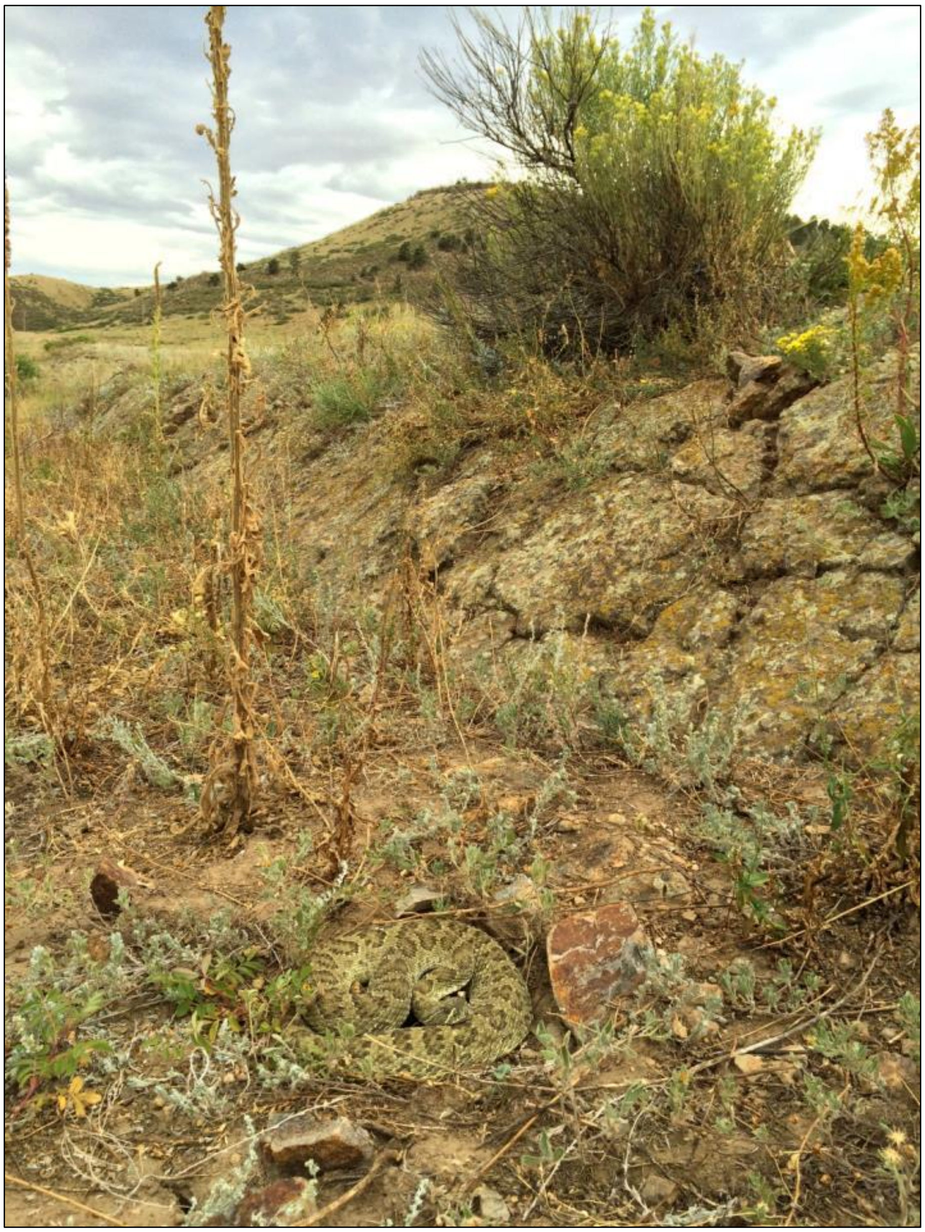
IDENTIFICATION OF WINTER DENS OF PRAIRIE RATTLESNAKE ON RABBIT MOUNTAIN OPEN SPACE



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Identification of Winter Dens of Prairie Rattlesnakes on Rabbit Mountain Open Space

Prepared for:

Boulder County Parks and Open Space

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Executive Summary

We radio–tracked 15 externally transmittered adult Prairie Rattlesnakes (6 male, 9 female) to their winter dens on Rabbit Mountain Open Space. Contrary to our main expectations, only one den was verifiably communal (14 dens were presumed single–occupancy) and only four snakes selected dens in rocky areas; the remainder selected prairie dog burrows despite there being much less acreage of prairie dog colony than rocky habitat. No dens were in close proximity to existing trails or other public areas. Entrance into hibernation as judged by % snakes below ground and incidences of complete transmitter attenuation was associated with the first major drops in daytime maximum temperature and the arrival of freezing nighttime temperatures in early November. Mean heat load index at den sites in rocky outcrops was significantly higher than that for randomly located sites. Mean heat load index at den sites in prairie dog burrows was significantly lower than that for dens in rock outcrops and randomly located sites. Thus dens at rocky sites appear to be dependent on high insolation, whereas those in prairie dog burrows, which typically extend far below the maximum winter frost line, are not. Late summer–fall areas of use (minimum convex polygons on relocation points) were small to quite extensive [0.002 – 42 ha, mean = 5.8 ha, (0.006 – 103.5 ac., mean = 14.3 ac.)]. The abundance of rock outcrops, rocky hillsides, and prairie dog colonies on Rabbit Mountain likely allows rattlesnakes to engage in individualistic opportunistic hibernaculum selection rather than dependence on few large communal dens. Ensuring the continued existence of healthy prairie dog colonies on the western, interior, and eastern sections of the property is the best management practice for maintaining healthy population of rattlesnakes on Rabbit Mountain Open Space.

The results of the survey will be provided to BCPOS in GIS format.

Acknowledgments

We thank Boulder County Parks and Open Space for providing funding for this study. This work would not have been possible without the help of the many volunteers who helped find the snakes used in this study: Anthony Bottagaro, Tom Bottagaro, Mike Currie, Nicole Elizabeth, Ben Fisher, Carissa Fisher, Jackson Green, Jeff Green, Jenni Green, William Green, Sean Hutcheson, Tavion Hutcheson, Jay Hutchins, Katie Irwin, Cam Johnson, Melissa Johnson, Linda Koch, Sam Koch, Karen Green, Zach Green, Brandon Green, Ian Jessup, Wendy McMullen, Sean McMullen, Hayley Urbanek, Ryan Urbanek, Lisa Visnosky, Nicole Weprin Cole Wild, and Heather Wild. Special thanks to Hunter Johnson for help as above and for assistance radio–tracking snakes.

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INTRODUCTION

For rattlesnakes to survive the winter at higher latitudes they must locate hibernation sites belowground beneath the frost line. Winter hibernacula are a critical habitat resource serving several functions, including avoidance of freezing temperatures and predation, reducing body water loss and use of fat stores (Costanzo 1989), and contributing to sociality behaviors (Clark et al. 2008, 2012). Availability and type of hibernacula may vary greatly with geologic characteristics of the habitat. Hibernacula of Prairie Rattlesnakes (*Crotalus viridis*) throughout its range may be located in talus slopes, caves, fissures in south–facing canyon walls or rock outcrops, prairie dog colonies, and deep burrows constructed by other animals (Ernst and Ernst 2012).). The number of Prairie Rattlesnakes within a single hibernaculum may vary from a single snake up into the hundreds (Hirth et al. 1969, Klauber 1972, Parker and Brown 1975, Macartney et al. 198, Leonhardt and Brown 1990), but communal denning is considered the norm for the species. These communal dens are not exclusive to conspecifics and may contain other reptile, amphibian, and mammalian species (Ernst and Ernst 2012; Kissner and Nicholson 2003).

Prairie Rattlesnakes commonly occur on Rabbit Mountain Open Space (Ehrenberger et al. 2015), a 4,793–acre property containing six miles of public hiking trails. Despite being the most commonly encountered species of snake on the property, there is only one putative den location (Ehrenberger et al. 2015). Our primary objective was to identify locations of winter dens of Prairie Rattlesnake on Rabbit Mountain Open Space. Our second objective was to determine whether this species prefers denning in rocky outcrops, as widely reported in the literature (e.g., Hill 1943, Ludlow 1989), *vs*. burrows in prairie dog colonies (Shipley et al. 2013). Prairie dog burrows are said to be used by this species in Colorado when rocky areas are unavailable (Hammerson 1999). Rabbit Mountain Open Space offers an ideal setting to evaluate this question of preference because there are numerous rock outcroppings on the property and Black–tailed Prairie Dog (*Cynomys ludovicianus*) colonies occur in and around these rocky areas. Our third objective was to collect as much movement and habitat data as possible on individual snakes prior to their entering into hibernation. Knowledge of den locations, areas of use for individual snakes, and microhabitat selected within these areas of use, will help managers develop management guidelines for this species and inform decisions on recreational use and public safety (e.g., Gardiner et al. 2013).

METHODS

Study Site

Rabbit Mountain is situated on the boundary of Great Plains and the Southern Rocky Mountains Provinces at an elevation of 1646 to 1847 m. The property is geologically complex, consisting of sedimentary sandstones, limestones and shales of the Morrison, Dakota, Benton and Niobrara formations that contribute to an overall topographic relief of 183 m. These formations, pushed up during the Rocky Mountain uplift, tilt eastward forming a number of "hogbacks" merging onto the eastern plains.

Acquisition of Snakes

Our secondary objective was to determine whether Prairie Rattlesnakes at Rabbit Mountain Open Space preferred winter dens in rock outcrops or prairie dog colonies. Because it is possible that the location of a snake when first encountered could be associated with the location of its chosen hibernaculum, we therefore attempted to locate snakes (August 12, 2015 – September 25, 2015) in a diversity of habitat types and locations throughout the property. To do so, we attached transmitters to snakes encountered opportunistically during a concurrent general herpetofauna survey at Rabbit Mountain (see Ehrenberger et al. 2015). Because only four snakes were transmittered by Sept 2, 2015 (transmitters came off of two snakes, another shed its skin along with transmitter), three surveys were conducted in the close vicinities of prairie dog towns and associated rocky surroundings which yielded four additional snakes. Therafter, snakes were captured opportunistically while in transist by vehicle on the property and while radiotracking snakes by foot. This work was conducted under Colorado Parks and Wildlife Scientific Collection permit #15HP993 issued to J. Ehrenberger.

Handling of Snakes, Transmitter Attachment, and Radio Telemetry

At least two persons with previous experience handling Prairie Rattlesnakes were present whenever a snake was captured. Upon sighting a snake, snake tongs or a hook were used to move the snake to the closest open area so that it could be processed more safetly. On the ground, the snake was coaxed into a clear plastic tube of a diameter such that the snake could not turn around once it was inside. The snake was allowed to crawl into the tube until its head was about at tube midpoint. It was then gently restrained by simultaneousely grasping the end of the tube and the body of the snake (Figure 1.A.).

Figure 1. A. Prairie Rattlesnake in restraining tube on Boulder County Parks and Open Space, Rabbit Mountain, Boulder County, Colorado. **B.** Placement of externally attached radio–transmitter on Prairie Rattlesnake (see Methods).

This method prevented the snake from moving forward or backwards inside the tube and allowed other persons safe access to the snake's distal half. Only snakes with snout–vent lengths greater than 24 mm snout–vent length were used (adults), and each snake was sexed by probing for hemipenes.

A radio transmitter (Model PD–2; Holohil Systems Ltd; 3.2–3.8 g) was secured to the snake's dorsum using a 1.5 inch wide strip of carpet tape covered by a camofluage colored cloth tape wrapped once around the snakes' body such that the transmitter antenna was directed posteriorly (Figure 1.B.). The snake was was then released at its point of capture. Attachment of the transmitter took no more than 60 seconds. Previous work showed that this attachment method does not impede movement or otherwise harm Prairie Rattlesnakes, and transmitters are unlikely to come off (Joseph Ehrenberger, pers. comm.). However, transmitters secured this way will always come off when a snake sheds its skin. In such cases we located shed transmitters and attached them to a new snake. We had 15 transmitters available to us. Over the course of this study, 19 snakes were transmittered; two transmitters fell off immediately after attachment early on in the study, one was naturally shed early on, and the other fell off late in the study. By recovering transmitters and attaching them to additional snakes, we were able to track 15 snakes to their winter dens.

Each transmittered snake was initially located at 2–3 times weekly during daylight hours (Usually Monday, Wednesday and Friday) using a hand–held radio receiver (Model R–1000, Communications Specialists, Inc.) with a three–element folding Yagi antenna (AF Antronics, Inc.). In November when temperatures became much cooler we located snakes twice weekly. Upon relocation of each snake, its position was recorded in decimal degree coordinates, datum

North American Datum of 1983, using a handheld global positioning system (GPS) unit (Model GPSmap 62stc, Garmin International Inc.).

The criteria for determining the location of a winter den was >2 consecutive locations obtained in November with essentially identical coordinates (i.e., distance between coordinates less than GPS error estimates) together with no visual sightings of the snake (i.e., the snake was belowground).

Data Collection

On each relocation we attempted to visually locate the snake. If observable, we noted its general health and assessed whether the transmitter was still firmly attached. If the snake was below ground or out of sight beneath surface cover, the receiver was used to locate the snake to within a 1.5 m^2 radius. Upon determining a snake's location, it was photographed in situ with surrounding microhabitat. If the snake was belowground, we photographed the likely entrance to its underground position (e.g., prairie dog burrow, hole leading below rock). At each relocation, a snake was recorded as "visible" or "not visible". This behavioral descriptor, calculated as percent snakes visible, was part of the data used to determine dates when snakes were entering into winter dens. In few cases, snakes recorded as not visible may have been above ground (e.g., in dense shrub but unseen), but generally, most were unambiguosly below ground. Starting in mid to late October, signals from some transmitters were occasionally undetectable, presumably because a snake was so far below ground that the transmitter signal was attentuated. In these cases it was not possible to know if the snake was at that location, but too far underground, or whether it had moved overland beyond receiver range. In each case, we searched the surrounding area for a radio signal being certain to check any depressions or far sides of rises that might block a transmitter signal. If no signals were detected in the area, we recorded that snake as being at its last known location, but too far below ground to detect. In all cases, the radio signal of a “missing snake” was later detected at or near its last known location. These data were also used to infer dates when snakes were entering into hibernation. Descriptive factors about each relocation site were recorded to assess habitat use. Each relocation event was placed in one of 11 microhabitat categories: In Grass or Forbs, Under Dense Grass, Under Shrub, Under Rock, On Rock, Down Prairie Dog Burrow, Resting in Mouth of Prairie Dog Burrow, Down Small Rodent Burrow, Resting in Mouth of Small Rodent Burrow, Down Large Mammal Burrow, and Road or Trail. Because some animals were transmittered for only a short time, data are ommitted for snakes relocated less than seven times (n = 3).

Area of Use Estimation

We estimated each snake’s “area of use” (AOU) by calculating a Minimum Convex Polygon (MCP) Geospatial Modelling Environment 0.7.2 (www.spatialecology.com/gme). Here, the term “area of use” refers to the area each snake was using in late summer–early fall prior to seeking a winter hibernaculum. We caution that MCP’s probably overestimate actual AOU’s because individuals may follow fairly straight paths from one location to the next. Furthermore snakes that were radioed later in the season and thus have fewer relocations likely have smaller AOU’s than snakes followed for longer durations (but see Results). *ArcGIS* 10.0 software was used to display spatial data. Global Information System data for all snake locations and winter dens are provided as electronic files in NAD 1983 HARN State Plane Colorado North (horizontal projected coordinate system).

Geomorphological Features of Winter Dens

To characterize the thermal environment of the entrance area for each den we calculated a heat load index based on aspect, slope, and latitude, using the corresponding tool within the Geomorphometric and Gradient Metrics ArcGIS Toolbox (Evans 2011). This method takes into account that a slope with afternoon sun (southwestern) will have higher maximum temperatures than an equivalent slope with morning sun (southeastern) by "folding" the aspect so that the highest values are southwest and the lowest values are northeast (McCune and Keon 2002). Elevation data required for this analysis was obtained as a tile from the U.S. Geological Survey's National Elevation Dataset (NED) at 1 meter resolution. Values for elevation, aspect, and slope at each den were also extracted from this NED similarly. To characterize these parameters for Rabbit Mountain property overall, we generated 1500 random points within the property boundaries east of N 55th Street and extracted values at each random point on the NED for heat index, elevation, aspect, and slope. To test for differences in measures of central tendency for these parameters at locations of winter dens *vs*. the surrounding environment, sets of 100 point–associated values were drawn from the pool of 1500 values (no replacement) so that parameter values for each hibernaculum were paired with 100 unique randomly generated values for each parameter. These sets of 100 parameter values were averaged by parameter such that there was a single value paired with each single value for a hibernaculum. So for example, to obtain a single value for elevation at a "random point" on the property, 100 values were drawn from the 1500 randomly generated points and then averaged. Because data were not normally distributed and sample sizes for dens in rock outcrops small, differences between medians for heat index, elevation, and slope were assessed using Kruskal–Wallis tests. Statistically significant outcomes were then evaluated using Mann–Whitney pairwise tests with the sequential Bonferroni correction applied. Circular statistics were used to evalute data for directionality (aspect). Two sample Watson–Williams tests for equal means were used to test for differences in aspect.

Statistical analyses were performed in R (R Development Core Team 2011). Measures of central tendency for heat index, elevation, and slope are reported as median and interquartile range (Q_1, Q_3). Those for aspect are reported as circular mean and bootstrapped 95% CI. Tests with $P \leq 0.05$ were considered statistically significant.

Daily values for minimum and maximum air temperature were obtained from a personal weather station (Station ID: KCOLONGM2, Name: Yellowstone Vistas, Madis ID: E2088, Hardware: Davis Vantage Pro 2) located approximately 6.3 kilometers east of the Rabbit Mountain Open Space visitor parking lot.

RESULTS

Timing of Entrance into Hibernation and Winter Den Identification

Despite loss of transmitters from five snakes during the study, we were able to recover all transmitters and reattach them to new snakes before they selected winter dens (Table 1). By November 9, 2015 all 15 Prairie Rattlesnakes (n = 6 male, n = 9, female) were considered to be at their winter dens. All snakes selected different dens. There was only one den site where we observed snakes other than the transmittered individual (CR213). The hibernaculum used by snake CR213 was an unoccupied prairie dog burrow in the reintroduced colony located on the north central section of the property. On November 9, 2015 while confirming that snake CR213 was within a prairie dog burrow that it had been using previously, we observed an additional adult rattlesnake and a neonate at the burrow entrance. On September 21, 2015 we experienced the first instance of a snake being belowground beyond transmitter range (Figure 2. A). This date coincides with the first substantial decrease in the fraction of the 15 transmittered snakes that were visible (Figure 2.A., i.e., because they were belowground). These events coincide with a substantial decrease in daily maximum air temperature (Figure 2. B.). Daily minimum air temperatures during this period were uninformative other than they exhibited a steady decrease since late

September. Freezing nighttime temperatures first arrived on November 5, 2015. We interpret the behavior of a snake going belowground deep enough to cause complete attenuation of the transmitter signal as investigative behavior to discern whether it could get far enough below ground to avoid freezing winter temperatures. All such cases (n = 9, different individuals) occurred in prairie dog burrows, and in each case the previously undetectable snake was detected at a later date at the same burrow. These observations indicate that in November some snakes are moving upwards and downwards within den passageways.

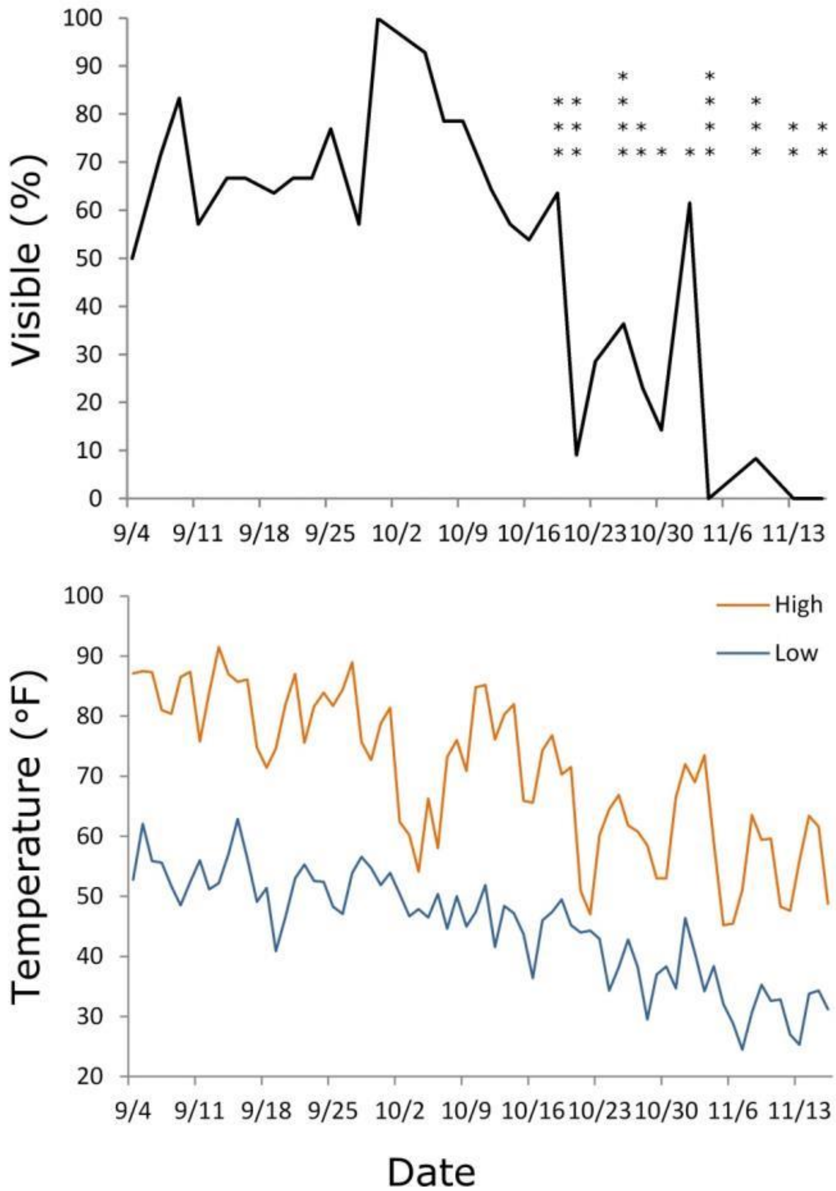

Figure 2. A. Relationship between percent radio–transmittered Prairie Rattlesnakes visible and date. B. Relationship between daily maximum and minimum air temperatures and date. Generally if a snake was not visible, it was because it was below ground. The number of asterisks above a date indicate the number of snakes for which radio transmitter signals were undetectable (attenuated). These snakes were presumed to be so far belowground that the receiver could not detect a transmitter signal (see Methods).

Winter Den Locations and Characterization

Locations of all 15 winter dens and summer–fall AOU's are shown in Figure 3. Maps of individual AOU's are shown in Figures 4–7. Note that the overall spatial distribution of dens coincides closely with the distribution of prairie dog colonies on the property (2013 and 2014 colony boundaries used here). The one geographic outlier is snake CR204 in northeastern section of property approximately half a km distant from the nearest prairie dog colony. This snake chose its den site in an abandoned large mammal burrow in a shale outcropping. The majority of dens were in old or active prairie dog burrows (n = 11; Table 1). However, three dens, despite their close proximity to a prairie dog colony, were located in rock outcrops (Table 1). The AOU's for these two of these snakes did not overlap with boundaries of any prairie dog colony. Snake CR209 exhibited a large north–south directed AOU that bisected a number of prairie dog colonies including a large colony to the south on the Dowe Flats–CEMEX property (colony not shown in Figures). Between 9–12 October, CR209 initiated a large northward movement from a prairie dog colony on the southern part of its AOU arriving at the prairie dog colony adjacent to the visitor's parking lot by October 21. From there it moved up into the rocky outcrop backing the visitor's parking lot, and then initiated another relatively long distance movement (0.3 km) arriving at another rocky outcrop approximately 301 m higher by October 28 where its den was located. In summary, 11 dens were located in prairie dog burrows and four were in rock outcroppings. Photographs of winter dens entrances are shown in Figures 8–10.

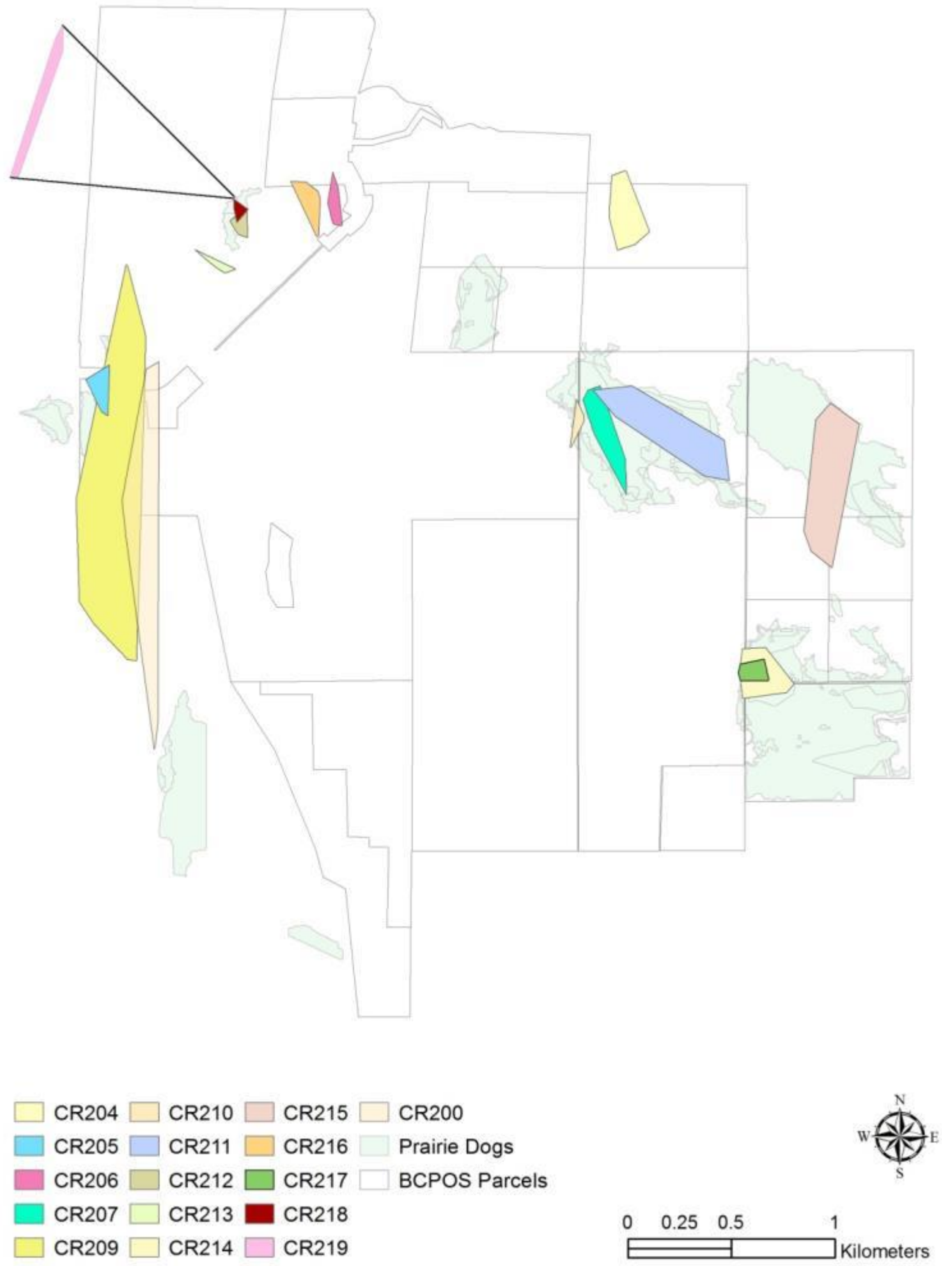

Figure 3. Late summer–fall areas of use (Minimum Convex Polygons) for 16 radio–transmittered Prairie Rattlesnake on Boulder County Parks and Open Space, Rabbit Mountain, Boulder County, Colorado. Snake CR200 was not tracked to its winter den (See Results). The AOU of snake CR19 is too small to see and is indicated by the callout.

Geomorphological Features of Dens

A heat index value map with the 15 dens by den type (Prairie dog burrow or Rocky outcrop) is shown in Figure 4. The four dens located in rocky outcrops are associated with the highest heat index values; the 11 dens located in prairie dog burrows were associated with the lowest heat index values. Summary statistics for heat index, elevation, slope, and aspect at den sites and randomly located sites are shown in Table 1. Kruskal–Wallis tests were significant for heat index ($H_{(2)} = 1.054$, $p < 0.001$) and slope ($H_{(2)} = 1.054$, $p < 0.001$), but not for elevation ($H_{(2)} = 1.449$, p = 0.4821). The Watson–Williams test of equal means (aspect) was significant for the comparisons, Rock Outcrop *vs.* Random Site (U = 4.684, $p = 0.0449$), but not Prairie Dog Burrow *vs.* Random Site (U = 0.038, $p = 0.8481$) or Prairie Dog Burrow *vs.* Rock Outcrop (U = 1.880, $p = 0.1935$). Results of pairwise Mann–Whitney tests for heat index and slope are shown in Table 2.

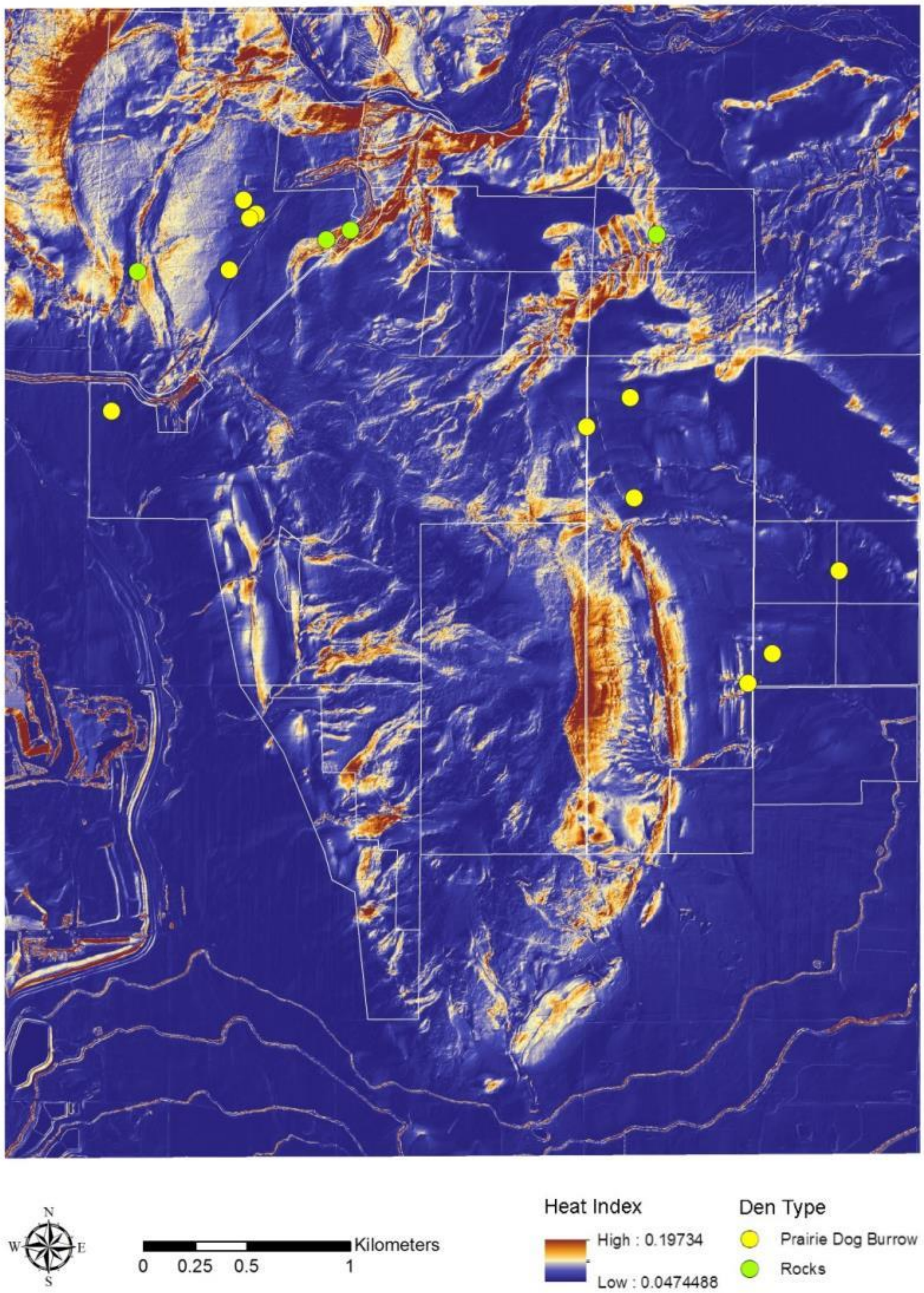

Figure 4. Heat index map and locations of winter dens of 15 radio–transmittered Prairie Rattlesnake on Boulder County Parks and Open Space, Rabbit Mountain, Boulder County, Colorado. Note that the 11 dens in prairie dog burrows are associated with lower heat index values; the four dens in rocks are associated with higher heat index values.

Table 1. Summary statistics for heat index, elevation, slope, and aspect for winter dens sites and random sites of Prairie Rattlesnakes on Boulder County Parks and Open Space, Rabbit Mountain, Boulder County, Colorado.

		Den Type		
		Prairie Dog Burrow	Rock Outcrop	Random Site
Heat Index	Median	0.04807	0.05214	0.04874
	Q1, Q3	0.04786, 0.04824	0.05134, 0.05775	0.04859, 0.04886
Elevation	Median	1669.95	1687.32	1690.24
	Q1, Q3	1623.61, 1726.50	1639.31, 1777.50	1684.38, 1692.74
Slope	Median	1.167	18.724	5.935
	Q1, Q3	0.851, 1.967	7.555, 41.302	5.468, 6.728
Aspect	Circular Mean	105.12	147.92	102.85
	CI	82.49, 132.40	108.2, 242.80	95.19, 111.00

Notes: Q1 and Q3 are interquartiles. CI is a bootstrapped 95% confidence interval.

Table 2. Results of pairwise Mann–Whitney U tests for heat index and slope at winter dens of Prairie Rattlesnakes on Boulder County Parks and Open Space, Rabbit Mountain, Boulder County, Colorado.

Comparison	*p*–values	
	Heat Index	Slope
Prairie Dog Burrow *vs.* Rock Outcrop	0.005	0.005
Prairie Dog Burrow *vs.* Random Site	< 0.0001	< 0.0001
Rock Outcrop *vs.* Random Site	0.003	0.019

Individual Areas of Use and Microhabitat Features

We were able to accumulate enough movement locations for some snakes to provide good estimates of individual AOU's for late summer – fall spatial use. For completeness though, AOU's were generated for all transmittered snakes regardless of number of relocations. As would be expected given the disparities in numbers of relocations per individual, AOU's were variable among individuals ranging from 0.0024 ha in CR219 to 41.86882 ha in CR209. Although the expected negative relationship was observed between

AOU area and date a snake was first transmittered, the correlation was not significant (Pearson's Product–Moment Correlation: $r = –0.37$, $n = 15$, $p = 0.37$).

Microhabitat of sites snakes chose for cover was highly variable among individuals (Table 2), but this was primarily a reflection of the different higher level habitat types inhabited by individuals (e.g., prairie dog colonies *vs*. upland rocky areas). Most snakes were observed in “Grass or Forbs” (28.6%) but this is the dominant cover type on the property and is therefore relatively uninformative. Three findings were informative: 30.2 % of all observations were associated with prairie dog burrows (“Down Prairie Dog Burrow” + “Mouth Prairie Dog Burrow”), 16.1% were associated with rocky areas, and 15.5% were “Under Shrub”. Snakes usually used shrubs that were low and dense, primarily *Rhus trilobata*, and to a lesser extent, *Cercocarpus montanus*. While in a shrub, a snake generally assumed a coiled position close to the base of the shrub where it was fully or partly shaded. The small mammal holes used were approximately 3 inches in diameter and were probably those of Northern Pocket Gophers (*Thomomys talpoides*) which has been documented on the property (Rabbit Mountain Management Plan, 1984).

One of the first snakes transmittered (August 12, 2015) was a small pregnant female (CR200) which took refuge for about eight days under a large flat rock (~ 1 m x 1 m) where she gave birth (Figure 11). We observed her and three neonates basking around the edges of the rock that we consider to be a rookery on August 27, 2015. She left the rookery shortly thereafter and began a long distance movement southwards losing her transmitter on the southern end of her AOU approximately October 14, 2015.

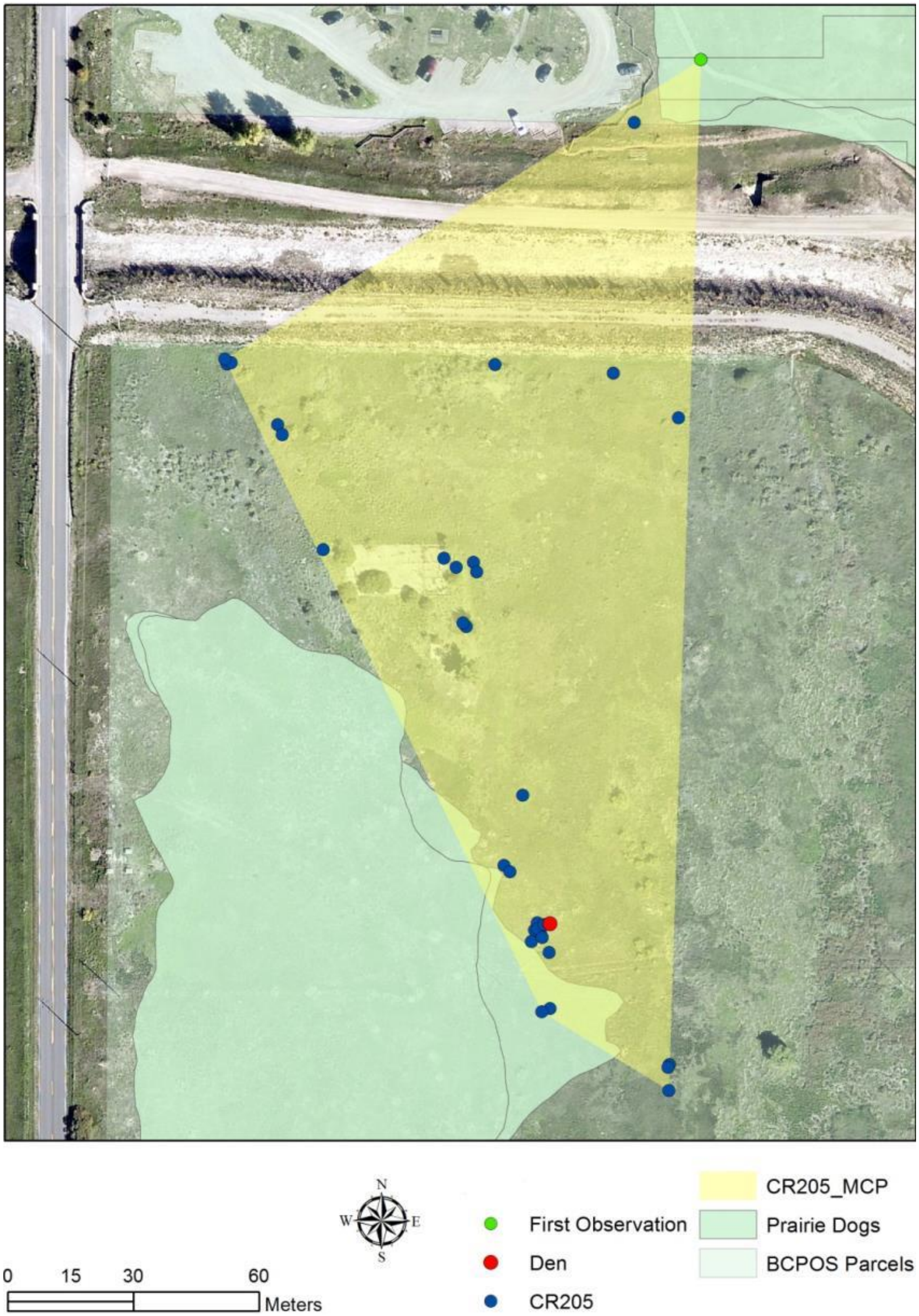

Figure 5. Location of winter den and late summer–fall area of use (Minimum Convex Polygons) for Prairie Rattlesnake CR205 on Boulder County Parks and Open Space, Rabbit Mountain, Boulder County, Colorado.

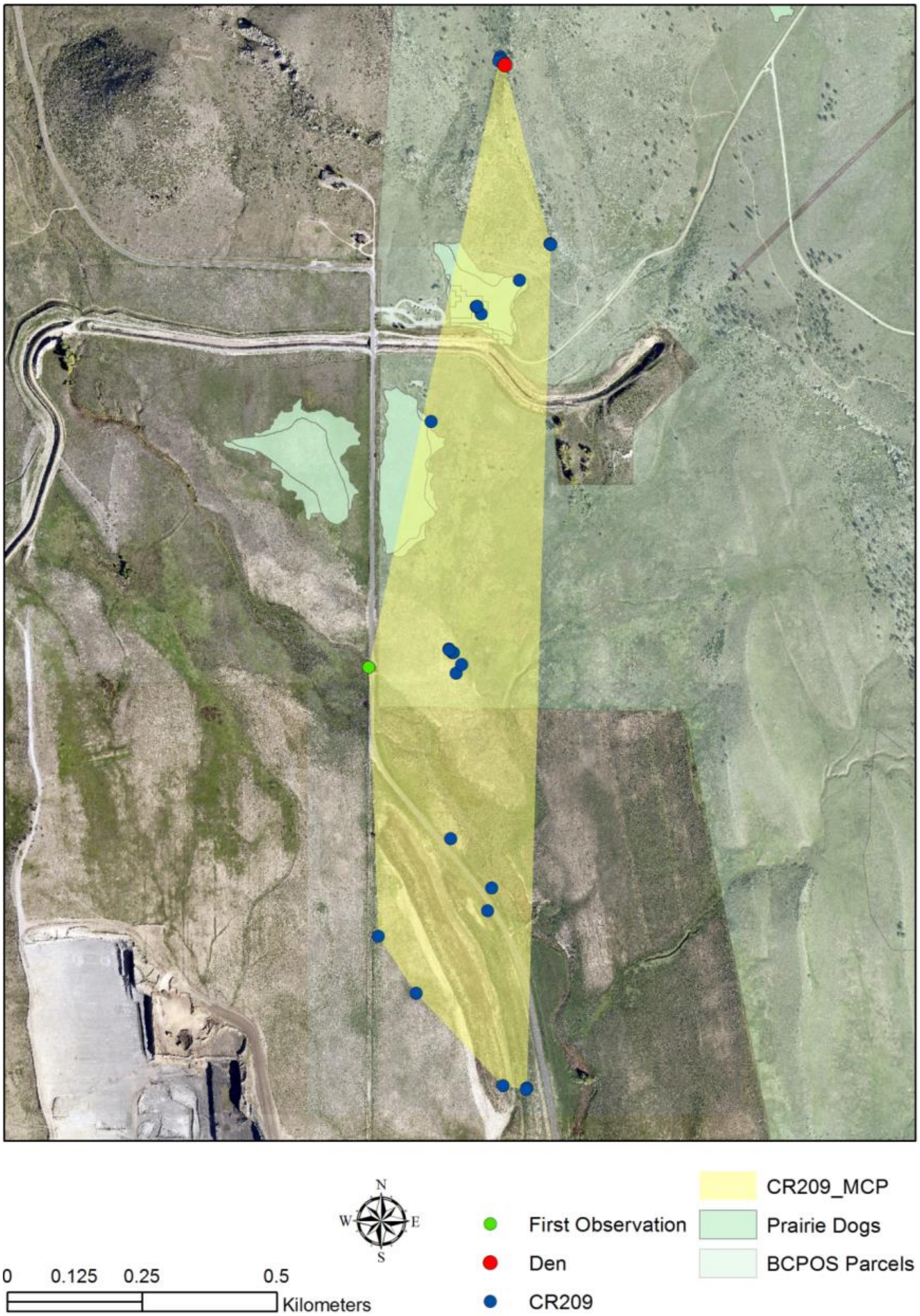

Figure 6. Location of winter dens and late summer–fall area of use (Minimum Convex Polygons) for Prairie Rattlesnake CR209 on Boulder County Parks and Open Space, Rabbit Mountain, Boulder County, Colorado.

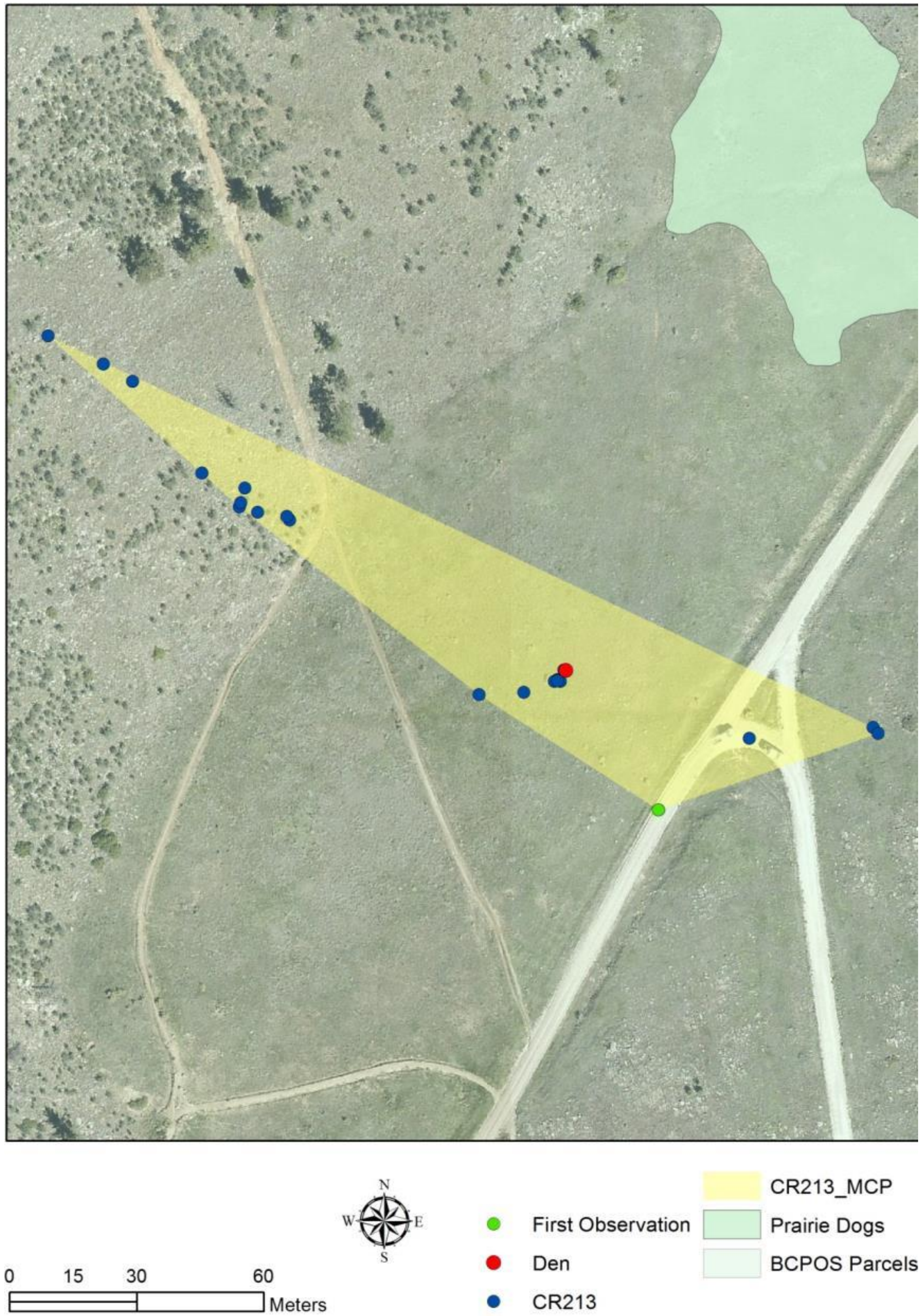

Figure 7. Location of winter den and late summer–fall area of use (Minimum Convex Polygons) for Prairie Rattlesnakes CR213 on Boulder County Parks and Open Space, Rabbit Mountain, Boulder County, Colorado.

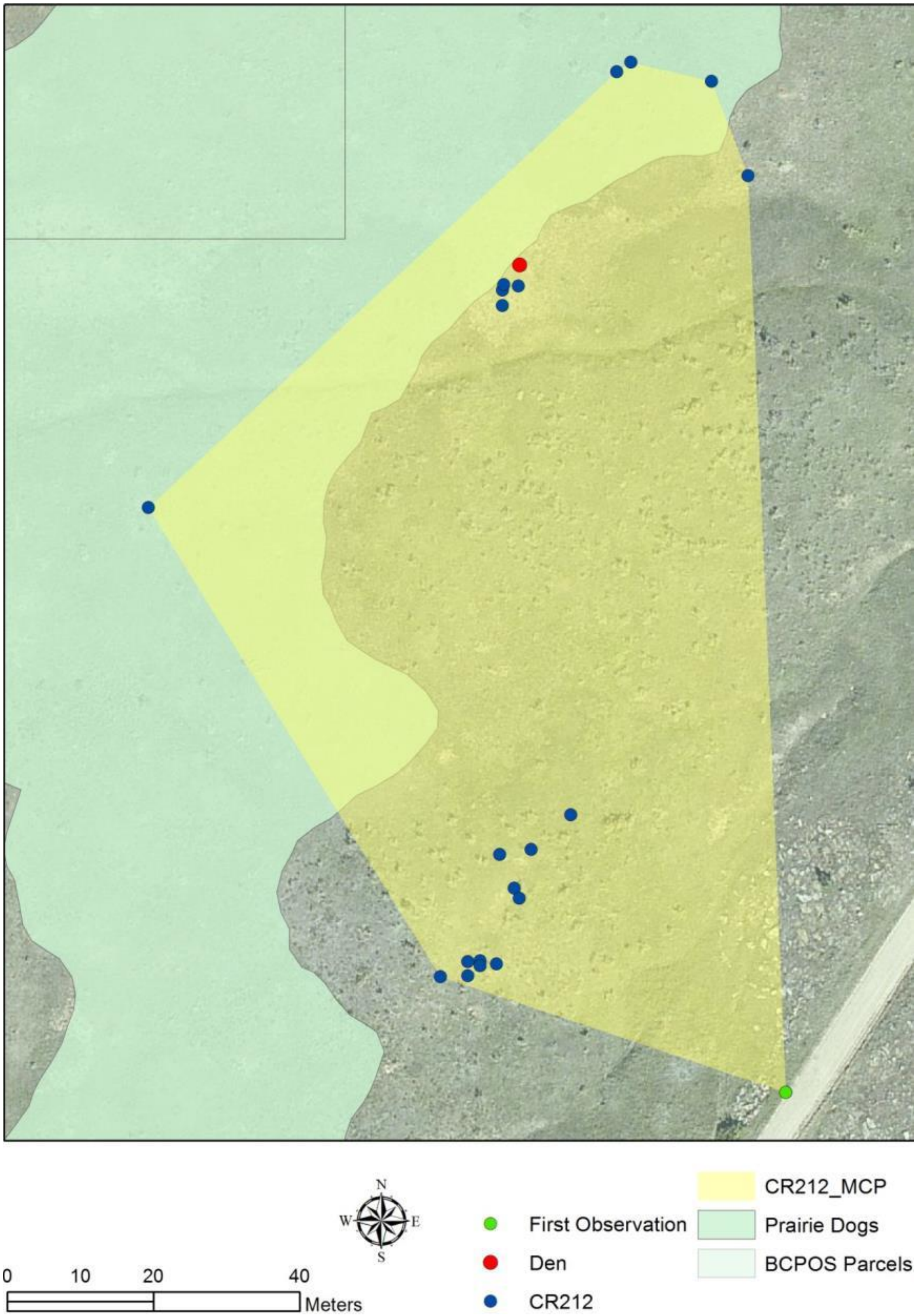

Figure 8. Location of winter den and late summer–fall area of use (Minimum Convex Polygons) for Prairie Rattlesnakes CR212 on Boulder County Parks and Open Space, Rabbit Mountain, Boulder County, Colorado.

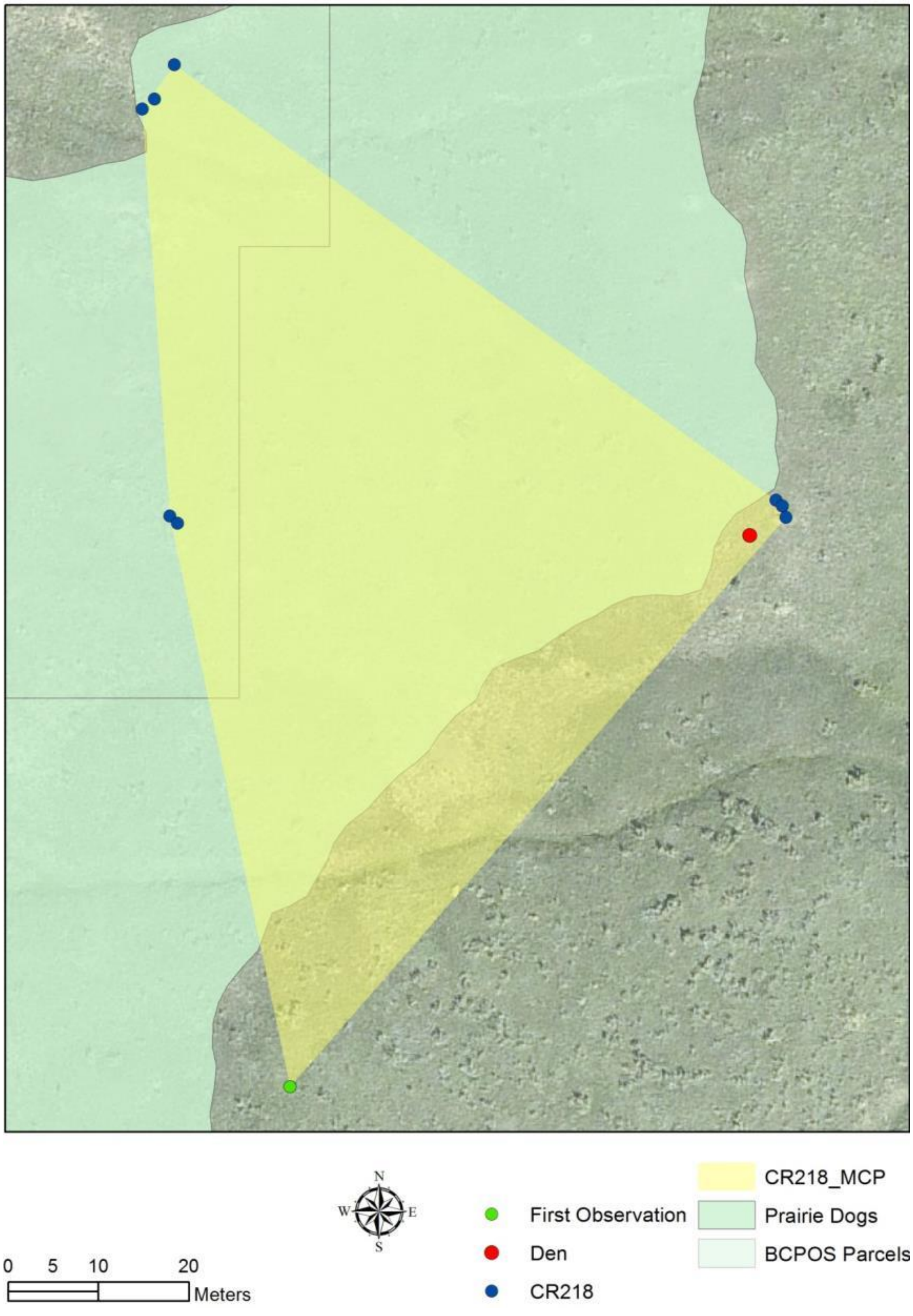

Figure 9. Location of winter den and late summer–fall area of use (Minimum Convex Polygons) for Prairie Rattlesnakes CR218 on Boulder County Parks and Open Space, Rabbit Mountain, Boulder County, Colorado.

Figure 10. Location of winter den and late summer–fall area of use (Minimum Convex Polygons) for Prairie Rattlesnakes CR219 on Boulder County Parks and Open Space, Rabbit Mountain, Boulder County, Colorado.

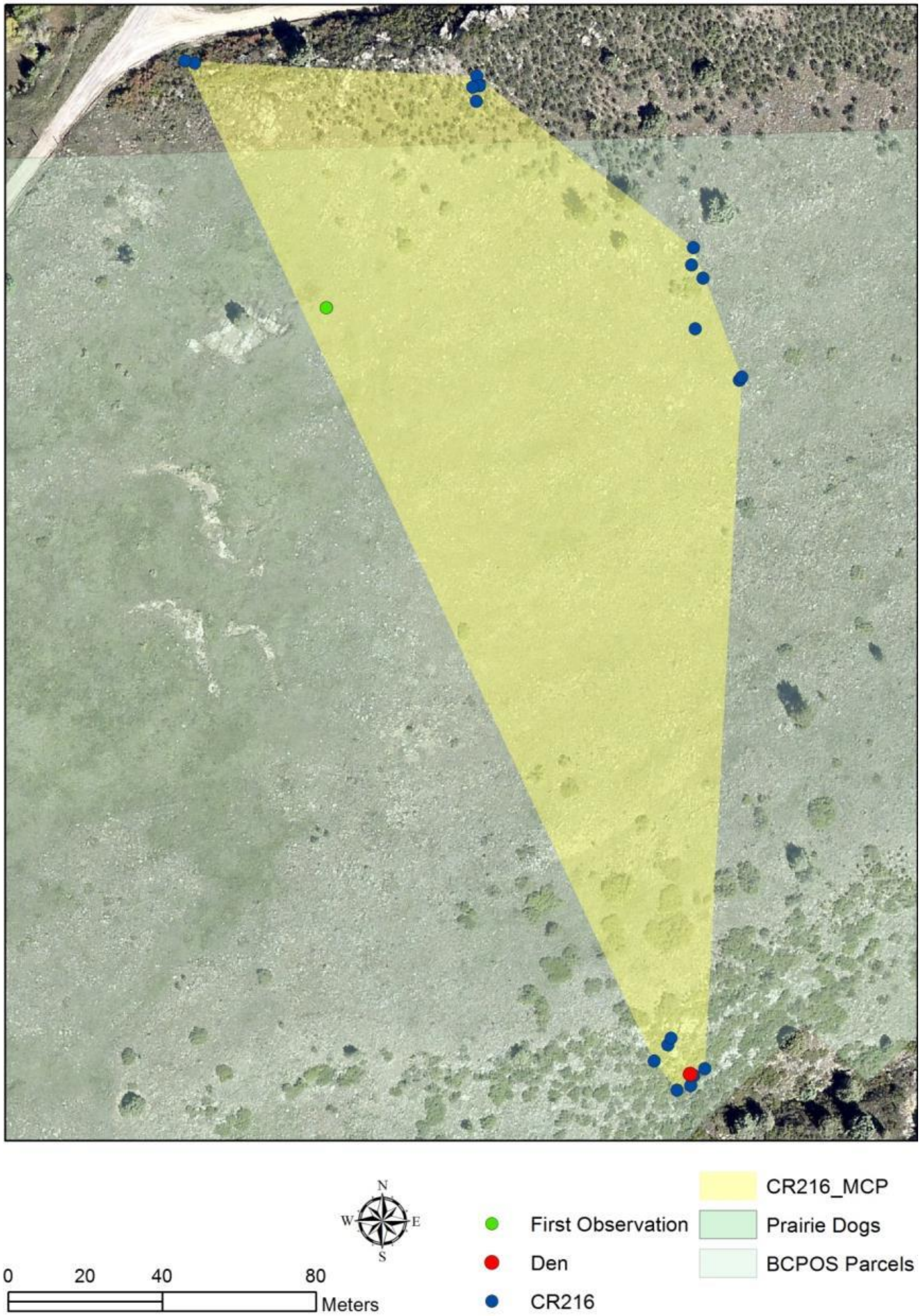

Figure 11. Location of winter den and late summer–fall area of use (Minimum Convex Polygons) for Prairie Rattlesnakes CR216 on Boulder County Parks and Open Space, Rabbit Mountain, Boulder County, Colorado.

Figure 12. Location of winter den and late summer–fall area of use (Minimum Convex Polygons) for Prairie Rattlesnakes CR206 on Boulder County Parks and Open Space, Rabbit Mountain, Boulder County, Colorado.

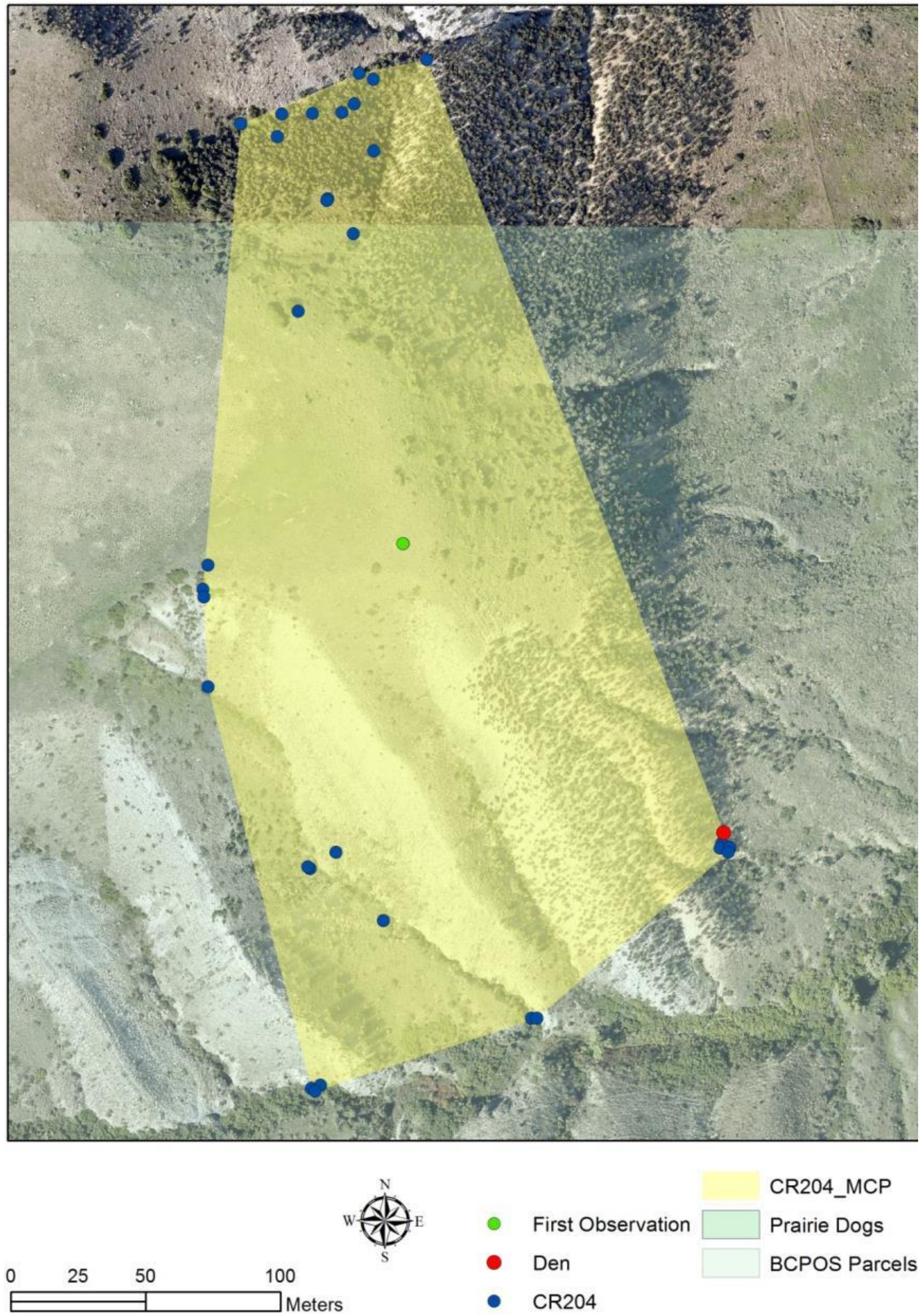

Figure 13. Location of winter den and late summer–fall area of use (Minimum Convex Polygons) for Prairie Rattlesnakes CR204 on Boulder County Parks and Open Space, Rabbit Mountain, Boulder County, Colorado.

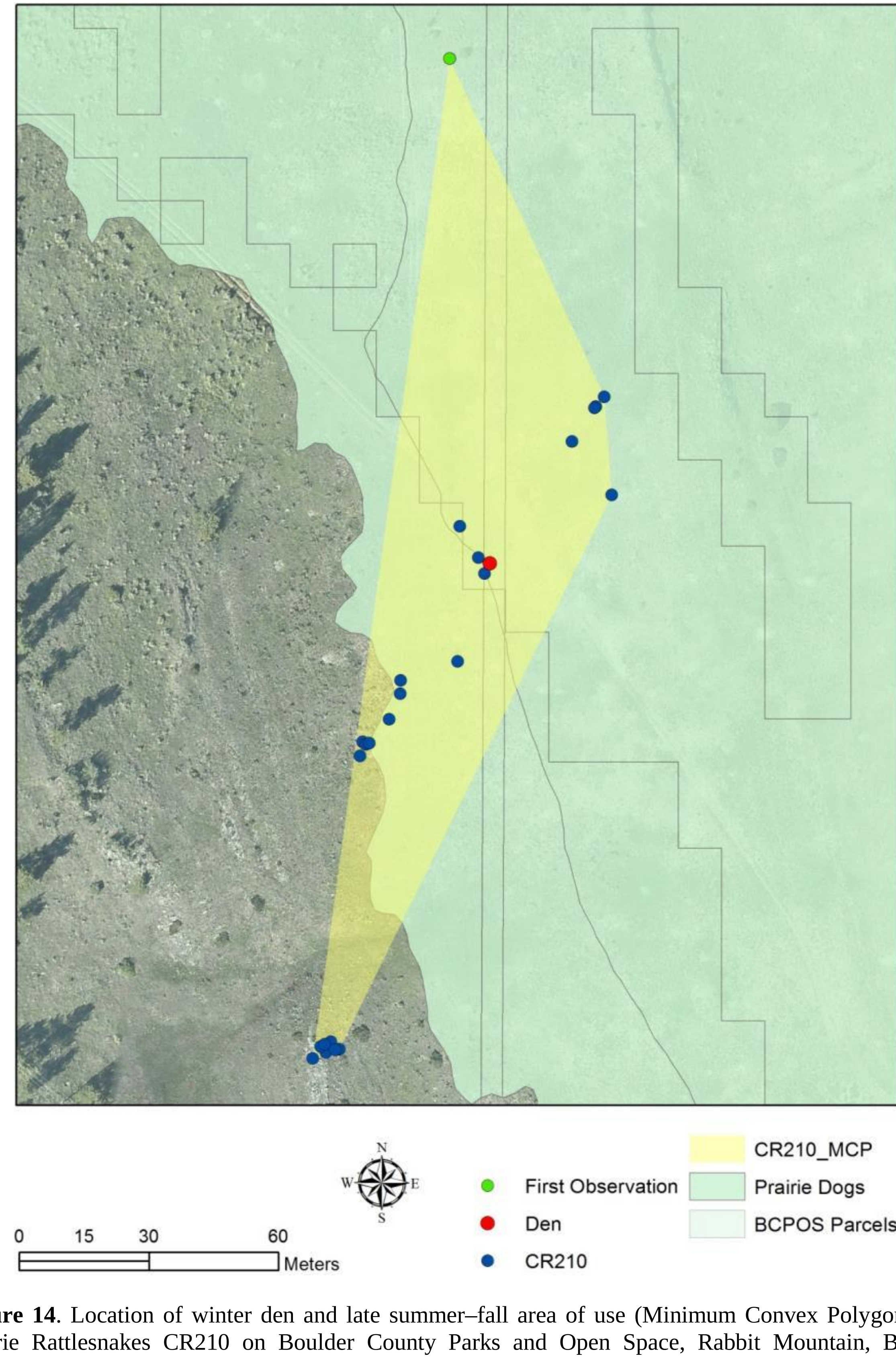

Figure 14. Location of winter den and late summer–fall area of use (Minimum Convex Polygons) for Prairie Rattlesnakes CR210 on Boulder County Parks and Open Space, Rabbit Mountain, Boulder County, Colorado.

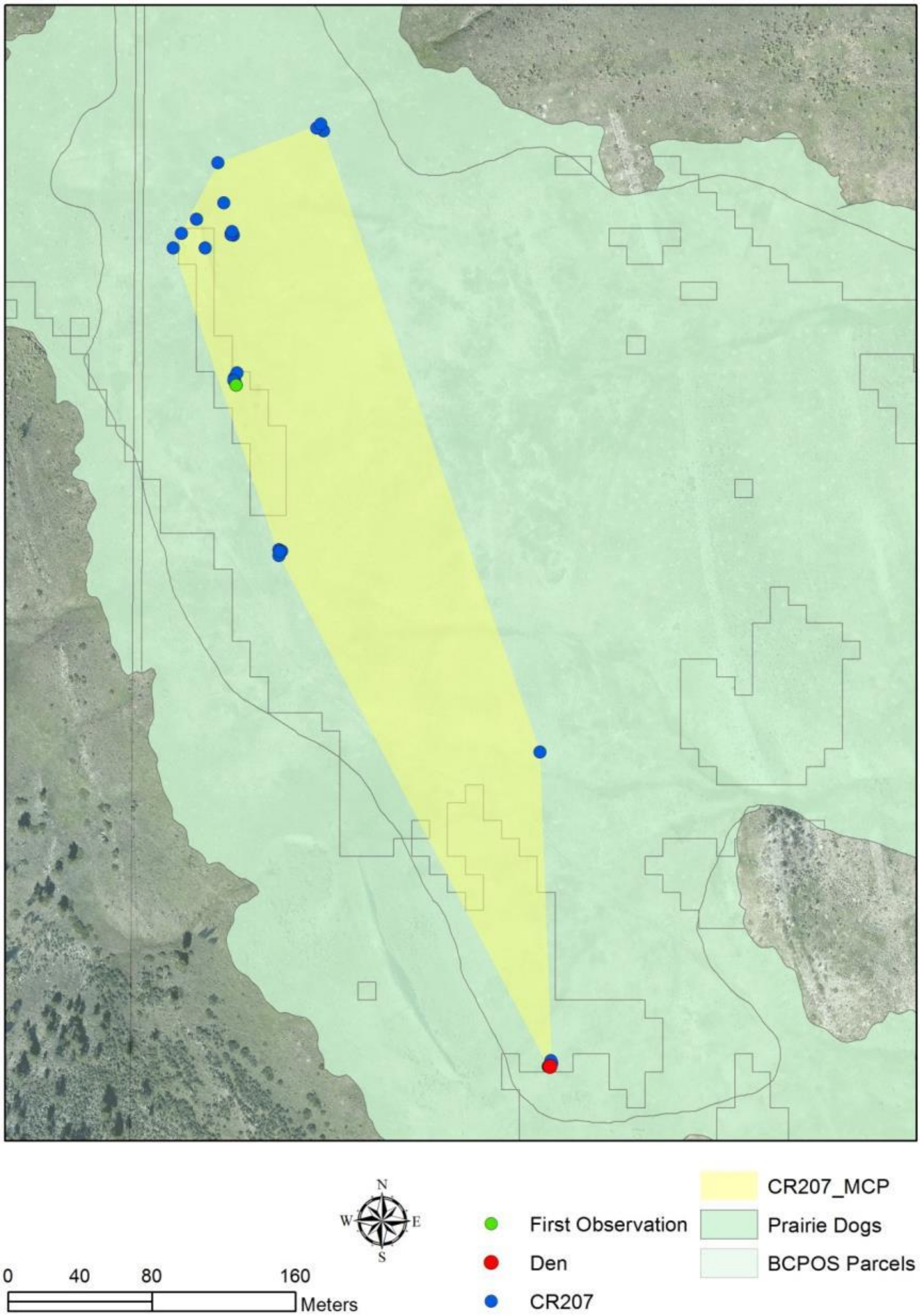

Figure 15. Location of winter den and late summer–fall area of use (Minimum Convex Polygons) for Prairie Rattlesnakes CR207 on Boulder County Parks and Open Space, Rabbit Mountain, Boulder County, Colorado.

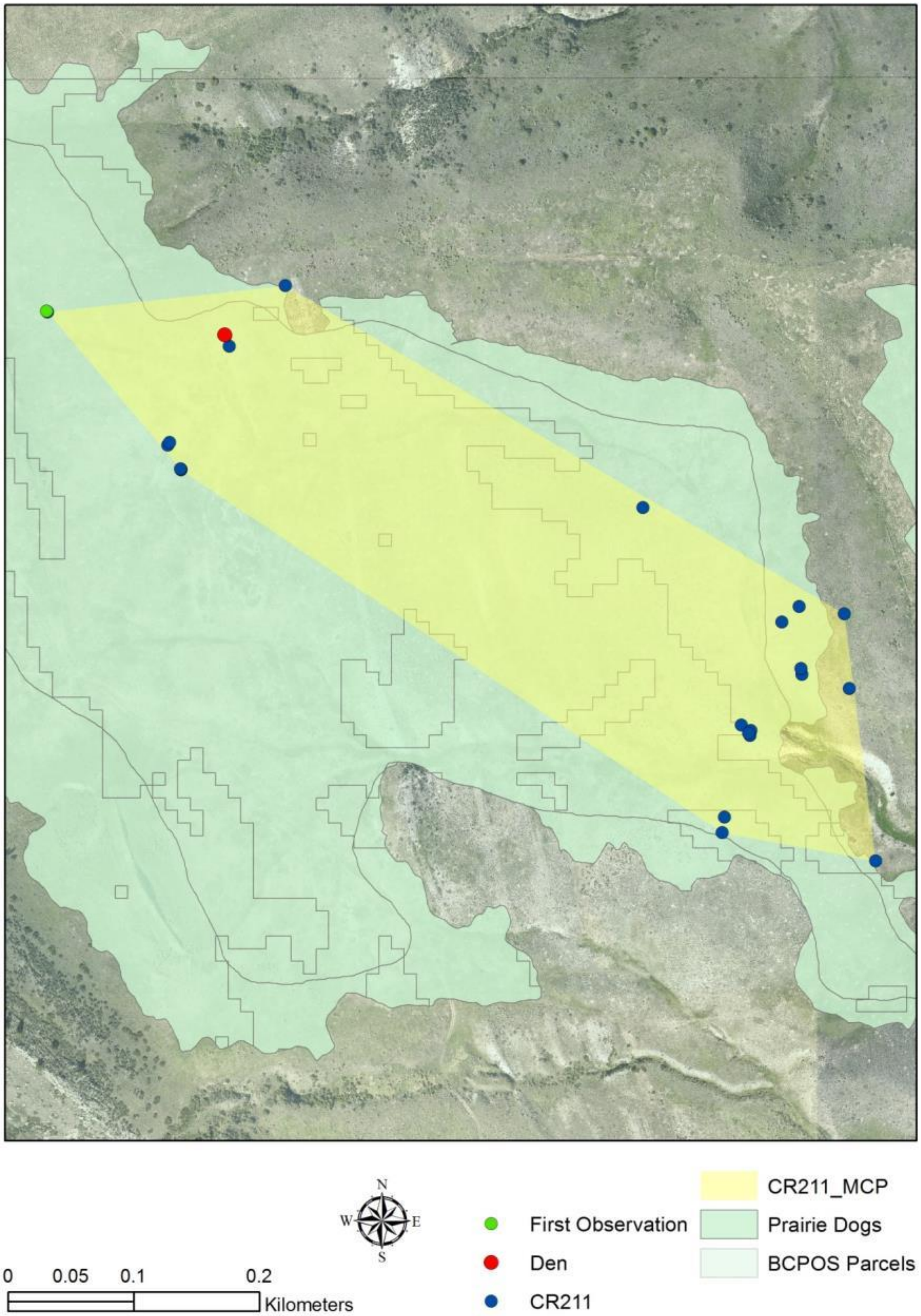

Figure 16. Location of winter den and late summer–fall area of use (Minimum Convex Polygons) for Prairie Rattlesnakes CR211 on Boulder County Parks and Open Space, Rabbit Mountain, Boulder County, Colorado.

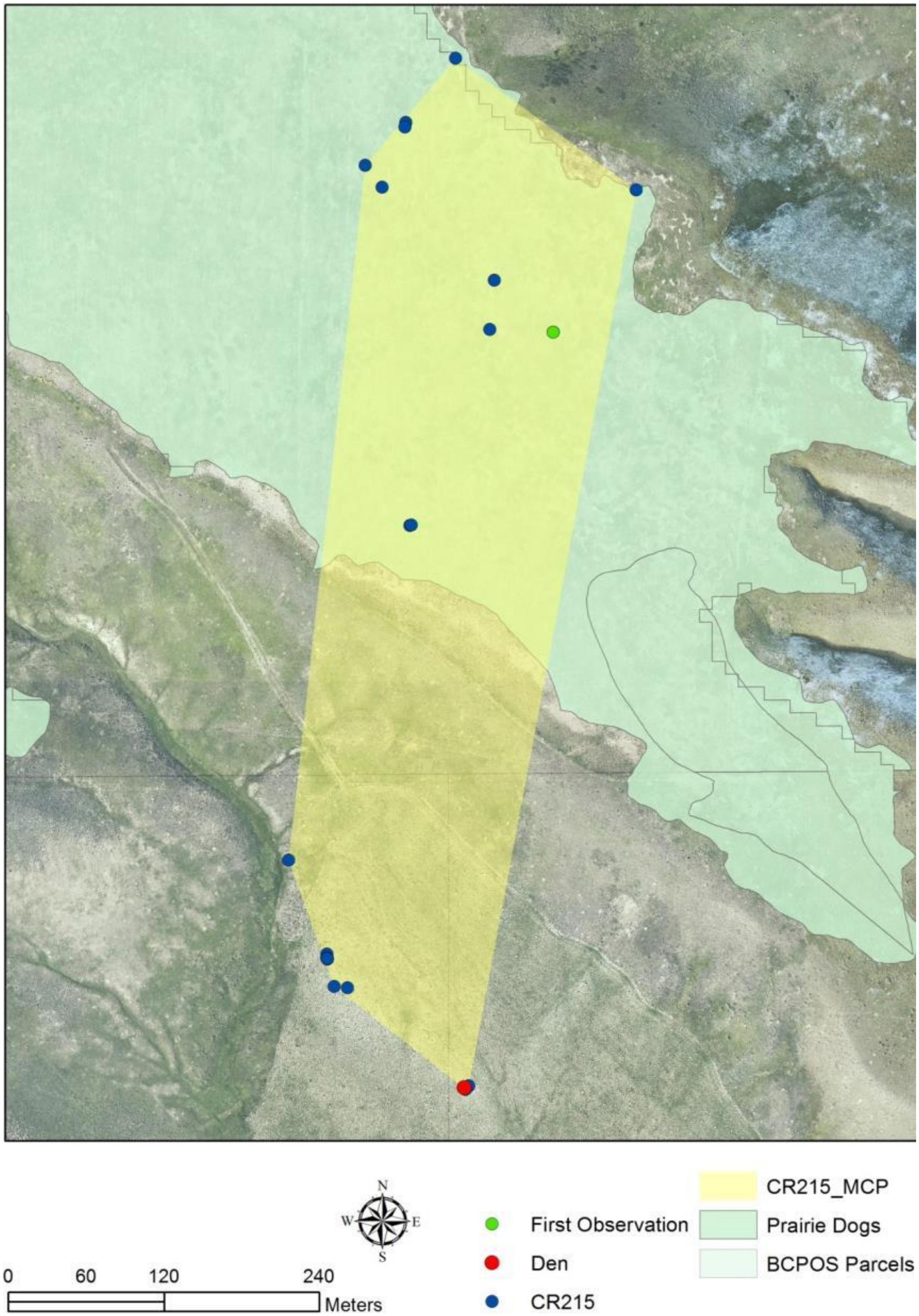

Figure 17. Location of winter den and late summer–fall area of use (Minimum Convex Polygons) for Prairie Rattlesnakes CR215 on Boulder County Parks and Open Space, Rabbit Mountain, Boulder County, Colorado.

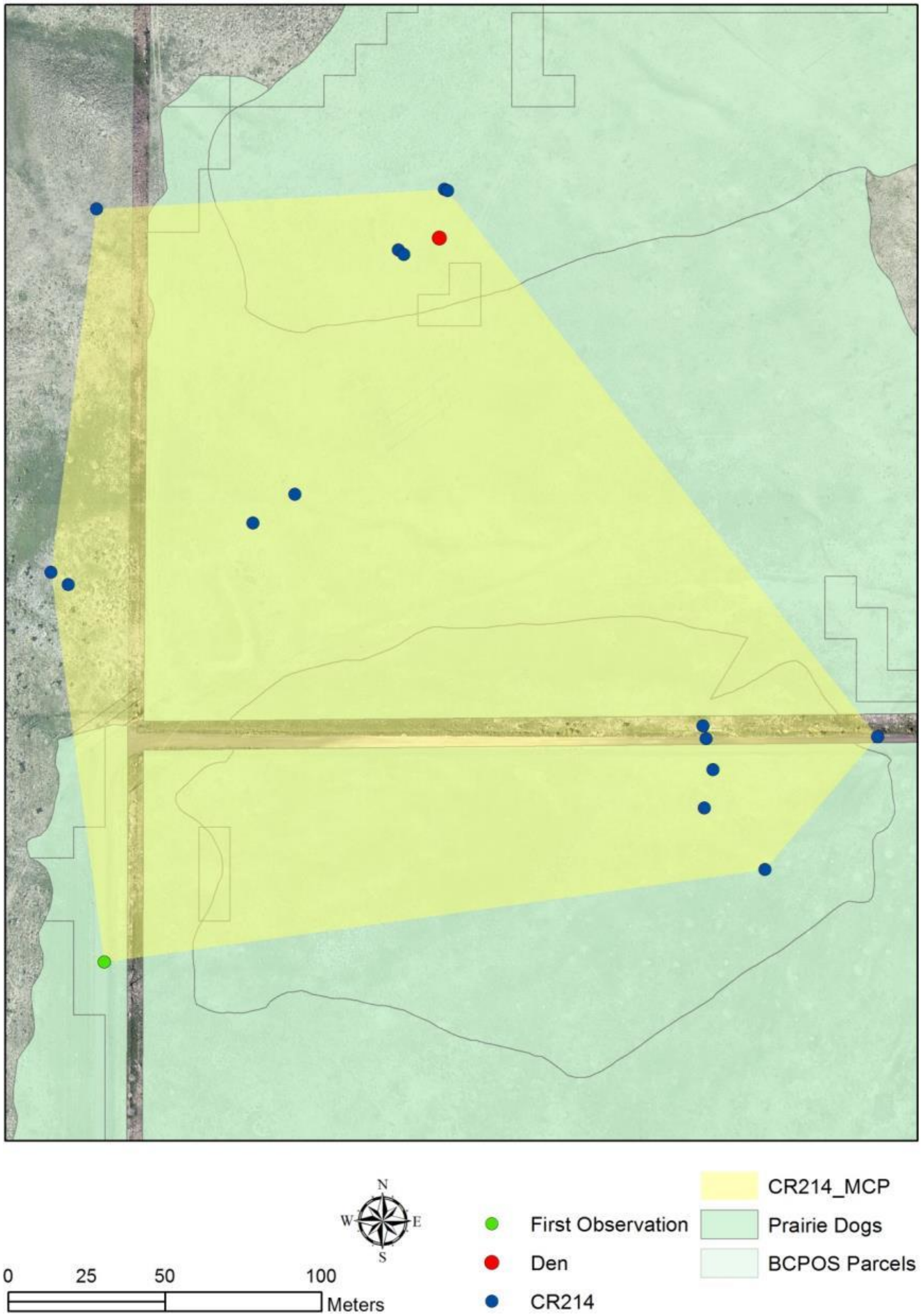

Figure 18. Location of winter den and late summer–fall area of use (Minimum Convex Polygons) for Prairie Rattlesnakes CR214 on Boulder County Parks and Open Space, Rabbit Mountain, Boulder County, Colorado.

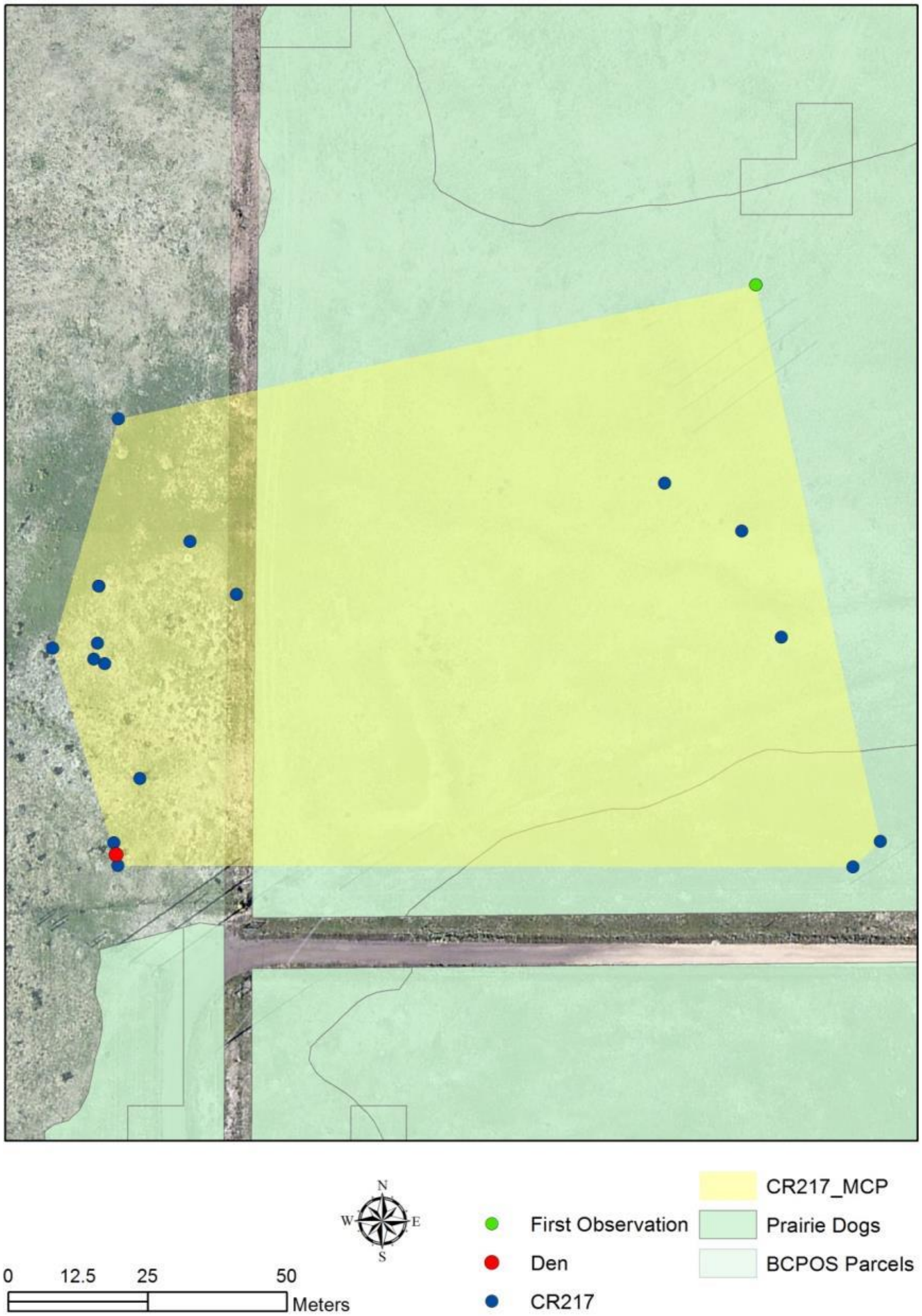

Figure 19. Location of winter den and late summer–fall area of use (Minimum Convex Polygons) for Prairie Rattlesnakes CR217 on Boulder County Parks and Open Space, Rabbit Mountain, Boulder County, Colorado.

Figure 20. Late summer–fall area of use (Minimum Convex Polygons) for Prairie Rattlesnakes CR200 on Boulder County Parks and Open Space, Rabbit Mountain, Boulder County, Colorado. Transmitter for this snake fell off before snake could be tracked to its winter den.

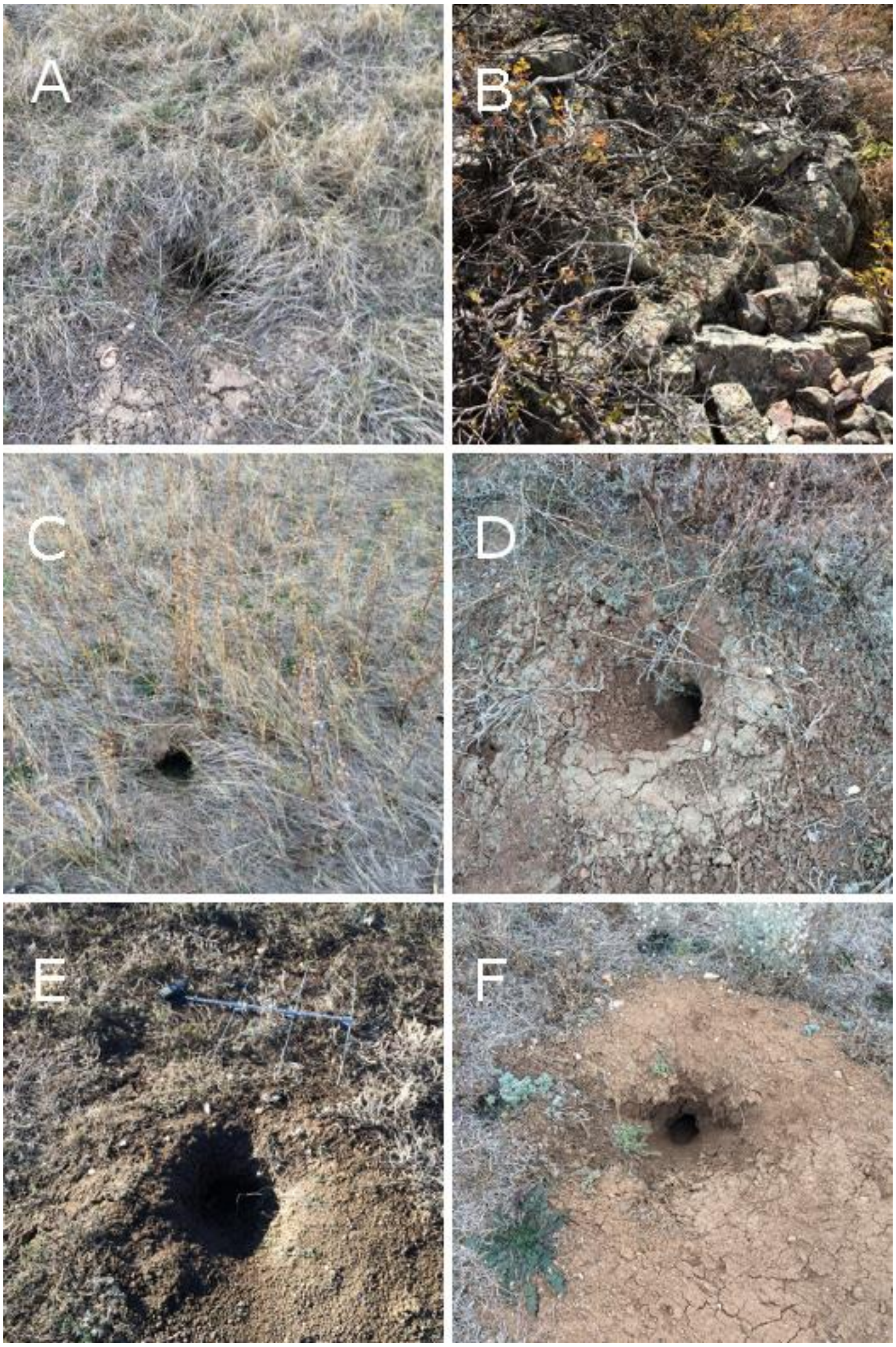

Figure 21. Winter den entrances of individual Prairie Rattlesnakes, **A.** CR205, **B.** CR209, **C.** CR213, **D.** CR212, **E.** CR218, and **F.** CR219, on Boulder County Parks and Open Space, Rabbit Mountain, Boulder County, Colorado. Dens for CR205 and CR213 are abandoned prairie dog burrows; CR212, CR218, and CR219 are active burrows. Entrance for CR209 in rock slide has multiple entryways.

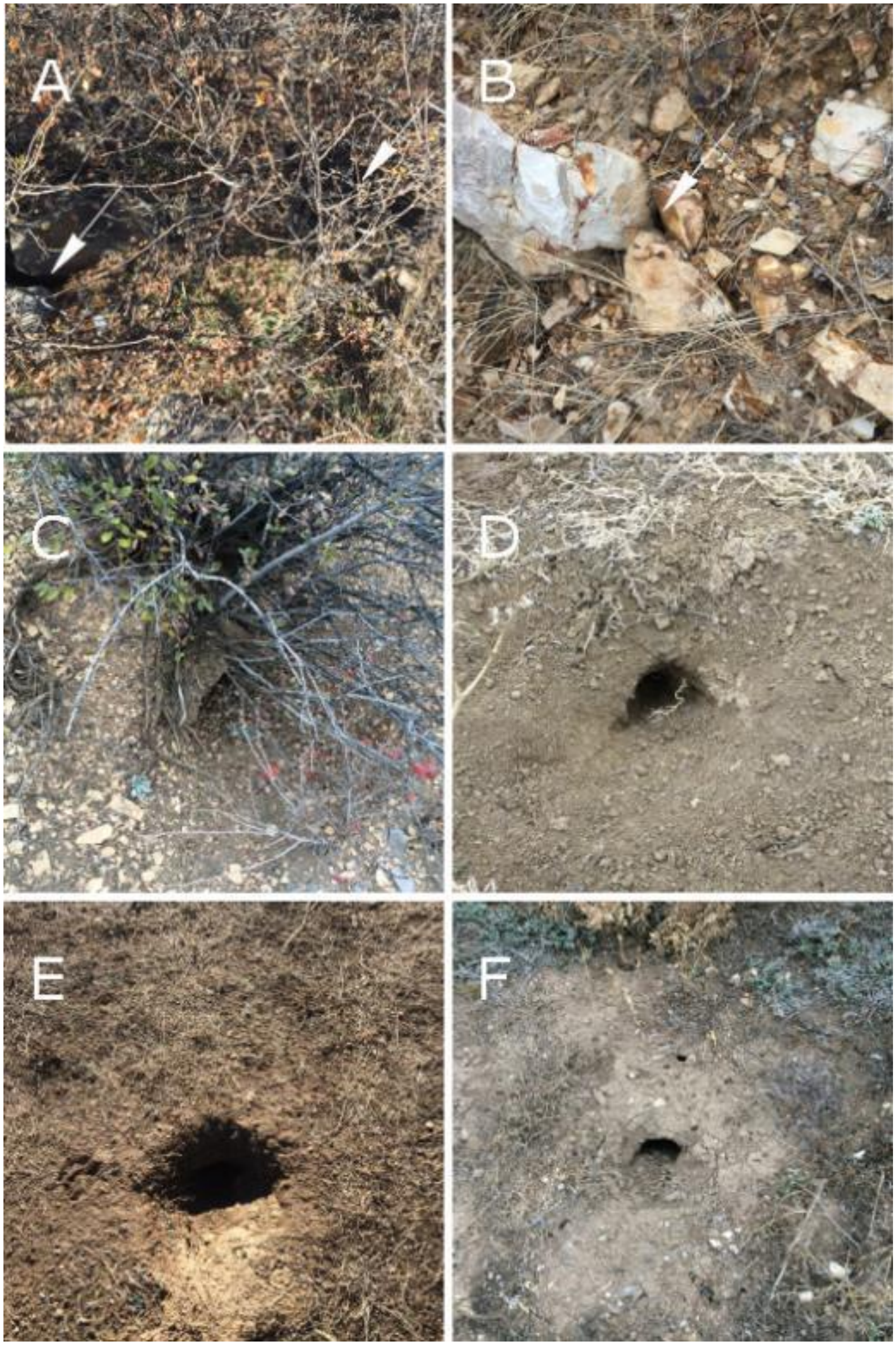

Figure 22. Locations of winter den entrances of Prairie Rattlesnakes, **A.** CR216, **B.** CR206, **C.** CR204, **D.** CR210, **E.** CR211, and **F.** CR207 on Boulder County Parks and Open Space, Rabbit Mountain, Boulder County, Colorado. **A–B**. Arrows indicate den entrances. **C.** Abandoned large mammal burrow in shale outcrop. **D–F**. Active prairie dog burrows.

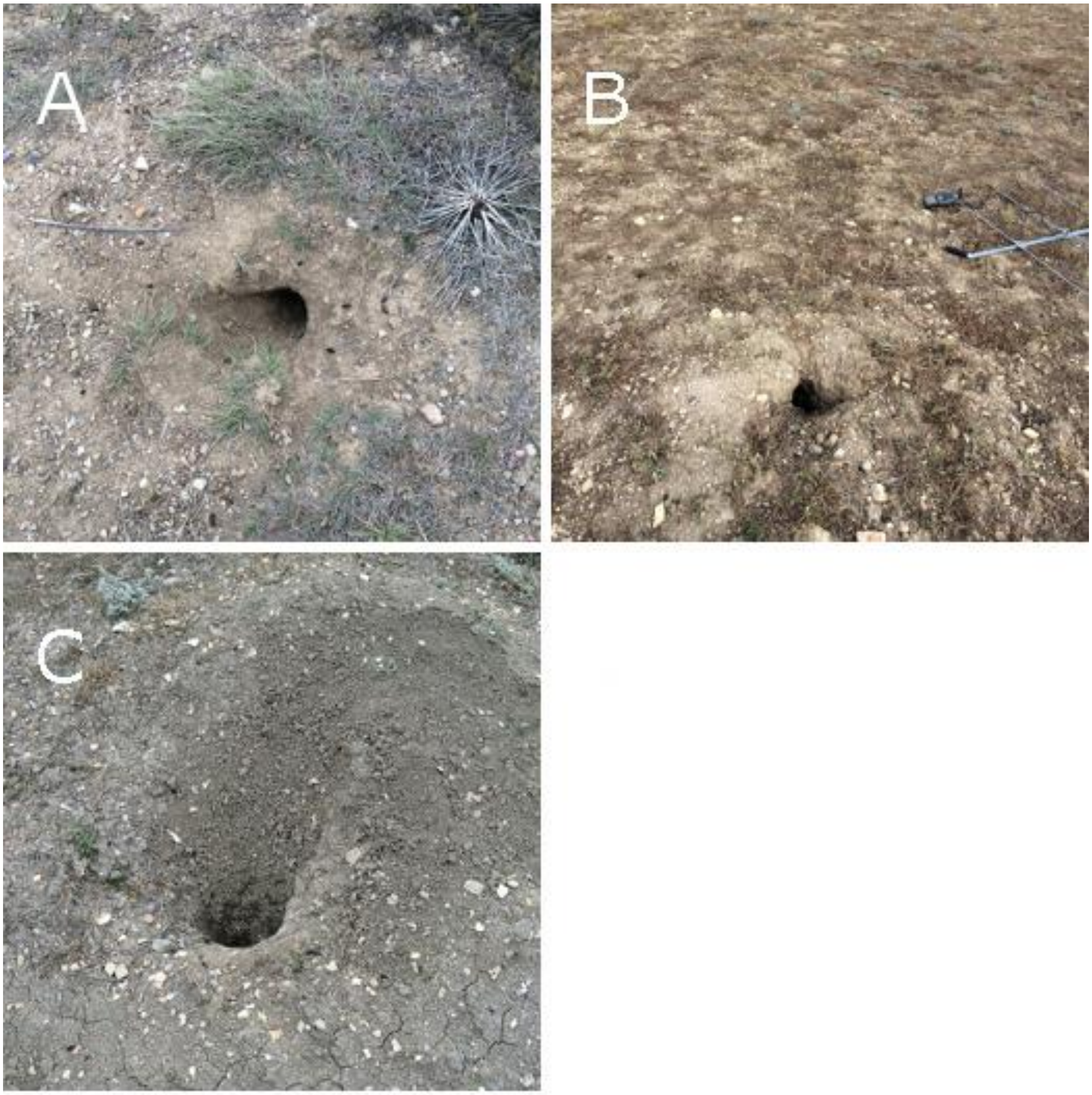

Figure 23. Locations of winter den entrances of Prairie Rattlesnakes, **A.** CR215, **B.** CR214, and **C.** CR217 on Boulder County Parks and Open Space, Rabbit Mountain, Boulder County, Colorado. **A**,**C** active prairie dog burrows. **B**, inactive prairie dog burrow.

Figure 24.A. Rookery rock on Boulder County Parks and Open Space, Rabbit Mountain, Boulder County, Colorado where female Prairie Rattlesnake CR200 gave birth to at least three neonates. **B.** Newly–born Prairie Rattlesnake basking next to rookery rock.

Table 3. Summary results of radio–tracked Prairie Rattlesnakes at Rabbit Mountain Open Space.

Animal Identification	Attachment Date	Days Monitored	Sex	Disposition	Tracked to Hibernaculum?
CR200	August 12	64	F, Pregnant	T	No
CR201	August 12	7	M	T	No
CR202	August 21	25	M	S	No
CR203	August 12	7	M	T	No
CR204	August 21	80	M	A	Yes
CR205	August 21	80	F	A	Yes
CR206	August 28	73	M	A	Yes
CR207	September 4	66	M	A	Yes
CR208	September 4	22	M	S	No
CR209	September 4	66	M	A	Yes
CR210	September 11	59	F	A	Yes
CR211	September 11	59	F	A	Yes
CR212	September 19	51	M	A	Yes
CR213	September 19	51	F	A	Yes
CR214	September 23	47	F	A	Yes
CR215	September 23	47	F	A	Yes
CR216	September 25	45	F	A	Yes
CR217	September 28	42	F	A	Yes
CR218	October 19	21	M	A	Yes
CR219	October 26	14	F	A	Yes

Note: F = Female, M = Male, T = Transmitter fell off, S = Shed transmitter along with skin, A = Alive.

Table 4. Late summer–fall areas of use, occasions snakes were visible, and microhabitat of radio–tracked Prairie Rattlesnakes on Boulder County Parks and Open Space, Rabbit Mountain, Boulder County, Colorado.

				Microhabitat Type										
Animal ID	AOU (ha)	Occasions Visible (%)		In Grass or Forbs	Under Dense Grass	Under Shrub	Under Rock	On Rock	Down Large Mammal Burrow	Down Prairie Dog Burrow	Mouth Prairie Dog Burrow	Down Small Rodent Burrow	Mouth Small Rodent Burrow	On Road or Trail
CR200	4.770	76.9		13	1	2	5	1	0	2	1	1	0	0
CR204	1.533	61.3		2	0	18	4	1	6	0	0	0	0	0
CR205	1.068	46.9		9	2	9	1	0	0	9	2	0	0	0
CR206	4.166	67.9		7	0	10	6	0	0	0	0	4	1	0
CR207	4.770	73.1		7	0	2	1	0	0	9	8	0	0	0
CR208	—	—		—	—	—	—	—	—	—	—	—	—	—
CR209	41.869	57.7		9	0	2	6	0	0	4	3	1	0	0
CR210	0.663	39.1		6	0	1	3	0	0	11	2	0	0	0
CR211	11.964	81.8		9	0	2	1	0	0	5	0	0	0	0
CR212	0.752	55.0		8	0	1	0	0	0	8	1	1	0	1
CR213	0.483	35.0		4	0	0	8	1	0	4	0	0	1	1
CR214	4.590	58.8		5	0	0	0	0	0	7	0	4	0	1
CR215	12.928	45.0		3	0	0	0	0	0	6	0	5	0	0
CR216	1.850	36.8		5	0	1	13	0	0	0	0	0	0	0
CR217	1.226	23.5		3	0	1	0	0	0	13	0	0	0	0
CR218	0.398	—		—	—	—	—	—	—	—	—	—	—	—
CR219	0.002	—		—	—	—	—	—	—	—	—	—	—	—
$\bar{x}$	5.8	54.2												
			%	28.6	0.9	15.5	15.2	0.9	1.9	24.8	5.4	5.1	0.6	1.0

Note: RO = Rock outcrop, LMB = Large mammal burrow, PDB = Prairie dog burrow. Observations recorded after November 9, 2015, the date of entrance into hibernation, are not included. Data for snakes with fewer than seven relocations not presented.

DISCUSSION

The two major findings of this work with respect to our objectives, that Prairie Rattlesnakes on Rabbit Mountain Open Space tend to 1) select single–occupancy winter dens, and 2) select dens in prairie dog burrows, run counter to that typically reported for the species. An unexpected third finding was the dichotomy in insolation dependence between dens in rocky areas (dependent) and prairie dog burrows (independent).

Of the 15 winter dens we located, only one was observed to contain individuals other than the transmittered individual. The fact that three other transmittered snakes selected individual dens in this same prarie dog colony makes it difficult to ascribe any special significance to the one communal den. We cannot rule out, however, the possibility that these apparent single–occupancy dens did not contain other snakes because we could not examine the interiors of dens. In most cases though, transmittered snakes were observed repeatedly at or near their den sites in absence of conspecifics. Of the 15 winter dens we located, only four were in rock outcrops, whereas all others were in prairie dog burrows. Given that the preponderance of area on Rabbit Mountain is rocky habitat, it would seem that prairie dog colonies and their burrows provide favored sites for winter dens for Prairie Rattlesnakes on Rabbit Mountain.

Hamilton and Nowak (2009) presented evidence that rattlesnakes in cool climates (*Crotalus lutosus* and *Crotalus molossus*) utilize hibernacula with insolation values higher than those of their surroundings. Our finding that dens in rocky outcrops had higher heat index values than randomly located sites is consistent with this finding. The high median heat index we observed for dens in rocky outcrops resulted from slopes and aspects that were steeper and more southerly than those in the general environment. These findings suggest that high insolation is a requirement for den selection in rocky outcrops on Rabbit Mountain. Conversely, suitability of prairie dog burrows as winter dens apparently does not depend on insolation. Soil surface temperatures of dens in prairie dog burrows were lower than those in the general environment. They are lower because Black–tailed prairie dogs do not establish colonies on sites having slopes greater than 10% (Clippinger, 1989) and flat slopes receive much less insolation compared to steep south–facing slopes, particularly during the winter months. But despite the differences in insolation received at dens in rocky outcrops and prairie dog burrows, it is likely that temperatures inside both types of hibernacula are similar. The burrows of Black–tailed prairie dogs, average 2 m deep (Sheets et al., 1971), may be up to 5 m deep (Hoogland 1995), and are thus well below the maximum frost line in Boulder County, which reaches a maximum depth in January. The nearest weather station to Rabbit Mountain that provides subsurface soil temperatures is located at the USDA Central Plains Experimental Range (CPER), Soil Climate Analysis Network site at 1625 m elevation ~77 km northeast of Rabbit Mountain (http://www.wcc.nrcs.usda.gov/index.html). There, soil temperatures 1 m belowground (lowest depth measured on CPER) reach minimums in January, averaging about 1°C. In addition, soil on prairie dog colonies is typically denuded and bare soils have a lower albedo and thus higher temperatures than vegetated soils. For example, Archer and Detling (1986) found that soil surface temperatures averaged approximately 2.5 °C higher on prairie dog colonies than in the more densely vegetated uncolonized areas nearby. Last, it is possible that Black–tailed Prairie Dogs, because they do not hibernate, add some additional heat to the burrow system by virtue of their presence. Temperature in the nest of the European badger (*Melesmeles*) is about 2.4°C higher than in unoccupied chambers in the same depth (Moore and Roper 2003).

Prairie dog colonies have other attributes important to Prairie Rattlesnakes besides providing protection from freezing winter temperatures per se. First, prairie dog colonies, with their numerous burrows, likely provide Prairie Rattlesnakes with a wide number of thermally suitable winter dens to choose from. Individuals using areas overlapping prairie dog towns as their summer foraging area (e.g., Lomolino et al. 2004) do not have to migrate far, if at all, to their winter dens. Rattlesnakes usually occupy burrows that are abandoned and located at the periphery of the active colony boundaries (Shipley et al. 2013), because these burrows provide relative quietude and retain vegetative cover normally removed by prairie dogs. Moreover, colony peripheries are in close proximity to areas of increased vegetative density and associated habitat resources. Prairie dog burrows run many meters in length, contain numerous subterranean outpockets, and have 2–3 entrances (Hoogland 1995). This arrangement provides important conditions for successful hibernation including temperature moderation, humidity, predator avoidance, and protection from flooding. Burrows selected by rattlesnakes for hibernation may not be reused annually as there are usually a large number of burrows available and a particular burrow may only be occupied by a few rattlesnakes (Shipley et al. 2013).

The suitability of dens in rocky outcrops and rocky hillsides on Rabbit Mountain is apparently dependent on high insolation, but these den types likely offer other hibernatorial advantages not found in prairie dog colonies. They likely offer numerous interconnected subsurface spaces between rocks and beneath individual boulders each potentially serving as hibernacula. The spaces between rocks closer to the surface along with overlying vegetative cover may simultaneously provide easy access to basking surfaces, and just as important, quick escape routes from predation (Keenlyne 1972). Because of numerous suitable potential hibernacula present in these geologic features, it is likely that only a few snakes use each one (Bauder et al. 2015), just as in prairie dog colonies where presence of numerous suitable burrows all in close proximity obviates dependence on any single one.

Given the presence of rock outcrops, rocky hillsides, and prairie dog colonies, Rabbit Mountain rattlesnakes may exhibit opportunistic hibernaculum selection, a behavior noted in some timber rattlesnake and gopher snake populations (Sealy 2002; Williams et al. 2015, respectfully). In these cases, numerous suitable hibernacula choices exist and enable snakes to avoid dependency on only a few hibernacula for which over–wintering conditions are supportive, a condition found in other Prairie Rattlesnake habitats (e.g. Duvall et al. 1985). Rock outcrops, rocky hillsides, and prairie dog colonies all seem to confer hibernatorial advantages that may differ from each other but still provide necessary survival attributes, including readily accessed basking spots for gravid females that do not require otherwise extensive movements to specific microhabitats where gravid females aggregate (i.e. rookeries). Even diffusely scattered hibernacula may maintain an inter–connectivity that represents the integrity of the whole rattlesnake population in terms of survivorship and genetic interchange (Clark et al. 2008). Rabbit Mountain Open Space remains as an ideal site for answering these and other conservation related questions.

LAND MANAGEMENT RECOMMENDATIONS

General Recommendations

Perhaps the most pressing conservation need for this species on Rabbit Mountain, as is currently recognized by BCPOS (S. Spaulding, pers. com), is insuring the continued existence of the reintroduced prairie dog colony on the north central part of the property. Despite the relatively small size of this colony, it seems to harbor a large number of Prairie Rattlesnakes. Twenty seven percent of the snakes used this study (n = 4) were encountered on this colony and two others close by. It is speculative, but perhaps the reason we only observed one communal winter den, and on this site, was because of the large number of snakes in the area. We do not know if the number of snakes in this area is result of this colony being larger in the past, or whether snakes in this area favor this colony because it is the only colony in the area. Recently the colony has become heavily invaded by moth mullein (*Verbascum blattaria*), a biennial with high seed production and a seed bank capacity of 90 years (see Figure 21. C.). The primary concern, as recognized by BCPOS, is this tall plant (0.6 – 1.0 m.) may reduce ability of prairie dogs to see predators and allow predators to approach prairie dogs closer than if this invasive was absent. Although prairie dogs were observed to be cutting down some the erect stems of this plant in the immediate areas of burrows, the remaining stiff and spiky stems may impede their ability move quickly from one burrow entrance to another. Unfortunately, it is the surface soil disturbance caused by prairie dogs that may facilitate establishment of this species. Application of herbicide in the spring followed hand pulling as needed when flower stalks are bolting are recommended.

Regarding locations of wintering dens of Prairie Rattlesnakes we identified, because no large communal dens were observed, we can only presume that individuals of this species have a large number of potential overwintering sites available to them, and probably throughout the property. If so, then there may be no need for an individual to return to a specific den year after year as has been reported in the literature. Therefore we do not think it is necessary provide any special protection to dens identified here. All den sites we recorded are well off existing trails and roadways and do not appear to be under any imminent threats. Follow up work to determine if these particular den sites are used year after year would be worthwhile and necessary to confirm conclusions offered here. However, as discussed above, peripheries of prairie dog colonies are important foraging and denning habit for Prairie Rattlesnakes on Rabbit Mountain, and as such, should be considered in management decisions for both species. The one rookery we found is of some importance because individual female Prairie Rattlesnakes are known to use the same individual rookeries for birthing year after year (Graves and Duvall 1993).

Data on movements of Prairie Rattlesnakes presented here show that certain individuals do conduct long distance movements on and off the property and their AUC's are accordingly large. Other individuals move about within relatively small areas, at least during the period when we monitored them. Whether the large AUC's exhibited by some individuals are important for their well–being of is unknown. What should be clear, however, is that it may be inappropriate to manage for this species on a small geographic scale — some individuals of this species use a surprisingly large fraction of the total area of Rabbit Mountain, sometimes exiting the property entirely before returning.

Open Space Safety/Outreach

There is presently no signage on Rabbit Mountain Open Space advising the public that rattlesnakes are common on the property. Such signage should point up the importance of staying on trails where snakes can be seen more easily. Our snake point location data shows that this species infrequently chooses resting places on trails or roads. The fact that rattlesnakes are commonly seen on roads and trails is in part due to their proclivity to bask in these places when temperatures are ideal (e.g., dusk in summer). On Rabbit Mountain, however, the fact they are commonly observed by visitors on trails and roads is mainly a result of their overall abundance; we observed transmittered snakes on trails and roads as only 1% of our observations. Data presented here shows that Prairie Rattlesnakes are much more likely to be encountered off–trail in grassy areas, rocky areas, and particularly in and around prairie dog colonies. Appropriate signage is recommended to increase the awareness level of visitors to be alert for snakes, particularly during those times of day when both visitors and Prairie rattlesnakes are most active, early morning and near dusk during the warmer months. Some visitors are unaware that rattlesnakes are present; others are less than observant — one of us (T. Mathies) observed a couple and their dog on a gravel road step within striking distance of an adult rattlesnake stretched out on the road without ever seeing it. Another couple, again with a dog, were observed throwing rocks at something in the road. Upon investigation, we observed a Prairie Rattlesnake in strike position, a leashed dog attempting to reach the snake, and two agitated adults. They communicated to us that they did not know rattlesnakes were present on the property. We examined the snake for wounds (none visible), put a transmitter on it, and moved it off the road. Thus, signage could benefit both visitors and snakes. Although our data suggests Prairie Rattlesnakes are most common in the lower areas of the property, we believe this species occurs widely throughout the property in nearly every habitat. When building new trails or repairing old ones, care should be taken to direct trails such that they are well away from rocky and shrubby situations or adjacent to stands of thick grass. In preexisting places, certain rocks can be set back from trails, shrubs trimmed down, and grasses mowed. Any kind of berm work for trails should use dirt rather than stacked rocks.

Three of our transmittered snakes crossed over the St. Vrain Supply Canal near the visitor parking lot. We do not know if they swam the canal or crossed via the large corrugated metal drainage pipe that crosses beneath the canal just south of the parking lot, but the latter method is likely. Public access should be kept limited, as it is now, by maintaining fencing and other structural deterrents.

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