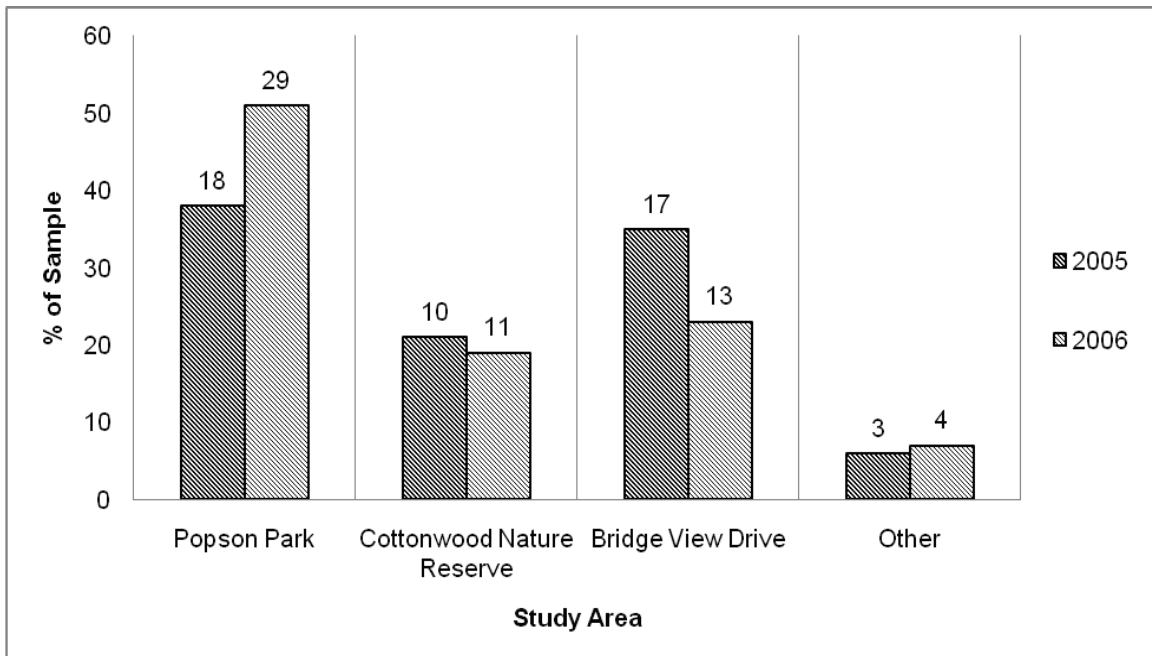


Figure 7: Proportional distribution of 48 prairie rattlesnakes in 2005 and 57 snakes in 2006 at 3 study sites and from other off-site locations. Numerals above each bar indicate the number of snakes at each location in each year.

Ninety-six percent of prairie rattlesnake detections occurred because individuals were occupying the same site as transmitter-equipped individuals. At the completion of my study, PIT-tags had been implanted in 137 rattlesnakes, 82 by me (2005-2006) and 55 through the Lethbridge Rattlesnake Conservation Program (2002-2004). I recaptured 14 LRCP PIT-tagged snakes (13 at the Cottonwood Nature Reserve, 1 at Popson Park). Nine individuals PIT-tagged by me in 2005 were recaptured in 2006. Closed population estimates generated using the Schabel technique predicted that the prairie rattlesnake population in Lethbridge contained ~374 individuals, inclusive of all cohorts, following the conclusion of the 2006 field season (Table 2). A more conservative estimate generated using open population modeling (i.e., Jolly-Seber method) and incorporating confirmed deaths suggested the population is composed of ~204 prairie rattlesnakes, inclusive of all cohorts (Table 2).

Table 2: Population estimations of prairie rattlesnakes occurring in Lethbridge, AB using both open and closed population models and cohort estimation using 2 different aging protocols.

Aging Protocol Author	Population Modelling Technique	Total Population Estimate	Juvenile Population Estimate	Adult Population Estimate
Didiuk (2007), Macartney <i>et al.</i> (1990)	Schabel	~374	79	295
	Jolly-Seber	~204	43	161
Gannon & Secoy (1984)	Schabel	~374	183	191
	Jolly-Seber	~204	100	104

In 2005, 34 prairie rattlesnakes were adults, 7 were juveniles, and 7 could not be assigned age because SVL measurements were not completed. In 2006, 39 prairie rattlesnakes were adults, 14 were juvenile, and 4 could not be assigned age with certainty. SVL was significantly affected by age (adults longer than juveniles, ANOVA, $F=87.02$; $DF=1, 86$; $P<0.0001$) and by sex for the age class juvenile (females longer than males, ANOVA, $F=4.47$; $DF=1, 19$; $P=0.0480$), but not by sex for the age class adult (ANOVA, $F=2.25$; $DF=1, 70$; $P=0.1385$) (Table 3).

Table 3: Average snout-vent length of prairie rattlesnakes in Lethbridge, AB for 2005 and 2006 by age and sex cohorts.

Cohort	2005				2006			
	Mean (cm)	Standard Deviation (cm)	Range (cm)	n	Mean (cm)	Standard Deviation (cm)	Range (cm)	n
All Individuals	83.7	11.4	57.0-106.0	41	79.0	13.7	44.5-106.0	52
Adults	87.3	8.9	70.0-106.0	34	84.9	9.3	65.6-106.0	38
Juveniles	67.0	5.5	57.0-73.0	7	63.1	10.6	44.5-80.5	14
Female Adults	87.9	9.5	75.3-106.0	13	88.0	8.5	75.5-106.0	15
Male Adults	86.6	8.8	70.0-103.0	21	82.9	9.5	65.5-103.0	23
Female Juveniles	68.6	3.7	64.8-73.0	6	65.1	11.3	44.5-80.5	11
Male Juveniles	57.0	N/A	57.0-57.0	1	56.0	1.3	55.0-57.5	3

TL was significantly affected by age (adults longer than juveniles, ANOVA, $F=25.15$; $DF=1, 83$; $P<0.0001$) and by sex for the adult age class (males longer than females, ANOVA, $F=13.28$; $DF=1, 67$; $P=0.0005$), but not for juvenile age class (ANOVA, $F=1.48$; $DF=1, 19$; $P=0.2386$). TL differed significantly by year for adult females (longer in 2006, $\chi^2=33.276$; $DF=16$; $P=0.0068$) and adult males (longer in 2005, $\chi^2=25.849$; $DF=15$; $P=0.0396$) (Table 4).

Table 4: Average tail length of prairie rattlesnakes in Lethbridge, AB for 2005 and 2006 by age and sex cohorts.

Cohort	2005				2006			
	Mean (cm)	Standard Deviation (cm)	Range (cm)	n	Mean (cm)	Standard Deviation (cm)	Range (cm)	n
All Individuals	6.9	2.0	2.4-10.8	39	6.4	1.3	4.0-9.5	51
Adults	7.3	1.9	3.7-10.8	32	7.0	1.1	4.5-9.5	37
Juveniles	4.8	1.2	2.3-6.0	7	5.0	0.6	4.0-6.0	14
Female Adults	6.2	1.6	3.7-9.5	12	6.5	0.9	5.1-8.5	15
Male Adults	8.0	1.7	4.0-10.8	20	7.3	1.2	4.5-9.5	22
Female Juveniles	4.5	1.2	2.2-5.5	6	5.0	0.7	4.0-6.0	11
Male Juveniles	6.0	N/A	6.0-6.0	1	5.2	0.3	5.0-5.5	3

Body mass was significantly affected by the individual snake's age (adults heavier than juveniles, ANOVA, $F=32.82$; $DF=1, 86$; $P=0.0001$), but not by sex for the adult age class (ANOVA, $F=0.44$; $DF=1, 67$; $P=0.5088$) or for the juvenile age class (ANOVA, $F=0.03$; $DF=1, 17$; $P=0.8550$). Mass

differed significantly by year for adults in Popson Park (heavier in 2005, $\chi^2=37.7461$; DF=23; P=0.0271) (Table 5).

Table 5: Average mass of prairie rattlesnakes in Lethbridge, AB for 2005 and 2006 by age and sex cohorts.

Cohort	2005				2006			
	Mean (g)	Standard Deviation (g)	Range (g)	n	Mean (g)	Standard Deviation (g)	Range (g)	n
All Individuals	727.6	221.2	226.8-1474.2	43	492.6	301.0	70.9-1048.9	49
Adults	776.6	207.5	425.2-1474.2	33	562.7	174.2	269.3-1048.9	36
Juveniles	484.3	195.5	226.8-694.6	6	294.9	126.6	70.9-524.5	13
Female Adults	757.8	172.2	496.1-1048.9	13	617.2	161.7	439.4-978.1	13
Male Adults	788.8	231.0	425.2-1474.2	20	531.9	176.8	269.3-1048.9	23
Female Juveniles	516.0	200.6	226.8-694.6	5	280.0	122.1	70.9-503.2	10
Male Juveniles	326.0	N/A	326.0	1	344.9	155.5	255.1-524.5	3

Rattle count was significantly affected by the individual snake's age (adults had more rattles than juveniles, ANOVA, F=6.59; DF=2, 85; P=0.0022), but not by sex for the adult age class (ANOVA, F=1.20; DF=1, 69; P=0.2764) or age for the juvenile age class (ANOVA, F=3.67; DF=1, 17; P=0.0722) (Table 6).

Table 6: Average rattle count of prairie rattlesnakes in Lethbridge, AB for 2005 and 2006 by age and sex cohorts.

Cohort	2005				2006			
	Mean (#)	Standard Deviation (#)	Range (#)	n	Mean (#)	Standard Deviation (#)	Range (#)	n
All Individuals	7	2	2-12	44	6	2	2-11	49
Adults	7	2	2-12	34	7	2	2-11	37
Juveniles	7	2	5-10	7	5	1	3-7	12
Female Adults	7	1	5-10	13	7	1	5-9	14
Male Adults	7	2	2-12	21	7	2	2-11	23
Female Juveniles	7	2	5-10	6	5	1	3-7	9
Male Juveniles	5	N/A	5-5	1	4	1	3-5	3

Sex ratio did not differ significantly from 1:1 for adult prairie rattlesnakes ($\chi^2=3.459$; DF=1; P=0.063) but did differ significantly from 1:1 for juvenile prairie rattlesnakes (more females than males, $\chi^2=7.2000$; DF=1; P=0.0073). Body mass of prairie rattlesnakes was significantly positively correlated to SVL (Pearson's $r=0.725$, $\alpha=0.01$) and TL (Pearson's $r=0.305$, significant at $\alpha=0.01$). SVL was additionally positively correlated to TL (Pearson's $r=0.489$, $\alpha=0.01$) and rattle count, $\alpha=0.01$ (Pearson's $r=0.473$, $\alpha=0.01$). Rattle count and TL were also found to be positively related (Pearson's $r=0.282$, $\alpha=0.01$).

Death of only 1 of the 18 radio-implanted snakes was confirmed. An all-terrain vehicle (ATV) user reported hitting a prairie rattlesnake on 23 July 2005 on the Bridge View Drive study site while using unofficial trails on private land, which was consistent with the location and injuries observed for a dead implanted snake recovered in 25 July 2005. A non-implanted rattlesnake without PIT-tags was collected along the perimeter of the gravel road leading to Cottonwood Nature Reserve and vehicular-related mortality was confirmed from witness descriptions and the condition of the remains. Two other snakes were reportedly hit by a single vehicle within a few minutes of each other on September 4, 2005, but the bodies were not recovered.

6.3 Active Season: Egress from hibernacula occurred 20-26 May 2005 and 18-24 May 2006. Ingress to hibernacula occurred 4-24 September 2005 and 29 August-27 September 2006. The definitive date of the start of hibernation was 25 September in 2005 and 16 October in 2006. Timing of active season did not vary significantly between years (Table 7).

Table 7: Overview of active season length, calculated as date of egress until hibernation, and tracking of transmitter-equipped prairie rattlesnakes in Lethbridge, AB in 2005 and 2006.

	2005				2006			
	Mean	Standard Deviation	Range	n	Mean	Standard Deviation	Range	n
Season Length (days)	110	33	62-145	8	128	23	91-153	9
# Days Tracked	102	31	58-128	8	125	23	89-151	9

6.4 Movement of Transmitter-Implanted Prairie Rattlesnakes: Nine prairie rattlesnakes received a radio-transmitter and were followed using radio-telemetry in each year of my study. All movement variables (average greatest distance moved between consecutive observations, average frequency of movement, average distance moved per day, average distance per movement event, average range length, average cumulative distance moved) indicated that the 9 prairie rattlesnakes implanted in 2005 moved more than the 9 snakes implanted in 2006 (Table 8). Movement per day was significantly affected by study year (individuals moved farther in 2005, ANOVA, $F=6.71$; $DF=1, 11$; $P=0.0251$). Range length was significantly affected by study year (range length longer in 2005, ANOVA, $F=6.53$; $DF=1, 11$; $P=0.0267$). Rayleigh's Z ($n=14$, range=0.04-0.54) revealed no preferred directionality of movement.

Table 8: Movement parameters for transmitter-equipped prairie rattlesnakes in Lethbridge, AB for 2005 and 2006.

	Greatest Linear Distance Moved Between Consecutive Locations (m)	Mean Distance Moved Per Day* (m)	Mean Distance Per Move** (m)	Frequency of Movement	Range Length (m)	Cumulative Distance Moved (m)
2005						
N	8	8	8	8	8	8
Mean	875	42	333	0.62	1159	4240
Standard Deviation	368	16.0	180	0.14	578	2130
Range	400-1420	24-70	140-635	0.41-0.82	489-2109	2320-8890
2006						
N	9	9	9	9	9	9
Mean	444	16	222	0.48	495	1850
Standard Deviation	391	11.8	266	0.27	366	1410
Range	78-1360	4-37	47-912	0.14-0.93	123-1366	520-4870

* Mean Distance Moved Per Day = The average of all linear distance moved by an individual over all days the individual was tracked.

** Mean Distance Per Move = The average of all linear distances moved by an individual between successive relocations.

Average site fidelity was significantly higher in 2006 than 2005 (ANOVA, $F=5.65$; $DF=1, 11$; $P=0.0367$). All home-range variables (95% MCP, 95% KD) and core activity-area variables (50% MCP, 50% KD) indicated prairie rattlesnakes had larger home ranges and core activity areas in 2005 than in 2006 (Table 9). MCP home range areas were significantly affected by study year (larger home ranges in 2005, ANOVA, $F=12.49$; $DF=1, 11$; $P=0.0047$). Fidelity, home range, and core activity values are reflective of the greater movement distances by prairie rattlesnakes in 2005 than in 2006, indicating that snakes spent less time revisiting sites and more time moving to locations further away from their original occurrence sites in the 2005 than 2006.

Table 9: Site fidelity, home range, and core activity area parameters for transmitter-equipped prairie rattlesnakes in Lethbridge, AB for 2005 and 2006.

	Site Fidelity	MCP 95% (ha)	MCP 50% (ha)	KD 95% (ha)	KD 50% (ha)
2005					
N	8	8	8	8	8
Mean	0.42	31.51	8.23	63.75	14.85
Standard Deviation	0.16	17.36	13.56	110.02	22.91
Range	0.16-0.68	6.9-52.40	1.94-41.52	3.39-324.09	0.72-66.7
2006					
N	9	9	7	7	7
Mean	0.64	3.72	1.17	5.89	1.53
Standard Deviation	0.22	3.98	1.61	8.23	2.20
Range	0.19-0.91	0.09-10.31	0.02-4.20	0.74-23.31	0.17-6.21

6.5 Habitat Use by Prairie Rattlesnakes: I verified 15 hibernacula as active in at least 1 season: 6 in Popson Park, 4 in Cottonwood Nature Reserve study site, and 5 at the Bridge View Drive site. I included an artificially created hibernaculum located on the Cottonwood Nature Reserve, which may or may not be used voluntarily during the winter months. Previous reports of a hibernaculum in Cottonwood Nature Reserve could not be verified, though its close location to another active hibernaculum would allow its inclusion as part of the same complex. I included 2 nearby sites on the Bridge View Drive study site as part of the same system. Late season occupancy of an additional area at each of Popson Park and Cottonwood Nature Reserve in

2006, as well as the presence of numerous shed snake skins, could be indicative of hibernacula but spring emergence of rattlesnakes at these sites was not verified. Hibernaculum locations in Lethbridge were found within close proximity (<850 m) to the shoreline of the Oldman River. The majority of sites were on south, south-east or east facing slopes (Figure 8); no hibernacula occurred on a steeper incline than 30°.

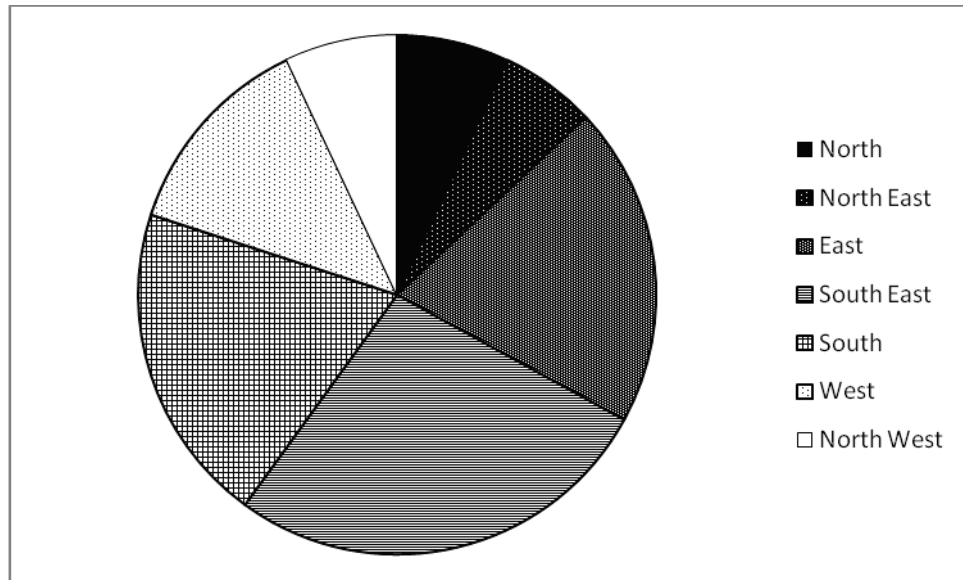


Figure 8: Aspects of 15 prairie rattlesnake hibernacula locations in Lethbridge, AB.

Hibernacula resulting from natural processes such as coulee slumping (n=6) were most often characterized by multiple openings with sizes ranging from approximately 0.05 m to close to 2 m in diameter and had entrance formations that varied in size and shape. These entrances were often heavily terraced, with many sunken areas associated with exposed sides, very loose soils, and sparse vegetative cover (Figure 9). Entrances of hibernacula in association with sagebrush (*Artemisia cana*) or skunkbrush (*Rhus trilobata*) were often through the plant itself, into the crevices created by the roots, or through small holes beyond the vicinity of the plant which may be indicative of small mammals burrowing along the root system. In such circumstances the hibernaculum origin was still deemed to be the result of root system development, since burrowing may be due to ease of excavation along a root system (Nicholson & Rose, 2001; Figure 9).



Figure 9: Hibernacula sites associated with coulee slumping (top) and sagebrush (bottom).

Hibernacula solely associated with abandoned rodent burrows (n=5) were always found in relatively unbroken grassland and entrances were more uniform in size (5-20 cm) and shape than for hibernacula resulting from coulee slumping (Figure 10). Hibernacula associated with human activity or development (n=4) were characterized by large slabs of concrete and iron or were found in vicinity of human-created trails (Figure 10). Whether these hibernacula were further related to coulee slumping, mammal burrowing or root system development could not be

confidently determined, as it was not practical or safe to attempt to move such structures or peer beneath them.



Figure 10: Hibernacula sites associated with an abandoned mammal burrow (top) and concrete (bottom).

Seven functioning rookeries and 1 suspected rookery were confirmed for the 3 study sites. Two rookeries located in Cottonwood Nature Reserve occurred separately from any hibernacula locations. Hibernacula functioned as rookeries in 2 sites located at Popson Park, 2 locations at

Bridge View Drive, and 1 site at Cottonwood Nature Reserve. An additional rookery was suspected in Popson Park due to the discovery of extremely small snake skin sheds at the site, though this location is also suspected to function as hibernacula. Use of an independent rookery on the Popson Park study area was reported by the Lethbridge Rattlesnake Conservation Program (LRCP, R. Ernst, *pers. comm.*, 2005) but was not observed during my study.

Surviving transmitter-implanted prairie rattlesnakes (n=17) in Lethbridge utilized 8 of 23 habitat types (Table 10), of which flood plain/grassland and coulee/grassland accounted for 41% and 47%, respectively, of 456 locations.

Table 10: Utilization of 23 habitat types by 17 prairie rattlesnakes at 456 locations in Lethbridge, AB.

Habitat Type	Number of Snake Locations	Proportion of Snake Locations
City/Other	0	0.00
Lowland/Water	0	0.00
Flood Plain/Grassland	189	0.41
Flood Plain/Cottonwoods	9	0.02
Flood Plain/Cottonwoods/Campground	0	0.00
Flood Plain/Campground	0	0.00
Flood Plain/Dog Run	17	0.04
Flood Plain/Dog Run/Cottonwoods	0	0.00
Flood Plain/Cottonwoods/Golf Course	0	0.00
Flood Plain/Golf Course	0	0.00
Coulee/Grassland	216	0.47
Coulee/Cottonwoods	3	0.01
Coulee/Cottonwoods/Green Spaces	0	0.00
Coulee/Green Spaces	0	0.00
Coulee/Campground	0	0.00
Uplands/Golf Course	0	0.00
Uplands/Green Spaces	4	0.01
Uplands/Green Spaces/Cottonwoods	0	0.00
Uplands/Acreages	0	0.00
Uplands/Urban Residential	0	0.00
Uplands/Other	6	0.01
Uplands/Water	0	0.00
Uplands/Agriculture	12	0.03

Habitat preference by prairie rattlesnakes in Lethbridge occurred at all examined spatial scales (home range, maximum range of movement, study site). Preference for flood plain/grassland occurred at the home range (n=3), maximum movement range (n=7), and study site levels (Bridge View Drive, n=7; Popson Park, n=1). Coulee/grassland habitat was used both preferentially (n=8) and less than expected (n=1) by prairie rattlesnakes at the maximum range of movement level. Preference for the coulee/grassland habitat type was again seen at the study site level (Cottonwood Nature Reserve, n=4), but avoidance occurred at the home range (n=4) and study site (Bridge View Drive, n=3; Popson Park, n=1) levels. Preference for flood plain/dog run habitat occurred at the maximum movement range (n=1) and study site level (Popson Park, n=1). Uplands/agriculture habitat was used less than expected at the home range (n=1), maximum movement range (n=10), and study site (Bridge View Drive, n=6) levels.

6.6 Examination of Habitat Fragmentation on Prairie Rattlesnakes: The habitat suitability grid predicted that the majority of residentially dominated areas and areas of high road density or arterial road types are inappropriate habitats for use by prairie rattlesnakes and therefore are indicative of habitat fragmentation at a species-specific perspective. The river valley and areas surrounding city development remain suitable for snake activity; however, areas developed along the flood plain for recreational activities such as golf courses are highly unsuitable for use by these animals due to costs associated with the increased potential for human/snake conflicts (Figure 11). Validation of the habitat suitability model was successful with all observed snake locations occurring within the areas predicted as being suitable, suggesting the results are reflective of rattlesnake habitat requirements (Figure 11).

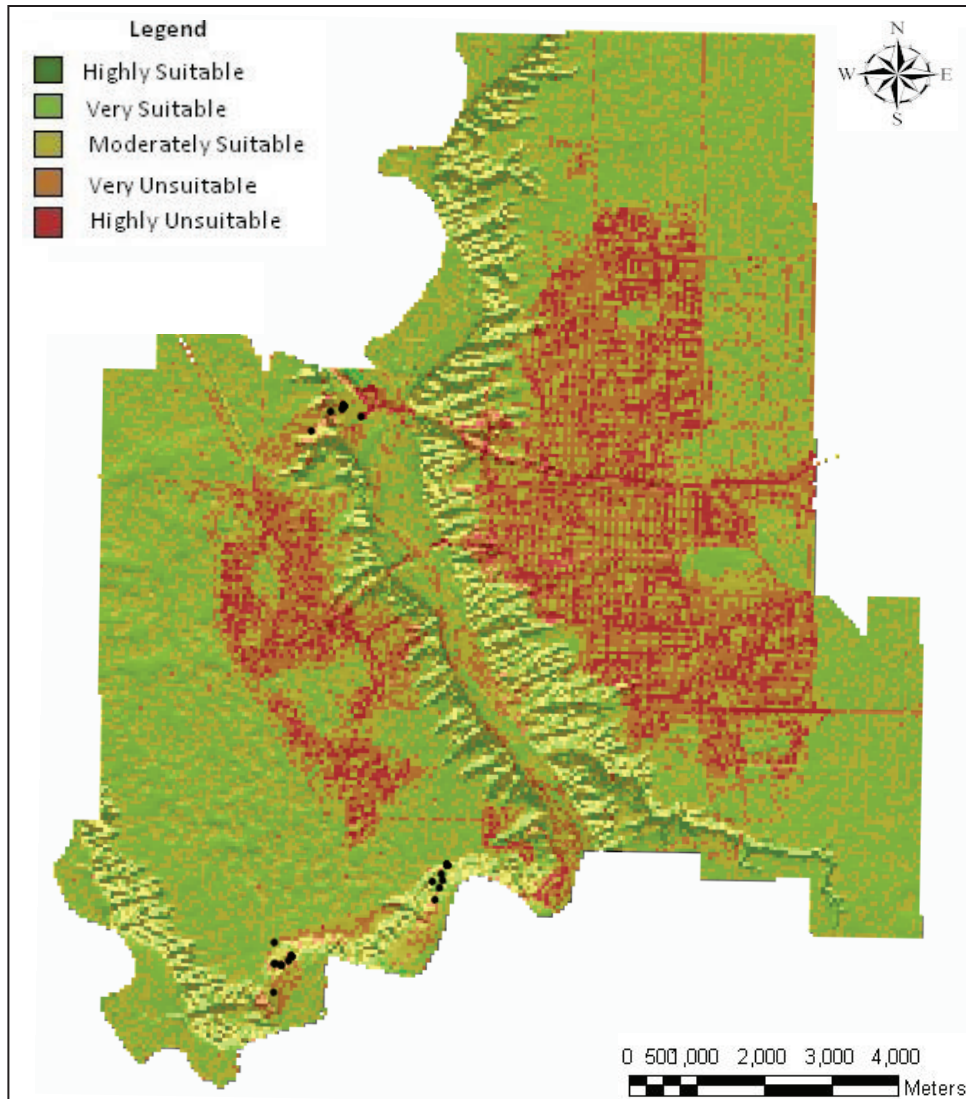


Figure 11: Habitat suitability grid for the prairie rattlesnake in Lethbridge, AB, validated against observed prairie rattlesnake location sites (black dots).

Models exploring cost to movement/occurrence and corridor appropriateness suggest that movements of prairie rattlesnakes in Lethbridge, AB are optimal and have minimized associated cost along the Oldman River Valley and adjacent coulee systems (Figure 12 and Figure 13). Movement corridors are unfavourable on the west side of the city in residential areas (Figure 12) showing greater associated cost (Figure 13). Highly inappropriate areas for prairie rattlesnake movements occur on the east of the river valley due to the greater presence of residential development and human activity (Figure 12) with a high cost associated to these areas (Figure

13). The most unlikely areas for rattlesnake movements (Figure 12) with the highest associated cost (Figure 13) are found along the eastern boundaries of Lethbridge, AB due to the increased distance from the river valley, where remaining suitable habitat patches and known hibernacula occur, and the large amount of habitat fragmentation occurring between eastern Lethbridge and the river valley.

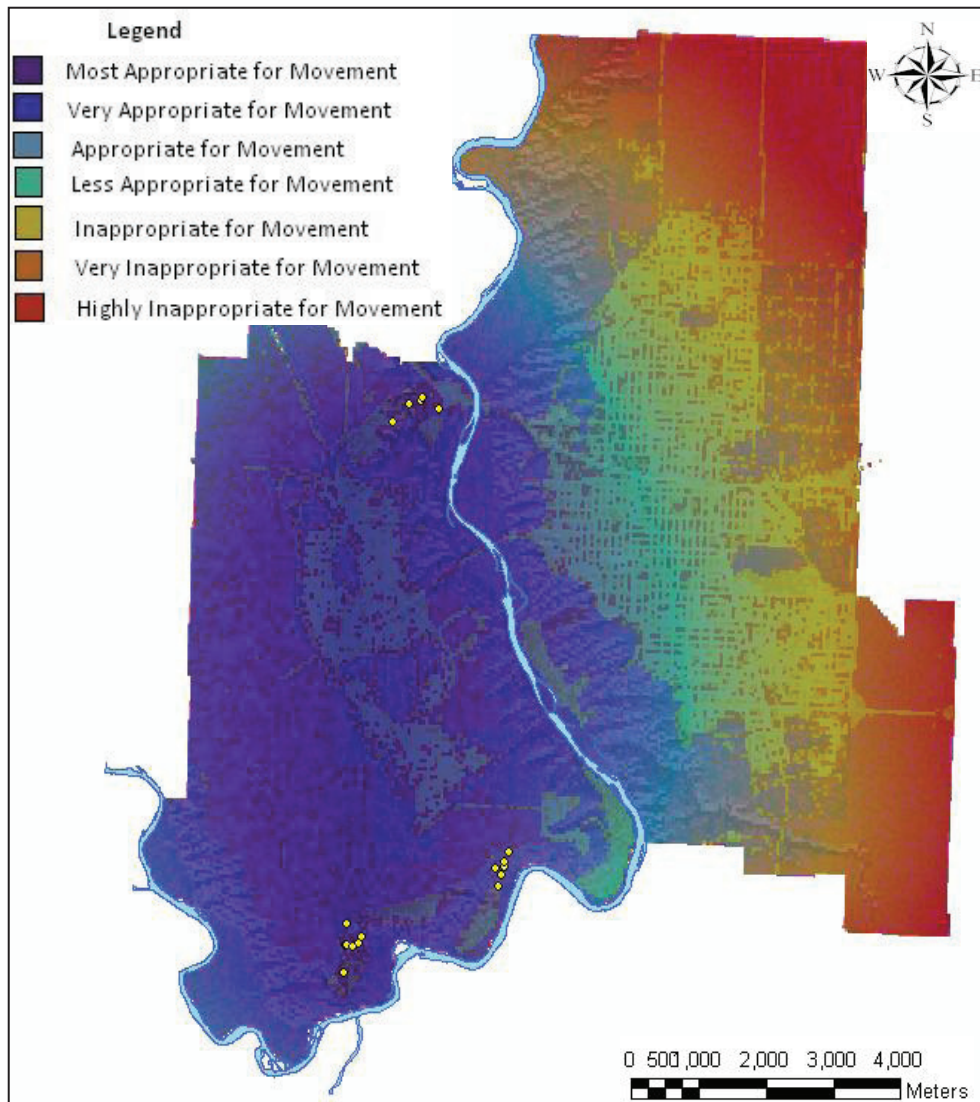


Figure 12: Corridor appropriateness for prairie rattlesnake movement in Lethbridge, AB, based on transmitter-implanted snake locations. Model validated against non-implanted prairie rattlesnake location sites (yellow dots).

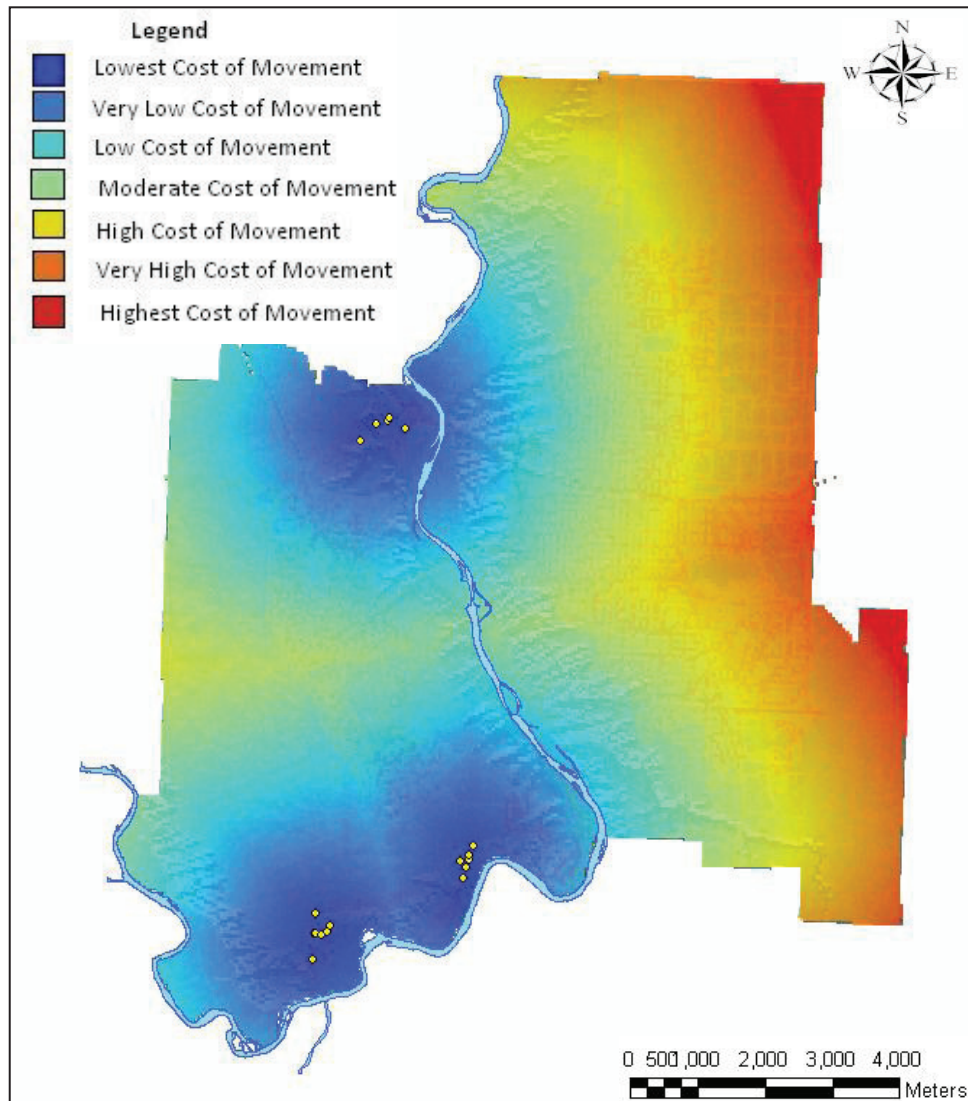


Figure 13: Costs of movement associated with habitat fragmentation and human activity effects for prairie rattlesnakes in Lethbridge, AB, based on transmitter-implanted snake locations. Model validated against non-implanted prairie rattlesnake location sites (yellow dots).

Validations of the models exploring corridor appropriateness and cost associated with movement/occurrence were also successful as observation cases clearly fall within the predicted optimal corridor area (Figure 12) and the predicted lowest cost-distance area (Figure 13). Movement corridors are predicted to exist between all plotted prairie rattlesnake locations (Figure 12). However, while cost of movement is minimal between snake locations occurring in the south-west of the city, there is increased cost to movement between these and those in the north-west of the city (Figure 13). That is to say, cost to movement between Cottonwood Nature

Reserve and Popson Park is minimal, but movement between these study sites and the Bridge View Drive site is more dangerous.

6.7 Weather Effects on Prairie Rattlesnakes: The frequency of basking by prairie rattlesnakes significantly increased with higher monthly minimum temperatures (ANOVA, $F=10.12$; $DF=1, 26$; $P=0.0038$) and mean temperatures (ANOVA, $F=8.28$; $DF=1, 26$; $P=0.0079$). The frequency of shading by prairie rattlesnakes significantly increased with higher monthly maximum temperatures (ANOVA, $F=12.3663$; $DF=1, 26$; $P=0.0016$) and higher mean monthly temperatures (ANOVA, $F=8.50$; $DF=1, 26$; $P=0.0072$). Use of vegetative cover by prairie rattlesnakes significantly increased higher monthly maximum temperatures (ANOVA, $F=9.37$; $DF=1, 26$; $P=0.0051$), higher minimum temperatures (ANOVA, $F=9.51$; $DF=1, 26$; $P=0.0048$), and higher mean monthly temperatures (ANOVA, $F=10.17$; $D=1, 26$; $P=0.0037$).

7.0 DISCUSSION

Understanding of a species' ecology, demographics, movement patterns, and resource use is critical to determining factors affecting its distribution and long-term viability at any location. Prairie rattlesnake populations in Lethbridge, AB are suspected to be in decline, with population size estimated at <50 adults for the 2002-2004 period (Ernst & Quinlan, 2006). Life-history factors, such as biennial reproduction and dependency on limited hibernacula/rookery sites, potentially lead to high vulnerability of populations (Kissner *et al.*, 1996). Ernst & Quinlan (2006) expressed concern for the long-term viability of the prairie rattlesnake population in Lethbridge resulting from habitat fragmentation and alteration and deliberate human harassment.

Mark and recapture techniques implemented in my 2-year study has provided information on population size, cohort proportions, species distribution, and condition of individual prairie rattlesnakes throughout Lethbridge, AB. Calculation of habitat use and preference, observed variation in movement distances and home range sizes, evidence of interaction between study site locations, and examination of habitat fragmentation limitations on the prairie rattlesnakes in Lethbridge provide further information into the degree of isolation, the quality of remaining habitat parcels, and the adaptability of the species to anthropogenic alterations of its natural range occurring throughout the city.

7.1 Prairie Rattlesnake Distribution, Population Estimates, and Demographics: The low number of recaptures between the Lethbridge Rattlesnake Conservation Program (LRCP) and my own study and between study years was somewhat expected due to the secretive nature of the prairie rattlesnake, which makes detection and capture of the species challenging. The difficulty in detecting prairie rattlesnakes is highlighted by the fact that majority of snakes detected during my study occurred either in aggregation or at the same sites as transmitter-equipped individual. The limited use of radio-telemetry by the LRCP may have therefore contributed to the

lower capture success (55 PIT-tagged individuals in 3 years) compared with my study (105 individuals captured and 82 PIT-tagged in 2 years).

My population estimates based on closed (P=374 snakes [295 adults]) and open (P=204 snakes [161 adults]) models differ substantially from Ernst and Quinlan's (2006) estimate of <50 adult prairie rattlesnakes in Lethbridge, regardless of the aging protocol employed. The rattlesnake population is unlikely to have increased two-fold or more between the end of the LRCP study in 2004 and my study in 2005-2006, so the difference in population estimates between studies most likely results from improved detection, in part associated with use of radio-telemetry.

Furthermore, after my study, 38, 10, and 31 rattlesnakes were translocated within Lethbridge in 2007, 2008, and 2009 (B. Downey, *pers. comm.*, 2010), further indicating that the resident population in Lethbridge is greater than 50 adults. Of 31 prairie rattlesnakes checked in 2009 for PIT-tags, 30 were unmarked.

While prairie rattlesnake distribution in 2005 did not vary significantly between study sites, a significantly higher amount of snakes were detected at Popson Park site in 2006 over the Bridge View Drive or Cottonwood Nature Reserve. This suggests annual fluctuations in population sizes at these sites and in Lethbridge may occur and points to the importance of long-term monitoring of the entire Lethbridge population.

During my study, reported prairie rattlesnake mortalities were lower (2 confirmed mortalities in 2 years) than in previous years (15 deaths in 2001-2004; Ernst, 2004; Ernst & Quinlan, 2006).

While lowered mortality rates may reflect the effectiveness of conservation initiatives in the city, annual variations could also be influenced by numerous factors, such as changes in resource quality, human activity in rattlesnake habitat, or lowered predation rates, and require further study. I could not verify 2 reported vehicular mortalities due to failure to locate the carcasses; however, all other mortalities were confirmed as vehicular. Vehicular road mortality continues to be a major threat to the Lethbridge prairie rattlesnake population, with 9 roadside mortalities

occurring in 2009 (B. Downey, *pers. comm.*, 2010), and is a major factor leading to snake species decline (Rosen & Lowe, 1994; Bonnet *et al.*, 1999; Whitaker & Shine, 2000; Enge & Wood, 2002; Aresco, 2005; Richardson *et al.*, 2006; Roe *et al.*, 2006; Row *et al.*, 2007). This suggests that conservation of prairie rattlesnake sub-populations in Lethbridge requires preservation of remaining habitat parcels with limited road development.

Prairie rattlesnakes in my study attained maximum lengths similar to those reported for the species in Saskatchewan (Gannon & Secoy, 1984; Kissner *et al.*, 1996; Macartney & Weichel, 1993), Medicine Hat, AB (Jorgensen & Nicholson, 2007), and previously in Lethbridge, AB, (Ernst, 2003) (Table 11). Prairie rattlesnakes in my study also attained maximum weights similar to those previously reported for the species in Lethbridge, AB (Ernst, 2003) and Saskatchewan (Gannon & Secoy, 1984) and higher than reported for prairie rattlesnakes in Medicine Hat, AB (Jorgensen & Nicholson, 2007) (Table 11). SVL and mass measurements suggest that the ability of prairie rattlesnakes to achieve and maintain typical masses and lengths is not adversely affected by occurrence in an urban setting such as Lethbridge, AB.

Table 11: Overview of maximum snout-vent length and mass for prairie rattlesnakes at various locations.

Author	Location	Maximum Snout-Vent Length (cm)	Maximum Mass (g)
Gannon & Secoy (1984)	Saskatchewan	122	1212
Kissner <i>et al.</i> (1990)	Saskatchewan	117	N/A
Macartney & Weichel (1993)	Saskatchewan	135	N/A
Jorgensen & Nicholson (2007)	Medicine Hat, Alberta	106	406
Ernst (2003)	Lethbridge, Alberta	110	900
Andrus (unpublished data)	Lethbridge, Alberta	106	1474

Variations in body size measures across study sites, sex, or study years may have been artifacts of the number of individuals captured for each cohort. Establishment of trends regarding the physical characteristics of prairie rattlesnakes in Lethbridge is only possible through long-term population monitoring. Mass, SVL, and TL were predicted to be positively correlated in animals

nearing completion of the growth cycle, with adult animals being larger in both length and mass than juveniles (Klauber, 1982), and these predictions were supported by the findings of my study.

While a lack of sexual bias was observed in numbers of adult prairie rattlesnakes, the sex ratio of juveniles was female-biased, suggesting that female survivorship is higher than males in this cohort. As juvenile representation in my study was hampered by advisory restrictions on sampling methodologies, I suggest that these findings are likely an artifact of the low capture and handling rates of juvenile prairie rattlesnakes. However, immediate and continuing research should be focused on better inclusion of the juvenile cohort into population assessments, specifically to determine if sex-biased survivorship is occurring, as this would directly affect the long-term viability of the species in Lethbridge.

7.2 Active Season: Egress and ingress dates within both years of my study coincided closely to those found for prairie rattlesnakes across their geographical range. Vernal emergence of prairie rattlesnakes occurs from mid to late May in Wyoming (King & Duvall, 1990) and the Suffield Base (Didiuk, 1999). Ingress by prairie rattlesnakes typically occurs from late August to early October in Wyoming (King & Duvall, 1990) and the Suffield Base (Didiuk, 1999). Prairie rattlesnakes in Lethbridge are apparently participating in an annual activity cycle that is normal for the species, suggesting at this point they maintain the capacity to respond to their ectothermic limitations and life-history requirements appropriately.

7.3 Movement of Transmitter-Implanted Prairie Rattlesnakes: Comparisons of movement parameters identified in my study to other studies of prairie rattlesnakes were limited due to differences in methodologies, but mean distance per movement event, cumulative movement distances, and angles of movement have been described for other populations. Distances per movement event were longer in 2005 (333 m) and shorter in 2006 (222 m) during my study than was observed for a population of prairie rattlesnakes in Wyoming in consecutive studies (245 m for males and 118 m for females; Duvall *et al.*, 1985; 196 m for males and 133 m for females;

King & Duvall, 1990). Maximum distance ranges for Lethbridge prairie rattlesnakes were also greater in 2005 (range=400-1420 m) and 2006 (range=78-1360 m) than those found for the Arizona study (range=78-365 m; Reed & Douglas, 2002). The cumulative movement distances in 2005 (mean=4.24 km) were also greater than those reported for prairie rattlesnakes in Wyoming (mean=3.51 km for males; 2.76 km for females; King & Duvall, 1990).

No preferred directionality of movement was observed for transmitter-implanted prairie rattlesnakes tracked during my study. Angles of movement calculated for prairie rattlesnakes in Wyoming were $41^{\circ} \pm 73^{\circ}$ for males and $28^{\circ} \pm 75^{\circ}$ for females (King & Duvall, 1990), with males travelling a significantly straighter path than females ($F_{1, 19}=6.53$, $P<0.02$). This indicates that males in the study were more likely to travel along a particular angle than females; however, no individuals travelled a fixed-angle consistently. Movement of Northern Pacific rattlesnakes in British Columbia revealed that some individuals showed fixed-directionality in movement, whereas others did not (Gomez, 2007). Directionality in movements was observed for sidewinders in California only during return to over-wintering areas (Secor, 1995). Similarly, prairie rattlesnakes in the Lethbridge population did not appear to travel in a consistent direction until returning to communal hibernacula, despite fixed-angle movements being reported for the species elsewhere, so individual variation in this type of movement is suggested.

Movement of snakes, such as prairie rattlesnakes, occurs when resource availability or requirements, such as receptive mates, prey sources or shelter sites, change over time or are physically separated (Gregory *et al.*, 2001). Movement, home range or activity area size therefore fluctuates with alterations in these conditions. Long-distance, fixed-angle movements may be unnecessary if prey or mates are evenly distributed or occur within a small area, as seen in Grand Canyon rattlesnakes in Arizona (Reed & Douglas, 2002) and midget-faded rattlesnakes in Wyoming (Ashton, 2003). Low prey availability near hibernacula may result in long-distance movements, as in Northern Pacific rattlesnakes in British Columbia (Gomez, 2007). Limited long-distance movement and home range or core activity area size for prairie rattlesnakes in

Lethbridge could provide further indication that resource quality is adequate in remaining habitat parcels throughout the city. Differences in movement response, home range, and activity area sizes amongst individuals, sexes or species may be influenced by a variety of factors including size of the snake, interrelation with other animals (e.g., conspecifics, predators, humans, etc.), life-history requirements (e.g., ecdysis, reproduction, prey availability), geographical location, and environmental fluctuations (e.g., temperature) (Macartney *et al.*, 1988; Gibbons & Semlitsch, 2001; Gregory *et al.*, 2001). Changes in prairie rattlesnake movement or habitat use in Lethbridge over time may provide evidence of the modification of natural movement patterns by the species in response to fragmentation occurring within city boundaries.

Successful movement of 1566 m by a transmitter-implanted prairie rattlesnake between Popson Park and the Cottonwood Nature Reserve provided evidence that the remaining habitat tract between the 2 sites is sufficient to allow immigration or emigration amongst sub-populations. Migration of snakes from the Cottonwood Nature Reserve to hibernacula adjacent and across the river means intermingling with prairie rattlesnake populations outside the city is probable (Ernst & Quinlan, 2006). Movement between Popson Park and the Cottonwood Nature Reserve, along with crossing of the river by a transmitter-equipped individual from Popson Park, indicates the possibility of successful snake movement to areas outside of the city. Complete isolation of these sub-populations has not taken place and is suggestive that the Lethbridge prairie rattlesnake population is still genetically viable

7.4 Habitat Use by Prairie Rattlesnakes: Characteristics of hibernacula that I located in Lethbridge were consistent with elsewhere in Canada. Hibernacula in south-eastern Alberta were also closely associated with the banks of rivers and the sub-surface cavities formed by faulting or slumping along them (Powell *et al.*, 1998; Nicholson & Rose, 2001). Sites were often terraced and characterized by slight depressions, loose soil, fissures, and sagebrush, which provided security and shade at the entrances (Nicholson & Rose, 2001). Mammal burrows were also used as hibernacula, primarily on south aspects where Sun exposure was high (Powell *et al.*, 1998;

Nicholson & Rose, 2001). Nicholson & Rose (2001) reported that entrance sizes ranged from 5 to 60 cm in diameter. The strong similarities between characteristics of prairie rattlesnake hibernacula in Lethbridge and those identified by other studies in Alberta clearly indicate that appropriate habitat for the species is still present within the city, primarily in the coulee/grassland habitat type. Development initiatives that leave large parcels of prairie untouched within the city are needed, as all of naturally occurring hibernacula were centralized in or on the periphery of such parcels.

Prairie rattlesnake rookeries in Wyoming were found in hillside fissures (Graves & Duvall, 1987), and those near Medicine Hat, AB occurred in abandoned burrows or slump blocks, typically along valley breaks or within riparian zones (Jorgenson & Nicholson, 2007). Rookeries at both locations were 30-600 m from a hibernaculum, with a hibernaculum used as a rookery on at least 1 occasion at the Alberta site. In Leader, SK, a rookery was located on a hill summit just above a hibernaculum (Gannon & Secoy, 1985). Locations and descriptions of rookeries in Lethbridge are consistent with these studies, though Lethbridge hibernacula may be more frequently used as rookeries than elsewhere.

Rookery locations are dependent on appropriate site availability in close proximity to hibernacula (Jorgenson & Nicholson, 2007). Increased use of hibernacula as rookeries could suggest a lack of appropriate locations near hibernacula and indicate remaining habitat parcels in Lethbridge are not meeting the species' life-history requirements in this context. It may also be indicative that male and juvenile female prairie rattlesnakes are occupying rookeries during the summer months (due to limitations in available cover, prey patch distributions, mate searching opportunities, etc.) forcing gravid females to remain at hibernacula locations until parturition. Regardless, differences in hibernacula use in Lethbridge compared with other areas is testament to the adaptability of the species and accentuates the importance of remaining hibernacula in the city, whether naturally or artificially created, strongly indicating the need for preservation of these sites.

The use and importance of artificial structures as hibernacula and cover sites for prairie rattlesnakes in Lethbridge, specifically on the Bridge View Drive site, may indicate that appropriate naturally occurring options are becoming limited when compared to areas where human development is less aggressive or less apparent. While Northern Pacific rattlesnakes in British Columbia sometimes utilized anthropogenic material, only 1 of 13 individuals used these features more than naturally occurring rock or wood cover (Bertram *et al.*, 2001). I suggest that use of anthropogenic cover by prairie rattlesnakes in Lethbridge would also be reduced if study sites offered alternative natural cover in the same areas. However, use of anthropogenic structures also illustrates the ability of the species to occupy habitat that is not in natural condition. The population of prairie rattlesnakes at the Bridge View Drive site is maintaining at similar levels to the other study sites, has proven to be reproductively viable, and has continued to produce obviously large and healthy animals. Therefore, while the conditions at the Bridge View Drive site are not pristine, the habitat is capable of fulfilling the life-history requirements of prairie rattlesnakes in terms of providing appropriate hibernacula and cover sites. Given that it is 1 of only 3 verified areas occupied year round by prairie rattlesnakes in Lethbridge, I suggest that efforts be made to protect and maintain the site.

High fidelity to hibernacula is typical for prairie rattlesnakes (Watson & Russell, 1997; Kissner, 2004) and was confirmed in Lethbridge by the return of most individuals to the hibernacula where they were captured. Higher fidelity to individual sites in Lethbridge in 2006 than in 2005 is reflective of the lowered movement frequency and distance in that year. Misrepresentation of site fidelity may occur if individuals were located during movement episodes at a time of rest, rather than at a final destination. Yearly variations in site fidelity could be indicative of annual fluctuations in resource availability in relation to environmental or life-history factors (e.g., high availability of prey near hibernacula or female receptivity changes due to biennial/triennial breeding cycle) and to some degree is reflective of the necessary inclusion of hibernacula appropriate sites into prairie rattlesnake home ranges.

Home range size for prairie rattlesnakes has not been widely documented so comparisons to other studies were not possible. As predicted, MCP analysis of prairie rattlesnake movement in Lethbridge resulted in more reliable home range and core activity area estimates than that of KD analysis, providing lower average home range and activity area sizes with less variance (Dodd & Barichivich, 2007). Variation in home range sizes between years is reflective of the smaller movement distances and higher site fidelity in 2006 than in 2005 and may be indicative of variation in resources availability between years.

Preference of prairie rattlesnakes for flood/plain grassland habitat was observed at all levels of analysis, with no indication of avoidance by any of 17 individuals. Occupancy of this habitat may be necessary to meet a major life-history requirement such as appropriate foraging areas. Preference for flood plain habitat further accentuates the need for consideration of flood plain habitat when employing conservation initiatives, as it is indicative that use of this habitat by prairie rattlesnakes occurs despite human presence for off-leash dog runs and recreation. Alternatively, habitat types that are used preferentially at levels of analysis or by some individuals but not others, such as coulee/grasslands, obviously have characteristics that are of value to prairie rattlesnakes but the importance may fluctuate based on individual needs and opportunities. However, the significance of coulee/grassland to prairie rattlesnakes in Lethbridge cannot be ignored as all hibernacula occurred within this habitat, making it a critical habitat type for meeting the species' ectothermic requirements. The importance of the coulee/grassland habitat type is further emphasized by the fact that utilization of this habitat was seen at all levels of analysis, even when less than expected occupation occurred. It is apparent that prairie rattlesnakes in Lethbridge continue to occur where traditional habitat descriptors for the species are maintained or where development is limited. Appropriate habitat for the species does still exist within the city, allowing species' persistence.

Similarly, while uplands/agriculture was utilized less than expected at all levels of analysis, occasional occupancy of this habitat by prairie rattlesnakes suggests that the habitat does

provide sporadic resource opportunities or movement corridors and should be maintained to ensure continued population health. I suggest that while agricultural practices can potentially be detrimental to prairie rattlesnake populations (e.g., potential mortality due to machinery and alterations to prey base), they allow more natural movement and access than other forms of anthropogenic development (e.g., residential areas or road networks) and some continuance of prey populations and protective covering. This would also be true for dog runs, campgrounds, and acreages, and inclusion of these habitat types in home ranges confirms movement through these areas is still occurring. Although prairie rattlesnakes were capable of accessing human-dominated habitat types, such as urban residential areas or golf courses, utilization or incorporation into home ranges was not seen. This was despite adjacency of 2 study sites to these habitats types and occurrence of at least 1 hibernaculum along the border of an urban residential community.

Analysis of movement patterns revealed no evidence of fixed-directionality in movement by transmitter-equipped prairie rattlesnakes, so all habitat types occurring within the potential maximum range of movement should have been equally accessed. I suggest that the lack of snake occurrence in urban/residential areas, despite high availability, is indicative of deliberate avoidance of this habitat type. Inclusion of other anthropogenic habitat types (acreages/dog runs/campgrounds) in home range areas, which have lower road and human population densities than urban residential areas, suggest that not all human-occupied areas are selected against and provide further evidence that prairie rattlesnakes are undergoing modification of movement patterns to specifically avoid highly concentrated human density or use.

Vegetative ground cover is important for thermoregulation by prairie rattlesnakes in Lethbridge. Unlike anthropogenic and non-vegetative ground cover, vegetative ground cover was accessed more as temperatures climbed regardless of the indicator used. Movement may be limited by extended periods of rain and by extreme cold or heat due to this type of cover seeking behaviour. Increased participation in basking activity in response to decreased mean minimum and average

monthly temperatures and increased use of vegetative cover or shading activity in response to increased mean maximum and average monthly temperatures reflect biological limitations of the species.

Caution needs to be taken when making generalizations regarding snake occurrence, movement, and habitat use within Lethbridge, as natural fluctuations undoubtedly occur in response to environmental variation. Management decisions that have an effect on potential foraging areas or movement corridors should aim towards maximum retention of remaining habitat parcels and connective areas, to compensate for such alterations. Failure to observe animals in habitat tracts that were previously used, or areas where snake presence was expected but not found, should not lead investigators to conclude that these areas are unutilized by the species. Rather, snake presence should be assumed until detailed, long-term examination of the areas can be carried out since climatic shifts may be affecting snake activity and therefore visibility.

7.5 Effect of Habitat Fragmentation on Prairie Rattlesnakes: Confirmation of actual prairie rattlesnake occurrence sites against predicted movement corridors suggests habitat fragmentation factors were correctly incorporated into my model and are affecting distribution of the Lethbridge population. Examination of northern watersnake (*N. sipedon*) movement in Pennsylvania revealed snakes occurring at an urban locale exhibited less movement and greater site fidelity than those occupying natural areas, with mortality being primarily human induced (Pattishall & Cundall, 2008). Modification of movement patterns by the urban population was in response to increased risk of human conflict and associated hazards (Pattishall & Cundall, 2008). Similar modification of movement may be occurring in Lethbridge and explain the reduction in distances moved by snakes and home range sizes from 2005 to 2006 and associated change in site fidelity. When considered with the observed avoidance of urban/residential areas, associated vehicular mortalities, restriction of long-distance movements reported for the species at other locations, and increased use of anthropogenic cover, it becomes clear that habitat fragmentation

effects are having an observable impact on the prairie rattlesnake population in Lethbridge, AB and immediate mitigation is required.

8.0 CONTINUED THREATS TO PRAIRIE RATTLESNAKES AND RECOMMENDATIONS FOR MITIGATION

8.1 Harassment as a Result of Human/Snake Interaction: Human harassment of prairie rattlesnakes, such as deliberate capture, killing, and destruction of hibernacula, contributes to rattlesnake loss in Lethbridge (Ernst, 2002; Ernst & Quinlan, 2006). Negative perception of the species is a hindrance to conservation initiatives, and harassment results in amplified survival pressure. Based on related literature, numerous recommendations towards mitigating human/snake conflicts can be suggested.

Educational programming aimed at altering such perceptions is likely to be the most successful approach for alleviating snake and human conflict in the long term (Whitaker & Shine, 2000). Past implementation of educational programs focused on prairie rattlesnakes in Lethbridge have had some success; however, current public education approaches aimed at snake recovery or understanding may not be as effective as they could be (Ernst, 2004). Conservation or management initiatives must be designed to meet the concerns and requirements of those in close association with the species and requires inclusion of citizens into the process (Pough *et al.*, 2001). Education-directed programming can be used to alter perceptions regarding snakes; however, the means by which information is delivered is influential on the degree to which perceptions are changed (Morgan & Gramann, 1989). Provisions of factual information or exposure opportunities alone have little impact on student understanding or sensitivity towards snakes (Morgan & Gramann, 1989). Rather, implementation of educational approaches that reinforce positive associations with snakes through adult modelling, while delivering factual information and direct exposure opportunities are required to alter student appreciation.

Brochures and posters may do little in the long-term to alter public perception about snakes or nullify the negative attitudes that abound. Programs should be focused on delivering educational messages that encourage emulation of positive behaviours and invite the public to be involved in recovery efforts. These include more direct and interactive approaches such as interpretive walks, guided programs or classroom visits by biologists, and creation of sponsorship programs, as well as continued response to snake related incidences.

Programs need to be aimed at specific user groups in rattlesnake prone areas, such as hikers, park maintenance workers, campers or golfers and should be tailored to user needs and concerns. Unbiased assessment of the effectiveness of current information campaigns should be completed, to assist in allowing better allocation of resources and organization for such programs. Additionally, punishment for deliberate killings or illegal collection and destruction of hibernacula should be implemented with strict adherence to dissuade future incidences, as per the Alberta Wildlife Act. Reduction of accidental human/snake interactions is required, potentially through use and promotion of fencing, mowing or commercial products marketed as snake deterrents around residential areas. Proactive considerations and restrictions on development or activities in areas where prairie rattlesnakes occur may also be effective, but would need to be examined on a case by case basis.

8.2 Habitat Loss and Alteration: Habitat destruction may be the single greatest threat to the continued existence of all snake species (Dodd, 2001). Habitat destruction or degradation is a major factor contributing to population decline of several species of snakes in North America and may lead to changes in population demography and distribution resulting in potential loss of genetic diversity, alterations in behaviour, and reduction in population sizes (Greene & Campbell, 1992; Dodd, 2001). Declines in populations of all rattlesnake species in Canada are directly linked to habitat disturbances (Charland *et al.*, 1993; Watson & Russell, 1997; Rouse & Willson, 2002; Didiuk *et al.*, 2004; SIRART, 2008). The extensive replacement of natural habitat on the south-western side of Lethbridge with urban development is undoubtedly a cause for concern

(Ernst & Quinlan, 2006). If habitat alteration continues at the rates observed since 1991, without contingencies for preservation of remaining connected parcels of appropriate habitat, prairie rattlesnake populations in Lethbridge are unlikely to recover (Ernst & Quinlan, 2006).

Prairie rattlesnake movement and behaviour in Lethbridge are showing some modification in response to habitat fragmentation and alteration, though snakes continue to attempt to traverse between study locations through remaining grassland patches, are using the river to reach locations across from the study sites, and are moving to the farthest peripheries of the study areas. Continued vehicular mortalities on roads intersecting or on park peripheries and observed occurrence of transmitter-implanted animals in ditches along major highways and connective routes accentuate the risks to prairie rattlesnakes in accessing remaining habitat both inside and outside city boundaries.

Habitat conservation is a prerequisite for the survival of a species or population in the long-term, with large-scale conservation management schemes that incorporate many species being the most effective (Dodd, 1993). Whenever financial constraints occur, species conservation in native habitat is more appropriate than relying on unproven techniques such as relocations, and in some cases habitat preservation may be achieved through extension or assignment of park status, creation of reserves or negotiation of conservation easements on private land (Dodd, 1993). Managers should ensure that preserved habitat and wildlife corridors in Lethbridge show large degrees of heterogeneity to meet all life-history requirements of a species. A variety of geographical locations and terrain features should be incorporated to ensure areas of different slopes, elevations, aspects, soil types, vegetative components, ground cover options and subterranean features. Re-examination of development regulations for residential, agricultural, and industrial projects may be necessary to assess their effectiveness at maintaining critical and required habitat for prairie rattlesnakes. Detailed pre-site assessments and surveys of all developments within the coulees and river valley should be standard, with unbiased consideration of long-term impacts of proposed projects on prairie rattlesnake populations. Surveys to

determine snake presence or absence must occur before approval of land development projects within Lethbridge to ensure critical habitat or snake populations will not be negatively impacted. Twelve to 34 surveys per site may be needed to achieve 95% certainty that an area is unoccupied by a given snake species, so absence can only be inferred after snakes have not been observed on numerous occasions (Kery, 2002). I captured and tagged more prairie rattlesnakes during my 2-year study than in the 3 years previous (105 captured and 82 PIT-tagged versus 55 PIT-tagged by LRCP), primarily due to the more intensive and repetitive survey of the study locations resulting from the use of radio-telemetry, reaffirming the need for multiple, in-depth surveys to detect prairie rattlesnake occupancy. Detection probabilities vary by year, month, snake population size, and habitat type, further emphasizing the necessity of thorough searching methodologies throughout the year (Kery, 2002). Thus, the City of Lethbridge and land developers ought to commission such investigations by an experienced, unbiased field herpetologist who does not have ties to either group. Surveying of this nature is consistent with management implementations employed in conservation strategies aimed at protecting other snake species including the eastern indigo (*Drymarchon couperi*; Stevenson *et al.*, 2003).

Mitigation efforts regarding road-side mortality effects on reptile species have been largely unexplored. Roadside drift-net fencing significantly lowers turtle mortality along high-density traffic routes in Florida but reductions in snake mortality has not been confirmed (Aresco, 2005). Employment of drift-net fencing along park/roadside boundaries could provide insight into its effectiveness as a conservation initiative within Lethbridge, both for mitigating road-side mortality and reducing human/snake conflict especially in residential areas. Proven use of culverts by snakes for crossing roads or railroad tracks indicate anthropogenic tunnels assist with safe snake crossing over major thorough-fares and should be considered in Lethbridge in areas with a high degree of road fragmentation, such as Bridge View Drive (Yanes *et al.* 1995). Culverts could increase accessibility of prairie rattlesnakes to areas beyond the study site, such as the Elizabeth Hall Wetlands and the Oldman River, which may allow potential interaction with external sub-

population and access to additional foraging grounds. Further study regarding the application and effectiveness of this management technique in Lethbridge, AB is required.

Ultimately, responsibility lies with resource managers to ensure implementation of the Alberta Wildlife Act and/or any other applicable regulative policies aimed at rattlesnake conservation regardless of development initiatives or mandates. Cooperative stewardship programs, such as conservation easements, voluntary land sales or completion of best management practices, are key approaches for ensuring habitat protection of western rattlesnakes in British Columbia (SIRART, 2008) and should be considered in Lethbridge.

9.0 UPDATE OF ONGOING RESEARCH ACTIVITIES

Recent conservation and research initiatives focused on prairie rattlesnakes in Lethbridge, AB include the development in 2009 of a survey for city residents gauging their current knowledge and understanding of the species. From this survey, it is hoped that creation of an awareness program will be undertaken to further educate and address knowledge gaps related to prairie rattlesnakes (B. Downey, *pers. comm.*, 2010). Outcomes of the survey are not available for review at this time (B. Downey, *pers. comm.*, 2010). New activities have otherwise been restricted to responding to citizen reports of rattlesnake/human interactions and subsequent translocations of collected individuals (B. Downey, *pers. comm.*, 2010) to limit the potential for future rattlesnake/human interaction. Only 1 PIT-tagged prairie rattlesnake has been noted as recaptured during these translocations, and exact distances and origins of translocations are not currently available for review (B. Downey, *pers. comm.*, 2010). Interestingly, citizen reports have indicated observation of rattlesnakes in areas where previous occurrence has been restricted including north-east Lethbridge, Southridge Estates in south-west Lethbridge, and the Lethbridge airport (B. Downey, *pers. comm.*, 2010). Proposed development of the Bridge View Drive study site location continues to be discussed. No prairie rattlesnakes have been marked in the

Lethbridge population since the conclusion of my study in 2006 and further research initiatives have not been pursued.

10.0 RECOMMENDED FUTURE RESEARCH FOCUSES AND FINAL THOUGHTS

Mitigation of factors contributing to prairie rattlesnake population decline in Lethbridge, AB can only begin with in-depth understanding of species requirements and life history. Resource managers face development pressures throughout the city, particularly at Bridge View Drive where a development initiative has recently been proposed. Without extensive, detailed information on species-specific needs and population health, decisions cannot be made without risk to the long-term viability of the rattlesnake population. Examinations of habitat quality, use, modification effects, and association with life-history and behavioural patterns are essential and must be undertaken by the City of Lethbridge and governing bodies. Information on prey abundance, inter-patch connectivity, and activity allocation require immediate focus to determine the importance of varying habitat types to rattlesnake ecology. Mortality rates in relation to roads, recreational, residential, and industrial expansions and the effects of these factors on dispersal and movement patterns specific to the Lethbridge population is required due to its unique presence within an urban setting.

Examination of the genetic structure of the Lethbridge prairie rattlesnake population needs to occur before further management decisions regarding snake relocation, introduction or habitat alterations take place. Collection of scale clippings from individuals processed throughout the course of my study could provide baseline samples for future analysis of DNA that would allow researchers to begin assessing the current degree of genetic heterozygosity, examine inter-population relationships, and better determine the long-term viability of this species (Prior *et al.*, 1997). Determination of genetic diversity in prairie rattlesnake populations would provide insight into suitability of current management schemes and should take place before further development is approved that may result in ecological or physical impediment to the species' natural

movement (Prior *et al.*, 1997). Until an underlying study of this nature is undertaken, managers should exercise extreme caution when considering individual snake translocations beyond the animal's home range area (even if this movement is to an active hibernaculum), movement of sub-populations or approving alterations to parcels of remaining habitat, as such tactics are likely to undermine conservation efforts through alteration of genetic structure. Immediate investigation into the under-represented juvenile sex ratio and mortality rates is highly recommended as population recovery, maintenance, and growth are reliant on survivorship of this cohort.

My study of prairie rattlesnake movement and habitat use in Lethbridge has provided a solid baseline for future research aimed at rattlesnake conservation within the city and provided timely and relevant information to land managers, identifying areas where future effort and resources should be placed. It has also served to reiterate the importance of immediate development of a long-term, scientific and methodical study with emphasis on better assessment of population and genetic structure, habitat use, prey availability, emigration and immigration patterns, and mortality rates and causes. The need for full and immediate preservation of remaining sub-populations and associated habitat parcels is strongly emphasized.

Lethbridge remains unique in its position as an urban centre playing host to the prairie rattlesnake, and the city's contribution to species understanding and continuance needs to be a key consideration in future developments. Responsibility remains with land and resource managers, the scientific community, and the city itself, with joint partnership and cooperation being the only hope for continued maintenance and future sustainability of prairie rattlesnake populations in Lethbridge and surrounding areas. Without protection initiatives and better management of the remaining prairie rattlesnake habitat, conservation strategies for this species within Lethbridge will not be successful. However, long-term commitment to purposefully directed research and consideration of species' conservation during development planning may be the key to assuring a place for the prairie rattlesnake in this region.

REFERENCES

- Alberta Sustainable Resource Development. (2010).
- Andr n, H. (1994). Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat: A review. *Oikos*, 71(3), 355-366.
- Andrews, K., & Gibbons, J. (2005). How do highways influence snake movement? Behavioral responses to roads and vehicles. *Copeia*. 2005(4), 772-782.
- Aresco, M. (2004). Highway mortality of turtles and other herpetofauna at Lake Jackson, Florida, USA, and the efficacy of a temporal fence/culvert system to reduce road kills. In Irwin, C., Garret, P., McDermott, K. (Eds.), *Proceedings of International Conference on Ecology and Transportation-Making Connections* (pp. 433-449). Raleigh: North Carolina State University.
- Aresco, M. (2005). Mitigation measures to reduce highway mortality of turtles and other herpetofauna at a North Florida Lake. *The Journal of Wildlife Management*. 69(2), 549-560.
- Ashton, K. (2001). Body size variation among mainland populations of the western rattlesnakes (*Crotalus viridis*). *Evolution*. 55(12), 2523-2533.
- Ashton, K. (2003). Movement and mating behavior of adult male midget faded rattlesnakes, *Crotalus oreganus concolor*, in Wyoming. *Copeia*. 2003(1), 190-194.
- Ashton, K., & Queiroz, A. (2001). Molecular systematics of the western rattlesnake, *Crotalus viridis* (Viperidae), with comments on the utility of the D-loop in phylogenetic studies of snakes. *Molecular Phylogenetics and Evolution*. 21(2), 179-189.
- Baxley, D., & Qualls, C. (2009). Black pine snake (*Pituophis melanoleucus lodingi*): Spatial ecology and associations between habitat use and prey dynamics. *Journal of Herpetology*. 43(2), 284-293.
- Beaupre, S., Duvall, D., & O'Leile, J. (1998). Ontogenetic variation in growth and sexual size dimorphism in a central Arizona population of the western diamondback rattlesnakes (*Crotalus atrox*). *Copeia*. 1998(1), 40-47.
- Bertram, N., Larsen, K., & Surgenor, J. (2001). *Identification of critical habitats and conservation issues of the western rattlesnake and great basin gopher snake within the Thompson-Nicola region of British Columbia: Final Report for the British Columbia Ministry of Water, Land and Air Protection and the Habitat Conservation Trust Fund*. Victoria, B.C.: Department of Biology, University of Victoria.
- Blouin-Demers, G., Prior, K., & Weatherhead, P. (2002). Comparative demography of black rat snakes (*Elaphe obsoleta*) in Ontario and Maryland. *The Journal of Zoology*. 2002(256), 1-10.

- Bonnet, X., Naulleau, G., & Shine, R. (1999). The dangers of leaving home: dispersal and mortality in snakes. *Biological Conservation*. 89(1999), 39-50.
- Boyce, M. (1992). Population viability analysis. *Annual Review of Ecology and Systematics*. 1992(23), 481-506.
- Brito, J. (2003). Seasonal variations in movement, home range, and habitat use by male *Vipera Latastei* in northern Portugal. *Journal of Herpetology*. 37(1), 155-160.
- Campbell, J., & Brodie, E. (Eds.) (1992). *Biology of the pitvipers*. Tyler, TX: Selva.
- Carr, L., & Fahrig, L. (2001). Effect of road traffic on two amphibian species of differing vagility. *Conservation Biology*. 15(4), 1071-1078.
- Charland, B. (1989). Size and winter survivorship in neonatal western rattlesnakes (*Crotalus viridis*). *Canadian Journal of Zoology*. 67(7), 1620-1625.
- Charland, M., Nelson, K., & Gregory, P. (1993). *Status of the Northern Pacific rattlesnake in British Columbia, working report no. wr-54*. Victoria, B.C.: B.C. Ministry of the Environment, Lands and Parks, Wildlife Branch
- City of Lethbridge. (2009). <http://www.lethbridge.ca/home/Default.htm>
- Clark, D. (1974). The western ribbon snake (*Thamnophis proximus*): Ecology of a Texas population. *Herpetologica*. 30(4), 372-379.
- Cook, R. (1984). *Introduction to Canadian amphibians and reptiles*. Ottawa, O.N.: National Museum of Natural Science.
- Clark, R., Brown, W., Stechert, R., & Zamudio, K. (2008). Integrating individual behaviour and landscape genetics: the population structure of timber rattlesnake hibernacula. *Molecular Ecology*. 17(2008), 719-730.
- Daltry, J., Ross, T., Thorpe, R., & Wuster, W. (1998). Evidence that humidity influences snake activity patterns: A field study of the viper *Calloselasma rhodostoma*. *Ecography*. 21(1), 25-34.
- Department of Geography. (2005). DEM & LANDSAT image for Lethbridge, AB. Lethbridge, A.B.: University of Lethbridge.
- Didiuk, A. (1999). *Reptile and amphibian component report, Canadian Forces Base, Suffield National Wildlife Area, Wildlife inventory*. Edmonton, A.B.: Canadian Wildlife Services, Environment Canada.
- Didiuk, A., Macartney, J., & Gregory, L. (2004). *COSEWIC status report on the western rattlesnake Crotalus oreganus in Canada, in COSEWIC assessment and status report on the western rattlesnake Crotalus oreganus in Canada*. Ottawa, O.N.: Committee on the Status of Endangered Wildlife in Canada.

- Diller, L., & Wallace, R. (1996). Comparative ecology of two snake species (*Crotalus viridis* and *Pituophis melanoleucus*) in southwestern Idaho. *Herpetologica*. 52(3), 343-360.
- Dodd, C. (1993). Chapter 9: Strategies for snake conservation. In Collins, J., & Novak, S. (Eds.). *Snakes: Ecology and behavior* (pp. 363-393). Caldwell, N.J.: The Black Burn Press.
- Dodd, C. (2001). Chapter 15: Status, conservation, and management. Siegel, R., Collings, J., & Novak, S. (Eds). *Ecology and evolutionary biology* (pp. 478-513). Caldwell, N.J.: The Blackburn Press.
- Dodd, C., & Barichivich, W. (2007). Movements of large snakes (*Drymarchon*, *Masticophis*) in north-central Florida. *Florida Scientist*. 70(1), 83-94.
- Dodd, C., & Seigel, R. (1991). Relocation, repatriation and translocation of amphibians and reptiles: Are they conservation strategies that work? *Herpetologica*. 47(3), 336-350.
- Downey, B. (2009). Personal communications.
- Dyer, K. 2004. Habitat use and seasonal activity of selected snakes on John F. Kennedy Space Center, Florida (MSc. Dissertation, University of Central Florida, 2004).
- Durner, G., & Gates, J. (1993). Spatial ecology of black rat snakes on Remington Farms, Maryland. *The Journal of Wildlife Management*. 57(4), 812-826.
- Duvall, D., King, M., & Gutzwiller, K. (1985). Behavioral ecology and ethology of the prairie rattlesnake. *National Geographic Research*. 1(1), 80-111.
- Duvall, D., Goode, M., Hayes, W., Leonhardt, J., & Brown, D. (1990). Prairie rattlesnake vernal migration: Field experimental analyses and survival value. *National Geographic Research*. 6(4), 457-469.
- Duvall, D., & Schuett, G. (1997). Straight-line movement and competitive mate searching in prairie rattlesnakes, *Crotalus viridis viridis*. *Animal Behaviour*. 54(2), 329-334.
- Enge, K., & Wood, K. (2002). A pedestrian road survey of an upland snake community in Florida. *Southeastern Naturalist*. 1(4), 365-380.
- Environment Canada. (2009). http://www.weatheroffice.gc.ca/canada_e.html
- Erickson, W., McDonald, T., Gerow, K., Kern, J., & Howlin, S. (2001). Statistical issues in resource selection studies with radio-marked animals. In Millsaugh, J., & Marzluff, J. (Eds.). *Radio tracking and animal populations* (pp. 209-242). Diego, C.A.: Academic Press.
- Ernst, R. (2005). Personal communications.

- Ernst, R. (2002). *Management and recovery strategies for the Lethbridge population of the prairie rattlesnake, Alberta Species at Risk Report No. 40*. Edmonton, A.B.: Alberta Sustainable Resource and Development, Fish and Wildlife Division.
- Ernst, R. (2003). *Lethbridge prairie rattlesnake conservation project: 2002/2003 progress report, Alberta Species at Risk Report No. 64*. Edmonton, A.B.: Alberta Sustainable Resource and Development, Fish and Wildlife Division.
- Ernst, R. (2004). *Lethbridge rattlesnake conservation project: 2003 progress report, Alberta Species at Risk Report No. 81*. Edmonton, A.B.: Alberta Sustainable Resource and Development, Fish and Wildlife Division.
- Ernst, R., & Quinlan, R. (2006). *Rattlers and people: conserving rattlesnakes in Lethbridge, Alberta Species at Risk Report No. 109*. Edmonton, A.B.: Alberta Sustainable Resource and Development, Fish and Wildlife Division.
- Fahrig, L., Pedlarm, J., Pope, S., Taylor, P., & Wegner, J. (1995). Effect of road traffic on amphibian density. *Biological Conservation*. 73(1995), 177-182.
- Fahrig, L. (1997). Relative effects of habitat loss and fragmentation on population extinction. *The Journal of Wildlife Management*. 61(3), 603-610.
- Fitch, H. (1963). Natural history of the black ratsnake (*Elaphe o. obsoleta*) in Kansas. *Copeia*. 1963(4), 649-658.
- Fitch, H. (2001). Chapter 5: Collecting and life-history techniques. Seigel, R., Collins, J., & Novak, S. (Eds.). *Snakes: Ecology and evolutionary biology* (pp. 143-164). Caldwell, N.J.: The Blackburn Press.
- Fletcher, R. (2006). Emergent properties of conspecific attraction in fragmented landscapes. *The American Naturalist*. 168(2), 207-219.
- French, A., & Poulsen, J. (2002). Multivariate analysis of variance (MANOVA). Retrieved from: <http://www.cheffrench.com/Multivariate%20Analysis%20-%20MANOVA.pdf>
- Gannon, V. (1980). Some aspects of the ecology of the prairie rattlesnake, *Crotalus v. viridis*, in Saskatchewan (Unpubl. MSc. Dissertation, University of Regina, 1980).
- Gannon, V., & Secoy, D. (1984). Growth and reproductive rates of a northern population of the prairie rattlesnake, *Crotalus v. viridis*. *Journal of Herpetology*. 18(1), 13-19.
- Gannon, V., & Secoy, D. (1985). Seasonal and daily activity patterns in a Canadian population of the prairie rattlesnake, *Crotalus viridis viridis*. *Canadian Journal of Zoology*. 63(1), 86-91.
- Gardner-Santana, L., & Beaupre, S. (2009). Timber rattlesnakes (*Crotalus horridus*) exhibit elevated and less variable body temperatures during pregnancy. *Copeia*. 2009(2), 363-368.

- Gerald, G., Bailey, M., & Holmes, J. (2006). Movement and activity range sizes of northern pinesnakes (*Pituophis melanoleucus melanoleucus*) in middle Tennessee. *Journal of Herpetology*. 40(4), 503-510.
- Gibbons, J., Scott, D., Ryan, T., Buhlmann, K., Tuberville, T., & Metts, B. (2000). The global decline of reptiles, déjà vu amphibians. *Bioscience*. 50(8), 653-666.
- Gibbons, J., & Semlitsch, R. (2001). Chapter 13: Activity patterns. Seigel, R., Collins, J., & Novak, S. (Eds.). *Snakes: Ecology and evolutionary biology* (pp. 396–421). Caldwell, N.J.: The Blackburn Press.
- Gibbs, J., & Shriver, G. (2002). Estimating the effects of road mortality on turtle populations. *Conservation Biology*. 16(6), 1647-1652.
- Gomez, L. (2007). Habitat use and movement patterns of the Northern Pacific rattlesnake (*Crotalus o. oreganus*) in British Columbia (MSc. Dissertation, University of Victoria, 2007).
- Graves, B. & Duvall, D. (1987). An experimental study of aggregation and thermoregulation in prairie rattlesnakes (*Crotalus viridis viridis*). *Herpetologica*. 43(2), 259-264.
- Graves, B., & Duvall, D. (1993). Reproduction, rookery use, and thermoregulation in free-ranging, pregnant *Crotalus v. viridis*. *Journal of Herpetology*. 27(1), 33-41.
- Graves, B., & Duvall, D. (1995). Aggregation of squamates reptiles associated with gestation, oviposition and parturition. *Herpetological Monographs*. 9(1995), 102-119.
- Greene, H. (1992). The ecological and behavioural context for pit viper evolution. Campbell, J., & Brodie, E. (Eds.). *Biology of the pitvipers* (pp. 107-117). Tyler, T.X.: Selva.
- Greene, H., & Campbell, J. (1992). The future of pitvipers. Campbell, J., & Brodie, E. (Eds.). *Biology of the pitvipers* (pp. 421-427). Tyler, T.X.: Selva.
- Gregory, P., Macartney, J., & Larsen, K. (2001). Chapter 12: Spatial patterns and movements. Seigel, R., Collins, J., & Novak, S. (Eds.). *Snakes: Ecology and evolutionary biology* (pp. 366-395). Caldwell, N.J.: The Blackburn Press.
- Hardy, D., & Greene, H. (1999). Surgery on rattlesnakes in the field for implantation of transmitters. *Sonoran Herpetologist*. 12(3), 25-27.
- Harrison, S., & Bruna, E. (1999). Habitat fragmentation and large-scale conservation: What do we know for sure? *Ecography*. 22(3), 225-232.
- Hels, T., & Buchwald, E. (2001). The effect of road kills on amphibian populations. *Biological Conservation*. 99(3), 331-340.

- Jenkins, C., & Peterson, C. (2005). Linking landscape disturbance to the population ecology of great basin rattlesnakes (*Crotalus oreganus lutosus*) in the Upper Snake River Plain: *Idaho BLM Technical Bulletin 2005-07*. Idaho State Office: U.S. Department of the Interior Bureau of Land Management.
- Johnson, G. (1995). Spatial ecology, habitat preference, and habitat management of the Eastern Massasauga, *Sistrurus c. catenatus* in a New York Weekly-Minerotrophic Peatland (PhD. Dissertation, State University of New York, 1995).
- Jorgensen, D. (2009). Annual migrations of female prairie rattlesnakes, *Crotalus v. viridis*, in Alberta (MSc. Dissertation, University of Calgary, 2009).
- Jorgensen, D., & Nicholson, J. (2007). *Reproductive biology of female prairie rattlesnakes (Crotalus viridis viridis) in Alberta, Alberta Species at Risk Report No. 103*. Edmonton, A.B.: Alberta Sustainable Resource Development, Fish and Wildlife Division.
- Kapfer, J., Coggins, J., & Hay, R. (2008). Spatial ecology and habitat selection of bullsnakes (*Pituophis catenifer sayi*) at the northern periphery of their geographic range. *Copeia*. 2008(4), 815-826.
- Karns, D., Murphy, J., & Voris, H. (2010). Semi-aquatic snake communities of the central plain region of Thailand. *Tropical Natural History*. 10(1), 1-25.
- Keller, I., & Largiadér, C. (2003). Recent habitat fragmentation caused by major roads leads to reduction of gene flow and loss of genetic variability in ground beetles. *Proceedings of the Royal Society: Biological Sciences*. 270(1513), 417-423.
- Kernohan, B., Gitzen, R., & Millspaugh, J. (2001). Chapter 5: Analysis of animal space use and movements. Millspaugh, J., & Marzluff, J. (pp. 125-166). *Radio tracking and animal populations*. San Diego, C.A.: Academic Press.
- Kery, M. (2002). Inferring the absence of a species: A case study of snakes. *The Journal of Wildlife Management*. 66(2), 330-338.
- King, M., & Duvall, D. (1990). Prairie rattlesnake seasonal migrations: Episodes of movement, vernal foraging and sex differences. *Animal Behaviour*. 39(5), 924-935.
- Kingsbury, B., Roe, J, Herbert, N., & Gibson, J. (2003). *Ecology and status of northern populations of the copperbelly water snake: Final report for the Indiana and Ohio Departments of Natural Resources and the U.S. Fish and Wildlife Service*. Ft. Wayne, I.N.: U.S. Fish and Wildlife Service.
- Kissner, K., Secoy, D., & Forbes, M. (1996). *Annual report: Assessing population size and den use of prairie rattlesnakes (Crotalus viridis viridis) in southern Saskatchewan*. Grasslands National Park, S.K.: Grassland National Park Annual Report.
- Kissner, K., & Nicholson, J. (2003). *Prairie rattlesnake (Crotalus viridis) hibernacula: monitoring history in Alberta 1987-2002, Alberta Species at Risk Report No. 76*. Edmonton, A.B.: Alberta Sustainable Resource Management, Fish and Wildlife Division.

- Kissner, K. (2004). Prairie rattlesnake (*Crotalus viridis viridis*). Downey, B., Downey, B. L., Quinlan, R., Castelli, O., Remesz, V., & Jones, P. (Eds). *MULTISAR: The Milk River Basin project. Habitat suitability models for selected wildlife management species (pp. 112-120), Alberta Species at Risk Report No. 86*. Edmonton, A.B.: Alberta Sustainable Resource Management, Fish and Wildlife Division.
- Klauber, L. (1982). *Rattlesnakes: Their habits, life histories, & influence on mankind*. Los Angeles, C.A.: University of California Press.
- Lagory, K., Walston, L., Goulet, C., Lonkhuyzen, R., Najjar, S., & Andrews, C. (2009). An examination of scale-dependent resource use by eastern hognose snakes in south-central New Hampshire. *Journal of Wildlife Management*. 73(8), 1387-1393.
- Lande, R. (1987). Extinction thresholds in demographic models of territorial populations. *The American Naturalist*. 130(4), 624-635.
- Macartney, M., & Gregory, P. (1988). Reproductive biology of female rattlesnakes (*Crotalus viridis*) in British Columbia. *Copeia*. 1988(1), 47-57.
- Macartney, M., Gregory, P., & Charland, B. (1990). Growth and sexual maturity of the western rattlesnake, *Crotalus viridis*, in British Columbia. *Copeia*. 1990(2), 528-542.
- Macartney, M., Gregory, P., & Larsen, K. (1988). A tabular survey of data on the movements and home ranges of snakes. *Journal of Herpetology*. 22(1), 61-73.
- Macartney, M., & Weichel, B. (1993). *Final report: Population status and biology of the prairie rattlesnake and other reptile species in southwest Saskatchewan, 1990-1991*. Johnson and Weichel Resource Management Consultants Final Report: Saskatchewan Natural History Society (Unpublished Report).
- Madsen, T. (1984). Movements, home range size and habitat use of radio-tracked grass snakes (*Natrix natrix*) in Southern Sweden. *Copeia*. 1984(3), 707-713.
- Marshall, J., Manning, J., & Kingsbury, B. (2006). Movement and macrohabitat selection of the eastern massasauga in a fen habitat. *Herpetologica*. 62(2), 141-150.
- Martin, W. (1992). Phenology of the timber rattlesnake (*Crotalus horridus*) in an unglaciated section of the Appalachian Mountains. In Campbell, J., & Brodie, E. (Eds.). *Biology of the pitvipers (pp. 259-277)*. Tyler, T.X.: Selva.
- McDowell, S. (2001). Chapter 1: Systematics. Seigel, R., Collins, J., & Novak, S. (Eds.). *Snakes: Ecology and evolutionary biology (pp. 3-50)*. Caldwell, N.J.: The Blackburn Press
- Mills, M., Hudson, C., & Berna, H. (1995). Spatial ecology and movements of the brown water snake (*Nerodia taxispilota*). *Herpetologica*. 51(4), 412-423.

- Moore, J., & Gillingham, J. (2006). Spatial ecology and multi-scale habitat selection by a threatened rattlesnake: The Eastern Massasauga (*Sistrurus catenatus catenatus*). *Copeia*. 2006(4), 742-751.
- Morgan, J., & Gramann, J. (1989). Predicting effectiveness of wildlife education programs: A study of students' attitudes and knowledge towards snakes. *Wildlife Society Bulletin*. 17(4), 501-509.
- Nicholson, J., & Rose, R. (2001). *Utilization of air photo interpretation to locate prairie rattlesnakes (Crotalus viridis viridis) hibernacula in the South Saskatchewan River Valley, Wildlife Status Report No. 22*. Edmonton, A.B.: Alberta Environmental Protection, Wildlife Management Division.
- Nishimura, M., & Kamura, T. (1994). Survival rate and sex ratio in Habu, *Trimeresurus flavoviridis* (Viperidae), on the subtropical Okinawa Island, Japan. *Researches on Population Ecology*. 36(1), 115-120.
- Parker, J., & Anderson, S. (2007). Ecology and behavior of midget-faded rattlesnake (*Crotalus oreganus concolor*) in Wyoming. *Journal of Herpetology*. 41(1), 41-51.
- Parker, S., & Brown, W. (1974). Mortality and weight changes of great basin rattlesnakes (*Crotalus viridis*) at a hibernaculum in northern Utah. *Herpetologica*. 30(3), 234-239.
- Pattishall, A., & Cundall, D. (2008). Spatial biology of northern watersnakes (*Nerodia sipedon*) living along an urban stream. *Copeia*. 2008(4), 752-762.
- Peterson, C., Gibson, A., & Dorcas, M. (2001). Chapter 7: Snake thermal ecology: The causes and consequences of body-temperature variation. In Collins, J., & Novak, S. (eds.) 2001. *Snakes: Ecology and behavior* (pp. 241-314). Caldwell, N.J.: The Black Burn Press.
- Pontes, J., Pontes, R., & Rocha, C. (2009). The snake community of Serra do Mendanha, in Rio de Janeiro State, Southeastern Brazil: composition, abundance, richness and diversity in areas with different conservation degrees. *Brazilian Journal of Biology*. 69(3), 795-804.
- Pough, F., Andrews, R., Cadle, J., Crump, M., Savitsky., A., & Wells, K. (2001). *Herpetology*. 2nd Edition. Upper Saddle River, N. J.: Prentice-Hall, Inc.
- Powell, G., Russell, A., Hill, M., O'Brien, N., & Skilnick, J. (1998). *A preliminary investigation of movements, habitat uses, and population trends in the prairie rattlesnakes (Crotalus viridis) in a multiple-use rural landscape in southeastern Alberta: The 1997 field season. Report to Alberta Sports, Recreation, Parks and Wildlife Foundation*. Calgary, A.B.: University of Calgary.
- Price, A. (1988). Observations on maternal behaviour and neonatal aggregation in the Western Diamondback rattlesnake, *Crotalus atrox* (Crotalidae). *The Southwestern Naturalist*. 33(3), 370-373.

- Prior, K., Gibbs, H., & Weatherhead, P. (1997). Population genetic structure in the black rat snake: Implications for management. *Conservation Biology*. 11(5), 1147-1158.
- Reda, I., & Andreas, A. (2003). Solar position algorithm for solar radiation applications. 55 pp.; NREL Report No. TP-560-34302.
- Reed, R., & Douglas, M. (2002). Ecology of the Grand Canyon rattlesnake (*Crotalus viridis abyssus*) in the Little Colorado River Canyon, Arizona. *The Southwestern Naturalist*. 47(1), 30-39.
- Reinert, H. (1992). Radiotelemetric field studies of pitvipers: Data acquisition and analysis. In Campbell, J., & Brodie, E. (Eds.). *Biology of the pitvipers* (pp. 185-198). Tyler, TX: Selva.
- Reinert, H., & Cundall, D. (1982). An improved surgical implantation method for radio-tracking snakes. *Copeia*. 1982(3), 702-705.
- Reiserer, R., Schuett, G., & Earley, R. (2008). Dynamic aggregations of newborn sibling rattlesnakes exhibit stable thermoregulatory properties. *Journal of Zoology*. 274(2008), 277-283
- Richardson, M., Weatherhead, P., & Brawn, J. (2006). Habitat use and activity of prairie kingsnakes (*Lampropeltis calligaster calligaster*) in Illinois. *Journal of Herpetology*. 40(4), 424-428.
- Rodgers, A., Carr, A., Smith, L., & Kie, J. (2005). *HRT: Home range tools for ArcGIS*. Ontario Ministry of Natural Resources, Centre for Northern Forest Ecosystem Research. Thunder Bay, O.N.
- Roe, J., Gibson, J., & Kingsbury, B. (2006). Beyond the wetland border: Estimating the impacts of roads for two species of water snakes. *Biological Conservation*. 130(2), 161-168.
- Rose, S. (2001). *Prairie rattlesnake (Crotalus viridis viridis) monitoring in Alberta-Preliminary investigations (2000)*, Wildlife Status Report No. 28. Edmonton, A.B.: Alberta Environmental Protection, Wildlife Management Division.
- Rosen, P., & Lowe, C. (1994). Highway mortality of snakes in the Sonoran Desert of Southern Arizona. *Biological Conservation*. 68(2), 143-148.
- Rouse, J., & Willson, R. (2002). *Update COSEWIC status report on the massasauga Sistrurus catenatus in Canada, in COSEWIC assessment and update status report on the massasauga Sistrurus catenatus in Canada*. Ottawa, O.N.: Committee on the Status of Endangered Wildlife in Canada.
- Row, J., & Blouin-Demers, G. (2006). Kernels are not accurate estimators of home range size for herpetofauna. *Copeia*. 2006(4), 797-802.
- Row, J., Blouin-Demers, G., & Weatherhead, P. (2007). Demographic effects on road mortality in black ratsnakes (*Elaphe obsoleta*). *Biological Conservation*. 137(1), 117-124.

- Russell, A., & Bauer, A. (1993). *The amphibians and reptiles of Alberta: A field guide and primer of Boreal herpetology*. Edmonton, A.B.: University of Calgary Press & the University of Alberta Press.
- Santos, X., Brito, J., Sillero, N., Pleguezuelos, J., Llorente, G., Fahd, S., & Parellada, X. (2006). Inferring habitat-suitability areas with ecological techniques and GIS: a contribution to assess the conservation status of *Vipera latastei*. *Biological Conservation*. 130(2006), 416-425.
- Seaman, D., & Powell, R. (1996). An evaluation of the accuracy of kernel density estimators for home range analysis. *Ecology*. 77(1996), 2075-2085.
- Secor, S. (1992). A preliminary analysis of the movement and home range size of the sidewinder, *Crotalus cerastes*. Campbell, J., & Brodie, E. (Eds.). *Biology of the pitvipers* (pp. 389-394). Tyler, T.X., Selva
- Secor, S. (1994). Ecological significance of movements and activity range for the sidewinder, *Crotalus cerastes*. *Copeia*. 1994(3), 631-645.
- Secor, S. (1995). Ecological aspects of foraging mode for the snakes *Crotalus cerastes* and *Masticophis flagellum*. *Herpetological Monographs*. 9(1999), 169-186.
- Shepard, D., Dreslik, M., Jellen, B., & Phillips, C. (2008). Reptile road mortality around an oasis in the Illinois Corn Desert with emphasis on the endangered eastern massasauga. *Copeia*. 2008(2), 350-359.
- Shine, R. (1987). Intraspecific variation in thermoregulation, movements and habitat use by Australian blacksnakes, *Pseudechis porphyriacus* (Elapidae). *Journal of Herpetology*. 21(3), 165-177.
- Shine, R., Lemaster, M., Wall, M., Langkilde, T., & Mason, R. (2004). Why did the snake cross the road? Effects of roads on the movement and location of mates by garter snakes (*Thamnophis sirtalis parietalis*). *Ecology and Society*. 9(1), 1-13.
- Slip, D., & Shine, R. (1988). Habitat use, movements and activity patterns of free-ranging Diamond pythons, *Morelia spilota spilota* (Serpentes: Boidae): A radio-telemetric study. *Australian Wildlife Research*. 15(5), 515-531.
- Smith, R., & Smith, T. (1998). *Elements of ecology*, 4th Edition. N.Y.: Addison Wesley Longman.
- Southern Interior Reptile and Amphibian Recovery Team. (2008). *Recovery strategy for the western rattlesnake (Crotalus oreganus) in British Columbia*. Victoria, B.C.: Prepared for the B.C. Ministry of Environment.
- Stevenson, D., Dyer, K., & Willis-Stevenson, B. (2003). Survey and monitoring of the eastern indigo snake in Georgia. *Southeastern Naturalist*. 2(3), 393-408.
- Stevenson, D., Enge, K., Lawrence, C., Dyer, K., Norton, T., Hyslop, N., & Kiltie, R. (2009). An eastern indigo snake (*Drymarchon couperi*) mark-recapture study in southeastern Georgia. *Herpetological Conservation and Biology*. 4(1), 30-42.
- Subach, A., Scharf, I., & Ovadia, O. (2009). Foraging behavior and predation success of the sand viper (*Cerastes vipera*). *Canadian Journal of Zoology*. 87(6), 520-528.

- Sweet, S. (1985). Geographic variation, convergent cyrpsis and mimicry in gopher snakes (*Pituophis melanoleucus*) and western rattlesnakes (*Crotalus viridis*). *Journal of Herpetology*. 19(1), 55-67.
- Taylor, P., Fahrig, L., Henein, K., & Merriam, G. (1993). Connectivity is a vital element of landscape structure. *Oikos*. 68(3), 571-573.
- Templeton, A., Shaw, K., Routman, E., & Davis, S. (1990). The genetic consequences of habitat fragmentation. *Annals of the Missouri Botanical Garden*. 77(1), 13-27.
- Vitt, L. (2001). Chapter 11: Communities. Seigel, R., Collins, J., & Novak, S. (Eds.) *Snakes: Ecology and evolutionary biology* (pp. 335-365). Caldwell, N.J.: The Blackburn Press.
- Waldron, J., Lanham, J., & Bennet, J. (2006). Using behaviourally-based season to investigate canebrake rattlesnake (*Crotalus horridus*) movement patterns and habitat selection. *Herpetologica*. 62(4), 389-398.
- Watson, S., & Russell, A. (1997). *Status of the prairie rattlesnake (Crotalus viridis viridis) in Alberta, Wildlife Status Report No. 6*. Edmonton, A.B.: Alberta Environmental Protection, Wildlife Management Division.
- Weatherhead, P., & Prior, K. (1992). Preliminary observations of habitat use and movements of the eastern massasauga rattlesnake (*Sistrurus c. catenatus*). *Journal of Herpetology*. 26(4), 447-452.
- Webb, J., Brook, B., & Shine, R. (2002). What makes a species vulnerable to extinction? Comparative life-history traits of two sympatric snakes. *Ecological Research*. 17(1), 59-67.
- Whitaker, P., & Shine, R. (2000). Sources of mortality of large Elapid snakes in an agricultural landscape. *Journal of Herpetology*. 34(1), 121-128.
- Whitaker, P., & Shine, R. (2002). Thermal biology and activity patterns of the eastern brownsnake (*Pseudonaja textilis*): A radio-telemetric study. *Herpetologica*. 58(4), 436-452.
- Whitaker, P., & Shine, R. (2003). A radiotelemetric study of movements and shelter site selection by free-ranging brown snakes (*Pseudonaja textilis*, Elapidae). *Herpetological Monographs*. 17(2003), 130-144.
- White, G., & Garrott, R. (1990). *Analysis of wildlife radio-tracking data*. San Diego, C.A.: Academic Press.
- Wilcox, B., & Murphy, D. (1985). Conservation strategy: The effects of fragmentation on extinction. *The American Naturalist*. 125(6), 879-887.
- Wills, C., & Beaupre, S. (2000). An application of randomization for detecting evidence of thermoregulation in timber rattlesnakes (*Crotalus horridus*) from northwest Arkansas. *Physiological and Biochemical Zoology*. 73(3), 325-334.

- Wilson, P., & Provan, J. (2003). Effect of habitat fragmentation on levels and patterns of genetic diversity in natural populations of the peat moss *Polytrichum commune*. *Proceedings of the Royal Society: Biological Sciences*. 270(1517), 881-886.
- With, K., & King, A. (1999). Extinction thresholds for species in fractal landscapes. *Conservation Biology*. 13(2), 314-326.
- Worton, B. (1989). Kernel methods for estimating the utilization distribution in home range studies. *Ecology*. 70(1), 164-168.
- Wund, M., Torocco, M., Zappalorti, R., & Reinert, H. (2007). Activity ranges and habitat use of *Lampropeltis getula getula* (eastern kingsnakes). *Northeastern Naturalist*. 14(3), 343-360.
- Yahner, R. (1996). Habitat fragmentation and habitat loss. *Wildlife Society Bulletin*. 24(4), 592.
- Yanes, M., Velasco, J., & Suárez, F. (1995). Permeability of roads and railways to vertebrates: The importance of culverts. *Biological Conservation*. 71(1995), 217-222.
- Zar, J. (1999). *Biostatistical analysis*, 4th Edition. N.J.: Prentice Hall.

Appendix 1: Life-history information of PIT-tagged prairie rattlesnakes in Lethbridge, AB in 2005, n=48.

Pit-Tag #	Mass (g)	Snout-Vent Length (cm)	Tail Length (cm)	Sex	Rattle Count	Age Class	Study Area
474428	.	.	.	Male	.	.	Cottonwood Reserve
123956445A	1034.76	103.00	.	Male	9	Adult	Popson Park
124422593A	670.00	.	.	Male	.	.	Cottonwood Reserve
124444772A	.	.	.	.	.	.	Cottonwood Reserve
124447752A	864.66	87.45	8.50	Male	7	Adult	Cottonwood Reserve
124658691A	992.23	96.75	.	Female	7	Adult	Cottonwood Reserve
124773120A	.	.	.	Female	.	.	Cottonwood Reserve
124821446A	1048.93	96.00	3.70	Female	7	Adult	Cottonwood Reserve
133355233A	751.26	.	.	Male	8	.	Popson Park
133529637A	666.21	87.25	4.50	Male	7	Adult	Popson Park
133531237A	680.39	73.00	2.25	Female	5	Juvenile	Popson Park
133532247A	694.56	83.50	6.50	Male	8	Adult	Bridge View Drive
133551393A	226.80	64.75	5.50	Female	7	Juvenile	Popson Park
133553557A	524.47	.	.	Female	9	.	Bridge View Drive
133573560A	907.18	82.50	8.00	Male	6	Adult	Bridge View Drive
133644520A	581.17	66.25	4.50	Female	5	Juvenile	Popson Park
133934271A	1091.46	97.50	9.75	Male	7	Adult	Bridge View Drive
133937223A	893.01	81.50	10.75	Male	6	Adult	Popson Park
133939116A	893.01	79.50	8.00	Female	5	Adult	Popson Park
133939445A	737.09	80.50	8.00	Male	7	Adult	Other
133944450A	807.96	.	.	Female	5	.	Popson Park
133956173A	751.26	86.00	5.00	Female	6	Adult	Cottonwood Reserve
134444444A	.	71.25	4.75	Female	7	Juvenile	Bridge View Drive
134465344A	836.31	98.00	5.50	Female	7	Adult	Popson Park
134516537A	637.86	87.00	7.00	Female	10	Adult	Bridge View Drive
134673330A	666.21	76.00	6.75	Male	6	Adult	Popson Park
134712240A	893.01	93.00	8.00	Male	7	Adult	Popson Park
134872246A	722.91	85.00	4.00	Male	3	Adult	Popson Park
135121444A	850.49	79.75	7.53	Male	2	Adult	Popson Park
135131535A	581.17	75.25	5.35	Female	7	Adult	Popson Park
135136114A	694.56	84.50	9.00	Male	7	Adult	Popson Park
135215262A	694.56	65.00	5.25	Female	8	Juvenile	Other
135232710A	581.17	83.50	8.00	Male	12	Adult	Bridge View Drive
135265353A	1474.18	100.00	6.75	Male	6	Adult	Cottonwood Reserve
135314123A	425.24	74.50	8.00	Male	6	Adult	Popson Park
135316123A	623.69	94.50	5.50	Female	8	Adult	Bridge View Drive
135323146A	396.89	71.50	5.00	Female	10	Juvenile	Bridge View Drive
135328722A	.	97.00	10.00	Male	8	Adult	Cottonwood Reserve
135376485A	496.12	82.50	5.75	Female	9	Adult	Bridge View Drive
135424586A	737.09	91.50	9.00	Male	9	Adult	Bridge View Drive
135424763A	326.02	57.00	6.00	Male	5	Juvenile	Bridge View Drive
135461462A	680.39	105.00	9.50	Female	9	Adult	Bridge View Drive
135544597A	609.51	87.50	8.00	Female	8	Adult	Bridge View Drive
135546156A	935.53	79.50	5.75	Female	7	Adult	Bridge View Drive
135558690A	765.44	75.50	5.00	Female	6	Adult	Other
135625366A	552.82	85.00	10.00	Male	7	Adult	Bridge View Drive
135664356A	737.09	96.50	8.50	Male	9	Adult	Bridge View Drive
135671755A	552.82	70.00	9.00	Male	8	Adult	Popson Park

Appendix 2: Life-history information of PIT-tagged prairie rattlesnakes in Lethbridge, AB in 2006, n=57.

PIT-Tag #	Mass (g)	Snout-Vent Length (cm)	Tail Length (cm)	Sex	Rattle Count	Age Class	Study Area
0A00480816	779.61	103.00	9.50	Male	8	Adult	Cottonwood Reserve
123979463A	581.17	87.50	7.00	Female	5	Adult	Cottonwood Reserve
124422593A	623.69	80.50	4.50	Male	7	Adult	Cottonwood Reserve
124424212A	.	.	.	.	.	.	Cottonwood Reserve
124444772A	.	.	.	.	.	.	Cottonwood Reserve
124821446A	893.01	106.00	6.00	Female	.	Adult	Cottonwood Reserve
133531237A	453.59	79.00	6.00	Female	7	Adult	Popson Park
133532247A	666.21	94.00	8.00	Male	4	Adult	Bridge View Drive
133552333A	623.69	87.50	6.00	Male	7	Adult	Popson Park
133644520A	311.84	69.50	5.00	Female	6	Juvenile	Popson Park
133944450A	623.69	98.00	7.25	Female	7	Adult	Popson Park
134444444A	.	.	.	Female	.	.	Bridge View Drive
134872246A	.	.	.	Male	.	Adult	Popson Park
135131535A	510.29	84.50	6.25	Female	9	Adult	Popson Park
135235615A	255.14	55.50	5.00	Male	5	Juvenile	Popson Park
135245335A	255.15	62.00	5.40	Female	5	Juvenile	Bridge View Drive
135256222A	524.47	72.50	7.00	Male	7	Adult	Popson Park
135265353A	1048.93	97.50	6.50	Male	7	Adult	Cottonwood Reserve
135313143A	524.47	83.00	6.50	Male	7	Adult	Popson Park
135316123A	566.99	90.50	5.25	Female	9	Adult	Bridge View Drive
135325534A	340.19	82.50	6.50	Male	5	Adult	Bridge View Drive
135327364A	552.82	83.00	6.00	Female	8	Adult	Popson Park
135345574A	184.27	74.75	5.75	Female	6	Juvenile	Other
135356093A	609.51	90.00	9.00	Male	10	Adult	Popson Park
135361256A	326.02	69.50	4.75	Female	7	Juvenile	Bridge View Drive
135379535A	411.07	73.00	5.50	Female	5	Juvenile	Cottonwood Reserve
135414596A	.	.	.	Male	.	.	Cottonwood Reserve
135448223A	311.84	73.00	5.00	Female	.	Juvenile	Bridge View Drive
135457540A	496.12	86.50	7.00	Male	7	Adult	Popson Park
135473683A	.	88.00	6.00	Female	8	Adult	Cottonwood Reserve
135475791A	566.99	82.50	.	Male	7	Adult	Other
135537585A	425.24	75.00	8.00	Male	2	Adult	Popson Park
135539652A	652.04	89.00	9.00	Male	6	Adult	Other
135564790A	538.64	81.00	7.00	Male	6	Adult	Popson Park
135566615A	538.64	77.50	7.50	Female	6	Adult	Popson Park
135569624A	340.19	75.00	8.00	Male	7	Adult	Cottonwood Reserve
135611545A	581.17	90.50	6.10	Female	8	Adult	Popson Park
135611591A	453.59	79.00	7.00	Male	7	Adult	Popson Park
135614540A	566.99	84.50	7.00	Male	5	Adult	Popson Park
135632380A	978.06	96.00	7.50	Female	7	Adult	Other
135637144A	297.67	69.00	6.25	Male	5	Adult	Bridge View Drive
135644221A	595.34	95.50	9.00	Male	8	Adult	Popson Park
135649134A	524.47	55.00	5.50	Male	3	Juvenile	Popson Park
135662537A	.	61.00	4.25	Female	5	Juvenile	Popson Park
135669497A	.	75.50	5.13	Female	6	Adult	Popson Park
142254574A	226.80	60.50	5.00	Female	.	Juvenile	Popson Park
145152756A	70.87	44.50	4.00	Female	3	Juvenile	Bridge View Drive
145162254A	311.84	65.50	6.50	Male	5	Adult	Popson Park

145175227A	609.51	86.00	8.00	Male	11	Adult	Bridge View Drive
145179251A	198.45	47.50	4.00	Female	4	Juvenile	Bridge View Drive
145223244A	439.42	81.50	6.50	Female	7	Adult	Popson Park
145228337A	552.82	85.50	8.50	Female	6	Adult	Popson Park
145236511A	368.54	72.50	6.75	Male	6	Adult	Popson Park
145259694A	269.32	74.50	7.25	Male	8	Adult	Bridge View Drive
145309273A	503.20	80.50	6.00	Female	7	Juvenile	Popson Park
145515617A	255.15	57.50	5.00	Male	4	Juvenile	Bridge View Drive
145522286A	751.26	96.50	7.00	Female	7	Adult	Popson Park

*Appendix 2 continued.

June 23, 2010

Ms. Wonnita Andrus
Box 1, Bindloss, Alberta T0J 0H0

Dear Ms. Andrus

By this letter, I grant permission for you to use the map of North American distribution of the prairie rattlesnake that appears as Figure 2 in the *Status of the Prairie Rattlesnake (Crotalus viridis viridis) in Alberta* (by S.M. Watson and A.P. Russell, 1997, Wildlife Status Report Number 6) as part of your Master of Science thesis. All content of that report is jointly owned by the Fish and Wildlife Division of Alberta Sustainable Development (SRD) and the Alberta Conservation Association (ACA). We (SRD and ACA) request that any use of Figure 2 credit the original status report as the source of the map. Additionally, the map in Figure 2 was based on information from Stebbins, R.C. 1985. A field guide to western reptiles and amphibians. Houghton Mifflin Company, Boston, MA. 336 pp.; any use of Figure 2 should also cite Stebbins 1985 as the original basis for the map.

Sincerely



Robin Gutsell
Wildlife Status Biologist