SPATIAL ECOLOGY AND LIFE HISTORY OF THE GREAT BASIN GOPHERSNAKE (*PITUOPHIS CATENIFER DESERTICOLA*) IN BRITISH COLUMBIA'S OKANAGAN VALLEY

by

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Abstract

The range of a species often extends across a diverse landscape, necessitating that individuals make different movement and habitat decisions, despite consistent food and shelter requirements. Great Basin gophersnakes (*Pituophis catenifer deserticola*) are threatened in Canada, where they occur at the northern extent of their range in southern interior river valleys of British Columbia such as the Okanagan Valley. I followed 39 radio-transmittered adult gophersnakes at four sites in the Okanagan, to obtain information on life history, movement and range patterns, and habitat use. Habitat selection and movement patterns exhibited by gophersnakes differed between study sites, sexes, and months, indicating that snake choice varies depending on resources and life history traits. Despite these fine-grain differences, males moved more than females in the spring. In addition to this, females moved more than males in the summer and fall. Differences in movement and range were apparent among the study sites. Habitat selection differed by study site, however rock-outcrops were consistently selected overall. Microhabitat selection varied, but retreat sites including logs, rocks, and holes in the ground, were consistently located closer than random. Hibernation sites in the south Okanagan were in rock features, while in the north Okanagan a good proportion were in rodent burrows in hillsides. Hibernation site fidelity was low, and annual reproduction was common. Oviposition sites were on south-facing slopes of moderate grade with little to moderate grass cover. Three ecdysis periods were observed when most or all transmitter-equipped snakes shed their skin.

These findings will be very valuable to species conservation goals in British Columbia when developing guidelines on the habitats and sizes of areas to protect. With an

understanding of the movement and ranges patterns exhibited by individuals, the area required to sustain a healthy population of gophersnakes can be determined. Knowledge of the habitats and microhabitats gophersnakes select makes it possible to identify and protect important areas at sites known to contain gophersnakes, including the Vaseux, Ripley, and Vernon study sites. Characterization of hibernation and oviposition sites allows surveys to identify these areas in locations that may support gophersnakes. Finally, identification of the timing of various important life history behaviours means human disturbance can be avoided during mating and oviposition periods, especially on sites such as Vernon, where land is used for multiple purposes.

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Co-Authorship Statement

Dr. Karen E. Hodges and Dr. Christine Bishop provided assistance in the design and set up of this research, and provided guidance in data analyses and manuscript preparation. I was responsible for all aspects of fieldwork, conducted the data analyses, and wrote the thesis, and I participated fully in project design, being responsible for all but selection of three of the four study sites, which was done by Dr. Christine Bishop.

CHAPTER 1: Introduction

Many species have individuals in multiple habitats across a diverse landscape. Although a species may have uniform food and shelter requirements, differences in movement and habitat decisions may occur when the species' range places them across a varied landscape (e.g. Gregory et al. 1987, Macartney et al. 1988). As a result, findings from one part of a species' range do not necessarily apply to that species across its entire distribution. Both ecological understanding and effective management therefore benefit from studies that address a species' ecology at different locations within its range.

With a mild climate, hot dry summers, and short winters, interior British Columbia's Okanagan Valley is a northerly-extending extrusion containing many habitats and species more common further south, in the United States. Many species are becoming at risk with the ongoing loss of native habitat in the Okanagan. The Okanagan is one of the most endangered and biologically diverse regions in Canada, with over 250 species listed provincially or nationally as at risk (Bezener et al. 2004). Many of the 'at risk' species that occur in the Okanagan occur nowhere else in Canada, and for many of these species, their range extends across a gradient of habitat within the Okanagan unlike habitat occupied further south in their range.

The Great Basin gophersnake (*Pituophis catenifer deserticola*) is one such species, occurring in Canada only in interior British Columbian river valleys. Due to their limited and patchy distribution, gophersnakes are federally Threatened (COSEWIC 2002) and provincially blue-listed (of special concern in BC). Although previous research has described many aspects of species biology for other *Pituophis* species (Burger et al. 1988, 1992, Burger and Zappalorti 1986, 1988, 1989, 1991, 1992, Gerald et al 2006, Himes and Hardy 2006, Himes et al. 2006a, 2006b, Kapfer et al. 2008, Rodriguez-Robles 2002, 2003, Rudolph et al. 2007), the Canadian population of gophersnakes occurs at the northern extent of the species' range, and characteristics of their more southerly relatives may not apply. Furthermore, even within the Okanagan range of the gophersnake, the occupied landscape is varied, creating a need for knowledge of species movement and habitat decisions in a variety of habitat types.

Gophersnakes are oviparous mid-sized constrictors, preying upon small animals such as rodents and birds (Shewchuk 1996). Their predators include skunks (Shewchuk 1996), coyotes, badgers, and foxes (Waye and Shewchuk 2002). Gophersnakes spend a good portion of time underground in rodent tunnels, using these as short-term retreats, winter hibernacula, or while foraging (Rodriguez-Robles 2003).

Snake species vary in the amount of fidelity to specific locations and travel routes (e.g. Rouse 2006). While some species and individuals return yearly to identical shedding, mating, oviposition, and hibernation locations, following the same routes to and from these areas, other species show little fidelity. Movement patterns such as speed and distance moved also vary, even within a species (Gregory et al. 1987, Macartney et al. 1988). Across different regions, home range sizes of a species vary, due to differences in habitat and resources (Gregory et al. 1987, Macartney et al. 1988). Gophersnakes are known to revisit certain locations year to year (Shewchuk 1996). Distances moved to oviposition sites and hibernation sites vary across the species range in British Columbia (Bertram et al. 2001, Shewchuk 1996).

Gophersnakes are found in grassland, shrub-steppe, and rock habitats throughout their range (Bertram et al. 2001, Rodriguez-Robles 2003, Shewchuk 1996). Habitat selection can occur at multiple scales, whether forests or meadows, or logs or shrubs (Dussault et al. 2006, Nams et al. 2006, Newbury and Nelson 2007, Quirt et al. 2006, Roberts and Liebgold 2008). When habitat is selected first at the landscape level in greater proportion to its availability, even when microhabitat availability within habitats is considered, hierarchical habitat selection is occurring (Orians and Wittenberger 1991). Snakes often select habitats based on structure (Theodoratus and Chiszar 2000). Previous work on gophersnakes has identified their habitat preferences. However, no work has been done on microhabitat selection.

Differences in habitat and resource availability as well as seasonality can impact the timing of critical life history characteristics such as reproduction (Shine 2003). At different sites and in different regions, reproduction, hibernation, and foraging behaviours can vary, while an understanding of these basic life history characteristics is critical in adequately understanding and thus conserving species and populations. Gophersnakes in British Columbia emerge from hibernation in early April, mate in May, oviposit in late June or early July, and return to their hibernation sites by mid-October (Bertram et al. 2001, Shewchuk 1996).

In this thesis, I address three main questions about Great Basin gophersnakes in British Columbia's Okanagan Valley. In Chapter 2, I examine movement and range patterns, calculating movement distances and speed as well as range size characteristics. I compare the patterns seen at each study site, and examine whether males or females exhibit different movement and range patterns in different activity seasons. Understanding the movements and range choices snakes make allows comparisons with other regions within the species range. In Chapter 3, I examine hierarchical habitat selection, to determine if gophersnakes select at the habitat level, the microhabitat level, or both. Whether snakes select habitat at the landscape scale or at the microhabitat scale, and whether they select hierarchically, depends on the species, and gives insight into what components of the landscape are important to the species. In Chapter 4, I examine various life history characteristics, quantifying habitats selected for oviposition and hibernation, identifying causes of mortality, and defining the mating, oviposition, and ecdysis periods that gophersnakes in the Okanagan exhibit. With data on these critical life history behaviours, important time periods and habitats can be identified, allowing protection efforts to maximize their efficiency.

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CHAPTER 2: Spatial Ecology of the Great Basin gophersnake (*Pituophis catenifer deserticola*) in British Columbia's Okanagan Valley[1]

Introduction

Snake Spatial Ecology

In North America, snakes have yearly activity patterns, necessitated by seasonality. Snakes hibernate through the colder months, emerge in the spring, mate, forage, lay eggs or give birth, and then go to their hibernation sites. Re-use of movement corridors, specific rock complexes as hibernation or retreat sites, and reproduction grounds are commonly observed in the multiple species occurring on this continent, although species-specific variation in these activity patterns occurs (e.g. Macartney and Gregory 1988, Rouse 2006, Shewchuk 1996).

A variety of factors can affect snake movements. Among other things, a snake's sex, reproductive condition – male, gravid female, or nongravid female, and the time of year affects its movement patterns (Gibbons and Semleitsch 1987, Macartney et al. 1988, Whitaker and Shine 2003). The density of conspecifics can drive movement and range patterns (Pearson et al 2005). In addition, the density of female snakes can influence the movement patterns of males during the mating season (Brown and Weatherhead 1999). While searching for mates, male snakes have been found to increase their own movement frequency, rates, and distances, and also move more than females (Blouin-Demers and Weatherhead 2002, Bonnet et al 1999, Gregory et al. 1987, Jellen et al. 2007, Madsen

[1] A version of this chapter will be submitted for publication.

1984, Rouse 2006). In many areas, oviposition sites can be limiting, and females often make lengthy movements from their hibernation sites to oviposit (Blouin-Demers and Weatherhead 2002, Bonnet et al 1999, Brown et al 2005, Madsen 1984, Shewchuk 1996).

Habitat quality may vary yearly due to climatic factors, which can impact prey populations, as well as alter the suitability of retreat sites and oviposition sites. Yearly differences in prey and retreat site locations may cause snake movement patterns to vary as well. In addition, snakes may learn from their movements during one year and depending on the quality of the area, may either explore a novel area the next year, or return to the same area (Gomez 2007, Rouse 2006, Shewchuk 1996).

In addition to movement differences, snake range characteristics can vary. Depending on the species, home ranges can be large or small, oval or circular, and can vary with site, sex, or year (Gregory et al . 1987, Macartney et al. 1988). In addition, the location of critical features such as oviposition and hibernation sites within that range can vary. Hibernation sites may be close to the edge of an activity range, indicating that snakes move out in one direction from their hibernation site and may move away from it a good distance to find resources (Gomez 2007), or hibernation sites may be closer to the centre of the home range, indicating that resources on all sides of the hibernation site are used. Similarly, oviposition sites may be located centrally or more distally, suggesting that snakes must travel to locate a suitable site and the sites may be limiting (Shewchuk 1996).

Snake activity ranges also vary in size and shape with sex (Pearson et al 2005), and may depend on the behaviour of the opposite sex. For example, when females are clumped, males can have smaller home ranges compared to when females are dispersed (Brown and Weatherhead 1999). Snake activity ranges also vary with site (Macartney et al 1988, Moore and Gillingham 2006). Researching species at multiple sites allows identification of whether a larger scale pattern exists (Weatherhead and Prior 1992). This information enables an understanding of whether site-specific knowledge is applicable to other areas.

Great Basin Gophersnake

Great Basin gophersnakes (*Pituophis catenifer deserticola*) are mid-sized oviparous constrictors that spend a large portion of their time underground in rodent tunnels (Shewchuk 1996). Their range extends throughout much of the western United States and upwards into southern interior British Columbian river valleys, where they are identified as federally Threatened (COSEWIC 2002). Gophersnakes occur in Canada at the northern extent of their range, and thus may exhibit movement patterns that are unlike those shown elsewhere in the species range, and also unlike those of more common species in the Okanagan. In the Okanagan Valley, human development is causing habitat to be lost and fragmented at an alarming rate (Bezener et al. 2004). The limited work that has been done in Canada on gophersnakes has been in the extreme south Okanagan (Shewchuk 1996), and the more northerly Thompson-Nicola river valley (Bertram et al. 2001).

Previous work in British Columbia has indicated that individual gophersnakes tend to revisit certain locations both within and across years (Shewchuk 1996).

Movements to oviposition sites were between 440 and 2188 m (Bertram et al. 2001, Shewchuk 1996), suggesting extensive movements to locate suitable oviposition sites. During summer foraging, individual movements typically are <200 m (Bertram et al. 2001, Shewchuk 1996). In the south Okanagan, Shewchuk (1996) found that three snakes moved on average 934 m between their summer foraging grounds and their hibernation sites, while in the Kamloops area, Bertram et al. (2001) found that three snake return distances averaged 453 m.

Minimum Convex Polygon (MCP) home ranges of gophersnakes in the south Okanagan were 13.9 ha for females (n=7) and 5.3 ha for males (n=5) (Shewchuk 1996), while in the Thompson one female's home range was 25 ha, and two males' home ranges were 5 and 18 ha (Bertram et al. 2001). The large home ranges of female gophersnakes in the south Okanagan were suggested to be due to distant oviposition sites (Shewchuk 1996). In California, Rodriguez-Robles (2003) found that 95% fixed kernel home ranges of four individuals were not always consistent from year to year, and ranged from 0.89 to 1.78 ha in size.

I investigated gophersnake movement and range patterns using radio telemetry to provide insight into the choices that gophersnakes make in British Columbia's Okanagan Valley. I hypothesize that 1) the timing, speed, and amount of movement that snakes exhibit, and the shape and size of ranges that snakes occupy vary with site and sex, and that 2) sex, site, and year are important predictors of variation in movement and range.

Methodology

Study Area

Four study sites were selected in areas known to contain gophersnakes (M. Sarell, pers. comm.), to quantify the characteristics of gophersnakes through their range in British Columbia's Okanagan Valley (Table 3.1, Figure A2.1, Figure A2.2). Three sites were located in the south Okanagan and one in the north; each has distinct habitat characteristics and is situated at different latitudes, enabling comparative work. Ripley Wildlife Habitat Area is a crown land site in the south Okanagan protected for gophersnakes, composed of grassland, open ponderosa pine forests, and exposed rock features; it is adjacent to several houses with associated discarded automobiles and lumber piles that can act as refuges for gophersnakes. Vaseux-Bighorn National Wildlife Area in the south Okanagan is owned by the Canadian Wildlife Service, and contains two sites, one on either side of Vaseux Lake. East Vaseux is composed of a rocky bluff with grassy hills beside Vaseux Lake and Highway 97 (the primary highway running north-south in the Okanagan), while West Vaseux is composed of open ponderosa pine forests, antelope brush meadows, talus slopes, rock faces, and wetlands at a lake edge. In the north Okanagan, the Vernon Department of National Defence site is located on the Vernon Army Camp grounds, just outside of the city of Vernon, and is composed of highly disturbed and invaded grasslands, with infrequent shrubs and rock outcrops.

Table 2.1. Study site descriptions and locations for study sites used in this research; all UTM coordinates are in WGS 84 in Zone 11, in British Columbia's Okanagan Valley. Study site areas are based on total available habitat study site boundaries used for hierarchical habitat selection analyses.

Study Site	UTM east	UTM north	Area (ha)	Elevation (m asl)	Dominant Habitat	Owner
Vaseux East	316038	5464124	40	330 – 475	Grasslands/Rock	Environment Canada
Vaseux West	315005	5463705	90	330 – 595	Open Ponderosa Pine/Antelope Brush	Environment Canada
Ripley Wildlife Habitat Area	310468	5459386	50	435 – 645	Open Ponderosa Pine/Grasslands	British Columbia Ministry of Environment
Vernon Army Camp	316038	5464124	120	485 – 575	Invaded Grasslands	Department of National Defence

Field Methods

Gophersnakes were captured opportunistically through active searching on all sites. When a gophersnake was located, it was placed in an opaque bag for transportation, and then housed in an opaque bin with access to heat and water. Adult gophersnakes (17 females, 22 males) weighing ≥ 240 g were surgically implanted with radio-transmitters (12 g transmitter consisting of less than 5% of their total body mass; Holohil Systems Ltd., Ontario, Canada) between April and June of 2006 and 2007, and removed at the completion of the study in April 2008. Following Willson (2003), transmitters were implanted in the coleomic cavity, with the antenna wire running subcutaneously in a cranial direction in 2006 (Reinert and Cundall 1982) and a caudal direction in 2007. The shift in the methodology was due to several instances of the antenna wire poking through the skin, presumably due to the snakes' underground constrictive movements causing their wire to back up in bends and be forced through the skin. These findings have been observed in other snakes (R. Willson pers. comm.), and once transmitter wire direction was changed, no further problems were observed. Findings from other large-bodied oviparous snakes suggest that although transmitter presence produces slower weight gain, lighter eggs, and has the potential to reduce survival when compared with other snakes, when performed carefully the research outcomes outweigh these impacts (Weatherhead and Blouin-Demers 2004). I had only one instance of a snake with an infected incision site, which may have been due to a predation attempt. The snake's transmitter was removed and after the individual healed completely, it was released at the point of capture. For all snakes, Metacam® (meloxicam 0.1 mg/kg) and Baytril® (enrofloxacin 5 mg/kg) were injected intramuscularly 24 hours preceding surgery, at surgery, and 24 hours post-surgery to reduce pain and swelling. Following a 24 to 48 hour recovery period, each transmitter-equipped gophersnake was released at its capture location.

Each individual was relocated approximately every second day throughout the active season (late March through mid-October). Tracking occurred during daylight hours, typically between 7 am and 7 pm. Homing techniques were used to relocate individuals, with the infrequent exception (occurred <5% of the time) of using triangulation methods when snakes were located in wetland or rock features that did not permit direct access. Upon location of the individual, a GPS location was recorded (Garmin Map76S, accuracy of < 5 m, except when impossible due to interfering rock features).

Spatial data were imported into ArcView v. 3.2 with Spatial Analyst (Environmental Systems Research Institute 1999), and analysed using several extensions, primarily the

Animal Movement Analysis Extension (Hooge and Eichenlaub 1997). Statistical analyses were performed in Microsoft Excel 2003 and 2008 with the Poptools add-in (Hood 2000), and SPSS 12.0 and 16.0 for Windows (SPSS 2003, 2007). Krebs (1989), Manly (1992), and Zar (1984) were used as statistical reference texts.

This work was performed under University of British Columbia Okanagan animal care committee permit number A06-0068, Species At Risk Act permit numbers 59-05-0370 (2005), 6 (2006), 39 and 0068 (2007), and 0074 (2008), and British Columbia Ministry of Environment permit numbers PE06-20868 (2006) and PE07-30716 (2007-2008).

Snake Movement Calculations

Movements that were less than 5 m were not included in all calculations (see Table 2.2), since GPS positions were not always accurate to <5 m. Due to the significant differences in elevation exhibited by some snake movements, for all movements I used the elevation difference along with the calculated straight line difference to calculate the hypotenuse, and used that distance value in subsequent analyses. Distances were calculated for the entire active season from emergence to ingress, or from when snakes were first implanted to when they left the study (through transmitter removal or mortality). Distances were calculated for 3 periods: 1) spring emergence until oviposition, 2) from oviposition until the end of the summer, averaged to include summer foraging and not retreat to hibernation site, and 3) retreat to hibernation site in the fall. Snakes had to be tracked for at least half of the period to be used in data analysis of that period.

I calculated several movement quantities to examine movement patterns over different temporal scales (Gregory et al. 1987, Rouse 2006) (Table 2.2). I calculated the total minimum distance moved during the active season by summing all distances moved between subsequent relocations. I calculated mean distance moved per day by dividing the total distance by the number of days in the activity season, which includes days when no movement occurred. I also calculated the mean distance per movement by averaging the distance moved between relocations, excluding days when no movement occurred. I calculated the average movement rate for each snake, which was used to determine whether males, non-gravid females, or gravid females move faster, as well as whether snakes at different sites or in different months move at different rates. Movement rates in m/h were calculated for each individual, using the distance between subsequent tracking locations and the length of time between relocations. To keep time relatively constant, for movement speed I did not use relocations that occurred >72 h or < 24 h apart.

Table 2.2. Method of calculating movement metrics for location data from telemetry-equipped gophersnakes, including how unit concerns were dealt with.

Metric name	Calculated	Units handled
Total minimum distance moved (m)	Summed all distances moved between subsequent relocations	Did not include relocations that were <5 m
Mean distance moved per day (m/d)	Divided the total distance by the number of days in the activity season	Included days that had movements of <5 m
Mean distance moved per movement (m/movement)	Averaged distance moved between relocations	Did not use days when no movement occurred
Movement speed (m/h)	Averaged the distance moved between subsequent tracking locations after dividing by the length of time between relocations	Did not use relocations that occurred >72 h or <24 h apart

Snake Range Calculations

I calculated the ratio of range width to range length, which reflects the range shape. Values nearer 1 represent activity ranges that are more circular; lower values are more oval (Rouse 2006). This range shape allowed for an analysis of whether different sexes on different sites occupy differently shaped ranges. Range length was defined as the distance between the two most distant telemetry locations of an individual snake (Roth and Greene 2006, Rouse 2006). Range width was calculated using the Rotating Callipers Algorithm (Toussaint 1985) implemented by the ArcView extension Vector Geometry (Patterson and Huber 2004).

In order to characterize the location of the hibernation site within the snake's activity range, I calculated the ratio of maximum distance dispersed away from hibernation site to range length. This ratio is a measure of the snake's dispersal pattern in relation to its hibernation site, with values nearer 1 indicating a hibernation site at the edge of the activity range, and values nearer 0.5 indicating that the hibernation site is close to the range centre (Rouse 2006). The ratio allowed for an analysis of whether different sexes on different sites use the area around their hibernation site differently. Incidences of switching hibernation sites were noted, and the maximum distance dispersed from hibernation site was calculated for each hibernation site.

To define individual home ranges, I calculated 100% minimum convex polygons (MCP). Home ranges were calculated for each active season, and compared between sexes, sites, and years. Minimum Convex Polygons (MCPs) were used due to their common use in gophersnake literature (Rodriguez-Robles 2003, Shewchuk 1996), and due to recent findings that MCPs are the most suitable method for reptile home range area calculations (Row and Blouin-Demers 2007). However, there is much controversy over the use of home ranges in the reptile field (Gregory et al 1987, Row and Blouin-Demers 2007, Tiebout and Cary 1987). The design of the tracking season meant that I did not have hibernation sites from the spring previous to when all snakes laid their eggs. However I consistently had the hibernation site they used in the fall following oviposition, thus distances were calculated from oviposition sites to the subsequent hibernation site.

Statistical Analyses

I used three-way ANOVA with sex, site and year to analyse the movement and range data. Subsequently, I completed additional ANOVA grouping variables that did not show significant interaction effects or individual significance. Tukey post hoc tests were performed on study sites when they were shown to be significant, to determine which sites differed. Most females were gravid both years, thus due to the low number of non-gravid females tracked (n=2), I analyzed females together irrespective of reproductive condition. After initial analyses showed no significant difference between years in the movement data, years were grouped and analysed further using two-way ANOVA looking at sex and site patterns for all movement variables. Similarly, since only one range characteristic showed significant difference between years, years were grouped and the data were analyzed with two-way ANOVA.

Results

Movement

The mean total minimum distance moved by snakes exhibited differences with sex and site (Figure 2.1, Table 2.3). While there was no difference in movement between males and females when the entire active season was used, dividing the data into activity periods showed that males and females moved differently. Males moved further than females in the spring, while females moved further than males in the summer and in the fall.

For the complete active season, males and females did not show differences in movement speed, distance moved per day, or distance moved per movement (Table 2.4). However, sites differed in all of these metrics (Table 2.4, Table A2.2). Snakes at West Vaseux moved at higher speeds and further per movement and per day (3.3±0.3 m/h, 168.7±17.6 m/movement, and 39.3±4.8 m/d respectively, mean ± SE) than snakes at the other three other sites (on average 1.5±0.2 m/h, 83.0±9.3 m/movement, and 16.0±1.3 m/d respectively). Ripley had few snakes, and only one female, thus I also ran all analyses without including the Ripley data; only snake speed showed a different result with the removal of the Ripley data - sex as well as was site significant.

When data across the three activity periods were considered separately, differences appeared (Table 2.4, A2.3). For spring and summer, snakes at West Vaseux had higher movement speeds (0.5-2.5 m/h faster), moved further per movement (50-100 m/movement further), and moved further per day than snakes at other sites (10-30 m/d further). Across all sites in the spring, males had higher movement speeds than females

(1 m/h faster), and in the summer, females moved further per day than males (5-20 m/d further).

In the fall, females moved further per day and per movement than males, although there was a low sample size due to a number of snakes arriving at their dens in late summer or very early in the fall (Table 2.4). In addition, there was an interaction effect between sex and site for mean distance moved per movement; females moved on average 70 m more than males in the south and 27 m less than males in the north (Figure 2.2, Table 2.4, Table A2.3). Mean movement speed had a significant interaction effect between site and sex, due to the low sample size that resulted from some snakes returning to their hibernation sites earlier while others were still actively moving in their summer foraging grounds. As some snakes were not active in the fall active season, there was an interaction effect between site and sex, due to the sole male active in East Vaseux moving until very late in the fall, and the females at West Vaseux also moving back to their hibernation sites very late in the fall.

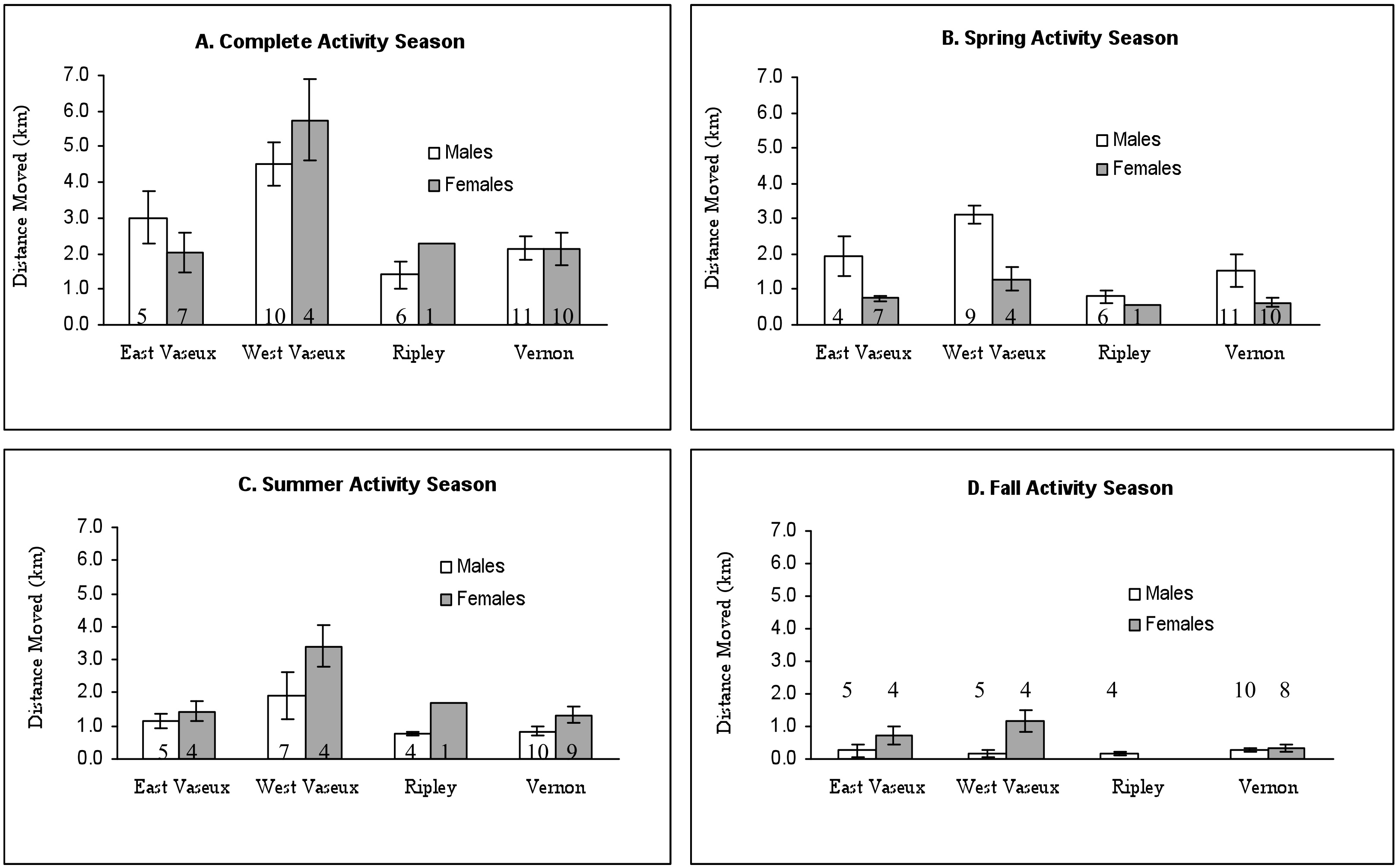

Figure 2.1. Minimum total distance moved during activity periods by site averaged across years. Values are mean +/- SE. Although no statistical difference was observed between individuals of each sex for the complete active season, when data were divided into distinct activity seasons, differences appeared (Table 2). Numbers on bars represent the sample size.

Table 2.3. Statistical results of two-way ANOVAs looking at sex, site, and the interaction of sex and site on minimum total distance moved by gophersnakes over the complete active season as well as all three activity periods. Results from Tukey post hoc tests determining which sites were different can be found in Table A2.2 and A2.3.

	SS	d.f.	F	P
Complete active season (error df=46)				
sex	630972.1	1	0.29	0.594
site	74449236.6	3	11.36	<0.001
sex*site	7757974.7	3	1.18	0.327
Spring activity period (error df=44)				
sex	8469490.7	1	10.26	0.003
site	11193692.6	3	4.52	0.008
sex*site	2233638.7	3	0.90	0.448
Summer activity period (error df=36)				
sex	4474133.8	1	5.00	0.032
site	17575563.1	3	6.55	0.001
sex*site	2222823.3	3	0.83	0.487
Fall activity period (error df=33)				
sex	2051837.2	1	16.61	<0.001
site	863620.8	3	2.33	0.092
sex*site	1223446.3	3	4.95	0.013

Table 2.4. Statistical results of two-way ANOVAs looking at sex and site as predictors of movement by gophersnakes for the complete active season as well as spring, summer, and fall activity periods. Results from Tukey post hoc tests determining which sites were different can be found in Table A2.2 and A2.3.

	SS	d.f.	F	P
Complete active season (error df=46)				
Distance moved per day				
sex	65.9	1	0.56	0.458
site	4243.2	3	12.00	<0.001
sex*site	417.5	3	1.18	0.327
Distance moved per movement				
sex	146.1	1	0.09	0.767
site	51579.1	3	10.43	<0.001
sex*site	9918.2	3	2.01	0.126
Movement speed				
sex	0.06	1	0.10	0.755
site	23.2	3	12.57	<0.001
sex*site	3.3	3	1.78	0.163
Spring activity period (error df=44)				
Distance moved per day				
sex	1473.4	1	9.12	0.004
site	2543.7	3	5.25	0.003
sex*site	389.4	3	0.80	0.499
Distance moved per movement				
sex	5268.5	1	2.40	0.128
site	27901.7	3	4.24	0.010
sex*site	10786.6	3	1.64	0.194
Movement speed				
sex	4.9	1	6.90	0.012
site	12.4	3	5.82	0.002
sex*site	4.2	3	1.98	0.131

	SS	d.f.	F	P
Summer activity period (error df=36)				
Distance moved per day				
sex	2228.2	1	7.87	0.008
site	5056.2	3	5.95	0.002
sex*site	896.7	3	1.06	0.380
Distance moved per movement				
sex	6491.6	1	1.97	0.169
site	35587.6	3	3.61	0.022
sex*site	10405.2	3	1.05	0.381
Movement speed				
sex	3.3	1	3.37	0.075
site	12.6	3	4.34	0.010
sex*site	2.3	3	0.79	0.509
Fall activity period				
Distance moved per day (error df=33)				
sex	1512.7	1	9.52	0.004
site	819.3	3	1.72	0.182
sex*site	737.5	3	2.32	0.114
Movement speed (error df=21)				
sex	1.1	1	0.60	0.447
site	13.6	3	2.53	0.085
sex*site	16.4	3	4.57	0.022

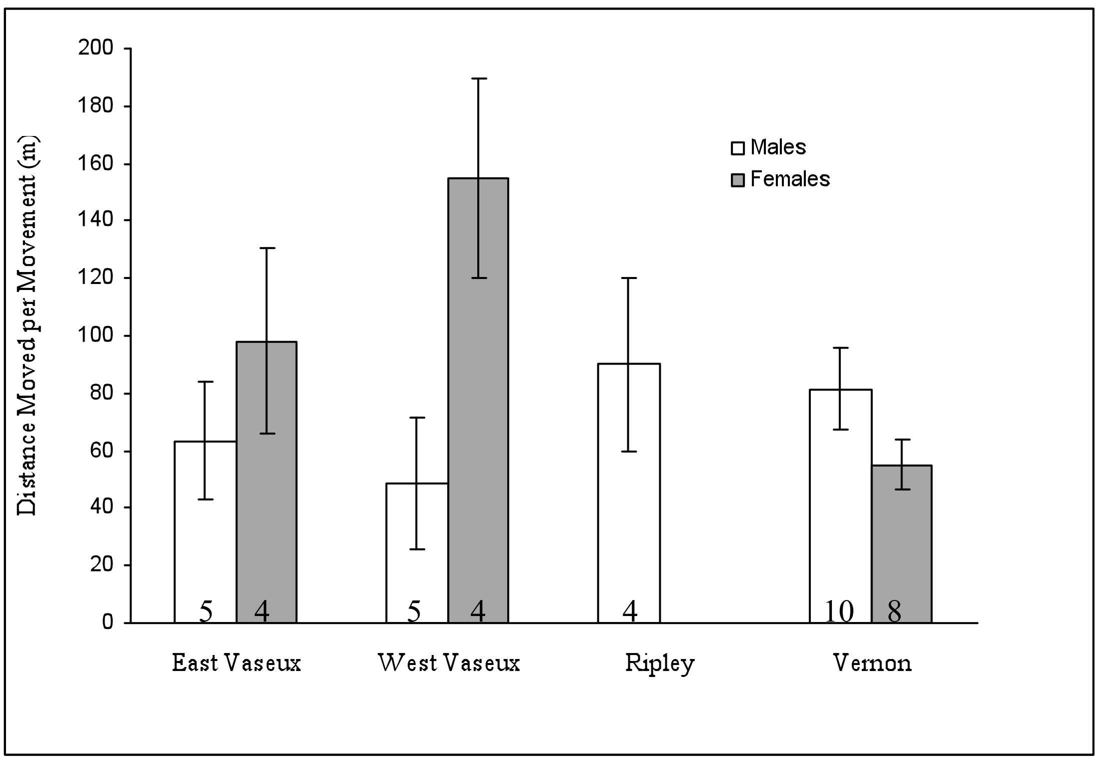

Figure 2.2. Distance moved per movement in the fall active period by site for male and female gophersnakes with year grouped. Values are mean +/- SE. Numbers in bars show sample size. Females moved further per movement than males in the south and less in the north (Table 3). No females were tracked at Ripley in the fall active period. (ANOVA. sex $F_{1,33} = 4.85$, p=0.035, site $F_{3,33} = 1.31$, p=0.287, site*sex $F_{3,33} = 5.57$, p=0.008).

Range Results

There was a significant difference in range length, width, and size between sites, with West Vaseux snakes having longer, wider, and larger ranges (Figure 2.3, Table 2.5). Neither sex nor site impacted the ratio of range width to range length. Site was significant for the maximum distance snakes dispersed from their hibernation site and the distance snakes moved from their hibernation site to their oviposition site, with West Vaseux snakes moving significantly further for both of these metrics than snakes at other sites (Figure 2.3). Snakes dispersed from their hibernation sites different distances each year, and the magnitude of the difference depended on the site (Figure A2.1). However, the main difference was observed at West Vaseux, where snakes dispersed on average 1191 ± 247 m in 2007 compared to only 755 ± 174 m in 2006. Site was significant for the ratio of the maximum distance dispersed from hibernation sites to range length, with Ripley hibernation sites located closer to the edge of the snakes' range than at the other sites, and Vernon hibernation sites located closer to the centre of the snakes' range than at the other sites (Figure 2.3). Snakes in the middle of the season were further dispersed from their hibernation sites than early and late in the season, with snakes at West Vaseux dispersing the earliest and the furthest (Figure 2.4).

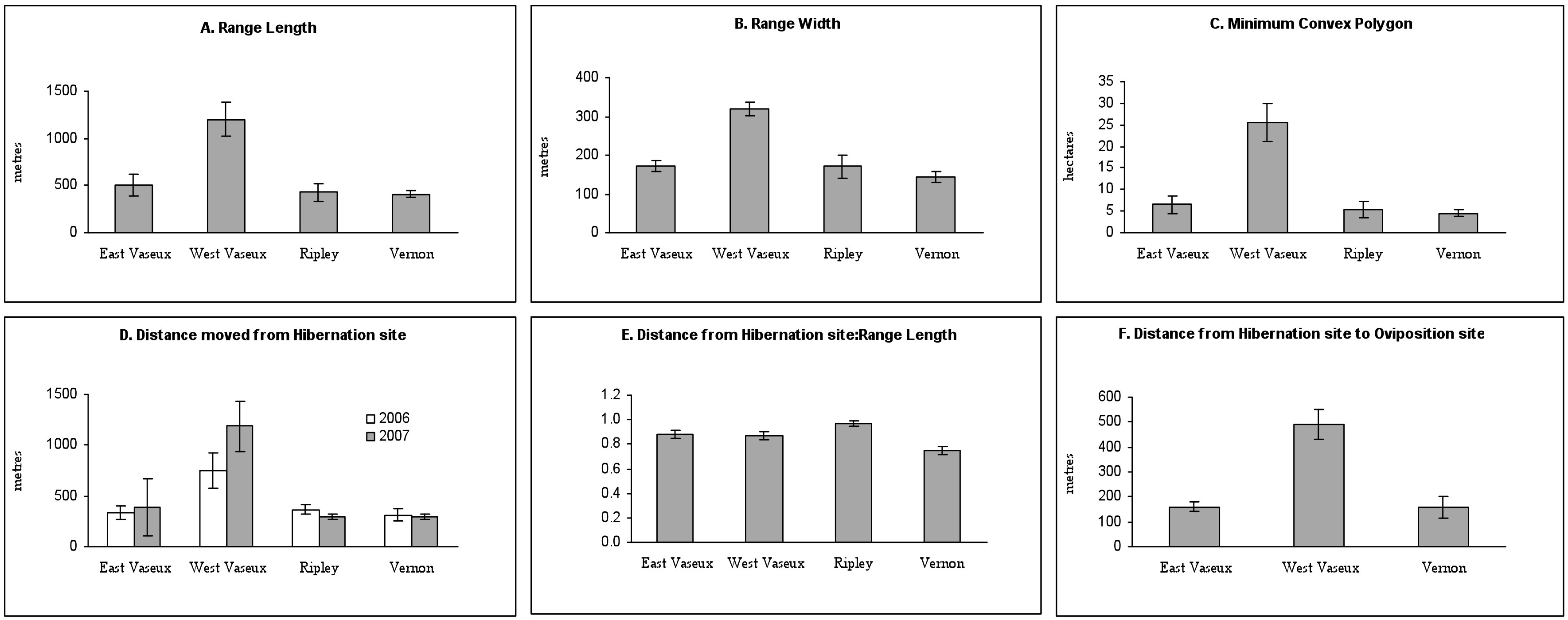

Figure 2.3. Range characteristics by site for gophersnakes over the complete active season. Values are mean +/- SE. Year was pooled in all cases except one where it was shown to be significant in preliminary analyses. Sex was pooled in all cases except for oviposition calculations (F) where only females were used. Ripley did not have any gravid females with known hibernation sites, thus it was not included in analysis of distance from hibernation site to oviposition site. Sample sizes are as follows: for panels A-C, East Vaseux: n = 12, West Vaseux: n = 14, Ripley: n = 7, Vernon: n = 21, for panels D-E, East Vaseux: n = 10, West Vaseux: n = 12, Ripley: n = 6, Vernon: n = 20, and for panel F, East Vaseux: n = 4, West Vaseux: n = 3, Vernon: n = 6. No females were tracked from oviposition sites to hibernation sites at Ripley. Statistics can be found in Table 5.

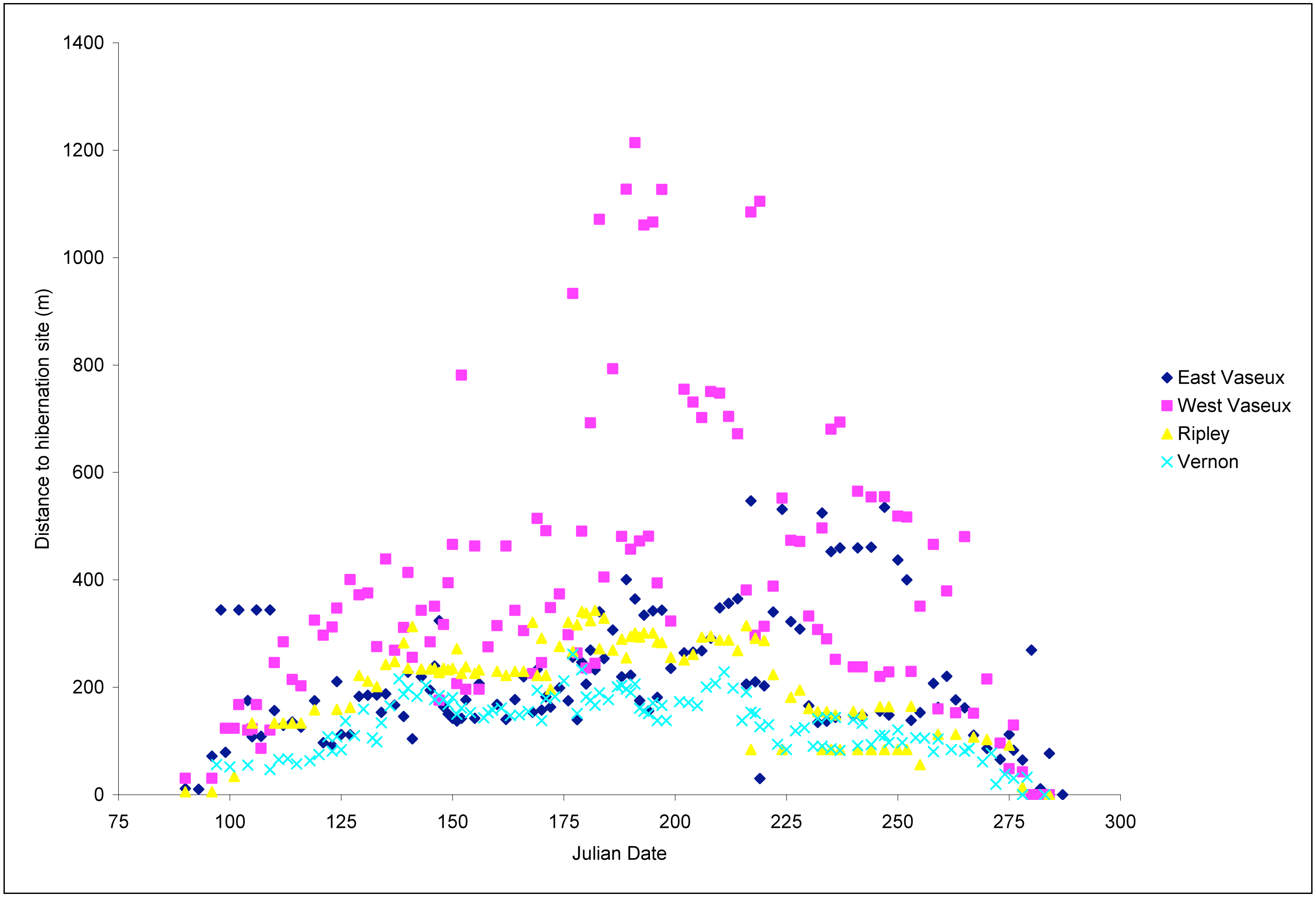

Figure 2.4. Distance from hibernation site throughout the active season for all snakes. Distance from hibernation site was averaged by data for individuals and years by study site.

Table 2.5. Statistical results of two-way ANOVAs looking at how sex and site affect range variables of gophersnakes for the complete active season. Distance from hibernation site to oviposition site was analyzed looking at site and year as only females had oviposition sites. Results from Tukey post hoc tests determining which sites were different can be found in Table A2.2.

	Sum of Squares	d.f.	F	P
Range length (d.f. error = 46)				
sex	343946.3	1	1.96	0.168
site	5815390.4	3	11.06	< 0.001
sex*site	513542.2	3	0.98	0.412
Range width (d.f. error = 46)				
sex	3538.7	1	1.00	0.323
site	210327.7	3	19.77	< 0.001
sex*site	27306.6	3	2.57	0.066
Range width:Range length (d.f. error = 46)				
sex	0.09	1	2.63	0.112
site	0.09	3	0.86	0.469
sex*site	0.07	3	0.66	0.580
Minimum convex polygon (d.f. error = 46)				
sex	59.1	1	0.64	0.426
site	3659.5	3	13.29	0.000
sex*site	129.2	3	0.47	0.705
Maximum distance dispersed from hibernation site (d.f. error = 41)				
sex	16025.5	1	0.12	0.729
site	3913649.6	3	9.90	< 0.001
sex*site	83832.5	2	0.32	0.729
Maximum distance dispersed from hibernation site:Range length (d.f. error = 41)				
sex	0.02	1	1.22	0.276
site	0.24	3	4.92	0.005
sex*site	0.10	2	2.98	0.062
Distance from hibernation site to oviposition site (d.f. error = 7)				
site	97320.0	2	9.57	0.010
year	50301.0	1	0.50	0.504
site*year	6642.2	2	0.65	0.549

Discussion

Movement Patterns

Gophersnakes in the Okanagan exhibit different movement patterns depending on the site. While snake movements differed depending on sex and season, the largest differences were observed between sites. These results suggest that site characteristics play a more important role in determining snake movement than do sex, season, or annual variation.

Snakes at West Vaseux consistently moved further and faster than snakes at the other three sites, a trend that was apparent both for the entire active season as well as within each activity period. One difference between West Vaseux and the other three sites is the lack of road development around the West Vaseux site, which may over time have resulted in increased mortality of wide-ranging individuals on sites other than West Vaseux. These movement differences may indicate natural selection or a behavioural shift towards lower movement rates, as individuals that disperse furthest experience a higher road mortality risk (Bonnet et al. 1999, Browne and Hecnar 2007, Gibbs and Chriver 2002, Gibbs and Steen 2005). Another reason for this difference might be that resources may be dispersed more than at other sites, necessitating increased movement.

Sex differences in snake movement patterns appeared only when the data were divided into the activity periods of spring, summer, and fall, explained by the differences in behaviour that males and females exhibit (Blouin-Demers and Weatherhead 2002). In the spring, males moved further and faster than females, which could be attributed to males moving more during the mating season searching for females. In the Eastern massasauga rattlesnake (*Sistrurus catenatus*), the distance males move is directly related to their success at finding mates (Jellen et al. 2007). If male snakes search a long time for mates, they are less likely to spend time on feeding and growth, but if their searching is successful they are more likely to father more offspring (Jellen et al. 2007). In the summer and the fall, I found that females moved further than males, which could be due to the greater distance females had to move to get to their oviposition site, as found in other species (Blouin-Demers 2002). In addition, female *Pituophis* that oviposit have been found to lose from 37-46 % of their body mass (reviewed in Shewchuk 1996), so may move more to search for food to replenish energy stores after oviposition (Gregory et al. 1987). Many snakes returned to their dens late in the summer, resulting in little movement in the fall, and spent a month or more shifting around underground in a 10-30 m radius area around their hibernation site. It may be that these snakes were digesting a food item prior to hibernating, or already had sufficient food stores to sustain them through hibernation, so returned to their hibernation site earlier than other snakes.

Since previous work on gophersnakes has focused more on home range estimates to approximate movements, there are few studies on *Pituophis* species that provide data on movement patterns. However, other work done on gophersnakes in British Columbia has calculated distance dispersed from hibernation sites, with similar results (Bertram et al. 2001, Shewchuk 1996). For many other snake species, the trends follow the same pattern –

elevated male movements during the mating season, and elevated female movements during oviposition (Blouin-Demers and Weatherhead 2002, Bonnet et al 1999, Brown et al 2005, Gregory et al. 1987, Jellen et al. 2007, Madsen 1984, Rouse 2006, Shewchuk 1996).

Range Patterns

The range data for the entire active season was significantly different when comparing sites. However, males and females did not exhibit a difference in range shape, nor was there a significant difference in range patterns due to year.

West Vaseux consistently had snakes with longer, wider, and larger ranges, perhaps due to the lack of roads surrounding the site. It also could be due to poorer quality habitat or key habitat features being more dispersed than at the other sites, necessitating more extensive movements. Vernon snakes had hibernation sites located nearer the centre of their ranges, suggesting that resources such as foraging grounds and retreat sites were distributed around and adjacent to the hibernation site, not distally. In contrast, Ripley hibernation sites were located nearer the edges of the snakes' ranges, suggesting that resources were distributed at a distance from the hibernation site in one direction – down off the hills into the valley bottom.

Shewchuk (1996) and Bertram et al. (2001) found movements to oviposition sites and summer foraging grounds that were comparable to those found in this study. Similarly, activity ranges occupied by gophersnakes were comparable between this study and those previously found in British Columbia (Bertram et al. 2001, Shewchuk 1996). In contrast, home ranges of Louisiana pine snakes (*Pituophis ruthveni*) were larger than those observed in this study (33 ha on average, n = 9, compared with 11 ha) (Himes et al. 2006). Compared to the uniformly small home ranges found in California by Rodriguez-Robles (2003) (1.74 ha, n = 4), individual gophersnakes in the Okanagan occasionally had drastically different activity ranges from one year to the next, with yearly differences of up to 24 hectares, although year was not significant when the entire dataset was analysed.

Conclusions

Snake movement and range patterns often varied by site. Sites often differed in critical movement determinants such as resource location, resource availability, and depredation risk. Similarly, the presence of roads and other forms of human disturbance has been shown to have a great impact on dispersing individuals by increasing mortality and fragmenting habitats, and can also be expected to have a greater influence on individuals with more extensive movements or ranges (Bonnet et al. 1999).

I have shown that gophersnake movement and range patterns also depend on the activities that the snakes are likely performing. Gophersnakes responded to site specific attributes, which may include variations in resources including the availability and proximity of prey, habitats, predators, or mates. Since movement and range decisions made by gophersnakes in the Okanagan vary by site, future work should concentrate on areas between the sites in the Okanagan and US, where patterns are not known and may differ. With more knowledge a better understanding of the reasons for the site differences in movement and range patterns observed in this study can be gained. In addition, longer term research that follows individuals over longer time periods to determine the amount of site revisitation and activity range overlap that is exhibited would be extremely beneficial.

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CHAPTER 3: Hierarchical habitat selection in the Great Basin gophersnake (*Pituophis catenifer deserticola*) in British Columbia's Okanagan Valley[2]

Introduction

Understanding habitat use patterns gives us insight into the habitat characteristics that are important to individuals and species (Roe et al. 2003). Comparing habitat selection and avoidance is insightful as it offers clues to the mechanisms, such as predation risk, prey availability, and thermoregulation, that drive patterns of habitat use (Ahnesjo and Forsman 2006, Downes 2001, Downes and Shine 1998, Rosenzweig 1991).

Various scales of habitat selection occur (Aubret and Shine 2008, Dussault et al. 2006, Fitzgerald et al. 2005, Nams et al. 2006, Newbury and Nelson 2007, Quirt et al. 2006, Roberts and Liebgold 2008). For example, animals might select for closed canopy forest, large trees, or the presence of rocks. Although research on many species has examined habitat use at multiple spatial scales (Barbaro et al. 2008, Beasley et al. 2007), comparatively few have examined hierarchical habitat selection (Harvey and Weatherhead 2006a, Marell and Edenius 2006). Hierarchical habitat selection occurs when organisms first select habitat at the larger scale, and then select microhabitat within that habitat type, selectively using areas that have certain small scale characteristics. 'Microhabitat' can include logs, shrubs, and rocks, whereas 'habitat' describes the coarser scale, for example meadows and forests.

[2] A version of this chapter will be submitted for publication.

Animals can use any level of habitat proportionally to its availability, or exhibit habitat selection by using certain habitats in higher proportion than their availability.

Snakes often select areas with increased structure, including rocks, sticks, and vegetation (Theodoratus and Chiszar 2000). Differences in habitat selection occur among sites (Reinert 1984a, 1984b), and due to different thermal requirements of gravid females, males and females may select habitat differently (Carfagno and Weatherhead 2006). While studies on snakes have examined habitat selection at multiple scales (Burger and Zappalorti 1989, Carfagno and Weatherhead 2006, Himes et al. 2006), to my knowledge only one has conducted hierarchical habitat selection analysis. In that study, the Eastern massasauga rattlesnake (*Sistrurus catenatus catenatus*) did not exhibit hierarchical habitat selection (Harvey and Weatherhead 2006a).

Species in the genus *Pituophis* exhibit habitat selection. For example, pine snakes (*P. melanoleucus*) prefer certain vegetation types, and males and females use sites with different ground cover types (Burger and Zappalorti 1989). Louisiana pine snakes (*P. ruthveni*) select for pine forests and grasslands, and avoid hardwood forests (Himes et al. 2006).

Great Basin gophersnakes (*Pituophis catenifer deserticola*) are a threatened species in Canada, occurring solely in interior British Columbian river valleys. In BC's Okanagan Valley, where the majority of gophersnakes occur, the ecosystem changes from desert in the south through antelope brush/sage brush, to grassland in the north, with Ponderosa pine forests occurring intermittently throughout and at higher elevations. Knowledge of which habitats and structural features are selected and avoided by gophersnakes is currently unknown anywhere in the species' range. Within the Okanagan, gophersnakes occur throughout a range of ecosystem types.

By examining the habitat and microhabitat decisions gophersnakes make throughout the active season across the varied landscape present in the Okanagan, we can determine whether these snakes exhibit hierarchical habitat selection, and determine the habitats and microhabitat features that they select and avoid, thus determining the habitat characteristics that best predict gophersnake presence. In the United States, Great Basin gophersnakes are consistently found in grassland habitats (Rodriguez-Robles 2003). Previous work in British Columbia on the Great Basin gophersnake did not look at detailed microhabitat use, although snakes primarily used shrub-steppe and rock outcrop habitats (Bertram et al. 2001, Brown 2006, Shewchuk 1996).

I analysed habitat selection in gophersnakes through habitat characterization of four study sites and locations using radio-telemetry-equipped gophersnakes. I hypothesized that 1) gophersnakes select habitat types that vary depending on the site, sex, and month in question, 2) gophersnakes select certain structural features when they choose locations, which do not vary by site although may vary by sex and month, and 3 gophersnakes in the Okanagan select habitat hierarchically.

Methodology

Study Area

Four study sites were selected in areas known to contain gophersnakes (M. Sarell, pers. comm.), to quantify the characteristics of gophersnakes through their range in British Columbia's Okanagan Valley (Table 3.1, Figure A2.1, Figure A2.2). Three sites were located in the south Okanagan and one in the north; each has distinct habitat characteristics and is situated at different latitudes, enabling comparative work. Ripley Wildlife Habitat Area is a crown land site in the south Okanagan protected for gophersnakes, composed of grassland, open ponderosa pine forests, and exposed rock features; it is adjacent to several houses with associated discarded automobiles and lumber piles that can act as refuges for gophersnakes. Vaseux-Bighorn National Wildlife Area in the south Okanagan is owned by the Canadian Wildlife Service, and contains two sites, one on either side of Vaseux Lake. East Vaseux is composed of a rocky bluff with grassy hills beside Vaseux Lake and Highway 97 (the primary highway running north-south in the Okanagan), while West Vaseux is composed of open ponderosa pine forests, antelope brush meadows, talus slopes, rock faces, and wetlands at a lake edge. In the north Okanagan, the Vernon Department of National Defence site is located on the Vernon Army Camp grounds, just outside of the city of Vernon, and is composed of highly disturbed and invaded grasslands, with infrequent shrubs and rock outcrops.

Table 2.1. Study site descriptions and locations for study sites used in this research; all UTM coordinates are in WGS 84 in Zone 11, in British Columbia's Okanagan Valley. Study site areas are based on total available habitat study site boundaries used for hierarchical habitat selection analyses.

Study Site	UTM east	UTM north	Area (ha)	Elevation (m asl)	Dominant Habitat	Owner
Vaseux East	316038	5464124	40	330 – 475	Grasslands/Rock	Environment Canada
Vaseux West	315005	5463705	90	330 – 595	Open Ponderosa Pine/Antelope Brush	Environment Canada
Ripley Wildlife Habitat Area	310468	5459386	50	435 – 645	Open Ponderosa Pine/Grasslands	British Columbia Ministry of Environment
Vernon Army Camp	316038	5464124	120	485 – 575	Invaded Grasslands	Department of National Defence

Field Methods

Gophersnakes were captured opportunistically through active searching on all sites. When a gophersnake was located, it was placed in an opaque bag for transportation, and then housed in an opaque bin with access to heat and water. Adult gophersnakes (17 females, 22 males) weighing ≥ 240 g were surgically implanted with radio-transmitters (12 g transmitter consisting of less than 5% of their total body mass; Holohil Systems Ltd., Ontario, Canada) between April and June of 2006 and 2007, and removed at the completion of the study in April 2008. Following Willson (2003), transmitters were implanted in the coleomic cavity, with the antenna wire running subcutaneously in a cranial direction in 2006 (Reinert and Cundall 1982) and a caudal direction in 2007. The shift in the methodology was due to several instances of the antenna wire poking through the skin, presumably due to the snakes' underground constrictive movements causing their wire to back up in bends and be forced through the skin. These findings have been observed in other snakes (R. Willson pers. comm.), and once transmitter wire direction was changed, no further problems were observed. Findings from other large-bodied oviparous snakes suggest that although transmitter presence produces slower weight gain, lighter eggs, and has the potential to reduce survival when compared with other snakes, when performed carefully the research outcomes outweigh these impacts (Weatherhead and Blouin-Demers 2004). I had only one instance of a snake with an infected incision site, which may have been due to a predation attempt. The snake's transmitter was removed and after the individual healed completely, it was released at the point of capture. For all snakes, Metacam® (meloxicam 0.1 mg/kg) and Baytril® (enrofloxacin 5 mg/kg) were injected intramuscularly 24 hours preceding surgery, at surgery, and 24 hours post-surgery to reduce pain and swelling. Following a 24 to 48 hour recovery period, each transmitter-equipped gophersnake was released at its capture location.

Each individual was relocated approximately every second day throughout the active season (late March through mid-October). Tracking occurred during daylight hours, typically between 7 am and 7 pm. Homing techniques were used to relocate individuals, with the infrequent exception (occurred <5% of the time) of using triangulation methods when snakes were located in wetland or rock features that did not permit direct access. Upon location of the individual, a GPS location was recorded (Garmin Map76S, accuracy of < 5 m, except when impossible due to interfering rock features).

Spatial data were imported into ArcView v. 3.2 with Spatial Analyst (Environmental Systems Research Institute 1999), and analysed using several extensions, primarily the Animal Movement Analysis Extension (Hooge and Eichenlaub 1997). Statistical analyses were performed in Microsoft Excel 2003 and 2008 with the Poptools add-in (Hood 2000), and SPSS 12.0 and 16.0 for Windows (SPSS 2003, 2007). Krebs (1989), Manly (1992), and Zar (1984) were used as statistical reference texts.

This work was performed under University of British Columbia Okanagan animal care committee permit number A06-0068, Species At Risk Act permit numbers 59-05-0370 (2005), 6 (2006), 39 and 0068 (2007), and 0074 (2008), and British Columbia Ministry of Environment permit numbers PE06-20868 (2006) and PE07-30716 (2007-2008).

Habitat

Using aerial photographs and extensive ground-truthing, I classified habitat at each site into six categories: pine stand, rock outcrop, riparian, grassland/meadow, shrub-steppe, and human-modified, following Brown (2006). Human-modifed habitats were areas that showed human disturbance, including roads and road-edges as well as human buildings and associated debris piles. Habitat delineation was used in further habitat analysis as well as to randomly select microhabitat plots. Available habitat was delineated within study site boundaries, which were determined by placing a buffer of at least 100 m around snake locations from 2006 as well as using defining features such as impassable cliff faces and lakes.

I calculated the area of each habitat on each study site using the Xtools extension in ArcView, and recorded the number of times male and female snakes were located in each habitat type in 2007. I first grouped male and female snakes, and months, keeping sites separate, and used log-linear analyses and then Manly's alpha tests to determine whether habitat use differed by site. To examine the details, keeping males, females, and the months separate, I then used log-linear analysis to determine whether the habitats used by male and female gophersnakes in the months of May, June, July, and August differed. Following this analysis, I used Manly's alpha tests to compare available and used habitats to determine whether the habitats used by male and female gophersnakes reflect random use or selection and avoidance for some habitat types, although tests of statistical significance are not possible with this test.

Microhabitat

I recorded specific microhabitat characteristics at each site where a snake was located (Burger and Zappalorti 1986, Harvey and Weatherhead 2006a, 2006b). I recorded distance from the snake location to the nearest tree (>2 m tall), shrub (<2 m tall), rock (length >20 cm), and retreat site (e.g. hole, rock crevice) within 30 m. I followed Harvey and Weatherhead's (2006a, 2006b) plot characteristics and in a plot of 1 m radius centred on the snake location I measured the percent cover of the following: rock, coarse woody debris, vegetation, and water. I also recorded the number of woody stems in the 1 m plot and identified the dominant species by percent ground cover. Lastly I measured the maximum droop height of grass clumps below which snakes were concealed, and recorded whether the snake was in the clump or underground.

To compare sites used by snakes with available microhabitat, I collected microhabitat data on sample plots at random locations on each site. Prior to the commencement of fieldwork, I randomly placed plots in a stratified design, so equal numbers of plots were placed in each habitat type. I measured available habitat plots once a month for May through September, completing 10 unique plots per habitat type per site each time.

Following Harvey and Weatherhead (2006a), I used multivariate analysis of variance (MANOVA) to test for differences by site and month between microhabitat characteristics at male and female gophersnake locations and random locations. I then used discriminant function analyses (DFA) to determine which characteristics best predicted snake presence, adding variables stepwise. When a microhabitat feature did not occur within the 30 m sampling radius, I used the mean value for the feature in place of the missing value, following Harvey and Weatherhead (2006a).

Hierarchical Habitat Selection

I used DFAs to determine the availability of suitable microhabitats within habitats, using the classification feature in DFA to provide the percentage of random plots that fit snake location characteristics in each habitat. To determine whether habitat preferences were due to the existence of microhabitat selection, I performed Manly's alpha tests after first weighting habitat availability by suitable microhabitat availability within habitats, following Harvey and Weatherhead (2006a). If a preference for certain habitats was still present after habitats were weighted by suitable microhabitat availability, then hierarchical selection was considered to be present.

Results

Habitat Selection

Log-linear analyses showed that male and female gophersnakes at each site selected different habitats each month (Table 3.2, Table A3.1, Figure 3.1), and that with the exception of Ripley snakes and females at East Vaseux, snakes used habitat significantly differently than in proportion to habitat availability. Manly's alpha tests, with month clumped for each site to increase the power of subsequent analyses, showed that the habitats that were selected and avoided on each site differed (Table 3.3). Further Manly's alpha tests showed differences by sex but not by month (Table A3.2).

Table 3.2. Log-linear results of the habitat data, comparing habitats used by males or females in May through August, to determine whether a difference existed in use by month for each sex. Significant results indicate a difference among months in habitats used by males or females at a specific site. As Ripley had different areas between months due to a difference in the number of telemetry-equipped snakes across the season, only June – August were pooled and analysed.

Site	Sex	G	df	p
East Vaseux	Female	9.44	12	0.665
	Male	34.76	12	<0.001
West Vaseux	Female	33.43	12	0.001
	Male	47.90	12	<0.001
Ripley	Male	2.91	4	0.573
Vernon	Female	20.20	9	0.017
	Male	84.02	9	<0.001

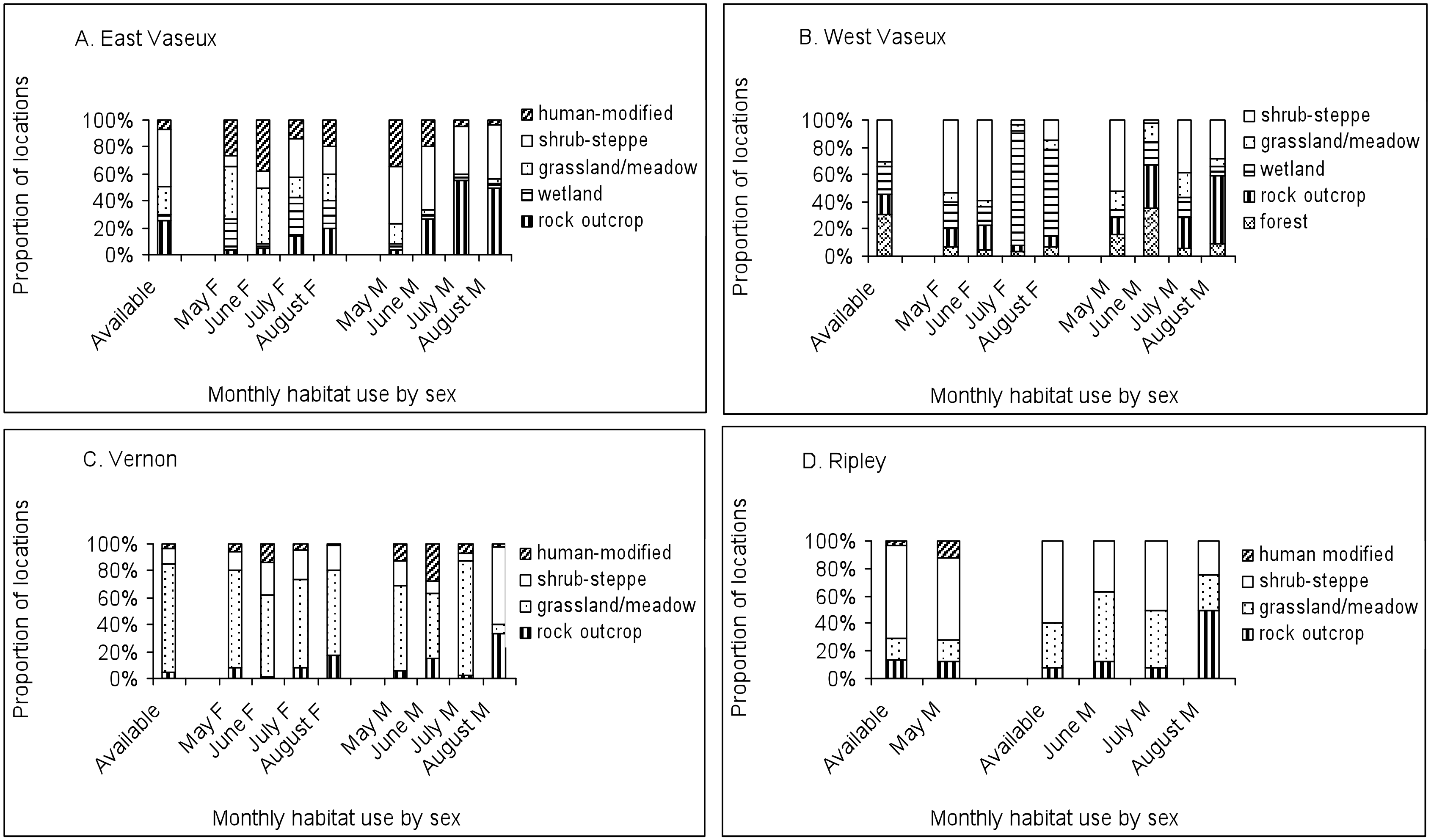

Figure 3.1. Monthly patterns of habitat use by male and female gophersnakes in the Okanagan, at each of four study sites. Available habitats differed among sites. F represents female habitat use, and M represents male habitat use. The first column is the available habitat at that study site by percent. No females were tracked at Ripley thus only male habitat use is shown, and since May available habitat was based on a larger study site than June - August, two available habitat columns are shown.

Table 3.3. Log-linear analyses and Manly's alpha results of the habitat data with months grouped at each site, separate for males and females. Dashes mean that the habitat type covered less than 3% of the entire study site and thus was removed. One count was added to every category, to make it suitable for the log transformation. Values greater than the Manly's alpha value indicate selection (shown in bold), whereas values lower than the alpha value indicate avoidance. Values further from the alpha indicate a greater degree of selection or avoidance, although values diverging from the alpha do not indicate statistical significance, which can not be tested with this metric. Ripley had a low sample size and only males, and the site area differed in May compared with the rest of the summer due to an increased number of individuals, thus May data were treated separately. The sample size represents the number of snakes from which habitat data were collected from. Habitat types are: forest, rock outcrop (rock), wetland, grassland/meadow (grass), shrub-steppe (shrub), human modified (human).

							Habitat Type					
Site	Sex	n	G	d.f.	p	Manly's alpha	forest	rock	wetland	grass	shrub	human
East Vaseux	F	3	43.8	4	<0.001	0.20	—	0.009	**0.310**	0.194	0.025	**0.430**
	M	4	23.7	4	<0.001	0.20	—	**0.333**	0.037	0.034	**0.213**	**0.383**
West Vaseux	F	2	35.4	4	<0.001	0.20	0.011	0.113	**0.546**	0.105	**0.225**	—
	M	5	22.2	4	<0.001	0.20	0.066	**0.242**	0.059	**0.496**	0.137	—
Ripley-May	M	3	2.0	3	0.569	0.25	—	0.148	—	0.179	0.151	**0.522**
Ripley-small	M	1	1.3	2	0.511	0.33	—	**0.414**	—	**0.379**	0.208	—
Vernon	F	6	6.7	3	0.080	0.25	—	**0.300**	—	0.128	**0.284**	**0.290**
	M	4	22.0	3	<0.001	0.25	—	**0.348**	—	0.071	0.227	**0.355**

Overall, at East Vaseux human-modified sites were selected and grassland/meadow were avoided. At West Vaseux grassland/meadow was selected and forest was avoided. At Ripley snakes generally selected rock outcrops and avoided shrub-steppe habitats. At Vernon, rock outcrops and human-modified areas were selected, and grassland/meadow was avoided.

Microhabitat Selection

I tested the correlation of the variables, and would have removed any that were highly correlated, however no variable pairs with correlations of greater than 0.6 emerged as significant in the DFAs. The MANOVAs showed that the microhabitat at random locations differed from microhabitat at snake locations, and that male and female gophersnakes used different microhabitats (Table A3.3). The variables most related to sites used by snakes were the distance to retreat, slope, aspect, percentage vegetation cover, and percentage soil cover (Figure 3.2). Female locations had a more east-facing aspect and higher percentage vegetation cover than male and random locations. Random locations were further from retreat sites, had shallower slopes, and had higher % soil cover than snake locations.

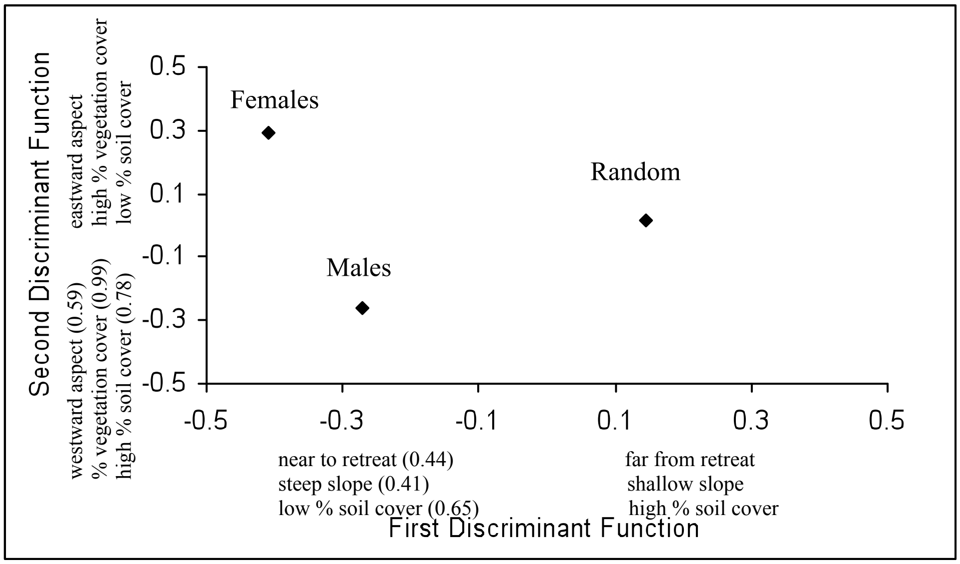

Figure 3.2. Mean discriminant function values of microhabitat use at female, male, and random locations. Variables with structure coefficients >0.3 are included. The first discriminant function described 67.6 % of the variance, and the second described 32.4 % of the variance.

In addition, based on the results of the MANOVA, I also ran separate DFAs for each site, pooling males and females across the months (Figure 3.3). Microhabitats varied between snake-selected and random locations at each site, although the trends were not the same among sites (Figure 3.3). Overall, snake-selected locations were closer to retreat sites, and had less soil cover than random locations.

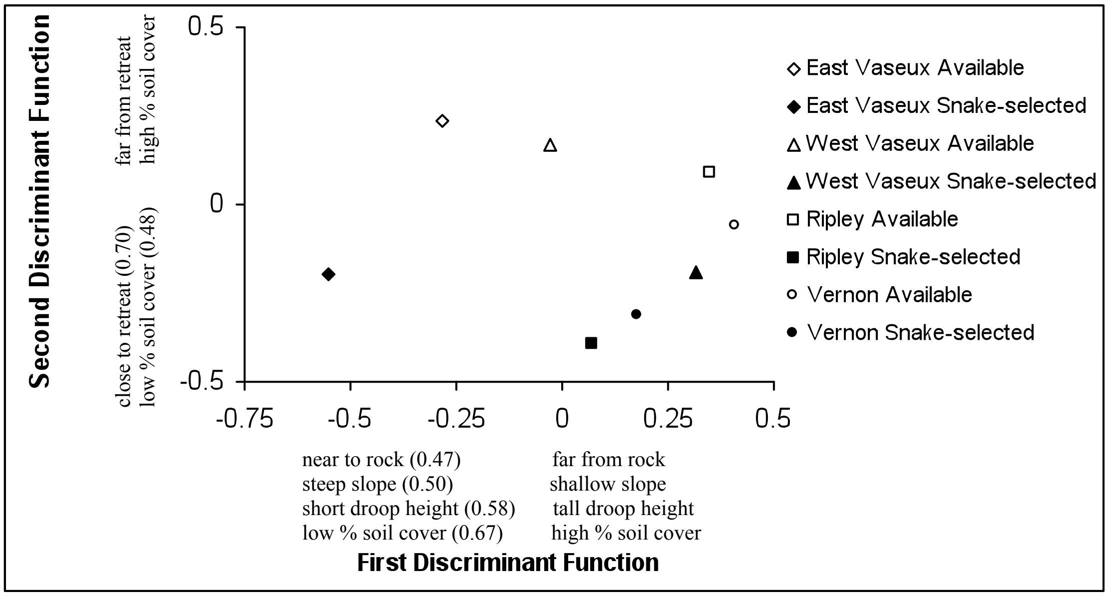

Figure 3.3. Mean (SE) discriminant function values of study site microhabitat at gophersnake-selected and random locations showing microhabitat selection in the Okanagan in 2007. Variables with structure coefficients >0.3 are included. The first two discriminant functions explained 88 % of the variance.

Hierarchical Habitat Selection

I could not perform hierarchical habitat selection analysis at Ripley, due to a very low sample size (n=3 male snakes). For the remaining three sites, I used the classification feature in DFA to weight habitats on each remaining site by the availability of suitable microhabitat within habitats, determined by the percentage of random locations that were incorrectly classified as snake-selected locations in each habitat. I pooled months to increase the sample size per site. After Manly's alpha tests were performed with the weighted habitats, habitat preferences were still apparent in some habitats, thus hierarchical selection was present, although not in all habitat types at each site (Table 3.4, Figure 3.4). Hierarchical habitat selection occurred at East Vaseux in human-modified habitat, by females in wetland habitat, and by males in shrub-steppe habitat. At West Vaseux, hierarchical habitat selection occurred by females in wetland habitat, and by males in grassland/meadow habitat. Finally, at Vernon, hierarchical habitat selection occurred in rock outcrop and human-modified habitats. In other habitats at each site, results varied, sometimes habitat selection was occurring, e.g. males at East and West Vaseux selected rock outcrop and females at West Vaseux and Vernon selected shrub-steppe, and sometimes microhabitat selection was occurring, e.g. females at East Vaseux were selecting microhabitat features in grassland/meadow habitats, as were males at East Vaseux in wetland habitats, and males at West Vaseux in forest habitats (Table 3.4).

Table 3.4. Manly's alpha tests of habitats weighted by available suitable microhabitat within habitats, with the observed male and female snake locations in that habitat, pooled by months. Dashes mean that the habitat type covered less than 3% of the entire study site and thus was removed. One count was added to every category as not all had one existing, to make it suitable for the log transformation. Values greater than the alpha value indicate selection (shown in bold), whereas values lower than the alpha value indicate avoidance. Values further from the alpha indicate a greater degree of selection or avoidance, although statistical significance is not indicated through this test. Grey highlighted values are habitats that were selected previously when analysing habitat selection (see Table 3.3). Hierarchical habitat selection occurred in habitats that have values in bold with grey highlighting. Ripley had a low sample size of transmitter-equipped snakes (n=3 for May, n=1 for June-August, all male), and thus was not analysed at this level. The sample size, n, represents the number of snakes from which habitat data were collected from. Habitat types are: forest, rock outcrop (rock), wetland, grassland/meadow (grass), shrub-steppe (shrub), human modified (human).

				Habitat Type					
Site	Sex	n	Manly's alpha	forest	rock	wetland	grass	shrub	human
East Vaseux	F	3	0.20	—	0.004	**0.430**	**0.308**	0.039	**0.218**
	M	4	0.20	—	0.068	**0.213**	0.121	**0.328**	**0.270**
West Vaseux	F	2	0.20	0.176	0.035	**0.570**	0.179	0.040	—
	M	5	0.20	**0.436**	0.073	0.100	**0.358**	0.033	—
Vernon	F	6	0.25	—	**0.324**	—	0.098	0.209	**0.368**
	M	4	0.25	—	**0.360**	—	0.049	0.164	**0.428**

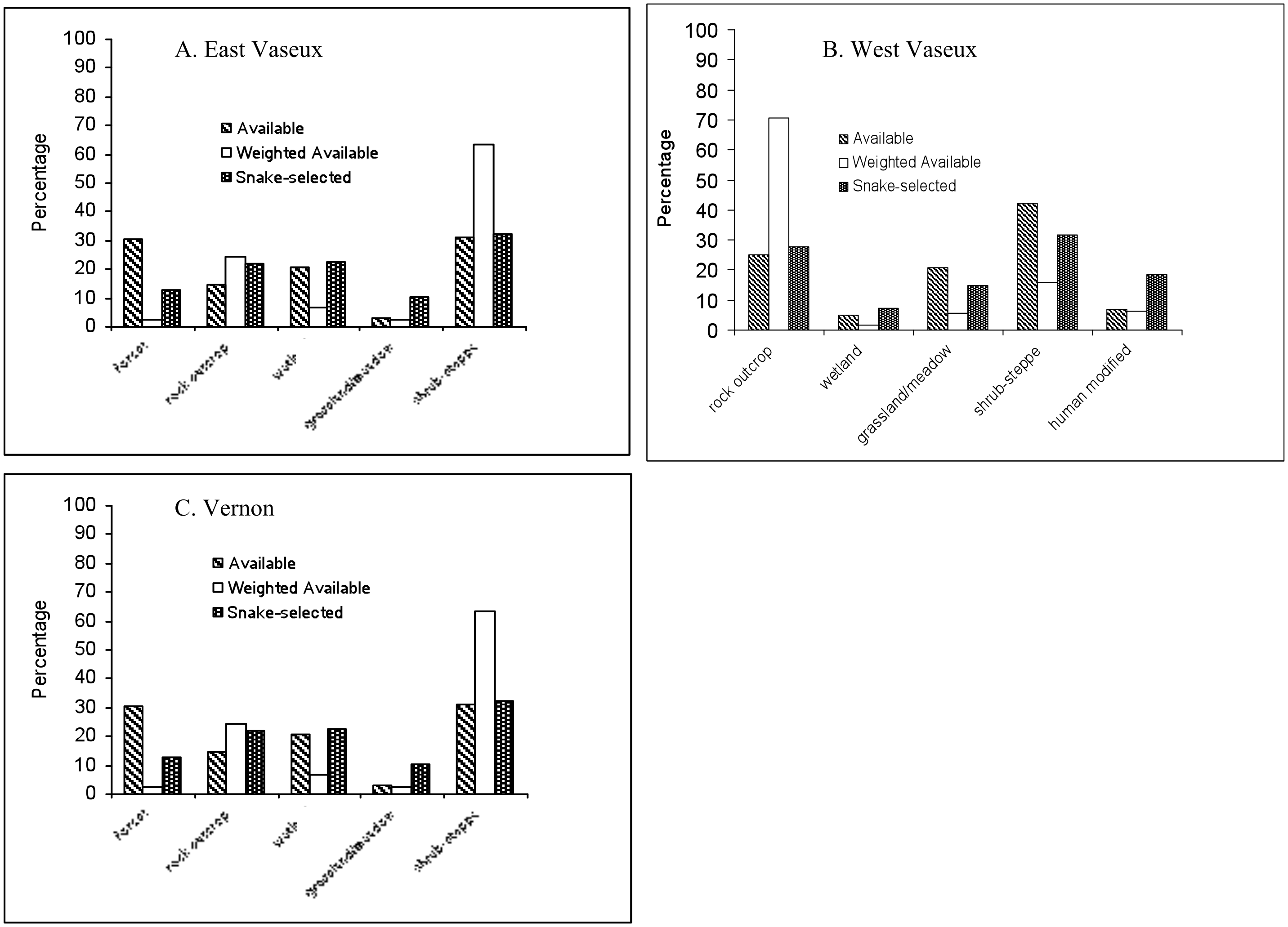

Figure 3.4. Percentage of available habitat, habitat availability weighted by the availability of microhabitats within habitats, and percentage gophersnake use of habitats for each study site. Hierarchical habitat selection occurred in those habitats where available and weighted available are lower than the snake-selected percentages. Each site had different habitats available.

Discussion

Gophersnakes selected and avoided certain habitats, with choices varying by site, sex, and month. Overall, rock outcrop and human modified habitats were selected most often, and grassland/meadow habitat avoided most often. Certain microhabitat features were selected for and thus useful to predict habitat suitability for gophersnakes, although the selected features varied slightly by site. Overall, gophersnakes selected for microhabitat locations that were closer than random to a retreat site such as a rock, hole in the ground, or shrub. Gophersnakes in the Okanagan exhibited hierarchical habitat selection in human-modified habitat, and occasionally in rock outcrop, wetland, grassland/meadow, and shrub-steppe habitats. Hierarchical selection was not apparent in every habitat of every site.

Habitat Selection

Overall, habitat selection varied across sites. Male and female gophersnakes selected different habitats depending on the site and the month. There were no habitats that were always avoided or selected across sites, suggesting that both habitat availability as well as snake use of habitats varies among sites. However, most of the time rock outcrop and human modified habitats were selected, and grassland/meadow habitat was avoided. Habitat selection also varied by month, however, trends were stronger for site patterns.

Snakes at East Vaseux selected human-modified habitats, spending a great deal of time around the edges of roads in exposed sandy banks, while avoiding nearby shrub-steppe and grassland/meadow habitats. At West Vaseux, wetlands, forests, and shrub-steppe were avoided, and grassland/meadow, occupying a small proportion of the site, was selected. This selection pattern is interesting because three snakes spent the majority of their summers in the wetlands, a habitat type that was avoided and thus used less than its availability. At Ripley, snakes selected rock outcrops and human-modified habitats, while avoiding grassland/meadow and shrub-steppe. With a small sample size, though, the power of the analyses at Ripley were limited. Vernon showed a similar interesting result as West Vaseux, with grassland/meadow habitat being avoided, although the majority of snake locations were in grassland/meadow habitat. Grassland/meadow was the most common habitat type, but snakes clearly selected rock outcrop, shrub-steppe, and human-modified habitats, although they were scarce.

These results are similar to those found elsewhere for gophersnakes, where grassland habitats were used extensively (Rodrigues-Robles 2003), along with shrub-steppe and rock outcrop habitats (Bertram et al. 2001, Brown 2006, Shewchuk 1996). Louisiana pine snakes also selected for grasslands (Himes et al. 2006). Wetland and human-modified habitats were not present or analysed in these studies.

Microhabitat Selection

Microhabitats at locations used by males and females and at random locations differed. Snakes selected sites closer to retreats, presumably to reduce predation risk, escape from hot temperatures, and access prey, as has been found in other reptiles (Huey et al. 1989, Shah et al. 2004). Milk snakes are known to select locations to thermoregulate more effectively, and alter behaviour to increase body temperature, although habitat selection may also be due to predator avoidance (Row and Blouin-Demers 2006). Gophersnakes selected steeper slopes, which may be to increase basking options. Finally, snakes chose sites that had less bare soil cover, which could reduce visibility to predators. Females selected sites that were more east-facing, perhaps to optimize sun exposure early in the day due to the thermal restraints of oviparity, and used sites with more vegetative cover, presumably to increase their protection from predators while optimizing the thermal properties for oviparity.

The differences apparent between snake-selected and available habitats at the different sites suggest that microhabitat use and availability differs among sites. Among sites, microhabitat use differed, with differences both in snake-selected features as well as random features. Snakes selected locations closer to retreats and with less bare soil cover than random sites.

In other areas, *Pituophis* species occurred in locations with different vegetative species, for example plant species such as blueberry (*Vaccinium* sp.) and pitch pine (*Pinus rigida*) were selected in New Jersey that do not occur at my Okanagan study sites (Burger and Zappalorti 1989). Similar to work on other snake species, though, snakes selected for areas with increased structure, including nearby retreat sites and rocks (Theodoratus and Chiszar 2000).

Hierarchical Habitat Selection

Hierarchical habitat selection occurred in some habitats at each site, although the habitats varied among sites. Hierarchical habitat selection has not been found previously in a snake species (Harvey and Weatherhead 2006a), however Great Basin gophersnakes were not exclusively demonstrating hierarchical habitat selection, only in some habitat types. Gophersnakes selected habitat hierarchically at East Vaseux in human-modified, wetland, and shrub-steppe habitats, at West Vaseux in wetland and grassland/meadow habitats, and at Vernon in rock outcrop and human-modified habitats. These results demonstrated that gophersnakes select habitat hierarchically in addition to selecting some habitats solely at the habitat scale and others based on their microhabitat features. Thus gophersnakes are aware of both small and larger scale features around them, and can consider habitat, microhabitat, or both when making site selection decisions. The differences in the level of selection at different sites and in different habitats may be due to some factor that I did not measure in my habitat characterization, which better explains snake preference, for example site-specific predation risks or prey abundance.

Conclusions

Depending on the habitat type, snakes selected and avoided habitats at different scales. In some habitats, snakes selected at the habitat level, in others snakes selected at the microhabitat level, and in some habitats, snakes selected first at the habitat level, and then at the microhabitat level, exhibiting hierarchical habitat selection. Snakes are more likely to be found in certain habitats at each site, and certain microhabitat characteristics were more indicative of snake presence. Overall, snakes selected for areas that had retreat sites close by, suggesting that retreat sites are a critical feature and necessary for gophersnake presence. Understanding the habitat types and microhabitat features that snakes select for is important in understanding gophersnakes in the Okanagan Valley, and means that species conservation efforts can protect the areas and features that are most important to the snakes. As little other work has examined whether snakes are selecting at the habitat or microhabitat level, or both, this direction would be valuable for future snake habitat analyses.

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CHAPTER 4: Life history characteristics of the Great Basin gophersnake (*Pituophis catenifer deserticola*) in British Columbia's Okanagan Valley[3]

Introduction

An understanding of the variability in the life history traits of a species is required for conservation of the species and its habitats (Dodd 1987). With a thorough understanding of life history characteristics, conservation efforts can focus on specific times and areas to best protect the species and populations in question, while without life history knowledge, conservation plans may provide incomplete or insufficient protection.

Differences exist in life history traits across reptile species' ranges, differences which may result from selection imposed by differences in resources due to different climates, latitudes, elevations, or habitats (Shine 2003), leading to different habitat and movement decisions as individuals seek resources. As differences exist across species' ranges, management plans tailored to one site could protect the wrong habitats at the wrong times if applied to another site. Thus, without an accurate understanding of the local life history traits of reptiles, conservation efforts cannot be as efficient as possible to preserve specific areas and protect individuals. In this paper, I will examine the local life history characteristics, including hibernation, ecdysis, mating, oviposition, and mortality, of the Great Basin gophersnake (*Pituophis catenifer deserticola*), near the species' northern limit.

[3] A version of this chapter will be submitted for publication.

Snake Life History

Hibernation sites are used by most snakes in temperate North America, where winter above-ground temperatures often fall lower than snakes can tolerate (Gibbons and Semlitsch 1987). Hibernation sites allow a snake to retreat below the surface to a place where temperatures do not drop below freezing during the winter. The fidelity of snakes to hibernation sites varies depending on the species and the location within the species' range (reviewed in Gibbons and Semlitsch 1987). Snakes can hibernate communally or singly, and communal hibernation sites can support more than one snake species (Parker and Brown 1973). Since hibernation sites are critical to species survival, hibernation site destruction is likely to have severe negative impacts on snake conservation when high hibernation site fidelity occurs, thus it is important to protect hibernation sites.

Ecdysis, or shedding of the skin, occurs throughout the active season as the snake grows, however for many species definite ecdysis periods exist when most or all individuals shed (Alexander and Brooks 1999, Shewchuk 1996). Knowledge of times that snakes are undergoing ecdysis is important as snakes may be more vulnerable to predation and less able to detect people at these times, producing altered behaviour (King and Turmo 1997).

Mating seasons vary depending on the species and the area, with mating commonly occurring in late spring after emergence, or late summer after reproduction occurs (reviewed in Seigel and Ford 1987). During the mating season, males typically move more than females while searching for mates (Blouin-Demers and Weatherhead 2002, Bonnet et al 1999, Gregory et al. 1987, Jellen et al. 2007, Madsen 1984, Rouse 2006). Knowledge of the times and instances at which snakes at different sites mate will allow for an understanding of the length of times snakes devote to searching for a mate, and the times at which site disturbances should be minimized to reduce impacts on the population.

Oviposition in various species of snakes occurs at different times of the year, due to seasonality and differences in habitat and resource availability (Shine 2003). Snakes must obtain enough heat units and resources for egg embryos and shells to sufficiently develop, and subsequent to laying, embryos must have enough time to develop, hatch, and locate suitable overwintering locations. Depending on site characteristics, in some species females oviposit yearly, while in other species females oviposit in alternate years. Seigel and Ford (1987) have suggested that population size or age structure, which vary temporally, may be primary determinants of reproductive frequency in snakes. Fidelity to oviposition sites occurs in many species, while others dig or locate new oviposition sites each time they oviposit. Some oviparous snakes nest communally (Blouin-Demers et al. 2004, Burger and Zappalorti 1986, Cunnington and Cebek 2005, Porchuk 1997). Oviposition site fidelity is suspected to be more prevalent in communal nests than in single nests (Blouin-Demers et al. 2004), and snakes selectively use sites with evidence of past successful hatching (Brown and Shine 2005).

There are several habitat and site-related quantities believed to be of importance to snake oviposition site selection that are often measured (Blouin-Demers et al. 2004, Burger and

Zappalorti 1986): these variables include soil type, texture, temperature, and moisture, and habitat characteristics such as vegetation type, percent ground cover by logs, soil, vegetation, and rock, and the distance to shrubs, trees, logs, and rocks. Soil moisture content is important to nesting – snakes must be able to excavate tunnels and chambers that do not collapse, suggesting soil type and texture are important (Burger and Zappalorti 1991). The temperatures experienced by a reptile embryo through development have critical importance on hatchling survival (Lourdais et al 2004), sex ratios (Burger and Zappalorti 1988), fitness (Booth 2006), and locomotor performance (Booth 2006). Since temperature during incubation has effects on neonate characteristics including sex, colour, and post-hatch growth rate (Booth 2006), females' choice of sites is important. Temperature during incubation is obtained from solar heating of the ground around the eggs. As latitude increases, sun angle changes and thus it may be necessary to use steeper slopes to obtain the same amount of thermal units for snake egg incubation.

Great Basin Gophersnakes

Great Basin gophersnakes have a distribution that stretches from California and Arizona in the south northwards into British Columbia's interior river valleys. In Canada, gophersnakes are designated as threatened by the Committee on the Status of Endangered Wildlife in Canada, due primarily to loss of habitat due to human development (COSEWIC 2002). The Okanagan Valley in BC's interior is home to one of the largest of the four Canadian populations of gophersnakes (BC Southern Interior Reptile and Amphibian Recovery Team 2005), although only 9% of native habitat in the Okanagan remains (Harper et al. 1993).

There has been very little research on gophersnakes in BC (Bertram et al. 2001), and only one telemetry study on gophersnakes in the Okanagan Valley (Shewchuk 1996). Previous research on gophersnake mortality in the Okanagan has extended only so far as to identify predators, including skunks (*Mephitis mephitis*), coyotes (*Canis latrans*), badgers (*Taxidea taxus*), and foxes (*Vulpes vulpes*) (Shewchuk 1996, Waye and Shewchuk 2002).

Gophersnakes re-use hibernation sites (Shewchuk 1996). Shewchuk (1996) identified three dens in the extreme south Okanagan, two of which were large communal dens. Bertram et al. (2001) found three single hibernation sites in the Thompson-Nicola region. Hibernation sites in the Okanagan are associated with rock features, and elevated above the valley bottom, thought to protect snakes from thermal inversions (Shewchuk 1996). However, findings from the Thompson-Nicola river valley suggest that at least some hibernation sites are associated with tunnels underground (Bertram et al. 2001).

Previous research on gophersnake ecdysis in the south Okanagan has reported shedding in all summer months, with a definite shedding period at the end of July (Shewchuk 1996). Shewchuk (1996) did not believe that the frequency of shedding was related to any one factor. This work did not identify whether all snakes shed at the end of July, or whether the same locations were used for ecdysis from year to year.

While some snakes mate in the fall, *Pituophis* mate in the spring shortly after they emerge from hibernation. In the Okanagan, gophersnakes mate in May (Shewchuk 1996).

Oviposition for snakes in the *Pituophis* genus typically occurs in June and July (Burger and Zappalorti 1991, 1986). Work in the US has determined that the percent of female *Pituophis* reproducing biannually varies from location to location (reviewed in Shewchuk 1996).

In some areas, *Pituophis* re-use the same site for oviposition in multiple years (Burger and Zappalorti 1992). Both communal and solitary oviposition have been reported for the genus (Burger and Zappalorti 1991, Shewchuk 1996). Nest site fidelity has been described for the pine snake (*P. melanoleucus*) by Burger and Zappalorti (1992), and nest site fidelity might be selected for as it would promote using sites that have suitable temperature conditions and are safe from predators. In BC, Bertram et al. (2001) tracked one snake who oviposited sometime between July 10 and 20 near Kamloops in the Thompson-Nicola region, while in the extreme south Okanagan, Shewchuk (1996) found oviposition for 6 snakes occurring between June 20 and July 6. Since infrequent tracking did not pinpoint exact oviposition dates, these dates may overestimate the length of the oviposition period. Longer females produced more eggs, an increase of one egg for every 75 mm SVL increase (Shewchuk 1996). The frequency of oviposition is unknown in the Okanagan, however based on recaptures, only 37.5 % of females were gravid any one summer, suggesting at the most biannual reproduction, although there was one instance of a snake being gravid in two consecutive summers (Shewchuk 1996). Seven gophersnake oviposition sites previously characterized in BC had only slope, aspect, dominant vegetation, and soil type recorded (Bertram et al. 2001, Shewchuk 1996). These oviposition sites were on south-facing grassy hillsides of moderate slope, with fine, sandy soils. Gophersnake oviposition sites in BC have contained eggs of multiple individuals and species (Shewchuk 1996).

To protect the sites that are used and suitable for oviposition, it is first necessary to understand the components that snakes select. Knowledge of the dates that snakes oviposit means understanding when movements to and from oviposition sites are likely to occur, and when disturbances of the oviposition sites will have the greatest impact on females. Understanding whether snakes exhibit oviposition site fidelity or use communal oviposition sites will allow conservation of oviposition sites to focus on specific sites or habitat types. If oviposition sites are destroyed, destruction of communal nests will have a greater impact on the population than destruction of single nests. If communal oviposition sites with high fidelity are destroyed, the consequences on the population might be devastating, as displaced females might be unable to locate suitable oviposition sites, resulting in few viable offspring.

Without knowledge of the life history traits as they apply to local areas, conservation efforts are limited in their ability to protect habitats and time periods of critical importance to species survival. As limited knowledge exists on gophersnake life history traits in BC, and with the wide divergence of several traits across the range, information based on one site may not be applicable to other sites. Increasing the site-specific knowledge will enable conservation plans to be tailored more specifically across the range of habitats that occur in the Okanagan.

When considered together, life history traits reflect yearly processes and events that are important to gophersnake ecology and conservation. I therefore aim to produce a better description of life history traits for gophersnakes in the Okanagan. I hypothesize that: 1) Hibernation sites will be similar to those found elsewhere in British Columbia, snake fidelity will be high, and communal hibernation sites will be common, 2) Ecdysis will occur several times throughout the active season, 3) Oviposition dates and habitat will be similar to those found elsewhere in British Columbia; soil characteristics will be different at oviposition sites than random sites; temperature will vary with slope and study site; and oviposition site fidelity, communal use, and annual oviposition will be infrequent, 4) Mortality risk will vary among months, while causes of mortality will be consistent with those found elsewhere for the species.

Methodology

Study Area

Four study sites were selected in areas known to contain gophersnakes (M. Sarell, pers. comm.), to quantify the characteristics of gophersnakes through their range in British Columbia's Okanagan Valley (Table 3.1, Figure A2.1, Figure A2.2). Three sites were located in the south Okanagan and one in the north; each has distinct habitat characteristics and is situated at different latitudes, enabling comparative work. Ripley Wildlife Habitat Area is a crown land site in the south Okanagan protected for gophersnakes, composed of grassland, open ponderosa pine forests, and exposed rock features; it is adjacent to several houses with associated discarded automobiles and lumber piles that can act as refuges for gophersnakes. Vaseux-Bighorn National Wildlife Area in the south Okanagan is owned by the Canadian Wildlife Service, and contains two sites, one on either side of Vaseux Lake. East Vaseux is composed of a rocky bluff with grassy hills beside Vaseux Lake and Highway 97 (the primary highway running north-south in the Okanagan), while West Vaseux is composed of open ponderosa pine forests, antelope brush meadows, talus slopes, rock faces, and wetlands at a lake edge. In the north Okanagan, the Vernon Department of National Defence site is located on the Vernon Army Camp grounds, just outside of the city of Vernon, and is composed of highly disturbed and invaded grasslands, with infrequent shrubs and rock outcrops.

Table 2.1. Study site descriptions and locations for study sites used in this research; all UTM coordinates are in WGS 84 in Zone 11, in British Columbia's Okanagan Valley. Study site areas are based on total available habitat study site boundaries used for hierarchical habitat selection analyses.

Study Site	UTM east	UTM north	Area (ha)	Elevation (m asl)	Dominant Habitat	Owner
Vaseux East	316038	5464124	40	330 – 475	Grasslands/Rock	Environment Canada
Vaseux West	315005	5463705	90	330 – 595	Open Ponderosa Pine/Antelope Brush	Environment Canada
Ripley Wildlife Habitat Area	310468	5459386	50	435 – 645	Open Ponderosa Pine/Grasslands	British Columbia Ministry of Environment
Vernon Army Camp	316038	5464124	120	485 – 575	Invaded Grasslands	Department of National Defence

Field Methods

Gophersnakes were captured opportunistically through active searching on all sites. When a gophersnake was located, it was placed in an opaque bag for transportation, and then housed in an opaque bin with access to heat and water. Adult gophersnakes (17 females, 22 males) weighing ≥ 240 g were surgically implanted with radio-transmitters (12 g transmitter consisting of less than 5% of their total body mass; Holohil Systems Ltd., Ontario, Canada) between April and June of 2006 and 2007, and removed at the completion of the study in April 2008. Following Willson (2003), transmitters were implanted in the coleomic cavity, with the antenna wire running subcutaneously in a cranial direction in 2006 (Reinert and Cundall 1982) and a caudal direction in 2007. The shift in the methodology was due to several instances of the antenna wire poking through the skin, presumably due to the snakes' underground constrictive movements causing their wire to back up in bends and be forced through the skin. These findings have been observed in other snakes (R. Willson pers. comm.), and once transmitter wire direction was changed, no further problems were observed. Findings from other large-bodied oviparous snakes suggest that although transmitter presence produces slower weight gain, lighter eggs, and has the potential to reduce survival when compared with other snakes, when performed carefully the research outcomes outweigh these impacts (Weatherhead and Blouin-Demers 2004). I had only one instance of a snake with an infected incision site, which may have been due to a predation attempt. The snake's transmitter was removed and after the individual healed completely, it was released at the point of capture. For all snakes, Metacam® (meloxicam 0.1 mg/kg) and Baytril® (enrofloxacin 5 mg/kg) were injected intramuscularly 24 hours preceding surgery, at surgery, and 24 hours post-surgery to reduce pain and swelling. Following a 24 to 48 hour recovery period, each transmitter-equipped gophersnake was released at its capture location.

Each individual was relocated approximately every second day throughout the active season (late March through mid-October). Tracking occurred during daylight hours, typically between 7 am and 7 pm. Homing techniques were used to relocate individuals, with the infrequent exception (occurred <5% of the time) of using triangulation methods when snakes were located in wetland or rock features that did not permit direct access. Upon location of the individual, a GPS location was recorded (Garmin Map76S, accuracy of < 5 m, except when impossible due to interfering rock features).

Spatial data were imported into ArcView v. 3.2 with Spatial Analyst (Environmental Systems Research Institute 1999), and analysed using several extensions, primarily the Animal Movement Analysis Extension (Hooge and Eichenlaub 1997). Statistical analyses were performed in Microsoft Excel 2003 and 2008 with the Poptools add-in (Hood 2000), and SPSS 12.0 and 16.0 for Windows (SPSS 2003, 2007). Krebs (1989), Manly (1992), and Zar (1984) were used as statistical reference texts.

This work was performed under University of British Columbia Okanagan animal care committee permit number A06-0068, Species At Risk Act permit numbers 59-05-0370 (2005), 6 (2006), 39 and 0068 (2007), and 0074 (2008), and British Columbia Ministry of Environment permit numbers PE06-20868 (2006) and PE07-30716 (2007-2008).

Hibernation Sites

I collected habitat data at the hibernation site of each gophersnake, measuring variables that might affect site suibability for snake occupancy, including sun exposure, penetrable substrate, and cover. Specifically, I recorded the distance within a 30 m radius to the nearest log >7.5 cm maximum diameter, tree >2 m tall, shrub <2 m tall, and rock >20 cm, the percent ground cover within 1m radius of rock, soil, vegetation, coarse woody debris and water, and the dominant vegetation. I also recorded the slope, aspect, percent ground vegetation cover within 5 m, and the number and species of any additional snakes observed at the site (Bertram et al. 2001, Burger and Zappalorti 1986, Burger et al. 1988, Harvey and Weatherhead 2006). Within circles of 5 and 10 m radius, I recorded the number of shrubs <2 m tall, number of trees >2 m tall, number of fallen logs >7.5 cm maximum diameter, and number of rocks >20 cm (Bertram et al. 2001, Burger and Zappalorti 1986, Burger et al. 1988, Harvey and Weatherhead 2006). I used MANOVA to determine whether there were differences by site or sex in hibernation site variables.

Through repeatedly visiting hibernation sites at fall ingress and spring emergence, I determined whether gophersnakes hibernated singly or in communal hibernacula. For each site I calculated the percentage of individuals in each hibernacula type. I also determined the extent to which snakes exhibit hibernation site fidelity from year to year in the Okanagan. When snakes in 2007 were found hibernating within 10 m of their 2006 hibernation site, they were deemed to be using the same rock feature and thus the same hibernation site.

Ecdysis

Through telemetry and recaptures (see Appendix I), I was able to determine how consistent previously observed ecydsis times were throughout the Okanagan and identify any additional shedding periods. Shedding periods were identified when most or all of the transmitter-equipped snakes were observed in shed (for example the appearance of cloudy eyes, darker overall appearance, and cloudy belly scales are pre-shed indicators; bright colouration and residual shed skin pieces are post-shed indicators). I was also able to determine whether shedding sites are re-used by gophersnakes across shedding periods or years.

Reproduction

Through observation of transmitter-equipped snakes, I recorded the start and end dates of the mating season. Instances of inferred multiple-pair matings and male-male combat dancing (ref) also were recorded, although my sampling design likely underestimates both of these phenomena.

Females were located through radio-telemetry every other day to identify when and where oviposition occurred. Oviposition was confirmed when females exhibited significant weight loss, obvious skin folds, and an emaciated appearance. Oviposition sites were inferred from tracking records and the confirmation of oviposition. The date that oviposition occurred and the length of time that each snake spent at her oviposition site were recorded. Nest sites were checked once or twice a month over the summer to record depredation events.

To determine both the frequency of oviposition in consecutive years and the site fidelity, I calculated the percentage of females who oviposited only one year, and the percentage who oviposited both years. From data on oviposition site location for females who oviposited both in 2006 and in 2007, I calculated the percentages of females who used two different oviposition sites; this percentage gives an indication of gophersnake oviposition site fidelity in the Okanagan.

Occurrence of multiple females of multiple species using the same nest site was recorded following Porchuk (1997). For each nest site located through telemetry, I noted whether the site was used by other individuals, and then classified it as an independent nest site (used by only one female), as an intraspecific communal nest site (used by more than one gophersnake), or as an interspecific communal nest site (used by more than one species). From these data I calculated the percent of females who nested in each type of nest site.

I collected the same general habitat data at the oviposition site of each gophersnake as I did at the hibernation sites. Habitat characteristics were analysed using MANOVA to determine whether sites differed in oviposition site characteristics. To characterize the soil in which gophersnakes oviposited, I collected soil samples from all oviposition sites used by transmitter-equipped snakes. To compare used and available soils, at each of the four study sites I collected soil samples at ten random locations on south-facing slopes of moderate grade and comparable vegetative cover to determine if chosen oviposition sites had different soil qualities than random. I conducted soil texture tests (Miller et al. 1996), and used a sieve (screen size of 2 mm; Hubbard Scientific Co. Northbrook, Illinois) and balance (Mettler Toledo, Switzerland) to determine percent particle size by mass. I used ANOVA to test whether available and used soil particle size percentage differed, or whether there was a site difference in soil particle size percentage. I used G tests to determine whether there was a difference between available and used soil texture, or whether there was a difference between sites.

In 2006 oviposition sites on different study sites had different slopes; specifically, slopes were steeper in the north than the south. In 2007, I tested whether different slopes resulted in different soil temperatures. Using oviposition sites identified through telemetry during the first field season, I determined the depth at which eggs are laid (5-10 cm) and the average aspect (157 degrees) of these sites. I used iButtons (information buttons, calibrated and programmed using a Dallas Semi Conductor 32 bit iButton viewer), placed at this depth and aspect, to record temperature every 2 hours from the beginning of nesting season to the end of the incubation period. I chose the two sites at which I had the most females and the most nests from 2006, East Vaseux and Vernon DND, and I selected 7 locations (at least 200 m apart) at each site. At each replicate location I placed 3 iButtons, at slopes of 32°, 39°, and 46°, based on the range of sites at which gophersnakes oviposited in 2006. The site characteristics of these locations all were within measured values for aspect, soil type, soil texture, percent vegetative cover, and dominant vegetation type, based on oviposition sites characterized in the first field season. I calculated the daily maximum temperature during the incubation period for each iButton, and compared sites and slopes in a two-way ANOVA. I used these data to determine the difference in temperatures due to slope, comparing the south site with the north site, as well as different slopes within sites.

Mortality

Mortality was recorded for transmitter-equipped gophersnakes. I used a staggered entry Kaplan-Meier method (Pollock et al. 1989) to test whether there was a difference in mortality across weeks, or whether mortality risk was uniform across the active season. I recorded the causes of death for all snakes included in this mortality estimate to develop a sense of the common predators of gophersnakes in the Okanagan. Cause of death was determined through examination of the carcass and transmitter, the location of the remains, or animal sign found around the remains.

Results

Hibernation

Telemetry-equipped gophersnakes tended to hibernate singly (n=22), although some (n=13) hibernated communally with other gophersnakes or snakes of other species (Figure 4.1). Gophersnakes emerged from hibernation in late March, and some were active until late October, although most returned to their hibernation sites in late September. Snakes tended to return to their hibernation site and then spend up to a month shifting around below ground at the den site (see Chapter 2). Hibernation fidelity was exhibited at all sites, although Vernon snakes were prone to switch hibernation sites from one year to the next. Of the five snakes in the three southern sites tracked both years, all used the same hibernacula in each year, while five of the seven Vernon snakes switched hibernation sites.

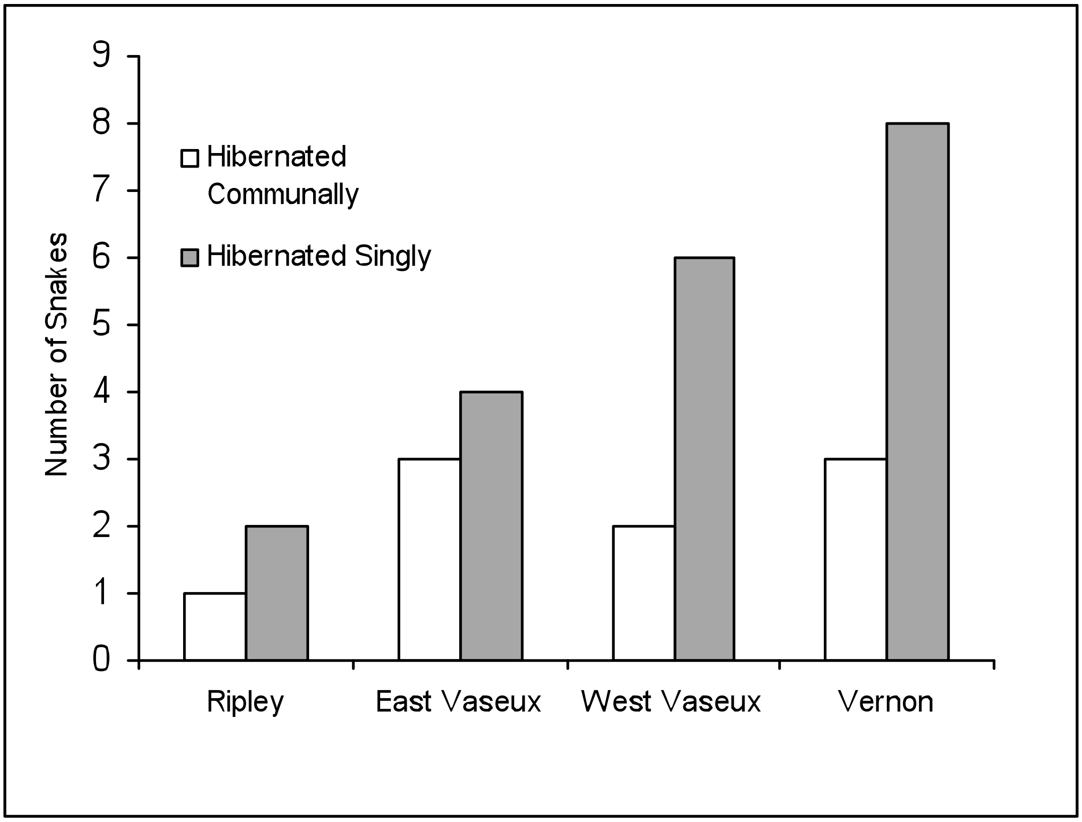

Figure 4.1. Number of gophersnakes occupying communal and single hibernation sites in 2006 or 2007 by study site in the Okanagan Valley. Only one snake, from Vernon, used both a communal hibernation site and a single hibernation site – this snake was recorded on this graph only once, as belonging to a communal hibernation site.

The most significant differences in habitat at hibernation sites were observed between hibernation sites in the south compared to those at the northern site (Table 4.2). In the south, hibernation sites were located in rock outcrops, associated with either a talus slide or a cracked rock feature. Trees were often found within 10 m, as were a high number of shrubs. Rock was the primary ground cover, and slopes were 27±2.4° on average. In contrast, in the north, Vernon hibernation sites were most often in the sides of slopes, accessed via rodent tunnels, although occasionally an emergent rock provided access below ground, slopes were on average 39±4.5°. Few trees or shrubs were located near the hibernation sites, and grass and exposed soil were the dominant ground covers at the sites.

Both communal and solitary hibernation sites were used by telemetry-equipped gophersnakes (Figure 4.1). In the south, other snake species, including western yellow-bellied racers (*Coluber contrictor mormon*), western rattlesnakes (*Crotalus oreganus*), western terrestrial garter snakes (*Thamnophis elegans*), and common garter snakes (*Thamnophis sirtalis*), were often seen hibernating with or near gophersnakes, and hibernation sites were more commonly communal. At Vernon, hibernation sites were primarily single, although several were also used by other gophersnakes and the occasional yellow-bellied racer (*Coluber constrictor mormon*).

Table 4.2. Hibernation site characteristics from snakes tracked in 2006 and 2007 (n=35), mean ± SE. In a few cases, sample sizes were lower due to features not being within the 30 m sampling radius. Statistics are from an ANOVA comparing characteristics between sites, with the exception of the starred rows (**), which are from a G-test.

	East Vaseux (n=8)	West Vaseux (n=8)	Ripley (n=3)	Vernon (n=16)	Sum of Squares	F/G	p
Distance to nearest log >7.5 cm maximum diameter	4.7±0.8 (n=7)	2.8±0.7 (n=7)	3.4±2.1 (n=2)	9.4±1.6 (n=7)	2105.0	4.24	0.013
Distance to nearest tree >2 m tall	6.7±1.7 (n=7)	2.7±0.7	4.8±2.3	8.7±2.2 (n=5)	3910.9	12.05	0.000
Distance to nearest shrub <2 m tall	1.8±0.8	3.2±0.9	0.8±0.5	11.1±2.0 (n=15)	938.1	6.50	0.002
Distance to nearest rock >20 cm	0.0±0.0	0.0±0.0	0.4±0.1	3.7±1.3	116.9	2.85	0.054
Distance to nearest retreat	0.4±0.3	0.2±0.2	0.7±0.5	0.4±0.1	0.6	0.47	0.702
percent ground cover within 1m radius of rock	85.0±3.8	73.1±3.9	48.3±24.0	5.9±2.9	40229.8	49.05	0.000
percent ground cover within 1m radius of coarse woody debris	0.0±0.0	3.8±2.1	1.7±1.7	0.0±0.0	85.8	3.49	0.027
percent ground cover within 1m radius of vegetation	9.3±3.1	16.9±4.9	33.3±15.9	72.2±9.0	26806.6	11.86	0.000
percent ground cover within 1m radius of dirt	5.7±2.1	6.3±2.5	16.7±14.2	21.9±6.9	1820.7	1.41	0.259
Number of woody stems within 1m	2.0±0.8	3.8±2.4	10.0±10.0	0.7±0.7	235.8	2.26	0.101

	East Vaseux (n=8)	West Vaseux (n=8)	Ripley (n=3)	Vernon (n=16)	Sum of Squares	F/G	p
Maximum droop height at centre of plot (cm)	24.3±5.2 (n=4)	38.7±8.4 (n=3)	22.0±6.0 (n=2)	22.6±3.3 (n=12)	128.3	0.16	0.920
Habitat type	Rock outcrop	Rock outcrop	Rock outcrop	Mostly shrub-steppe			
Slope	28.4±3.1	28.8±4.1	27.7±1.5	17.9±3.0	968.6	2.74	0.060
Aspect	216.1±8.8	95.5±13.0	139.0±39.1	117.6±20.5	69920.7	5.83	0.003
Percent vegetative cover within 5 m of site	14±3.9	27±6.1	40±7.6	83±4.5	31704.0	39.61	0.000
5 m radius:							
shrubs <2 m tall **	Mostly >100	27	Mostly >100	2		18.7	0.005
number of trees >2 m tall	0.8±0.4	6.8±2.0	6.7±5.2	0.1±0.1	310.5	7.84	0.000
number of fallen logs >7.5 cm maximum diameter	1±0.4	5.8±2.3	2.0±2.0	0.1±0.1	174.9	5.63	0.003
number of rocks >20 cm**	>100	>100	Mostly >100	23		25.0	0.001
10 m radius:							
shrubs <2 m tall**	Mostly >100	Mostly >100	Mostly >100	>100 or none		16.4	0.011
number of trees >2 m tall	4.1±1.3	12.6±2.5	28.7±24.3	0.5±0.3	2395.3	6.18	0.002
number of fallen logs >7.5 cm maximum diameter	4.3±1.2	18.3±7.1	9.0±8.5	0.5±0.3	1735.3	5.36	0.004
number of rocks >20 cm**	>100	>100	>100	>100 or 12		18.5	0.005

Ecdysis

In both 2006 and 2007, snakes shed mostly during June, July, and August, although most observations were in June (Table 4.3). Individual shedding sites were often re-used by individual snakes, and were also often used by other snakes both across years and within one active season. Vernon has few rock features, and two main rock features attracted many shedding snakes. At the southern sites, where there seemed to be many more shedding spots, snakes still were seen re-using the same shedding sites, although due to the availability of shedding spots, it is difficult to determine the exact number of shedding spots and whether all available spots were in use. I did not see all transmitter-equipped snakes in each shedding period, and it was not always possible to identify sites as shedding locations or foraging locations, thus complete quantification of the timing of shedding is not possible.

Table 4.3. Number of snakes observed exhibiting signs of ecdysis in each month. Shedding periods were indicated by the presence of either pre-shedding signs – cloudy eyes, cloudy belly scales, dark skin, or post-shedding signs – pieces of shed skin present on snake, bright skin. Data are combined for 2006 and 2007. Data from mark-recapture snakes are included, see Appendix I for mark-recapture protocols.

	Number of snakes	Date range
June	55	3-24
July	10	8-24
August	9	1-30

Reproduction

Mating events were observed or inferred to occur between May 5 and May 27 (Figure 4.2). I observed transmitter-equipped snakes scent tracking, coiled, and copulating with other transmitter-equipped snakes and with other snakes. I also had instances of male and female transmitter-equipped snakes being recorded underground or in dense shrubbery together during the mating season, which I inferred to be mating events. One instance of male-male combat dancing was recorded between two implanted snakes in 2006, and one instance of male-male scent tracking was recorded between two males in 2007, at West Vaseux.

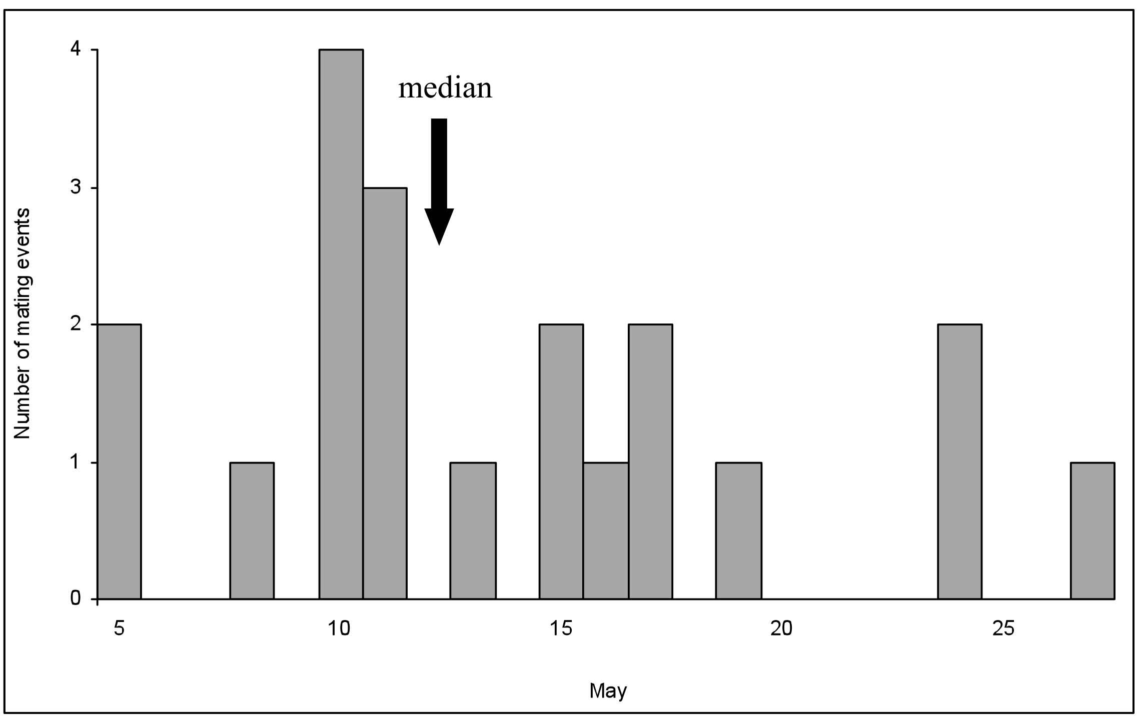

Figure 4.2. Number of observed or inferred mating events (n=20) during May in 2006 and 2007 from transmitter-equipped snakes at all study sites. All observations are male-female observations with snakes located in close proximity, coiled together, or copulating. Median date was May 12th.

The length of time females spent at their oviposition site prior to laying varied (Figure 4.3). The median date females oviposited was June 30th in 2006 (range June 27 to July 4, n=8), and June 24th in 2007 (range June 19 to July 4, n=8). Two depredation events of nests were observed, one in 2006 and one in 2007. Both occurred within 48 hours after oviposition, and based on the evidence at the scene (excavation at site) the probable predator was a coyote or other mid-sized mammal. In 2006, nine out of ten telemetry-equipped females oviposited, and in 2007 eight out of nine females laid eggs. Of the five females tracked both years, all oviposited in both years (were they the largest). One of these five exhibited oviposition site fidelity. As all but one snake each year was gravid, I did not test for a difference in the percentage of females gravid by site.

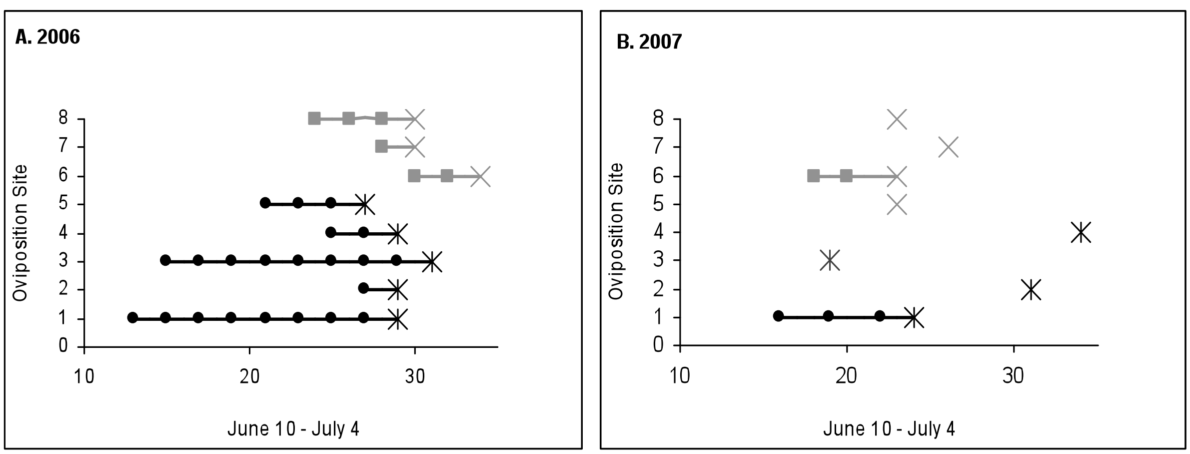

Figure 4.3: Range of time snakes spent at oviposition sites. Vernon snakes are represented by squares and X's, and southern snakes are represented by circles and stars. Dots/squares indicate days snakes were tracked at their oviposition site prior to ovipositing, and X's/stars indicate the last or only time snakes were tracked at their oviposition site, likely the date of oviposition. A: 2006 - Median lay date was June 30th. B: 2007 – Average lay date was June 24th. During 2007, unlike 2006, gravid gophersnakes did not spend time at their oviposition sites prior to ovipositing and moving away from the site; instead, they moved to the site, laid eggs, and quickly moved on to their summer foraging areas.

No snakes nested in interspecific communal nest sites; 6% (n=1) oviposited in intraspecific communal sites, and 94% (n=15) oviposited in independent sites. West Vaseux had the only observed instance of a transmitter-equipped gophersnake ovipositing in a communal oviposition site used by other gophersnakes but no other species. However, due to the frequency of checking these nest sites and the behaviour exhibited by gravid gophersnakes (each snake was located every other day during the nesting season, although they were often underground and thus not seen), it is possible that other instances of communal nesting were overlooked. Several sites had evidence of past use by gophersnakes, such as the uncovering of old eggs during female modifications of the hole.

Habitat characteristics of oviposition sites were averaged for the three study sites in the south and compared with those at the northern site due to a small sample size of oviposition sites at each of the three study sites in the south (Table 4.4). Oviposition sites were found on grassy slopes on south facing hills, with grass and exposed soil as the dominant ground covers. All nest sites were in old rodent burrows except one instance where a snake oviposited under a lone rock. Slopes in the north were steeper (43°) than those in the south (32°). In the north, cheatgrass (*Bromus tectorum*) and dead tumblemustard (*Sisymbrium spp*) dominated the nests, while in the south sand dropseed (*Sporobolus cryptandrus*) was the dominant plant cover. Nests at the northern site seldom had logs or trees nearby, although occasionally rocks and shrubs were found within 10 m. In the south rocks, logs, shrubs, and trees were found occasionally within 10 m of nest sites.

Soils at oviposition sites had soil with particles size primarily <2 mm, with 77% (range 56% – 96%) in the southern sites and 64% (range 58% – 74%), although no difference existed between sites or available and used locations (ANOVA, site: $F_{3,48}=0.812$, $p=0.494$; locations: $F_{1,48}=0.036$, $p=0.851$; site*locations: $F_{3,48}=1.717$, $p=0.176$), even when southern sites were pooled and compared with northern sites. Soil type in the south was primarily sandy loam or loamy sand, and in the north soil type varied from loam to silty loam and silty clam loam. Soil texture did not differ between oviposition sites throughout the Okanagan using a G test ($G=4.43$, $p=1.00$, df=18). In addition, no difference was detected when comparing used and available soil texture at each study site with G tests, and available soil textures among sites did not differ either.

Table 4.4. Oviposition site characteristics from north (n=7) and south (n=9) sites from gophersnakes tracked in 2006 and 2007 (mean ± SE). When variables were not present within the 30 m sampling radius, altered sample sizes are provided, otherwise the sample size is provided at the top of the table. Statistics are from t-tests comparing sites in the south with Vernon in the north. Where sample sizes were below 5, statistical tests were not performed.

	Southern Sites (n=9)	Northern Site (Vernon) (n=7)	t	p
Distance to nearest log >7.5 cm maximum diameter[4]	6.6±1.4 (n=4)	10.1 (n=1)	—	—
Distance to nearest tree >2 m tall[1]	6.4±1.3 (n=4)	16.2 (n=1)	—	—
Distance to nearest shrub <2 m tall[1]	5.3±1.5 (n=7)	8.6±1.2 (n=6)	-0.13	0.895
Distance to nearest rock >20 cm[1]	2.4±1.5 (n=8)	3.3±1.0 (n=7)	0.64	0.530
percent rock ground cover within 1m radius	4.0±2.2	0.0±0.0	1.71	0.109
percent soil ground cover within 1m radius	45.0±7.6	50.0±9.4	-0.46	0.650
percent vegetative ground cover within 1m radius	51.0±7.4	50.0±9.4	0.09	0.927
Slope	32.4±0.3	42.7±1.2	-2.47	0.027
Aspect	164.8±10.0	144.7±8.7	1.75	0.102
% soil particles <2 mm in diameter	77±4.2	64±2.1	2.45	0.028
Percent ground vegetative cover within 5 m of site	70.0±5.3	72.0±7.8	-0.24	0.818
# within 5 m radius:				

[4] When one was present within 30 m.

	Southern Sites (n=9)	Northern Site (Vernon) (n=7)	t	p
shrubs <2 m tall	10.3±8.1	0.1±0.1	1.10	0.292
trees >2 m tall	0.2±0.2	0.0±0.0	0.88	0.396
fallen logs >7.5 cm maximum diameter	1.8±1.0	0.0±0.0	1.54	0.146
rocks >20 cm	31.8±11.1	9.0±2.6	1.77	0.099
# within 10 m radius:				
shrubs <2 m tall	19±10.6	6.3±5.6	0.97	0.348
trees >2 m tall	1.8±1.0	0.0±0.0	1.96	0.071
fallen logs >7.5 cm maximum diameter	7.8±3.1	0.0±0.0	2.18	0.047
rocks >20 cm	66.8±13.6	32.1±10.1	1.94	0.073

At a depth of 5-10 cm, which was consistent with excavated nests in 2006, temperatures in the north were cooler than those in the south – the mean hourly temperatures in the north for all slopes was 24°C, while in the south it was 27°C (Figure 4.4). Although sites were significantly different in daily maximum temperature (ANOVA, $F_{1, 2769}$=1003.14, p<0.001), there was no difference among different slopes within each site (ANOVA, $F_{2, 2769}$=0.56, p=0.574).

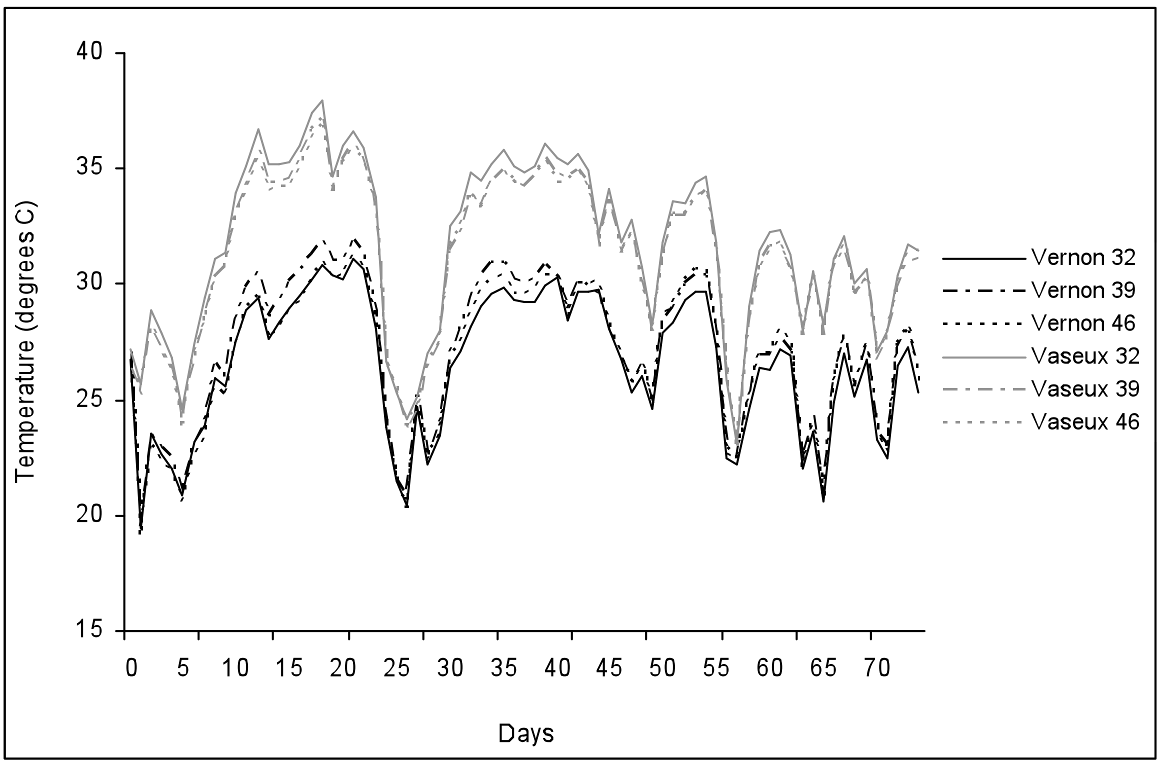

Figure 4.4. Average maximum daily temperature of three different slopes in the south (Vaseux) and north (Vernon) Okanagan during the incubation period from late June (day 1 = June 24) to early September 2007 (day 75 = September 9). Previous work on incubation times has suggested that the average incubation period is 73-74 days at a site slightly further south (Shewchuk 1996), thus I selected 75 days as the ‘incubation time’. The median lay date of telemetry-equipped gophersnakes in 2007 was June 24, thus that was the start date of the experiment.

Mortality

Mortality was highest in May (Figure 4.5, 4.6, Table A4.1), although more snakes were equipped with transmitters in April and May than the other months. Ripley had the most mortality events, and Vernon had the fewest. Most snakes died of natural causes although three were killed on the road by vehicular traffic (Table A4.1, Figure A4.1). Cause of death was determined by evidence found at the site of the deceased; seven snakes were eaten by birds (owl and hawk, determined by the presence of feathers, owl pellets, or peck marks on the carcass), and six snakes were eaten by terrestrial carnivores (coyote and small carnivore, determined by bite marks on the transmitter or carcass), and one snake died of unknown causes (Figure A4.1).

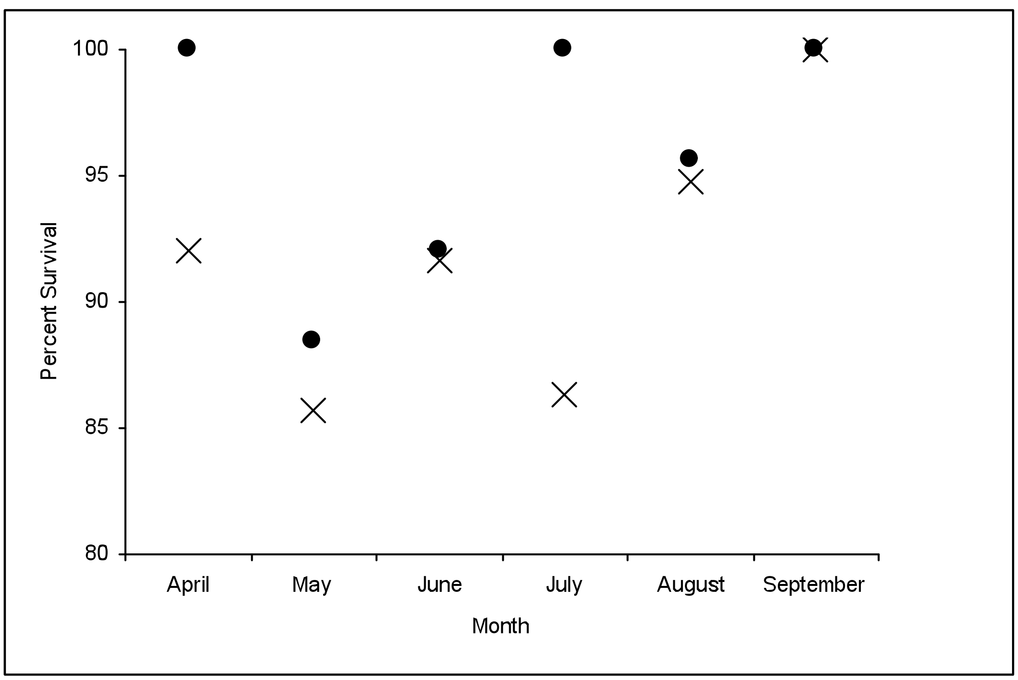

Figure 4.5. Transmitter-equipped snake survival by month for 2006 and 2007, all sexes and sites combined. 2007 survival percentages are indicated by crosses, and 2006 are indicated by dots. Mortality was highest during the mating season (May), perhaps due to increased snake movement in addition to little vegetative growth. In July 2006 no snakes died, while three snakes died in 2007, giving rise to the very different survival rates.

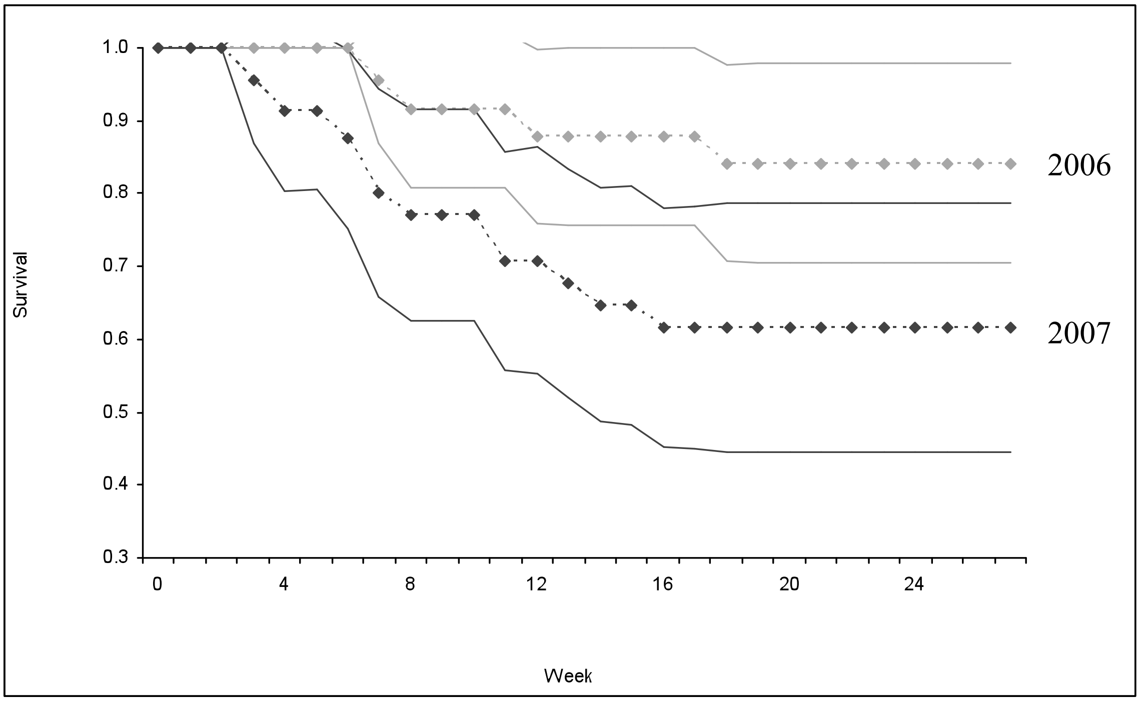

Figure 4.6. Kaplan-Meier survival ± 95% confidence intervals for transmitter-equipped gophersnakes in 2006 (grey) and 2007 (black), confidence intervals represented by lines, means represented by diamonds. Week 0 began April 1, and week 27 ended October 13.

Discussion

As predicted, hibernation sites were similar to those found elsewhere in British Columbia, while snake fidelity and communal use of hibernation sites were not as prevalent as expected. Ecdysis periods during which most snakes shed, occurred several times throughout the active season. As predicted, oviposition dates and habitats were similar to those found elsewhere in British Columbia, and oviposition site fidelity and communal use were rare. Contrary to my predictions, annual reproduction was common, soil characteristics did not differ from random locations, and soil temperature did not vary with slope although it did vary with study site. As expected, mortality risk varied among months, and causes of mortality were consistent with those found elsewhere for the species.

Hibernation

This project characterized several landscape features that are important for hibernating gophersnakes. The sites used for hibernation in the south Okanagan were in rock features comparable to those found in an earlier study in the south Okanagan (Shewchuk 1996). However, hibernation sites found at Vernon in the north were more comparable to those found in the Thompson-Nicola river valley around Kamloops (Bertram et al. 2001). These hibernation sites were most commonly single hibernation sites in the sides of grassy hills. Some were associated with a random rock, which may have underground rock features associated, but most were presumably deep rodent burrows that enabled snakes to escape the freezing above-ground temperatures. Similarly, hibernation sites of *Pituophis* elsewhere occur in soft sand in forested areas where snakes can burrow easily (Burger et al 1988).

More than half of the surviving snakes switched hibernation sites between the two years of this study. Hibernation site switching occurred even by a snake who hibernated with several other snakes, in a hillside where a lone rock appeared to provide access to a subsurface rock feature. The other gophersnake from that site remained there in the second year while the first individual relocated, suggesting hibernation site switching does not indicate a site has become unsuitable.

Ecdysis

The ecdysis periods I observed were comparable to that reported by Shewchuk (1996). It seems snakes shed after mating season and before oviposition or movement to summer foraging grounds, and then twice over the summer, once during summer foraging, and then again shortly prior to their retreat to their hibernation sites. I suspect that every transmitter-equipped snake did in fact shed during these later two periods, however during this time of year gophersnakes spent the majority of their time underground during the day, thus observations were infrequent.

Reproduction

Mating occurred during May, as was observed in earlier studies (Bertram et al. 2001, Shewchuk 1996). Oviposition sites located in this study had similar slope, aspect, soil type, and vegetative cover to other oviposition sites in British Columbia (Bertram et al. 2001, Shewchuk 1996), and also elsewhere for other *Pituophis* species (Burger and Zappalorti 1986). As expected based on previous work in the Okanagan (Shewchuk 1996), oviposition occurred between late June and early July. In 2006 snakes spent an extended length of time at their oviposition site, presumably prior to laying, whereas in 2007, females moved to their oviposition site, laid eggs, and shortly moved on to their summer foraging grounds. The spring of 2006 was cooler than 2007 (Figure A4.1), so when snakes reached their oviposition sites, perhaps their eggs had not yet developed sufficiently for them to lay, explaining their subsurface basking period prior to laying. In contrast, a warmer spring in 2007 (Figure A4.1), with more opportunities for maternal basking, may have resulted in eggs being ready at the time of arrival at females' oviposition sites, resulting in their short stays. In support of this idea, the median date of laying was six days earlier in 2007 than in 2006.

Since nest depredation occurred in only two cases, and only shortly after oviposition, it is possible that the scent or physical evidence of recent activity at the site may fade quickly, leaving no cue for predators.

Most females that I encountered, and all telemetry-equipped females tracked for both years, were gravid. Due to the results from two other studies in British Columbia, where most gophersnakes seemed to be ovipositing every other year, I was not anticipating that essentially all females would oviposit each year (Bertram et al. 2001, Shewchuk 1996). Consecutive oviposition suggests that resources are plentiful and the active season is long and warm enough for females to regain within one year the energy spent on oviposition to reproduce again the next (Seigel and Ford 1987). Perhaps around the time of my study, plentiful resources and favourable climatic conditions allowed consecutive oviposition, or perhaps past studies were done on poorer quality sites.

With so few females, it is possible that the low observed oviposition site fidelity may not accurately represent occurrence. However, it is more likely that since gophersnakes made use of existing rodent burrows for their nests and did not actively excavate their own oviposition sites, it may be that available burrows can change yearly and thus females may need to search for a new site each year. However, there was one case of three gophersnakes using a communal nest, and in two cases old eggs were uncovered adjacent to an oviposition site. It may be that some sites are more stable and thus re-used and communal, whereas other sites are used by snakes only once.

Oviposition sites were on south-facing hillsides of moderate slope, with moderate vegetation cover in the form of grasses. Shrubs and trees, which would impair ground heating, were not located near nests, which were typically old rodent burrows modified by the female. Compared to the soil that was available, snakes selected soil types that were more sand or loam than clay or silt, suggesting that structural or thermal properties of these soil types are better suited either to nest creation or embryo development. Soil texture was typically fine, composed primarily of particles <2 mm in diameter. Soil temperatures at the typical nest depth were higher on average in the south than in the north. A north-south soil temperature gradient was expected, as average daily air temperatures are warmer in the south than the north (Environment Canada www.weatheroffice.gc.ca). In 2007, the soil temperature at slopes that gophersnakes used in 2006 did not differ between slopes selected in the north and south, suggesting that fine-scale slope does not affect incubation as long as the general area is of sufficient grade. General oviposition site characteristics – sandy soils, little vegetative cover, south facing aspects - were comparable to those characterized elsewhere for gophersnakes (Bertram et al. 2001, Shewchuk 1996), as well as for other species of *Pituophis* (Burger and Zappalorti 1986).

Mortality

Mortality was highest during May, which is the mating season. I suspect that during this period snakes are more visible due to lack of vegetative cover, and also due to the greater movements of male snakes (six of seven snakes killed in May were males) attempting to find mates and their focus on scent tracking potential mates. However, deaths occurred in April through August. The predators that killed the snakes were similar to those found in other studies, e.g. raptors and coyotes (Shewchuk 1996, Waye and Shewchuk 2002). Road mortality was also a significant factor, killing three snakes. As adult mortality in reptiles is often a leading factor in reducing population viability, road mortality may have important implications for these populations (Shepard et al. 2008, Gibbs and Shriver 2002).

Conclusions

Life history traits of gophersnakes exhibited in this study were within the range found previously in BC, showing a gradient between the results previously found in the south Okanagan and those found to the north in the Kamloops area. This work provided higher sample sizes to support these patterns, which will support the development of guidelines for management of these areas to protect individuals and populations.

Hibernation sites that are rock-based should be protected carefully, because these sites are long-lasting, and snakes using them exhibit high fidelity, thus destruction of the site will impact the population. Hibernation sites in hillside areas where fidelity is not complete may not require the same level of protection, as snakes seem to be able to change sites, but it may be that snakes need to occasionally switch sites and thus require multiple sites. Some shedding spots should be protected, but not all are necessary if snakes can use other ones; protection efforts should focus on the sites that are used by the most individuals throughout the active season, while ensuring that a number are available. Sites that multiple snakes use for oviposition, and sites to which snakes return should be protected; however specific sites that are used once may not need protection, instead, protecting habitat types similar to those selected is critical.

In Vernon, different protection is needed than in the southern sites. At Vernon, specific rock outcrops should be protected for shedding and retreat sites, while certain habitat types should be protected as areas that gophersnakes hibernate, oviposit, and forage in. At the southern sites, rock hibernation sites should be protected, as should some specific shedding and retreat sites that show high use, and certain habitat types should be protected as areas that gophersnakes mate and forage in.

Future work should focus on the occurrence of hibernation site switching, as fidelity has important implications for hibernation site protection. Further work in the regions between the north and south sites may give insight into why snakes in the north select for different habitats for hibernation sites than those in the south. Understanding the genetic structuring exhibited by these populations would further our understanding of mating and dispersal patterns. Increased understanding of the impact of different temperature regimes on offspring quality might also offer insight into the relative conservation value of oviposition sites. Detailed roadkill surveys may indicate whether long term population viability is threatened due to high adult mortality on roads.

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CHAPTER 5: Conclusion

In this thesis, I examined three major aspects of species biology for the threatened Great Basin gophersnake near the northern range limit. My main goals were to research how sex, location, year, and season affected movement and range patterns, habitat selection, and life history characteristics. I hypothesized that gophersnakes would exhibit different behavioural patterns in the four study areas due to site-specific differences in resource availability. I anticipated that the sex of the snakes would impact their behaviour since males and females perform different activities that require different resources. I predicted that the time of the year would affect snake behaviour as different life history traits are performed during different seasons.

By radio-tracking 39 adult male and female gophersnakes over two years, I collected location data every other day, and characterized habitats at snake-selected and random locations. I observed snake behaviour, recording events including mating, oviposition, ecdysis, and hibernation.

Movement and Range Patterns

Overall, male and female gophersnakes displayed different movement patterns depending on the season, consistent with results from other species (Gibbons and Semleitsch 1987, Macartney et al. 1988, Whitaker and Shine 2003). In the spring, during mating season, male gophersnakes moved further and faster than females. In the summer, during oviposition and summer foraging, and in the fall, during retreat to hibernation sites, females moved further and faster than males. Differences in movement speeds and distances were exhibited between the study sites, with West Vaseux snakes consistently moving further and faster than snakes at other sites. Site-specific movement patterns are important, as snakes at some sites may require more extensive habitat areas to support their larger movement rates.

Differences in range size and shape were exhibited between sites, while no differences existed between males and females. West Vaseux snakes had the largest ranges, while Vernon snakes had the smallest, although range sizes were within the range found previously in British Columbia (Bertram et al. 2001, Shewchuk 1996). The location of critical sites within the range was different between the sites as well, with variation in the centrality of hibernation and oviposition sites. Vernon had hibernation and oviposition sites close to the centre of snakes' ranges, while Ripley had hibernation sites located at the edge of the snakes' ranges. These differences indicate that site-specific differences in resources play an important role in the development of snake ranges.

Future work on movement patterns should examine movement in other regions besides the Okanagan, in addition to genetic work examining the connectivity among and within the subpopulations present in British Columbia.

Habitat Selection

Gophersnakes exhibited both habitat and microhabitat selection, which varied by site, sex, and month, similar to other species (Burger and Zappalorti 1989, Carfagno and Weatherhead 2006, Harvey and Weatherhead 2006, Himes and Hardy 2006). The overall trend was that gophersnakes consistently selected microhabitat locations that were closer than random to some form of retreat site, for example rocks, holes in the ground, or shrubs. When sites were considered together, gophersnakes selected rock outcrop and human-modified habitats and avoided grassland/meadow habitat. Gophersnakes in the Okanagan selected habitat hierarchically in human-modified habitats and occasionally in rock outcrop, wetland, grassland/meadow, and shrub-steppe habitats, unlike results for another snake species which did not exhibit hierarchical habitat selection at all (Harvey and Weatherhead 2006). Future work should examine habitat selection at other areas in British Columbia, especially outside of the Okanagan.

Life History Characteristics

The life history characteristics that I observed were consistent with those found by other studies both in British Columbia and elsewhere on other species of *Pituophis* (Bertram et al. 2001, Burger and Zappalorti 1992, 1991, 1986, Shewchuk 1996, Rodriguez-Robles 2003). Hibernation sites were associated exclusively with rock features in the south Okanagan, and associated with some rock features but mostly hillside rodent tunnels in the north Okanagan. Both single and communal hibernation sites occurred, and between-year fidelity was higher in the south Okanagan than the north Okanagan. As hibernation sites are critical for individual survival, site-specific identification and protection of these areas would be required. In areas where single or communal dens associated with particular rock features are common, it is critical to protect these specific hibernacula. In areas like the Vernon site, where snakes tended to hibernate singly in dens accessed via rodent holes, specific features will be difficult to identify, thus suitable habitat areas rather than specific features should be identified for protection.

Three ecdysis periods were observed, in June, July, and August, suggesting more frequent shedding events than previous work has documented (Shewchuk 1996). Mating events were clustered around May 12th, and oviposition was observed between June 19th and July 4th. Most females oviposited in consecutive years, although non-gravid females were occasionally observed. Oviposition site characteristics were very similar across the Okanagan, typically south facing slopes of moderate grade, with sparse grass cover and sandy soils. These results suggest that suitable areas at other locations can be identified and thus protected. As some females made lengthy journeys from oviposition sites to foraging grounds, critical corridors between these sites should be protected as well. Future work should focus on identifying hibernation and oviposition sites in other areas, especially outside of the Okanagan, to determine the extent to which rodent burrows and rock features are used in other regions.

Conservation Implications

I found that while the small details of movement patterns, habitat selection, general life history, and thus snake behaviour, vary widely even within a restricted region such as the Okanagan Valley, the bigger patterns are consistent across these sites. Gophersnakes require sites with suitable oviposition and hibernation areas situated within approximately 500 m, while with the presence of suitable retreat sites, most habitats suffice for summer foraging and daily existence. However, site-specific characteristics result in differences in movements and range sizes, thus the area large enough to sustain a viable population suitable for protection will differ depending on the location.

Disturbances, either by livestock or humans, should be minimized at critical times such as the mating season and oviposition period, to allow reproduction to occur. By identifying potential hibernation and oviposition sites, areas suitable for protection for gophersnakes can be conserved. As a significant percentage of mortality events of telemetry-equipped snakes were due to vehicles, mitigating the impact of existing and new roads will be an important component of management plans.

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Appendix I: Snake Capture Protocols

Gophersnakes were captured by hand through active searching and opportunistic sightings. Upon capture, GPS coordinates were recorded, and the snake was placed in a secure ventilated snake bag, transported out of the field, and placed in a secure opaque ventilated bin until processing could occur. Time in captivity was limited to less than 48 hours, with the exception of snakes undergoing surgery or those with injuries. While snakes were in captivity, they were housed in opaque ventilated secure containers containing a heat gradient, water, and substrate to hide beneath.

While in a restraining tube, snakes were sexed, PIT tagged, and blood was sampled. Sexing consisted of probing for hemipenes using a blunt sterile metal probe. PIT tagging involved injecting Passive Integrated Transponder tags (PIT tags, TX1440L10S, Destron Technologies, small rice-size devices used to uniquely identify individuals) under the skin in the left side approximately 20 cm anterior to the vent. The use of a PIT tag scanner (Destron Technologies) allowed visualization of the PIT tag code after implant. Blood was collected by inserting small-gauge insulin needles into the caudal vein via the ventral tail surface. Approximately 0.2 cc of blood was collected using this method and was stored in filter paper for future genetic work. Snakes were measured to the nearest centimetre by gently stretching them along a measuring tape to record snout-to-vent (SVL) and vent-to-tail (VTL) lengths, and weighed to the nearest gram using a Pesola spring scale. After processing, snakes were released at their capture location. All items that came into contact with a snake while in captivity were sterilized using dilute Quatsyl-D Plus to minimize the risk of disease or parasite transfer. Snakes recaptured after more than 30 days since they were last processed were reprocessed, collecting data on weight, SVL, and VTL.

Appendix II: Study Site Locations

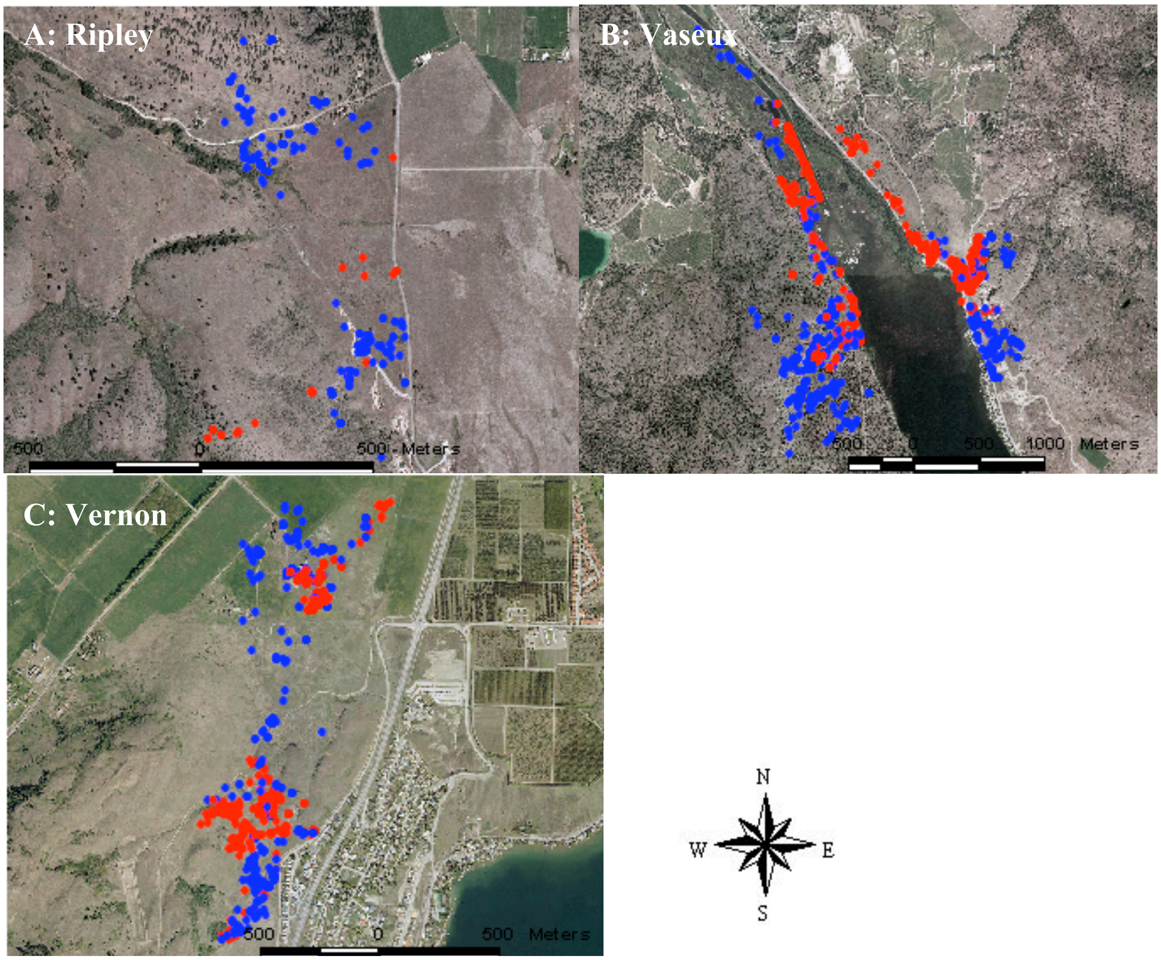

Figure A2.1. Airphotographs with snake locations of each of the four sites; East and West Vaseux are on the same panel. Panel A = Ripley, Panel B = East Vaseux on the right and West Vaseux on the left sides of Vaseux Lake, Panel C = Vernon. Locations for transmitter-equipped snakes are represented in red for females and in blue for males.

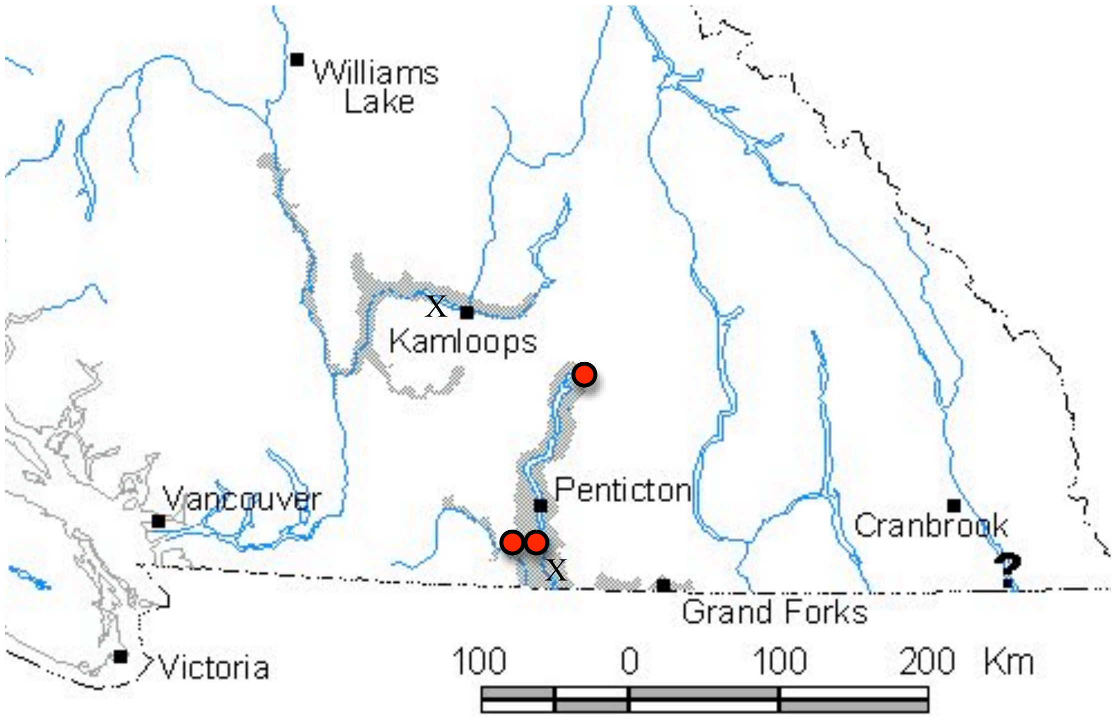

Figure A2.2. Map of southern British Columbia showing the Canadian range of the Great Basin gophersnake, adapted from Hobbs and Sarell (2002). Grey shading represents areas where gophersnakes have been found. The location of my study sites are shown with red dots, the northern one being Vernon, and the southern two representing Vaseux Lake (on the right), and Ripley (on the left). The study areas of Bertram et al. (2001) near Kamloops, and Shewchuk (1993) near the US border are shown with X's. (Hobbs J., M.J. Sarell. 2002. An assessment of racer and gopher snake habitat in the Williams Lake and 100-Mile forest districts. Canada -- Williams Lake: Report prepared for BC Environment.)

Table A2.1. Movement and range data for telemetry-equipped gophersnakes in 2006 and 2007. Study sites are: East Vaseux (EV), West Vaseux (WV) Ripley (Rip), Vernon (Vern). Data is for the entire active season; for data divided by activity season, please contact the author. Movement metrics are: minimum total distance moved (m) (MTDM), distance moved per day (m/d) (D/D), distance moved per movement (m/movement) (D/M), movement speed (m/h) (Spd). Range metrics are: range length (m) (Length), range width (m) (Width), ratio of range width to range length (W:L), minimum convex polygon (ha) (MCP), maximum distance dispersed from hibernation site (m) (Hib), ratio of maximum distance dispersed from hibernation site to range length (H:L), distance from hibernation site to oviposition site (m) (H:O).

Snake ID	Sex	Site	MTDM	D/D	D/M	Spd	Length	Width	W:L	MCP	Hib	H:L	H:O
2006													
3098BU	M	EV	1120.1	13.0	62.2	1.26	440.1	183.3	0.42	5.32	406.2	0.92	—
3912DA	M	EV	3454.6	21.1	101.6	1.88	515.6	167.0	0.32	6.10	397.3	0.77	—
3928GR	F	EV	1093.1	18.2	91.1	1.29	204.0	151.5	0.74	2.07	204.0	1.00	—
4442HI	F	EV	1648.0	9.6	51.5	0.92	222.7	146.4	0.66	2.32	219.8	0.99	189.8
3891RU	F	EV	2201.5	11.7	57.9	1.02	215.2	95.0	0.44	1.30	185.8	0.86	154.4
3450TU	F	EV	2681.0	18.6	78.9	1.53	709.3	192.8	0.27	8.76	606.4	0.85	108.5
4051BA	M	WV	5044.8	30.8	148.4	2.90	715.5	384.1	0.54	21.72	715.5	1.00	—
3870DA	F	WV	3606.1	19.3	80.1	1.76	439.7	216.0	0.49	6.16	387.1	0.88	—
4110JE	M	WV	3434.5	17.8	114.5	2.16	700.5	267.8	0.38	12.61	700.5	1.00	—
4358KE	M	WV	4924.2	26.8	158.8	3.23	612.5	410.6	0.67	15.47	566.2	0.92	—
4384LO	M	WV	1551.6	32.3	110.8	1.92	618.0	239.7	0.39	10.92	—	—	—
3962WE	F	WV	5098.4	38.1	159.3	3.00	1746.6	333.7	0.19	33.47	1410.0	0.81	401.1
4031WI	M	WV	4000.6	74.1	250.0	3.30	1993.2	303.5	0.15	32.24	—	—	—
4500BA	M	Rip	1184.7	7.8	43.9	0.76	298.3	109.6	0.37	2.46	298.3	1.00	—
4411BR	M	Rip	1928.0	15.9	71.4	1.48	344.2	191.4	0.56	3.52	344.2	1.00	—
4466JA	M	Rip	2417.2	13.3	93.0	1.86	470.1	269.6	0.57	8.50	456.5	0.97	—
3722NO	F	Rip	2297.7	31.1	153.2	2.54	972.4	262.1	0.27	15.10	—	—	—
4328DA	F	Vern	2367.8	16.7	74.0	1.56	414.8	136.0	0.33	3.76	247.0	0.60	—
4141DA	M	Vern	1484.2	9.6	67.5	1.13	323.4	148.7	0.46	3.30	245.1	0.76	—
4091HI	M	Vern	1576.3	9.6	92.7	0.94	571.3	120.1	0.21	3.82	294.0	0.51	—
4162KU	M	Vern	3817.8	22.2	159.1	2.54	858.8	278.3	0.32	16.02	778.4	0.91	—
3059LU	M	Vern	1733.3	12.2	82.5	1.18	320.3	120.7	0.38	2.55	216.3	0.68	—
3803MA	F	Vern	1137.8	8.2	43.8	0.68	152.6	93.8	0.61	1.14	136.4	0.89	75.0

Snake ID	Sex	Site	MTDM	D/D	D/M	Spd	Length	Width	W:L	MCP	Hib	H:L	H:O
3993TA	F	Vern	2854.1	26.9	86.5	1.45	441.1	100.2	0.23	3.17	278.4	0.63	133.2
3482TI	F	Vern	1989.8	14.4	76.5	1.54	593.2	97.9	0.17	4.25	349.5	0.59	314.3
3020TU	M	Vern	1751.6	13.0	67.4	1.17	439.0	160.6	0.37	4.70	255.0	0.58	—
2007													
3381BL	M	EV	2082.5	15.9	109.6	1.75	349.7	252.3	0.72	5.59	349.7	1.00	—
3098BU	M	EV	2890.9	16.1	103.3	1.64	516.5	208.6	0.40	7.05	416.2	0.81	—
4442HI	F	EV	4879.9	27.6	108.4	1.96	1596.0	238.8	0.15	26.94	1527.6	0.96	185.4
3256HO	F	EV	970.2	13.7	64.7	1.42	302.2	101.7	0.34	2.03	—	—	—
3277SL	M	EV	5504.6	32.6	144.9	3.09	802.5	215.1	0.27	9.58	514.0	0.64	—
3223WI	F	EV	674.4	11.2	56.2	1.33	208.9	119.8	0.57	1.38	—	—	—
4051BA	M	WV	3100.6	35.2	172.3	5.51	1131.9	413.7	0.37	34.56	851.1	0.75	—
3177CA	M	WV	7409.5	47.8	211.7	4.70	1487.5	248.4	0.17	25.09	1474.6	0.99	—
4110JE	M	WV	3430.1	39.4	127.0	3.04	683.6	379.0	0.55	15.02	626.5	0.92	—
4358KE	M	WV	4160.9	23.6	126.1	2.78	657.0	352.0	0.54	16.51	592.7	0.90	—
3361TI	F	WV	6263.8	45.7	189.8	3.03	1418.1	214.7	0.15	20.26	817.7	0.58	605.0
3962WE	F	WV	8045.6	42.1	174.9	2.95	2034.3	371.1	0.18	46.90	1610.6	0.79	464.0
4031WI	M	WV	8123.5	77.4	338.5	5.87	2589.4	334.1	0.13	66.74	2365.1	0.91	—
4500BA	M	Rip	387.9	6.6	64.7	1.10	300.5	88.5	0.29	1.60	300.5	1.00	—
4411BR	M	Rip	2054.0	12.4	76.1	1.34	385.5	199.4	0.52	5.20	333.7	0.87	—
4466JA	M	Rip	402.2	13.9	50.3	0.88	247.5	77.9	0.31	1.33	247.5	1.00	—
4328DA	F	Vern	484.8	8.2	69.3	0.45	225.0	38.8	0.17	9.97	157.1	0.70	—
4141DA	M	Vern	2627.9	14.9	93.9	1.78	351.7	162.9	0.46	3.53	329.0	0.94	—
4091HI	M	Vern	2325.9	14.3	105.7	2.39	352.4	275.3	0.78	5.91	297.9	0.85	—
4162KU	M	Vern	677.4	21.9	75.3	1.21	286.7	191.6	0.67	2.69	286.7	1.00	—
3059LU	M	Vern	4062.4	23.9	112.8	2.11	512.5	148.6	0.29	6.27	425.8	0.83	—
3803MA	F	Vern	2036.9	12.8	92.6	1.18	163.4	104.4	0.64	1.39	158.5	0.97	67.1
3993TA	F	Vern	2329.9	14.0	66.6	1.28	468.5	126.0	0.27	3.77	260.3	0.56	77.4
3338TH	F	Vern	1998.2	13.7	86.9	1.36	506.3	110.5	0.22	3.62	452.0	0.89	—
3482TI	F	Vern	5232.1	28.8	130.8	2.56	585.1	104.9	0.18	4.32	297.6	0.51	272.4
3323TR	F	Vern	992.3	10.6	47.3	0.63	227.3	78.8	0.35	1.08	—	—	—
3020TU	M	Vern	2790.5	15.9	84.6	1.39	404.3	311.6	0.77	6.77	339.9	0.84	—

Snake ID	Sex	Site	MTDM	D/D	D/M	Spd	Length	Width	W:L	MCP	Hib	H:L	H:O
3692YA	M	Vern	1120.1	8.4	52.3	0.63	301.2	117.4	0.39	2.21	231.6	0.77	—

Table A2.2. Significance levels from Tukey's post hoc tests on movement and range data for the entire active season, to determine which sites exhibit different patterns for each metric. Significant values are shown in bold. Study sites are as follows: East Vaseux (EV), West Vaseux (WV), Ripley (Rip), Vernon (Vern). Movement metrics are as follows: Minimum Total Distance Moved (MTDM), Distance Moved per Day (D/D), Distance Moved per Movement (D/M), Movement Speed (Spd). Range metrics are as follows: Range Length (Length), Range Width (Width), Ratio of Range Width to Range Length (W:L), Minimum Convex Polygon (MCP), Maximum Distance Dispersed from Hibernation Site (Hib), Ratio of Maximum Distance Dispersed from Hibernation Site to Range Length (H:L), Distance from Hibernation Site to Oviposition Site (H:O).

Site	Site	MTDM	D/D	D/M	Spd	Length	Width	W:L	MCP	Hib	H:L	H:O
EV	WV	0.001	**<0.001**	**<0.001**	**<0.001**	**0.001**	**<0.001**	0.581	**<0.001**	**0.008**	0.998	**0.004**
EV	Rip	0.572	0.936	0.984	0.969	0.981	1.000	0.987	0.994	0.848	0.492	—
EV	Vern	0.950	0.943	0.999	0.982	0.906	0.552	0.886	0.934	0.577	0.055	0.965
WV	Rip	<0.001	**<0.001**	**<0.001**	**<0.001**	**0.001**	**<0.001**	0.878	**<0.001**	**0.003**	0.382	—
WV	Vern	<0.001	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	0.898	**<0.001**	**<0.001**	0.060	**0.002**
Rip	Vern	0.769	0.998	0.991	1.000	0.999	0.726	0.995	0.996	0.998	**0.003**	—

Table A2.3. Significance from Tukey's post hoc tests on movement and range data for each activity season, to determine which sites exhibit different patterns for each metric. Significant values are in bold. Study sites are as follows: East Vaseux (EV), West Vaseux (WV), Ripley (Rip), Vernon (Vern). Movement metrics are as follows: minimum total distance moved (MTDM), distance moved per day (M/D), distance moved per movement (M/M), movement speed (Spd).

Site	Site	Activity Season	MTDM	M/D	M/M	Spd
EV	WV	Spring	**0.003**	**0.001**	**0.001**	**<0.001**
EV	Rip	Spring	0.770	0.971	1.000	1.000
EV	Vern	Spring	0.996	1.000	0.748	1.000
WV	Rip	Spring	**0.001**	**0.001**	**0.003**	**0.001**
WV	Vern	Spring	**<0.001**	**<0.001**	**0.002**	**<0.001**
Rip	Vern	Spring	0.814	0.954	0.799	1.000
EV	WV	Summer	**0.042**	**0.039**	0.090	0.117
EV	Rip	Summer	0.924	1.000	0.994	0.970
EV	Vern	Summer	0.949	0.976	0.998	0.907
WV	Rip	Summer	**0.027**	0.091	0.122	0.100
WV	Vern	Summer	**0.002**	**0.003**	**0.020**	**0.008**
Rip	Vern	Summer	0.994	0.995	0.999	1.000
EV	WV	Fall	0.796	0.721	0.881	0.992
EV	Rip	Fall	0.466	0.999	0.981	0.546
EV	Vern	Fall	0.633	0.900	0.968	0.683
WV	Rip	Fall	0.147	0.785	0.997	0.406
WV	Vern	Fall	0.129	0.246	0.564	0.835
Rip	Vern	Fall	0.890	0.980	0.876	0.140

Appendix III: Habitat Selection

Table A3.1. Count data of snake locations in each habitat type, grouped by site, separated by sex and month. Data are not altered from original count data, as it is in some of the Manly's alpha tests, where one count was added to each category to allow for log-linear analyses. Dashes occur when the habitat was not present on the study site. In May, several snakes at the Ripley site died, thus for June through August a smaller study site was used to better represent the habitats available to the sole remaining snake. Ripley snakes were all male.

			Habitat Type						
Site	Sex	Month	Offsite	Forest	Rock Outcrop	Wetl-and	Grassland/ meadow	Shrub-steppe	Human-modified
Vernon	Female	May	7	—	4	0	46	8	3
		June	4	—	0	0	34	14	8
		July	0	—	5	1	46	15	2
		August	0	—	10	0	30	11	0
	Male	May	0	—	1	0	19	5	3
		June	0	—	4	1	15	2	8
		July	0	—	0	0	34	1	2
		August	0	—	13	0	2	23	0
East Vaseux	Female	May	1	—	0	5	9	1	6
		June	1	—	0	0	9	2	8
		July	13	—	0	1	0	1	0
		August	10	—	0	0	0	0	0
	Male	May	5	—	0	0	3	10	8
		June	9	—	7	0	0	13	5
		July	0	—	25	0	0	16	1
		August	7	—	14	0	0	11	0
West Vaseux	Female	May	4	0	1	2	0	7	2
		June	5	0	3	2	0	12	0
		July	5	0	0	21	0	0	0
		August	9	0	0	8	0	1	3
	Male	May	2	7	6	2	6	26	2
		June	8	12	11	5	4	0	0
		July	16	1	8	5	6	14	0
		August	2	2	15	1	1	8	0
Ripley	Male	May (large)	6	0	2	0	3	14	2
		June	0	—	0	0	3	2	7
		July	0	—	0	0	4	5	5
		August	9	—	1	0	0	0	0

Table A3.2. Manly's alpha results of the habitat data at each site, separated by sex and month. Dashes mean that the habitat type covered less than 3% of the entire study site and thus was removed. One count was added to every category, to make it suitable for the log transformation. Values greater than the alpha value indicate selection (shown in bold), whereas values lower than the alpha value indicate avoidance; values further away from the alpha have a greater degree of selection or avoidance. Ripley had a low sample size (n=3 for May, n=1 for June-August, all males), that varied by month, thus May data are separate.

				Habitat Type					
Site	Sex	Month	alpha	Forest	Rock Outcrop	Wetland	Grassland/ meadow	Shrub-steppe	Human-modified
East Vaseux	F	May	0.20	—	0.014	**0.441**	0.169	0.017	**0.359**
	F	June	0.20	—	0.019	0.099	**0.228**	0.034	**0.620**
	F	July	0.20	—	0.058	**0.597**	0.069	0.068	**0.208**
	F	August	0.20	—	0.087	**0.447**	0.103	0.051	**0.312**
	M	May	0.20	—	0.020	0.104	0.096	0.130	**0.651**
	M	June	0.20	—	0.181	0.117	0.027	0.187	**0.489**
	M	July	0.20	—	**0.524**	0.104	0.024	**0.202**	0.145
	M	August	0.20	—	**0.468**	0.161	0.037	**0.221**	0.112
West Vaseux	F	May	0.20	0.037	0.153	0.163	**0.357**	**0.290**	—
	F	June	0.20	0.028	**0.229**	0.122	**0.268**	**0.353**	—
	F	July	0.20	0.022	0.045	**0.702**	**0.210**	0.021	—
	F	August	0.20	0.036	0.074	**0.474**	**0.346**	0.070	—
	M	May	0.20	0.066	0.120	0.036	**0.559**	**0.219**	—
	M	June	0.20	0.136	**0.259**	0.092	**0.504**	0.010	—
	M	July	0.20	0.018	0.167	0.079	**0.605**	0.132	—
	M	August	0.20	0.045	**0.493**	0.044	**0.288**	0.131	—
Ripley-large	M	May	0.25	—	0.148	—	0.179	0.151	**0.522**
Ripley-small	M	June	0.33	—	**0.436**	—	**0.399**	0.165	—
	M	July	0.33	—	**0.345**	—	**0.395**	0.260	—
	M	August	0.33	—	**0.849**	—	0.097	0.053	—
Vernon	F	May	0.25	—	**0.301**	—	0.154	0.210	**0.334**
	F	June	0.25	—	0.047	—	0.099	**0.272**	**0.582**
	F	July	0.25	—	**0.317**	—	0.135	**0.328**	0.220
	F	August	0.25	—	**0.571**	—	0.116	0.241	0.072
	M	May	0.25	—	0.183	—	0.099	0.212	**0.506**
	M	June	0.25	—	**0.256**	—	0.045	0.060	**0.639**
	M	July	0.25	—	0.128	—	0.243	0.099	**0.530**
	M	August	0.25	—	**0.563**	—	0.007	0.374	0.056

Table A3.3. MANOVA of microhabitat variables for males, females, and random locations, analysed separately by month and site. Entries in bold were statistically significant, indicating that the variable differs among males, females and random locations. Missing data indicate that all measured variables were zero (occurred only for percent cover by water). (d.f. was two except for in August at East Vaseux, and at Ripley, where it was one because of no females.)

Site	Month	Microhabitat Variable	SS	F	p
East Vaseux	May	Distance to tree	12.51	0.42	0.659
		Distance to shrub	9.27	0.20	0.822
		Distance to rock	27.62	1.51	0.226
		Distance to retreat	136.80	0.56	0.573
		Slope	813.93	4.55	**0.013**
		Aspect	16686.09	1.74	0.181
		# woody stems	221.08	1.37	0.259
		Droop height	825.80	2.06	0.133
		Retreat type	0.102	0.04	0.964
		% rock cover	2596.86	1.71	0.187
		% CWD cover	39.41	2.15	0.122
		% vegetation cover	811.47	0.35	0.709
		% water cover	146.58	0.92	0.401
		% soil cover	6295.43	3.32	**0.040**
	June	Distance to tree	32.01	0.39	0.682
		Distance to shrub	4.70	0.06	0.943
		Distance to rock	15.51	1.13	0.331
		Distance to retreat	33.03	2.89	0.064
		Slope	107.41	0.67	0.516
		Aspect	14590.09	0.87	0.425
		# woody stems	7.40	0.10	0.904
		Droop height	684.27	2.76	0.072
		Retreat type	0.08	0.04	0.962
		% rock cover	723.30	0.28	0.754
		% CWD cover	397.35	8.72	**0.001**
		% vegetation cover	2715.31	1.09	0.342
		% water cover	40.59	0.41	0.666
		% soil cover	378.27	0.19	0.830
	July	Distance to tree	25.24	0.49	0.613
		Distance to shrub	29.64	0.82	0.446
		Distance to rock	34.11	3.23	**0.046**
		Distance to retreat	67.95	6.24	**0.003**
		Slope	147.46	0.56	0.575
		Aspect	6170.62	0.41	0.669
		# woody stems	28.41	0.60	0.552

Site	Month	Microhabitat Variable	SS	F	p
		Droop height	1310.68	4.37	**0.016**
		Retreat type	3.69	1.90	0.157
		% rock cover	8226.68	4.73	**0.012**
		% CWD cover	23.27	0.62	0.542
		% vegetation cover	2958.95	1.48	0.235
		% water cover	8.81	0.19	0.831
		% soil cover	3190.13	1.80	0.173
	August	Distance to tree	205.75	13.55	**0.001**
		Distance to shrub	90.75	4.22	**0.045**
		Distance to rock	2.76	0.54	0.466
		Distance to retreat	29.30	3.06	0.086
		Slope	2.39	0.03	0.870
		Aspect	32416.69	4.02	0.050
		# woody stems	50.18	0.39	0.538
		Droop height	1253.28	16.32	**<0.001**
		Retreat type	1.45	1.82	0.183
		% rock cover	409.85	0.24	0.627
		% CWD cover	1.51	0.19	0.668
		% vegetation cover	526.43	0.39	0.535
		% water cover	0.00	—	—
		% soil cover	15.42	0.02	0.890
West Vaseux	May	Distance to tree	56.44	1.24	0.293
		Distance to shrub	3079.39	1.10	0.335
		Distance to rock	163.24	5.84	**0.004**
		Distance to retreat	585.29	20.83	**<0.001**
		Slope	346.81	1.79	0.171
		Aspect	11007.01	1.30	0.276
		# woody stems	583.98	3.51	**0.033**
		Droop height	285.75	0.52	0.594
		Retreat type	4.89	1.10	0.337
		% rock cover	9006.89	4.46	**0.014**
		% CWD cover	276.14	4.28	**0.016**
		% vegetation cover	13609.87	6.60	**0.002**
		% water cover	360.69	1.57	0.212
		% soil cover	552.55	0.69	0.505
	June	Distance to tree	85.77	2.17	0.123
		Distance to shrub	46.53	1.25	0.295
		Distance to rock	37.71	1.30	0.281
		Distance to retreat	12.21	0.63	0.534
		Slope	239.42	0.12	0.883
		Aspect	4006.64	0.28	0.758
		# woody stems	370.96	6.60	**0.003**

Site	Month	Microhabitat Variable	SS	F	p
		Droop height	45.14	0.13	0.880
		Retreat type	4.25	1.11	0.338
		% rock cover	1219.34	0.61	0.547
		% CWD cover	14.10	0.35	0.703
		% vegetation cover	607.43	0.26	0.769
		% water cover	14.34	0.31	0.736
		% soil cover	214.29	0.13	0.877
	July	Distance to tree	30.14	0.73	0.485
		Distance to shrub	26.18	0.90	0.412
		Distance to rock	49.81	1.90	0.157
		Distance to retreat	94.27	7.42	**0.001**
		Slope	310.28	1.92	0.153
		Aspect	27334.56	1.31	0.276
		# woody stems	67.49	1.44	0.244
		Droop height	4892.61	8.19	**0.001**
		Retreat type	9.20	3.09	0.051
		% rock cover	9133.52	6.01	**0.004**
		% CWD cover	190.58	3.30	**0.043**
		% vegetation cover	5946.85	3.14	**0.049**
		% water cover	137.24	3.86	**0.025**
		% soil cover	3920.89	2.79	0.068
	August	Distance to tree	346.29	6.07	**0.004**
		Distance to shrub	314.43	10.34	**<0.001**
		Distance to rock	62.02	8.51	**<0.001**
		Distance to retreat	15.73	3.57	**0.033**
		Slope	343.35	2.31	0.107
		Aspect	1816.51	0.09	0.911
		# woody stems	20.65	0.38	0.687
		Droop height	28.06	0.12	0.887
		Retreat type	3.19	1.48	0.234
		% rock cover	3970.45	2.54	0.086
		% CWD cover	11.79	0.09	0.912
		% vegetation cover	5162.48	2.36	0.102
		% water cover	299.73	3.88	**0.025**
		% soil cover	5246.24	3.44	**0.038**
Ripley	May	Distance to tree	273.73	0.25	0.620
		Distance to shrub	115.04	1.83	0.180
		Distance to rock	4.77	0.36	0.550
		Distance to retreat	17.77	14.61	**<0.001**
		Slope	434.27	3.89	0.052
		Aspect	1396.11	0.24	0.626
		# woody stems	171.57	5.78	**0.018**

Site	Month	Microhabitat Variable	SS	F	p
		Droop height	1420.85	6.49	**0.013**
		Retreat type	0.96	1.10	0.297
		% rock cover	2190.28	2.38	0.127
		% CWD cover	81.74	0.63	0.430
		% vegetation cover	386.99	0.29	0.589
		% water cover	9.39	0.62	0.434
		% soil cover	5248.99	8.29	**0.005**
	June	Distance to tree	0.04	<0.01	0.980
		Distance to shrub	4.36	0.10	0.759
		Distance to rock	1.16	0.12	0.726
		Distance to retreat	7.62	2.71	0.106
		Slope	0.11	<0.01	0.970
		Aspect	10270.55	1.12	0.296
		# woody stems	4.92	0.14	0.710
		Droop height	54.02	0.16	0.692
		Retreat type	0.01	0.02	0.899
		% rock cover	2.33	0.02	0.899
		% CWD cover	0.08	0.04	0.844
		% vegetation cover	623.08	0.71	0.403
		% water cover	0.48	0.04	0.844
		% soil cover	504.69	0.60	0.422
	July	Distance to tree	16.19	0.47	0.495
		Distance to shrub	11.57	0.35	0.560
		Distance to rock	1.49	0.32	0.575
		Distance to retreat	1.69	2.17	0.147
		Slope	10.45	0.17	0.679
		Aspect	21.69	<0.01	0.957
		# woody stems	6.45	0.20	0.658
		Droop height	1.25	<0.01	0.958
		Retreat type	0.23	0.58	0.450
		% rock cover	555.79	2.57	0.115
		% CWD cover	0.59	0.13	0.723
		% vegetation cover	310.08	0.45	0.506
		% water cover	4.48	0.08	0.780
		% soil cover	9.48	0.01	0.905
	August	Distance to tree	54.51	1.88	0.177
		Distance to shrub	16.16	0.97	0.329
		Distance to rock	0.78	0.49	0.487
		Distance to retreat	1.78	1.61	0.211
		Slope	96.01	2.49	0.121
		Aspect	818.39	0.14	0.713
		# woody stems	270.45	3.51	0.067

Site	Month	Microhabitat Variable	SS	F	p
		Droop height	3.92	0.01	0.927
		Retreat type	8.94	28.65	**<0.001**
		% rock cover	16.33	0.22	0.642
		% CWD cover	441.47	9.97	**0.003**
		% vegetation cover	43.11	0.11	0.743
		% water cover	0.00	—	—
		% soil cover	108.26	0.30	0.588
Vernon	May	Distance to tree	29.42	1.01	0.368
		Distance to shrub	99.81	1.32	0.271
		Distance to rock	36.17	0.48	0.618
		Distance to retreat	1333.35	1.79	0.171
		Slope	65.02	0.48	0.620
		Aspect	105441.51	5.69	**0.004**
		# woody stems	351.48	3.01	0.053
		Droop height	287.39	1.09	0.341
		Retreat type	3.17	2.98	0.054
		% rock cover	199.13	0.34	0.710
		% CWD cover	0.00	—	—
		% vegetation cover	5376.87	2.91	0.058
		% water cover	98.72	0.78	0.462
		% soil cover	3124.05	2.33	0.101
	June	Distance to tree	8.85	0.23	0.798
		Distance to shrub	069	0.01	0.989
		Distance to rock	35.03	1.02	0.365
		Distance to retreat	114.65	7.57	**0.001**
		Slope	523.99	3.28	**0.043**
		Aspect	58978.58	2.46	0.092
		# woody stems	3.52	1.09	0.341
		Droop height	1409.88	3.47	**0.036**
		Retreat type	0.78	0.96	0.389
		% rock cover	483.04	1.23	0.298
		% CWD cover	4.95	1.95	0.149
		% vegetation cover	294.10	0.12	0.892
		% water cover	0.00	—	—
		% soil cover	56.90	0.03	0.974
	July	Distance to tree	24.63	0.69	0.503
		Distance to shrub	83.81	1.75	0.179
		Distance to rock	85.56	3.31	**0.041**
		Distance to retreat	82.33	17.82	**<0.001**
		Slope	115.52	0.74	0.482
		Aspect	185948.18	8.10	**0.001**
		# woody stems	117.99	2.87	0.062

Site	Month	Microhabitat Variable	SS	F	p
		Droop height	395.96	1.71	0.187
		Retreat type	1.64	2.05	0.135
		% rock cover	1783.64	2.64	0.077
		% CWD cover	0.22	0.43	0.653
		% vegetation cover	8220.42	4.88	**0.010**
		% water cover	0.00	—	—
		% soil cover	2327.08	1.84	0.164
	August	Distance to tree	85.38	2.21	0.117
		Distance to shrub	496.89	8.80	**<0.001**
		Distance to rock	64.42	2.20	0.119
		Distance to retreat	21.66	7.87	**0.001**
		Slope	10.46	0.05	0.953
		Aspect	76387.72	4.06	**0.022**
		# woody stems	0.59	0.63	0.536
		Droop height	167.74	1.11	0.337
		Retreat type	0.80	0.74	0.482
		% rock cover	264.48	0.23	0.794
		% CWD cover	38.81	8.48	**0.001**
		% vegetation cover	832.29	0.36	0.700
		% water cover	0.00	—	—
		% soil cover	182.03	0.11	0.899

Appendix IV: Life History

Table A4.1 Transmitter-equipped gophersnakes that died in 2006 and 2007 with date, study site, and evidence and cause of mortality listed. Snakes with an F in front of their code are females and males are represented with an M.

Snake	Cause of Death	Date of occurrence	Study Site
F_3450TU	roadkill	April 24 2007	East Vaseux
M_3141DA	raptor	April 29 2007	East Vaseux
M_4466JA	owl	May 19 2007	Ripley
F_3692AV	coyote	May 22 2006	Vernon
M_4162KU	coyote	May 22 2007	Vernon
M_4528KO	unknown, likely raptor	May 23 2006	Ripley
M_3141HO	roadkill	May 23 2007	Ripley
M_4500BA	redtail hawk	May 30 2007	Ripley
M_3511BR	small carnivore, likely cat	May 31 2006	Ripley
F_4328DA	coyote	June 19 2007	Vernon
F_3223WI	roadkill	June 23 2007	East Vaseux
M_4384LO	unknown, likely carnivore	June 27 2006	West Vaseux
M_4051BA	owl	July 2 2007	West Vaseux
F_3256HO	unknown	July 10 2007	East Vaseux
M_4109JE	unknown, likely carnivore	July 27 2007	West Vaseux
F_3722NO	redtail hawk	August 4 2006	Ripley
F_3323TR	unknown, likely raptor	August 4 2007	Vernon

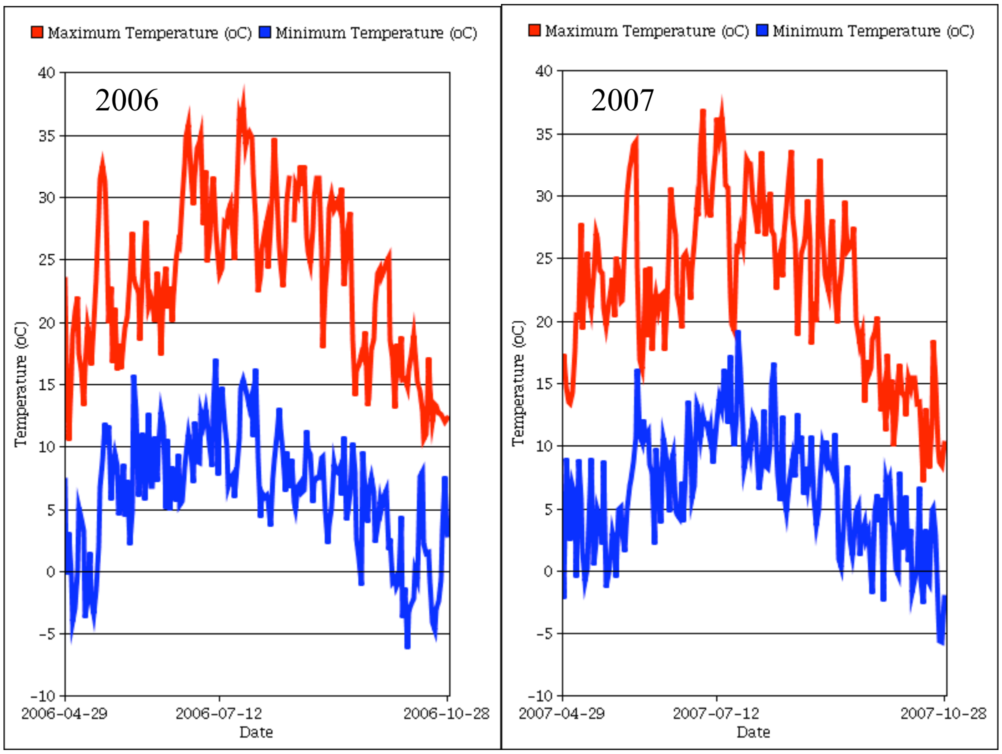

Figure A4.1. Maximum and minimum daily temperatures for Kelowna (midway between north and south study sites) for the summers of 2006 and 2007. Obtained from: http://www.climate.weatheroffice.ec.gc.ca/climateData/generate_custom_chart_e.html

Appendix V: Animal Care Certificates

THE UNIVERSITY OF BRITISH COLUMBIA

ANIMAL CARE CERTIFICATE

Application Number: A06-0068

Investigator or Course Director: Karen E. Hodges

Department: UBCO Admin Unit 2 Arts & Sci

Animals:

Snakes Pituophis catenifer deserticola 100

Start Date:	**March 31, 2006**	**Approval Date:**	**May 10, 2006**

Funding Sources:

Funding Agency:	BC Ministry of Environment, Lands and Parks
Funding Title:	Determining Habitat use by the Great Basin Gopher Snake in BC
Funding Agency:	World Wildlife Fund Canada
Funding Title:	Identifying critical habitat and determining habitat selection in Great Basin gophersnakes in BC

Unfunded title: N/A

The Animal Care Committee has examined and approved the use of animals for the above experimental project.

This certificate is valid for one year from the above start or approval date (whichever is later) provided there is no change in the experimental procedures. Annual review is required by the CCAC and some granting agencies.

A copy of this certificate must be displayed in your animal facility.

Office of Research Services and Administration
102, 6190 Agronomy Road, Vancouver, BC V6T 1Z3
Phone: 604-827-5111 Fax: 604-822-5093

THE UNIVERSITY OF BRITISH COLUMBIA

ANIMAL CARE CERTIFICATE

Application Number: A06-0068

Investigator or Course Director: Karen E. Hodges

Department: UBCO Admin Unit 2 Arts & Sci

Animals:

Snakes Pituophis catenifer deserticola 100

Start Date:	**March 31, 2006**	**Approval Date:**	**April 23, 2007**

Funding Sources:

Funding Agency:	British Columbia Ministry of Environment, Lands and Parks
Funding Title:	Determining Habitat use by the Great Basin Gopher Snake in BC
Funding Agency:	World Wildlife Fund Canada
Funding Title:	Identifying critical habitat and determining habitat selection in Great Basin gophersnakes in BC
Unfunded title:	N/A

The Animal Care Committee has examined and approved the use of animals for the above experimental project.

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THE UNIVERSITY OF BRITISH COLUMBIA

ANIMAL CARE CERTIFICATE

Application Number: A06-0068

Investigator or Course Director: Karen E. Hodges

Department: UBCO Admin Unit 2 Arts & Sci

Animals:

Snakes Pituophis catenifer deserticola 1000

Start Date: **March 31, 2006** **Approval Date:** **April 30, 2008**

Funding Sources:

Funding Agency: Natural Sciences and Engineering Research Council of Canada (NSERC)
Funding Title: Exploring the Genetic Basis of Adaptation within a Conservation Context

Funding Agency: British Columbia Ministry of Environment, Lands and Parks
Funding Title: Determining Habitat use by the Great Basin Gopher Snake in BC

Funding Agency: World Wildlife Fund Canada
Funding Title: Identifying critical habitat and determining habitat selection in Great Basin gophersnakes in BC

Unfunded title: N/A

The Animal Care Committee has examined and approved the use of animals for the above experimental project.

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