

Small reserves around hibernation sites may not adequately protect mobile snakes: the example of Great Basin Gophersnakes (*Pituophis catenifer deserticola*) in British Columbia

K.E. Williams, K.E. Hodges, and C.A. Bishop

Abstract: A common strategy for reptile conservation is to establish reserves around nesting or hibernation sites. The government of British Columbia, Canada, mandates protection of 200–300 ha wildlife habitat areas (WHAs) around hibernation sites of the federally threatened Great Basin Gophersnakes (*Pituophis catenifer deserticola* Stejneger, 1893), but practical constraints result in a mean size of 193 ha. To evaluate the efficacy of this reserve size, we radio-tracked 39 adult Gophersnakes at four study sites in the Okanagan Valley in 2006 and 2007. Home ranges averaged 10.5 ± 1.7 ha. The maximum distance traveled from a hibernation site was 2400 m, whereas the maximum distance dispersed averaged 520 ± 65 m. An idealized circular WHA of 193 ha with the hibernation site at the centre would be large enough to contain Gophersnake home ranges, but the dispersal data show that only 85% of snakes would stay within that area. Small or asymmetrical WHAs likely protect even fewer Gophersnake locations. We recommend that WHAs be expanded if possible because the high mobility of Gophersnakes suggests that current reserves may not offer adequate protection.

Key words: Great Basin Gophersnake, *Pituophis catenifer deserticola*, movements, home range, reserve size, wildlife habitat areas, British Columbia.

Résumé : Une stratégie courante pour la conservation des reptiles est l'établissement de réserves autour des sites de nidification ou d'hibernation. Le gouvernement de la Colombie-Britannique, Canada, impose l'établissement de zones d'habitat faunique (WHA, wildlife habitat area) de 200–300 ha autour des sites d'hibernation de la couleuvre à nez mince du Grand Basin (*Pituophis catenifer deserticola* Stejneger, 1893), qui figure sur la liste fédérale des espèces menacées; cependant, des contraintes pratiques font que la taille moyenne est de 193 ha. Afin d'évaluer l'efficacité d'une réserve de cette taille, nous avons suivi par radio 39 couleuvres à nez mince dans quatre sites d'étude dans la vallée de l'Okanagan en 2006 et 2007. Les domaines vitaux sont en moyenne de $10,5 \pm 1,7$ ha. La distance maximale moyenne parcourue depuis un site d'hibernation est de 2400 m, alors que la distance maximale de dispersion est de 520 ± 65 m. Une WHA circulaire idéale de 193 ha avec le site d'hibernation dans le centre serait assez grande pour contenir les domaines vitaux des couleuvres à nez mince, mais les données de dispersion indiquent que seulement 85 % des couleuvres resteraient dans la zone. Les WHA petites ou asymétriques protègent vraisemblablement encore moins de sites de couleuvres à nez mince. Nous recommandons d'agrandir, lorsque c'est possible, les WHA parce que la forte mobilité des couleuvres à nez mince fait penser que les réserves actuelles n'offrent pas une protection suffisante.

Mots-clés : couleuvre à nez mince du Grand Basin, *Pituophis catenifer deserticola*, déplacements, domaine vital, taille des réserves, zones d'habitat faunique, Colombie-Britannique.

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Introduction

Habitat loss is one of the dominant threats to species persistence (Wilcove et al. 1998; Gibbons et al. 2000; Lawler et al. 2002). Numerous types of protected areas have been implemented to protect imperilled species, but the adequacy of this protection is often unknown for individual species (Gaston et al. 2008), even in cases where reserves are designed

for particular species. For reptiles, small reserves have been designated around hibernation sites and nesting locations (e.g., beaches for sea turtles), as the localized and specialized nature of these habitats for specific life-history needs are relatively easy to identify. For snakes, it is not well established if protecting an area around hibernation sites also protects snakes during the active season. Protecting adults of long-

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K.E. Williams* and **K.E. Hodges.** Irving K. Barber School of Arts and Science, Institute for Species at Risk and Habitat Studies, University of British Columbia Okanagan, 3333 University Way, Kelowna, BC V1V 1V7, Canada.

C.A. Bishop. Science and Technology Branch, Environment Canada, 5421 Robertson Road, Delta, BC V2Z 1V7, Canada.

Corresponding author: K.E. Williams (e-mail: williamskathleene@gmail.com).

*Present address: 234 Benson Creek Drive, Twisp, WA 98856, USA.

lived species is often deemed more important than protecting hatchlings or juveniles, because of the high reproductive value of mature individuals, and hibernation-based reserves target mature snakes.

In British Columbia (B.C.), Canada, wildlife habitat areas (WHAs) are small protected areas that are designated around particular elements of the habitat of a species at risk. In the Okanagan region of south-central B.C., WHAs have been identified to protect habitat around the hibernation sites of two co-occurring at-risk snakes, the Great Basin Gophersnake (*Pituophis catenifer deserticola* Stejneger, 1893) and the Western Rattlesnake (*Crotalus oreganus oreganus* Holbrook, 1840). The WHA guidelines for Gophersnakes and Rattlesnakes stipulate that 200–300 ha of habitat should be protected surrounding identified hibernation sites, and should contain required egg-laying sites, travel corridors, and foraging areas (BCMWLAP 2004). Although the WHAs include habitat around hibernation sites, no research to date has examined whether Gophersnake movements during the active season are such that WHAs would include the majority of their movements. WHAs would be less effective as a conservation technique if snakes are routinely exposed to unprotected habitats during the active season than if snakes use the protected WHA habitats during the active season.

The sex of a snake, its reproductive condition (i.e., male, gravid female, or nongravid female), and the time of year all affect its movement patterns (Gibbons and Semleitsch 1987; Macartney et al. 1988; Whitaker and Shine 2003). In addition, the density of female snakes influences the movement patterns of males during the mating season (Brown and Weatherhead 1999). While searching for mates, male snakes increase their own movement frequency, rates, and distances, and also move more than females (Madsen 1984; Gregory et al. 1987; Bonnet et al. 1999; Blouin-Demers and Weatherhead 2002; Jellen et al. 2007). Snake movements may also vary owing to factors such as yearly differences in prey populations (Webb and Shine 1997).

Snake home ranges also vary in size and shape, both of which will affect whether snakes remain on reserves or travel off of them. Sex affects range attributes (Pearson et al. 2005). When females are clumped, males have smaller home ranges compared with when females are dispersed (Brown and Weatherhead 1999). Snake home ranges also vary with location in the geographic range and year, because habitat quality and resources affect snake movements (Gregory et al. 1987; Macartney et al. 1988; Moore and Gillingham 2006; Halstead et al. 2009; Kapfer et al. 2010). Oviposition sites may be located centrally or distally within the home range, thus affecting range shape (Madsen 1984; Bonnet et al. 1999; Blouin-Demers and Weatherhead 2002; Brown et al. 2005; Shewchuk 1996). Snakes of the genera *Pituophis* Holbrook, 1842 and *Crotalus* L., 1758 often reuse movement corridors, specific rock complexes as hibernation or retreat sites, and sites for reproduction (Shewchuk 1996; Macartney and Gregory 1988; Kapfer et al. 2008).

In this paper, we tested the biological hypotheses that sex, study site, year, and season affect Gophersnake movements and home ranges. We also asked whether WHAs are likely large enough relative to snake movements to protect Gophersnakes in the Okanagan. We predicted that (i) males will move more (faster, farther, and in larger home ranges) than

females; (ii) sites will affect snake movements and home ranges; (iii) yearly differences will be minimal; and (iv) in the spring, males will move farther and faster than females, in the summer females will move farther and faster than males, and in the fall there will be no difference in movement patterns between sexes.

Materials and methods

Study area

Four study sites were selected in areas known to contain Gophersnakes (Matsuda et al. 2006; Shewchuk 1996) in B.C.'s Okanagan Valley. Three sites were located in the south Okanagan and one in the north. East and West Vaseux in the south Okanagan are owned by Environment Canada and are part of the Vaseux–Bighorn National Wildlife Area. East Vaseux is a 40 ha area composed of grasslands and rock outcrops at elevations of 330–475 m; it rises from Vaseux Lake and a highway in the west to rock ridges and cliffs in the east. West Vaseux is a 90 ha area composed of open ponderosa pine (*Pinus ponderosa* Douglas ex P. Lawson & C. Lawson) and antelope bitterbrush (*Purshia tridentata* (Pursh) DC.) habitats at elevations of 330–595 m. The West Vaseux site is pinched between Vaseux Lake and a steep rock face, with a series of wetlands at the northern end. Also in the south Okanagan, Ripley WHA is a 50 ha area owned in part by the B.C. Ministry of Environment. It is composed of open ponderosa pine and grassland habitats at elevations of 435–645 m; snakes hibernate on the hillsides and move down-slope to fields and several private rural residences in the active season. There is an identified Gophersnake WHA at the upland edge of this study site and we knew one den location on this site. Of the snakes we tracked, we confirmed only one snake using this protected den, and apart from movements near the time of hibernation, all snake locations were down off of this WHA. In the north Okanagan, the Vernon site is a 120 ha area on the Vernon Military Camp owned by the Department of National Defence, composed of grasslands with invasive plant species at elevations of 485–575 m. Several dirt roads, a nature centre, and a firing range occur within the Vernon site, which is bordered to the east with residential developments.

WHA comparisons

We obtained permission from the B.C. Ministry of the Environment to use data on the size of 28 WHA reserves that had been designated around Gophersnake or Rattlesnake hibernation sites, but we were not provided the exact boundaries or the location of hibernation sites within each WHA (apart from knowing the location of one hibernation site at the Ripley study site). WHA information is not publicly available, in part to prevent vandalism of hibernation sites. Rattlesnakes hibernate communally with Gophersnakes, and as confirming Rattlesnake presence at hibernation sites is easier than confirming Gophersnake presence because Rattlesnakes are more visible at sites prior to and just after hibernating, we assumed WHAs for Rattlesnakes probably also contained Gophersnakes. Although the reality may be different, we assumed that WHAs were circular with one hibernation site in the middle of each site (21 WHAs had one known hibernation site, 6 WHAs had two, and 1 WHA had four).

We compared the areas and distances from the centre of each WHA to its unprotected edge to the Gophersnake movement data to assess how likely it was that WHAs were protecting areas actually used by Gophersnakes. These assumptions reflect an “idealized” WHA that would maximize habitat protection around a hibernation site; we suspect real WHAs are asymmetric with hibernacula not perfectly centred, meaning less habitat is protected in some directions than others.

Radiotelemetry

Adult Gophersnakes weighing ≥ 240 g were captured opportunistically through active searching in suitable habitats on all sites in 2006 and 2007. Seventeen females and 22 males were surgically implanted with radio transmitters (12 g transmitter; Holohil Systems Ltd., Ontario, Canada; Reinert and Cundall 1982; Willson 2003). At East Vaseux six females and five males were implanted, at West Vaseux three females and six males, at Ripley one female and five males, and at Vernon seven females and six males. To reduce pain and swelling, all snakes were injected intramuscularly with Metacam® (meloxicam 0.1 mg/kg) and Baytril® (enrofloxacin 5 mg/kg) 24 h preceding surgery, at surgery, and 24 h after surgery. Following a 24–48 h recovery period, each transmitter-equipped Gophersnake was released at its capture location. All remaining transmitters were removed in 2008 following the same protocol.

Each individual was located approximately every second day throughout the active season of late March through mid-October in 2006 and 2007. Tracking typically occurred between 0700 and 1900. Homing techniques were used to locate individuals, with the infrequent exception (<5%) of using triangulation when snakes were located in wetland or rock features that did not permit direct access. We recorded the location of individuals with a Garmin Map76S, which had an accuracy of <5 m, except when impossible owing to interfering rock features.

Spatial data were imported into ArcView version 3.2 with Spatial Analyst (ESRI 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.

Snake movement calculations

We calculated several movement metrics to examine movement patterns over different temporal scales (Gregory et al. 1987; Rouse 2006). We calculated the total minimum distance moved during the active season by summing all distances moved between subsequent relocations. We calculated the mean distance per movement by averaging the distance moved between locations, excluding movements that were <5 m (because GPS positions were not always accurate to <5 m).

Because of the significant differences in elevation, for all movements we 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 at the hibernation site, or from when snakes were first implanted to ingress, transmitter removal, or mortality. Distance metrics were calculated for 3 periods: (1) spring emergence until oviposition; (2) from oviposition until the end of the summer, including summer foraging but not retreat to the hibernation site; and (3) retreat to the hibernation site in the fall. Periods were separated on the mean date snakes oviposited or began moving from summer foraging grounds to hibernation sites. Snakes had to be tracked for at least half of each period to be used in data analysis for that period.

Snake home-range calculations

To define individual home ranges, we calculated 100% minimum convex polygons (MCP) for each active season. This metric has been heavily used in the Gophersnake literature (Rodríguez-Robles 2003; Shewchuk 1996), and recent findings show that MCPs are the most suitable method for calculating home ranges for reptiles (Row and Blouin-Demers 2006; but see Gregory et al. 1987; Tiebout and Cary 1987).

We calculated the ratio of home range width to length, which reflects the home-range shape. Values near 1 represent ranges that are more circular; lower values are more oval (Rouse 2006). 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 Calipers Algorithm (Toussaint 1985) implemented by the ArcView extension Vector Geometry (Patterson and Huber 2004).¹

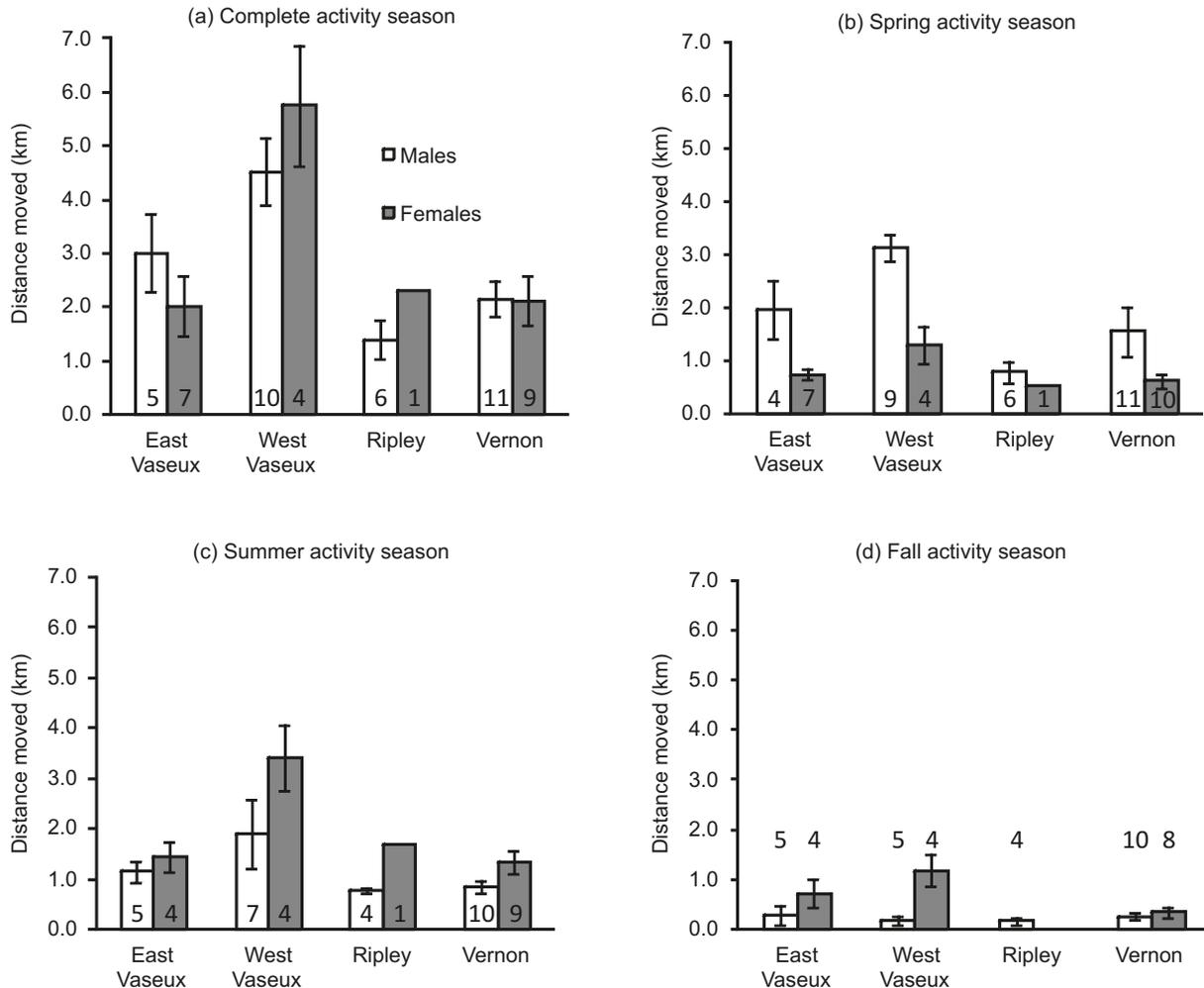
To characterize the location of the hibernation site within a snake's home range, we calculated the ratio of maximum distance dispersed away from hibernation site to range length. Values near 1 indicate a hibernation site at the edge of the home range, whereas values near 0.5 indicate a hibernation site close to the range centre (Rouse 2006). We noted when snakes switched hibernation sites, and the maximum distance dispersed was calculated for each hibernation site. Similarly, we calculated the distance from oviposition sites to hibernation sites. To maximize sample sizes, we examined the hibernation sites females used in the fall following oviposition, but not the hibernation sites prior to oviposition.

Statistical analyses

We detected minimal impact of year on our movement and home-range metrics (only one very small difference was found in distances moved from hibernation sites on one study site; analyses not shown). We therefore dropped year as a variable, using two-way ANOVAs with site and sex and their potential interaction as our predictor variables for all subsequent analyses. Tukey post hoc tests were performed on study sites when the ANOVA results were significant (at $p < 0.05$), to determine which sites differed. All but two females were gravid in both years, thus we analyzed females together irrespective of reproductive condition. Values are presented as mean \pm 1 SE.

¹D. Patterson and W. Huber. 2004. Vector Geometry (VectGeom.avx). Unpublished extension for ArcView3.x. D. Patterson and W. Huber, Carleton University, Ottawa, Ont.

Fig. 1. Minimum total distance moved by Great Basin Gophersnakes (*Pituophis catenifer deserticola*) during activity periods by study site, with year pooled. Values are mean \pm SE. Numbers in or above bars show sample size. Total distance moved for (a) complete activity season, (b) spring activity season, (c) summer activity season, and (d) fall activity season. ANOVA results are found in Table 1.



Results

Movement

The two most variable movement metrics across the entire active season were mean total minimum distance moved and distance moved per movement. The mean total minimum distance moved by snakes differed by sex and by site (Figs. 1a–1d, Table 1). There was no difference in movement between males and females over the entire active season. However, when activity was considered seasonally, both sex and site affected snake movements: males at all sites moved 1148 m farther than females in the spring, whereas females moved 662 m farther than males in the summer and 415 m farther in the fall. In addition, snakes at West Vaseux moved significantly farther than snakes at other sites during the spring, summer, and complete active seasons.

When examining the distance moved per movement for the complete active season, males and females did not differ; however, snakes at different sites moved different distances (Figs. 2a–2d, Table 1). Snakes at West Vaseux moved significantly farther per movement (169 ± 18 m) than snakes at the three other sites combined (84 ± 5 m). For spring and summer, snakes at West Vaseux moved significantly farther

(spring: 2565 ± 317 m; summer: 2459 ± 525 m) than snakes at other sites (spring: 1069 ± 163 m; summer: 1112 ± 97 m). In the fall, females moved significantly farther per movement (91 ± 16 m) than males (72 ± 10 m), although there was also an interaction between sex and site: females moved farther than males in the three southern sites, but less than males in the north.

Home ranges and dispersal from hibernacula

The ratio of home range width to length, i.e., range shape, did not differ significantly by site or sex; however, the absolute values of length and width did vary with site (Figs. 3a–3f, Table 1). Pooling all data, Gophersnakes in the Okanagan occupied home ranges that were 10.5 ± 1.7 ha (range 1.1–66.7 ha). Individual Gophersnakes in the Okanagan occasionally had drastically different activity ranges from 1 year to the next, with yearly differences as much as 24 ha, although year was not significant when the entire data set was analysed. West Vaseux snakes had significantly longer (Fig. 3a), wider (Fig. 3b), and larger (Fig. 3c) home ranges than did snakes on the other three sites.

Dispersal distances varied significantly by site; snakes at West Vaseux dispersed significantly farther from their hiber-

Table 1. ANOVA results for movements of Great Basin Gophersnakes (*Pituophis catenifer deserticola*) in the Okanagan Valley of British Columbia, 2006–2007.

Factor	df	F	p
Distance moved in complete activity season (Fig. 1a)			
Sex	1, 46	0.29	0.594
Site	3, 46	11.36	<0.001
Sex × site	3, 46	1.18	0.327
Distance moved in spring activity season (Fig. 1b)			
Sex	1, 44	10.26	0.003
Site	3, 44	4.52	0.008
Sex × site	3, 44	0.90	0.448
Distance moved in summer activity season (Fig. 1c)			
Sex	1, 36	5.00	0.032
Site	3, 36	6.55	0.001
Sex × site	3, 36	0.83	0.487
Distance moved in fall activity season (Fig. 1d)			
Sex	1, 33	16.61	<0.001
Site	3, 33	2.33	0.092
Sex × site	3, 33	4.95	0.013
Distance per movement in complete activity season (Fig. 2a)			
Sex	1, 46	0.09	0.767
Site	3, 46	10.43	<0.001
Sex × site	3, 46	2.01	0.126
Distance per movement in spring activity season (Fig. 2b)			
Sex	1, 44	2.40	0.128
Site	3, 44	4.24	0.010
Sex × site	3, 44	1.64	0.194
Distance per movement in summer activity season (Fig. 2c)			
Sex	1, 36	1.97	1.69
Site	3, 36	3.61	0.022
Sex × site	3, 36	1.05	0.381
Distance per movement in fall activity season (Fig. 2d)			
Sex	1, 33	4.85	0.035
Site	3, 33	1.31	0.287
Sex × site	3, 33	5.57	0.008
Ratio of home range width to length			
Sex	1, 46	2.63	0.112
Site	3, 46	0.86	0.469
Sex × site	3, 46	0.66	0.580
Range length (Fig. 3a)			
Sex	1, 46	1.96	0.168
Site	3, 46	11.06	<0.001
Sex × site	3, 46	0.98	0.412
Range width (Fig. 3b)			
Sex	1, 46	1.00	0.323
Site	3, 46	19.77	<0.001
Sex × site	3, 46	2.57	0.066

Table 1 (concluded).

Factor	df	F	p
Minimum convex polygon (Fig. 3c)			
Sex	1, 46	0.64	0.426
Site	3, 46	13.29	<0.001
Sex × site	3, 46	0.47	0.705
Distance moved from hibernation site (Fig. 3d)			
Sex	1, 41	0.12	0.729
Site	3, 41	9.90	<0.001
Sex × site	3, 41	0.32	0.729
Ratio of distance from hibernation site to range length (Fig. 3e)			
Sex	1, 41	1.22	0.276
Site	3, 41	4.92	0.005
Sex × site	3, 41	2.98	0.062

nation site than snakes at other sites (Fig. 3d, Table 1). Overall, dispersal distances averaged 520.0 ± 65.1 m (range 136.4–2365.1 m). The ratio of the maximum distance dispersed from hibernation sites to range length varied significantly by site (Fig. 3e, Table 1); hibernation sites at Ripley were located significantly closer to the edge of the snakes' home range than at the other sites, and hibernation sites at Vernon were located significantly closer to the centre of the snakes' range than at the other sites. Female snakes at West Vaseux moved significantly farther from their hibernacula to oviposition sites than did females at the other sites (Fig. 3f; 490.0 ± 60.3 m vs. 157.7 ± 26.7 m; $F_{[2,10]} = 14.86$, $p < 0.001$). Snakes in the middle of the season were farther from their hibernation sites than early and late in the season, with snakes at West Vaseux dispersing the earliest and the farthest (Fig. 4).

WHAs and snake movements

Sizes of Gophersnake and Rattlesnake WHAs ($n = 28$) ranged from 95 to 336 ha, with a mean of 193 ± 12 ha, and a median of 170 ha. Assuming the protected areas were circular and the hibernation site was in the centre, the distance to the nearest unprotected edge would be between 550 and 1035 m, with a mean of 774 m and a median of 736 m. Gophersnake home ranges, with a mean size of 10.5 ± 1.7 ha and a maximum size of 66.7 ha, could be contained within even the smallest WHA of 95 ha. When Gophersnake dispersal distances are compared with the radius of the WHA reserves, 11% of maximum dispersal distances recorded over the 2 years of this study fall outside the maximum distance protected by WHA reserves, and 15% fall outside the mean distance protected by WHA reserves. Thus, only 85% of snakes would be entirely protected by the mean WHA, assuming the hibernation site is located at the centre of a circular WHA.

Discussion

Gophersnake movements in the Okanagan Valley of B.C. were affected by sex, site, and season, with most impact from site. Snake movements differed slightly depending on sex and season, but snakes at West Vaseux consistently moved farther and faster than snakes at the other three sites,

Fig. 2. Distance moved per movement by Great Basin Gophersnakes (*Pituophis catenifer deserticola*) during activity periods by study site, with year pooled. Values are mean \pm SE. Numbers in bars show sample size. Distance moved per movement for (a) complete activity season, (b) spring activity season, (c) summer activity season, and (d) fall activity season. No females were tracked at Ripley in the fall activity season. ANOVA results are found in Table 1.

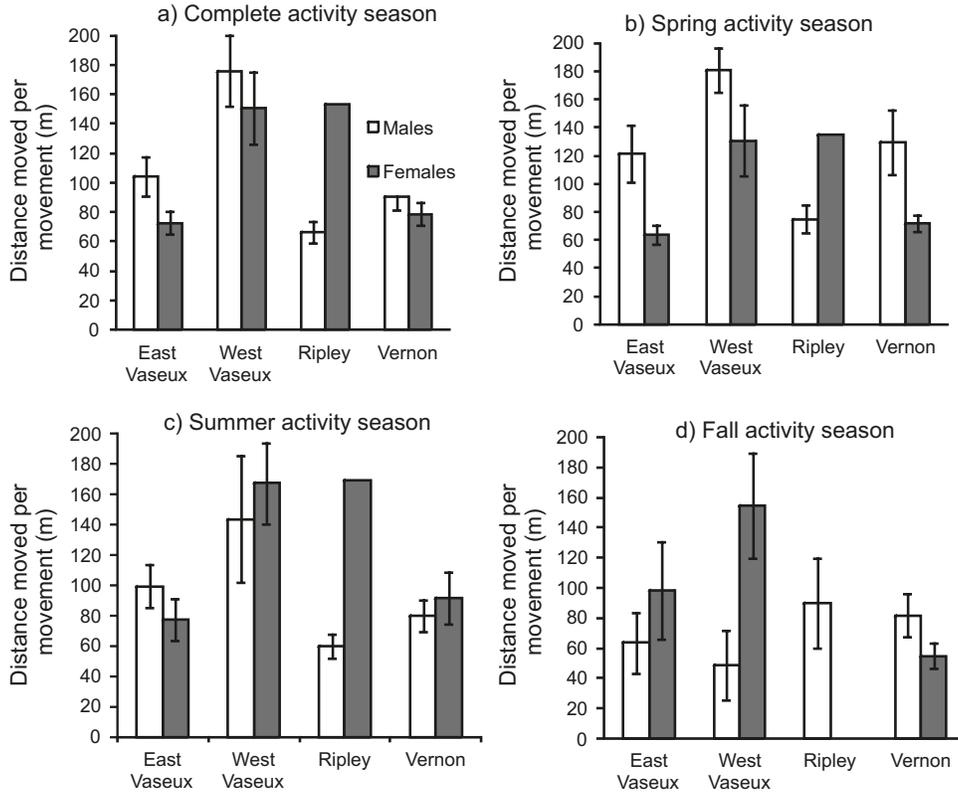
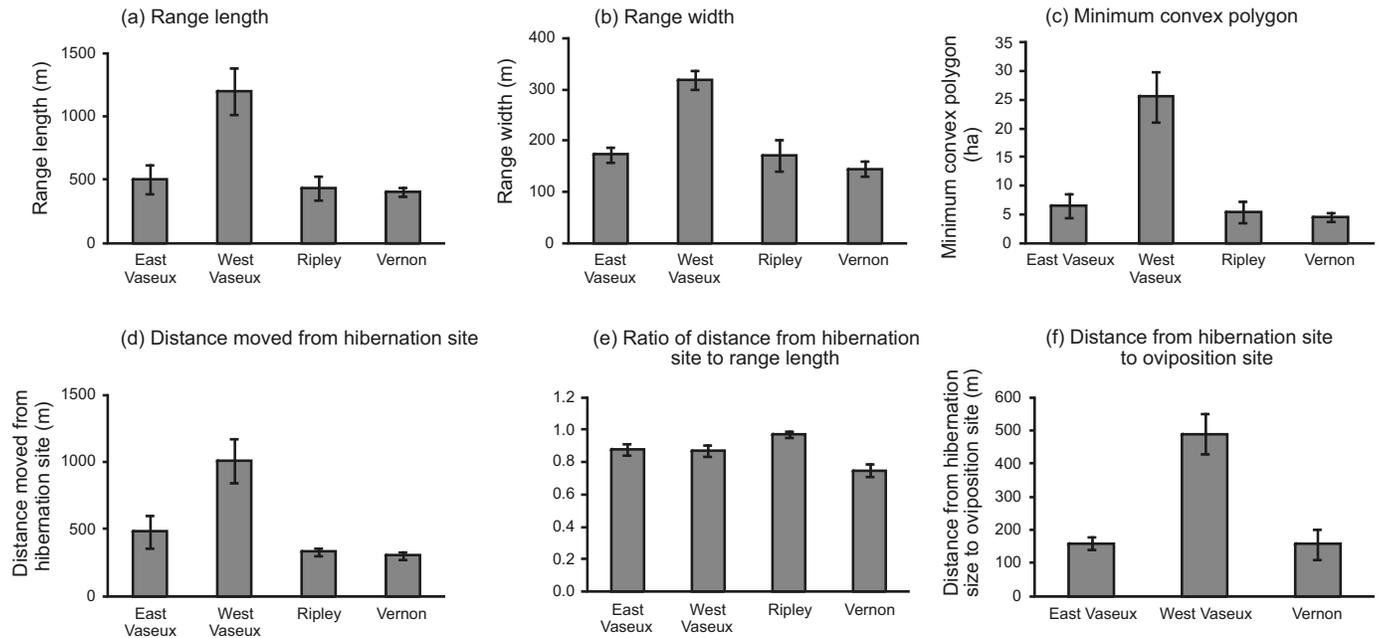
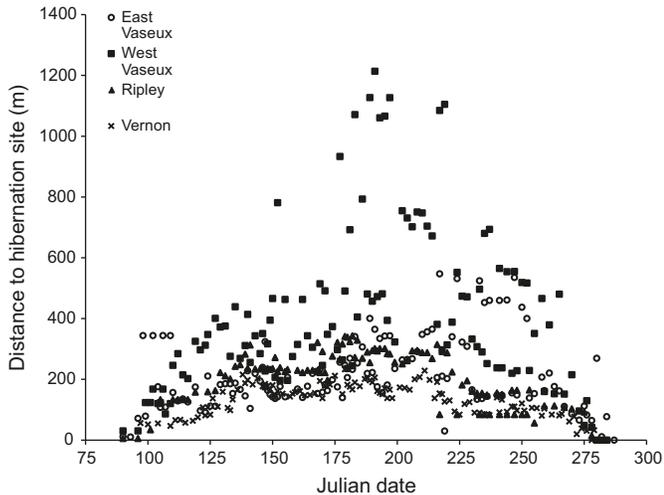


Fig. 3. (a–f) Home-range characteristics by site for Great Basin Gophersnakes (*Pituophis catenifer deserticola*) over the complete active season. Values are mean \pm SE. ANOVA results are found in Table 1. Sex was not significant for any of these metrics, so the figure presents results by site only. (f) Ripley did not have any gravid females with known hibernation sites, thus Ripley was excluded in analysis of distance from hibernation site to oviposition site. Sample sizes are as follows: (a–c) East Vaseux ($n = 12$), West Vaseux ($n = 14$), Ripley ($n = 7$), Vernon ($n = 21$); (d, e) East Vaseux ($n = 10$), West Vaseux ($n = 12$), Ripley ($n = 6$), Vernon ($n = 20$); (f) East Vaseux ($n = 4$), West Vaseux ($n = 3$), Vernon ($n = 6$).



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Fig. 4. Distance from hibernation site throughout the active season for all Great Basin Gophersnakes (*Pituophis catenifer deserticola*). Distance from hibernation site was averaged for individuals and years by study site.



a trend that was apparent both for the entire active season and within each activity period. Our study sites likely differed in food availability and predation risk, both of which likely impact movement patterns. One noticeable difference between West Vaseux and the other three sites is the lack of road development around West Vaseux. Roads often negatively affect dispersing snakes by increasing mortality and fragmenting habitats, and these impacts are expected to have a greater influence on individuals with more extensive movements or ranges (Bonnet et al. 1999; Gibbs and Shriver 2002; Gibbs and Steen 2005; Browne and Hecnar 2007). In Wisconsin, Bullsnares (*Pituophis catenifer sayi* (Schlegel, 1837)) enlarged their home ranges when in fragmented areas that forced snakes to include habitats they try to avoid (Kapfer et al. 2010). This explanation does not explain our results because the largest home ranges occurred in the least fragmented area. Still, we expect that snake movements at West Vaseux were so much larger than elsewhere because of habitat and disturbance differences.

Sex differences in snake movement patterns within and among sites appeared when the data were divided into the activity periods of spring, summer, and fall. In the spring, males moved farther and faster than females, which likely occurs because males are searching for females during the mating season. For example, in Eastern Massasauga Rattlesnakes (*Sistrurus catenatus catenatus* (Rafinesque, 1818)), the distance males move is directly related to their success at finding mates (Jellen et al. 2007). In the summer and the fall, females moved farther than males, which could arise if oviposition sites are distant, as reported in Ratsnakes (*Elaphe obsoleta* (Say in James, 1823)) (Blouin-Demers and Weatherhead 2002), or could reflect higher energetic needs of ovipositing females than males (Gregory et al. 1987). In B.C., 6 female *Pituophis* lost 35%–58% of their body mass during oviposition (Shewchuk 1996), suggesting that replenishing energy stores after oviposition is necessary. Many other snake species have elevated male movements during the mating season and elevated female movements during oviposition (Madsen 1984; Gregory et al. 1987; Bonnet et al. 1999;

Blouin-Demers and Weatherhead 2002; Brown et al. 2005; Jellen et al. 2007; Sperry and Weatherhead 2009). Although these seasonal sex differences are biologically interesting, it does not appear that WHAs would differentially impact male and female snakes because overall dispersal distances were similar despite these timing differences.

The mean size of WHAs was adequate to protect most Gophersnakes, with 85% of snakes moving entirely within the mean boundary distances of the circular WHAs that we assumed. Some 15% of snakes moved farther, and thus would likely move into unprotected areas. Because we did not have access to boundary information of the WHAs, we anticipate the reality for Gophersnakes is worse: it is unlikely that most WHAs are circular with the hibernation site at the centres. Any distortion of shape or location of hibernation sites within the WHA will mean that snakes that travel in some directions from their hibernation sites will be more likely to leave the protected area. Furthermore, because many of the WHAs are mapped around the more easily observable large communal hibernation sites that Rattlesnakes also use, it is quite likely that small or single Gophersnake hibernation sites of the type found often in this study (White 2008) are not near the centres of WHAs. We therefore think it likely the mean-sized WHA will in fact protect fewer snakes than we have calculated here on the basis of these idealized assumptions about shape and location of hibernacula.

Snakes at the Vernon site had hibernation sites located nearest to the centre of their home ranges, suggesting that perhaps resources such as foraging grounds and retreat sites were distributed around and adjacent to the hibernation site, not distally. In contrast, hibernation sites at Ripley were located closer to the edge of the home ranges, suggesting that resources were distributed at a distance from the hibernation site in one direction—down off the hills into the valley. Shewchuk (1996) and Bertram et al. (2001) found movements from foraging areas to oviposition sites (between 440 and 2188 m) that were farther than those found in this study (234 m, on average, albeit from hibernation sites to oviposition sites). Those previous studies reported that when females oviposited, they moved out of their foraging areas, whereas we found most snakes oviposited near or en route to their summer foraging areas.

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 Thompson–Nicola region (northwest from the Okanagan), Bertram et al. (2001) tracked three snakes with return distances that averaged 453 m. In our study, we measured maximum distance dispersed from hibernation sites, and found that the mean distance was 520 m and the farthest distance was 2365 m. All of these studies support the idea that existing WHAs may not protect Gophersnakes adequately, especially if the WHA is asymmetrical or the hibernation site is near an edge of the WHA.

Although WHA shapes and sizes are limited by crown land boundaries, the large size of existing WHAs appears adequate to protect the majority of the Gophersnakes that hibernate at the identified hibernation sites, even with the variable home-range sizes and movement characteristics described here. However, as Gophersnake hibernation sites are difficult to locate, and additionally since our work has found that

often Gophersnakes occupy nontraditional and single hibernation sites (White 2008), it is likely that additional hibernation sites exist in the vicinity of the identified hibernation site of any given WHA, housing snakes that may occupy home ranges that extend significantly outside of the WHA. Because we could not access the specific locations of WHAs, we do not know how dangerous or degraded the habitats are that are adjacent to WHAs. If, for example, a hibernation site was near to the edge of a WHA that was next to a road, we would expect higher off-WHA mortality than for WHAs adjacent to similar habitats that are privately owned.

We conclude that examining movements is useful for assessing whether snakes (and potentially other reptiles) are likely to be protected on reserves. A single Gophersnake could probably situate its entire home range mostly within the mean WHA, and have only a few forays beyond the boundaries. However, WHAs are unlikely to protect all of the resident Gophersnakes at a given hibernation site. We also note that over half of the WHAs are smaller than the official minimum guideline of 200 ha. We suspect this difference arises primarily from the geography of land ownership, but if that is the case it may be that Gophersnake WHAs are (or could become) islands of habitat surrounded by hostile terrain, which would likely have negative genetic and demographic consequences on Gophersnake populations.

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