FINAL REPORT

Conservation strategies for migrating populations of leaf-litter snakes at an Illinois State Park.

15 December 2013

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Grant #12-013W

Funded period: 1 July 2011 – 15 November 2013

Project Objectives

The relatively robust population of Midland Brownsnakes at FRSP is offset by a high rate of mortality experienced along a 2.7-km stretch of Ridge Lake Road during the snakes' return to hibernation sites each Autumn. As such, an important long-term goal of this project is to determine the viability of specific management strategies to reduce snake mortality during the periods of peak migration. I will monitor snakes species traversing sections of this road using drift fence-pitfall trap arrays adjacent to, and distant from, two existing culverts passing under the road to determine what proportion of these snakes use the culverts to reduce their mortality risk during migrations. I will collect life-history data from all snakes encountered. Each snake will receive a unique mark such that I can quantify recapture rates and estimate the population size for each species.

Data collected during this project will address the paucity of published information concerning the ecology of snakes in the leaf-litter guild. Of equal importance is that, by comparing capture rates at each of the different fence-trap arrays, I will be able to estimate the proportion of the brownsnake population that migrates across particular sections of Ridge Lake Road. This information can be used to inform management decisions such as the need to: (a) construct additional culverts that allow snakes to pass under the road surface; &/or, (b) construct one (or more) hibernaculum on the same side of the road as that occupied by the snakes during the activity season (thereby minimizing the need for snakes to cross the road). Although brownsnakes are the focus of the proposed research, the fence-trap arrays have the potential to sample other snake species inhabiting FRSP. As such, this project will also provide important life-history data for these species that contribute to ecosystem functioning at this site.

Because the fence installation will occur adjacent to a public road, I will also have the opportunity to interact with people visiting FRSP. As such, another activity will be informing the public about the snake community using this habitat and contributing to the functioning of the ecosystem at the park.

Project Description

In spite of being nearly surrounded by row-crop agriculture, Fox Ridge State Park (Coles Co.) has a relatively high diversity of amphibian and reptile species. Recent management activities at this site have targeted amphibians by constructing additional ephemeral or isolated wetland habitats for breeding activities. The research outlined in this proposal concerns the small snake species inhabiting the leaf-litter microhabitat. Of particular interest is the Midland Brownsnake (*Storeria dekayi wrightorum*) because of the relatively high mortality experienced by this species along a park road that separates the habitat used during the activity season from that used for over-wintering. Conducting research on a relatively common (but rarely observed) snake species can inform management decisions that impact rarer species that are historically known from these

habitats. The data collected provide a quantitative inventory of the snakes using these habitats, as well as life-history information about these species. The outcomes from this project also include recommendations among the options for future management of this site. An additional outcome of this project is increasing public awareness of the snakes traversing this road, so as to reduce the negative impacts of park visitors on the populations of these snake species.

Summary of Project Accomplishments

INTRODUCTION

This report details a 2-year study completed at Fox Ridge State Park (FRSP), Hutton Township, Coles County, Illinois, a property overseen by the Illinois Department of Natural Resources (IDNR). The overall project concerns the monitoring of a snake community that migrates between habitats separated by Ridge Lake Road that services the northwestern portion of FRSP (Fig. 1). This report describes the species composition of the reptiles and amphibians encountered along, and in habitats adjacent to, the road; and, more specifically, the spatial and temporal patterns of mortality experienced by Midland Brownsnakes (*Storeria dekayi wrightorum*) as they migrate across the road.

Studies of spatial and behavioral ecology in reptile communities have included investigations of road avoidance in a number of species with variable trophic niches and natural history traits (Andrews *et al*. 2008). Shepard *et al*. (2008) showed that snakes and box turtles in a moderately dissected habitat were far more likely to avoid crossing a road than would occur at random. Andrews & Gibbons (2005) observed interspecific variation in the propensity of snakes to cross a road, and in the behavioral responses to passing vehicles. In general, smaller species were less inclined to cross, and heavy-bodied species would begin to cross a road, but often return to their original side.

Direct road mortality rates are highest in vertebrates where the spatial connection among resources across a landscape is compromised by the road surface in question (Andrews *et al*. 2008). Seasonal movements in amphibian and reptilian populations increase the vulnerability of taxa to road mortality and population decline. For example, road mortality can skew the sex ratios in semi-aquatic turtle populations because females incur high mortality during migrations to their nesting sites (Beaurdy *et al*. 2010) which, in turn, limits the effective population size (Gibbs & Steen 2005). Snake populations can incur similar mortality, especially during seasonal activity peaks associated with the ingress and egress periods associated with over-wintering (Seigel & Pilgrim 2002; Shine & Mason 2004).

The general consensus among wildlife biologists is that indirect effects like road avoidance are more detrimental to vertebrate populations than direct road mortality (Andrews & Gibbons 2005; Forman & Alexander 1998). Some scientists caution against using road-kill numbers as estimators of overall mortality or population trends (Andrews *et al*. 2008; Bonnet *et al*. 1999). It could be argued, however, that direct mortality trends will ultimately promote the selection of road avoidance behavior, and the associated concerns of connectivity among subpopulations on either side of the road (Shepard *et al*. 2008). In situations where a road cannot be avoided, higher mortality among individuals of a particular age or sex can decrease a population's long-term viability.

This report provides data that describe the herpetofaunal species encountered along sections of Ridge Lake Road at FRSP throughout the activity season. By comparing specimens collected using drift fence-pitfall trap arrays adjacent to, and distant from, two

existing culverts passing under the road, I report the proportion of these snakes use the culverts to reduce their mortality risk during migrations. I also summarize life-history data from all snakes encountered, and quantify recapture rates and qualitatively describe the population size for each species. These data contribute to an otherwise sparse amount information concerning the ecology of snakes in the leaf-litter guild.

I also estimate the relative intensity of brownsnake movements across particular sections of Ridge Lake Road (Fig. 2) by comparing individual encounter rates at each of the different fence-trap arrays. Based on this information, I discuss the viability of various options that might reduce the incidence of snake mortality along the road:

- various modifications to the road surface that would minimize the likelihood of snake mortality during their migratory movements.
- constructing additional culverts under the road surface.
- constructing one (or more) hibernaculum on the same side of the road as that occupied by the snakes during the activity season.

Because the drift fence-pitfall trap array was installed along a public road within FRSP, I had the opportunity to interact with people visiting FRSP. I describe the efforts of my lab group members in informing the public about the snake community using this habitat and contributing to the functioning of the ecosystem at the park.

MATERIALS & METHODS

Nine drift fence-pitfall trap arrays were installed parallel to the northern-most 2.7-km section Ridge Lake Road (RLR) within FRSP (Fig. 3), and monitored daily during the activity season (typically from the last weekend in March to the first weekend in

November). Fences were each 100 m in length, spaced at least 170 m apart (adjusted to avoid abrupt slope changes, or physical obstructions), and installed 2.5 m from the eastern ("uphill") edge of RLR. Each fence consisted of a combination of 45 cm-tall silt fencing and tin flashing, affixed upright to 60 cm wooden stakes. The bottom 5-10 cm of fencing material was buried below grade and occasionally reinforced with coarse-grain sand. Seven 18-L plastic buckets were installed as pitfall traps adjacent to the fence, such that the rim of each bucket was flush both to the fence, and with the ground level. One bucket was associated with each end of the fence (intercepting herpetofauna that encountered either side of the fence), three buckets were evenly-spaced along the road side of the fence, and two buckets were evenly-spaced on the opposite side of the fence. Eight covermats (fabric-reinforced rubber, averaging 60 x 120 cm in size) were positioned immediately adjacent to all fences (four on each side, evenly spaced along the fence length).

The survey efforts not only targeted Midland Brownsnakes (Fig. 4), but other members of the leaf-litter snake community, and small life-history stages of other snake species (11 snake species in total; Table 1). During periods of peak snake movement across RLR (e.g., see Fig. 5), at least one researcher walked the 2.7-km section of RLR that follows the ecotone, in addition to checking all traps and covermats, on a daily basis. Non-target organisms in the traps were released, and all snakes were returned to the lab for processing.

For each snake collected (live or dead), I recorded species and position data (Magellan eXplorist 310 GPS unit; ±6 m accuracy). Where possible (live or recent road-killed specimens), I also recorded snout-vent length (SVL; ±1 mm), mass (±0.01 g), and

sex (*e.g.*, Fitch 1987; Dorcas & Willson 2009). I uniquely marked each live snake using a portable cautery unit (Winne *et al*. 2006), so as to monitor recapture rates. Because only brownsnakes were represented by a sufficiently-high sample size, I incorporated GPS data for this species into a geographic information system (GIS; ArcGIS v9.2, ESRI, Inc.) to visualize patterns of distribution for brownsnakes migrating across RLR. I used a kernel density function within ArcMap v10.1 (ESRI; Jenk's method) to identify migratory "hot spots" for snakes crossing RLR.

After processing (<48 h of capture), I released all live specimens on the side of the fence opposite that on which they were retrieved from either a trap or covermat. For those snakes collected live on RLR, I released them >6 m off the road in the direction of their body orientation at their time of collection.

With assistance from the Illinois Department of Transportation, I deployed a pressure-sensitive car counter at the southern end of RLR, less than 100 m from the beginning of the section of the road that passes along the ecotone separating the upland mesic forest (hibernation habitat) from the bottomland floodplain (activity-season habitat). From 4 October 2011 to 18 June 2012, readings from the car counter were recorded each time the fence-trap array was surveyed for snakes. Opportunistically, members of my lab group would engage in conversation with members of the public passing along RLR (either on foot, bike, or in a car); we typically described the techniques used to sample the snake community, the life-history characteristics of the snake species, and emphasized the mortality risk that the snakes were experiencing on account of having to migrate biannually across RLR.

RESULTS

Midland Brownsnakes made up the majority of all snakes observed along RLR even though some other species were recaptured with greater frequency (Table 1). Rates of snake mortality caused by traffic along RLR varied by species, but tended to increase for snakes of smaller body sizes (Table 2; though values generated with $n < 9$ should be interpreted with caution), again reflecting an influence from the large number of Midland Brownsnakes observed along the road. The average number of cars travelling along RLR (out of a mean of 232 cars/day visiting FRSP, <40 cars/day drove along this 2.7-km section) was higher on weekend days, and tended to be higher in Autumn (September through November) than during other months of the activity season (Fig. 6).

At the beginning of the activity season (Julian weeks 11-17), patterns of snake occurrence along RLR typically paralleled temperature fluctuations, with increases in mean high temperatures between weeks producing an increase in the number of snakes moving across RLR (Fig. 5). In addition to Midland Brownsnakes, several other snake species were observed crossing the road during this period (Table 2), as were other amphibians and reptiles (Table 3). At the end of the activity season (Julian weeks 39-46), an increased number of snakes encountered on the road was associated with a decrease in the weekly mean high temperature to 20°C. Even though this temperature threshold was not reached during the same week in each year of the study, a peak in brownsnake migration towards the upland habitat regularly coincided with this weekly mean temperature value. Many more snakes were encountered at the end of the activity season (*e.g.*, an average of over 200 snakes per week), and nearly all of these encounters involved Midland Brownsnakes (whether live or road-killed specimens).

Focusing on Midland Brownsnakes, mortality rates for this species were the highest in Autumn (Kruskal-Wallis statistic = 7.95, $p = 0.02$), with male snakes tending to incur higher mortality than females regardless of season ($p = 0.37$; Fig. 7). The orientation of live brownsnakes along the road (whether associated with the fence-pitfall array, or the road surface) varied by season (Kruskal-Wallis statistic = 14.28, $p = 0.001$), with more snakes heading towards upland habitat in the Autumn (Fig. 8). Subject orientation was similar for both male and female brownsnakes ($p = 0.19$), but males tended to show less consistent patterns of movement during the summer months. In contrast, both male and female brownsnakes oriented towards the upland habitat in the Autumn, with males exhibiting little variability in their direction of travel across the road.

Kernel density analyses revealed a shift from encounters of brownsnakes in association with the fence-pitfall array in Spring (Fig. 9a), to clusters of snake occurrence that included other parts of the road in Autumn (Fig. 9b). In particular, when returning to upland habitats in the Autumn, brownsnakes appear to be following landscape features having relatively low slopes, crossing the road in areas adjacent to culverts, or where the habitat on either side of the road has a shallow gradient. Brownsnakes were never observed using any of the five culverts that pass under this section of RLR, always being encountered on the road or as a result of being sampled by the drift fence-pitfall trap array.

The number of researchers checking the fence-pitfall array each day varied from one to ten, with more research assistants involved at times during the activity season when the fence needed repair or maintenance. The number of interactions with members of the general public who visited the park was generally higher on days when larger

research teams were present along RLR. This trend was especially true when more researchers were present on weekend days in the Autumn, when the number of park visitors was typically greater (Fig. 6). An outcome stemming from the interactions with the general public to that section of FRSP was that people (both "regulars" and infrequent visitors) were made aware of the snake community (many people admitted that they had never seen a brownsnake previously, in spite of repeated visits to the park), and sympathetic to the fact that so many snakes were killed during their migration across that portion of RLR. This is reflected, in part, in a decrease in the mortality rate of brownsnakes over successive years (Fig. 10). Another aspect contributing to the decreased mortality rate is likely the mere presence of my lab group members at the site. In other words, not only were we able to decrease brownsnake mortality simply by collecting snakes off the road surface before the next car passed, but our interactions with the public generally increased the level of appreciation for the non-game wildlife migrating across RLR.

DISCUSSION

Ridge Lake Road does not appear to fragment the populations of snakes occurring at FRSP because: (a) individuals freely cross the road both prior to, and following, their over-wintering period; and, (b) the pattern of crossing in the summer weeks is both inconsistent and infrequent. The relatively low number of recaptures (especially for those species represented by larger sample sizes; Table 1) indicates that, regardless of the season in which they are encountered, most snakes found near RLR are making

unidirectional movements across it to adjoining habitats (as opposed to remaining in areas immediately proximate to RLR for an extended duration, and possibly crossing the road repeatedly within that period). Should changes to the features of the roadbed (e.g., barricades, center dividers, etc.) be necessary in the future, these alterations should allow for a means by which snakes could continue their biannual transit across the road.

The seasonal difference in the orientation of live brownsnakes encountered on RLR is consistent with established patterns of snake movement between two habitats that provide different ecological functions. The bottomland floodplain on the west side of RLR provides suitable habitat for brownsnakes during the activity season (i.e., adequate prey resources, microhabitats for thermoregulation, etc.), whereas only the upland habitat on the east side of RLR allows these snakes to successfully overwinter below the frostline. The orientation of snakes moving across RLR in Spring and Summer is more variable (Fig. 8), which is likely explained by the more erratic movements of male snakes in search of mating opportunities with females. This pattern is consistent with that reported for other snake species that migrate away from overwintering areas (Reinert 1993; Bonnet et al. 1999).

The increase in brownsnake mortality during their return migration across the road in the Autumn is partially explained by a difference in the behavior of the snakes crossing RLR at this time. Whereas snakes were rarely encountered live on the road surface in the Spring (indicating that snakes crossed RLR without pause), many brownsnake encounters in the Autumn occurred because live snakes were spotted motionless on the road. If undisturbed, each snake would typically remain outstretched on the road surface, presumably thermoregulating before continuing towards the upland habitat. In addition

to an increase in the absolute number of snakes (because of the new cohort of neonates being added to the population during the activity season), I suspect that encounter (and mortality) rates in the Autumn are higher on account of this behavior.

The issue of brownsnake mortality along RLR is further exacerbated by another behavioral trait of this species. Instead of fleeing a potential threat, brownsnakes typically remain motionless such that their small body size will render them difficult to detect (Andrews & Gibbons 2005; Durso et al. 2011). This behavioral trait increases their probability of mortality on the road, regardless of snake size, gender, or directional orientation on the road. Even among motorists who might have the best intentions with regards to all species of non-game wildlife (and would want to avoid running over snakes on RLR), the motionless defensive posture adopted by brownsnakes makes them difficult to discern on the road because: (a) the species' general coloration is similar to the asphalt surface (presenting a cryptic coloration); and, (b) the species' body size across all life-history stages is similar to twigs, leaves, or other debris occurring on the road (presenting a cryptic physical resemblance). The higher mortality rate is especially compounded in the Autumn when: (a) more motorists visit the park (Fig. 6); (b) more material from deciduous plants in the area covers the road surface (which presents more objects that could physically conceal the migrating snakes); and, (c) there is a greater temporal synchrony to snake movements that follows the decline in temperature towards the end of the activity season (Fig. 5).

Although not statistically distinct, the mortality rate for male brownsnakes was higher than that of females, not only among seasons within years (Fig. 7) but also across all years of the study (Fig. 10). The trend of higher male mortality might be an artifact of

increased mate-searching behavior (Bonnet *et al*. 1999). In other words, given that male brownsnakes are likely to locate females by detecting chemical trails deposited on the substrate (Lemaster *et al*. 2001), male snakes might put themselves at greater risk for road mortality because the chemosensory information in readily available on that surface. Whereas male brownsnakes consistently orient towards the upland habitat during the Autumn migration, the variability in their movements during other portions of the activity season indicates that males are likely crossing the road sporadically in search of females.

The low recapture rate for marked individuals of the focal species in this study (≤0.05 % for brownsnakes) presents several possible, non-independent scenarios concerning the biology of this species:

- The sampling techniques employed along RLR are either lacking in their coverage of the road (*i.e*., allowing marked snakes to avoid subsequent detection), or present such a negative experience to snakes that they actively avoid the drift fence-pitfall trap array after initial capture. I suggest that both of these situations are unlikely because of the increased intensity in sampling effort (that does not rely solely on the fence-pitfall array) occurring during anticipated peaks in snake migration.
- The brownsnake population at FRSP is so large that the individuals marked following their capture along RLR are diluted by a much greater number of individuals making up this population, such that marked snakes are difficult to detect as recaptures. Although possible, I also question this scenario because if true, then I would expect to see many more brownsnakes in the stomach contents of other colubrid snakes that are known to eat snakes (*e.g., Coluber, Lampropeltis*). Although some small snakes were

recovered from the guts of larger species (SJM, unpubl. data), there was not a disproportionately high number of brownsnakes among them.

- The brownsnake population occurring in habitats on either side of RLR has a relatively high intrinsic turnover rate, such that there is little recruitment from the neonate cohort of snakes produced in one year to the adult segment of the population in subsequent years. Validating this hypothesis presents logistic challenges because it would require not only an understanding of the causes of mortality (*e.g*., predation, road-kill, failure to locate an appropriate over-wintering site, *etc*.), but also quantified mortality rates for each cause. Only with this information could road-based mortality during peaks in migration be ruled out as the sole explanation for the low recapture rates.

The small body size of brownsnakes prevents use of several available technologies typically employed to address questions about their ecology, behavior and natural history (*e.g*., long-term radio telemetry or satellite tagging). As such, alternative strategies should be pursued to understand the implications of the relatively low recapture rate reported in this study. While it is possible that this population can endure what appears to be a high rate of road-based mortality, the number of brownsnakes caught at this site was lowest in 2013. The uncertainty lies in whether this pattern is best explained by the rate of road-based mortality out-pacing recruitment in the population; or, if unusually heavy precipitation in June 2013 (flooding is not typical that late into the activity season) flushed many of the brownsnakes out of the area.

The diversity and abundance of the snake community at FRSP was unexpected given the size (835.3 ha) and relative isolation of this parcel (bordered by the Embarrass

River to the west, and otherwise surrounded by row-crop agriculture). In spite of the familiarity that some members of the general public had with a few species that might be encountered in more urban settings (*e.g., Thamnophis*), nearly all FRSP visitors who inquired about this project with members of my lab group had no knowledge of the presence or natural history of brownsnakes, or most of the other snake species encountered at this site. Our outreach efforts – ranging from responding to questions from passers-by, to direct engagement, to radio and web-based programming – left mostly positive impressions with the park visitors. I suggest that all of the people we spoke with were impressed to learn of the number of snakes occurring within FRSP, and of the mortality rate that brownsnakes experience as they cross RLR. Not only do the species making up the snake community at FRSP represent an impressive biomass, they play integral roles in the nutrient cycles within that ecosystem.

SUMMARY & RECOMMENDATIONS

Although Midland Brownsnakes contributed more data than other snake species, completion of this project revealed that a relatively healthy community of 11 snake species occurs in the habitats associated with RLR at Fox Ridge State Park. In addition to the other forms of recreation taking place at FRSP (*e.g*., hunting, canoeing, picnicking, hiking, *etc*.), I hope that the public will embrace the opportunity to appreciate and learn more the non-game wildlife that occurs there. To facilitate this goal, I encourage the IDNR to consider one or more of the following options for managing RLR when developing a strategic plan for the future of FRSP.

- Temporary closure of RLR – this option would require the least amount of financial investment (gates used to block the road are already installed at two locations along the 2.7-km section of RLR) and has the potential to offer the greatest decrease in road-killed snakes. Following a model already used in southern Illinois (FR345 – or, "Snake Road" – within the Pine Hills-Larue Swamp Ecological Research Area), vehicle access to the northern-most section of RLR could be restricted during a specified period each year. Given the greater number of snakes migrating in the Autumn, a well-timed span of 10-14 days (as determined by decreases in temperature) might be all that is necessary to drastically reduce mortality rates. This option would require minor additions to the existing management of RLR (in that the FRSP staff would have to close and re-open the gate), but would have a relatively minimal impact on park visitors (<15 % of cars entering FRSP each year drive along this section of RLR).
- Temporary conduits placed on the road surface at areas having the highest occurrence of migrating snakes. Snakes (and other wildlife species) are generally reluctant to enter a culvert that does not have some natural light along its length; as such, an appropriate device might be a split-top cable protector or hose bridge that has a gridded top surface that admits some daylight into the channels used by the snakes (*e.g.*, www.checkersindustrial.com/products/cable-protectors/hose-bridges/standard-hose-bridge/). These devices are industrial-grade (load capacity ≥ 6350 kg/axle), and can be easily deployed across the width of the road at those locations having the highest number of snake crossings during the peak in migration. To take full advantage of their potential to facilitate safe snake transit, drift fences along the road

edge – positioned to guide snakes to the conduit – should also be installed during the peak in migratory movements. An added advantage of the temporary placement of these "speed-bump-like" features would be an expected decrease in the average vehicle speed along that section of RLR.

- Permanent construction of road-width furrows in areas having the highest occurrence of migrating snakes. Rumble strips, like those installed along the shoulders of highways, could provide adequate depth for most of the leaf-litter snake species to migrate across the road below grade (avoiding the car tires). Like the conduits described previously, rumble strips would offer the added advantage of an anticipated decrease in the average speed of the vehicles along the road. Similarly, temporary drift fences along the edge of the road should be erected to guide the snakes to those sections of the road having rumble strips. These structures would have a higher initial cost of installation, and potentially higher cost of maintenance (sediment or other debris would have to be cleared out of the furrows in order to make them effective for the snake migration). But because the rumble strips would be installed permanently on-site, they could serve as a means for snakes to safely cross the road throughout the activity season.
- Permanent culverts constructed under the road surface, in areas having the highest occurrence of migrating snakes. In order to divert run-off without becoming clogged, these structures would need to be of similar size to the five existing culverts passing under RLR (ranging from 50-120 cm in diameter). As mentioned previously, most species of non-game wildlife do not use such culverts unless there are sources of daylight illuminating the length of the tunnels. None of the snake species occurring at

FRSP was observed using the existing culverts for any reason other than fleeing from a potential predator. So, the possible benefits from this option (Langen *et al*. 2009; Patrick *et al*. 2010) are not likely to offset the cost of installation and maintenance.

- Permanent artificial hibernacula constructed on the west side of RLR such that, over successive years, snakes would adopt to using these structures in place of their current hibernacula in the upland habitats (thereby minimizing the need to cross the road altogether). While artificial hibernacula have demonstrated benefits to snakes in some circumstances (*e.g*., Shine & Bonnet 2009; Shoemaker *et al*. 2009), positioning such structures in the bottomland habitat where snakes spend the activity season might result in their being seasonally flooded during periods of heavy rain. Furthermore, these structures would have to be built above-grade (presenting an unnatural feature in that habitat) so as to keep the core of each hibernaculum above the water table of the flood plain when in use. While the initial investment would be high, there would be few anticipated costs of future maintenance of such structures.

Any one, or a combination, of these options might generate some negative feedback from park visitors; as such, I recommend that any implementation should not proceed without continued engagement with the public. Given that FRSP has a number of natural resources and recreational opportunities available to its visitors, I suggest that attempts to mitigate road-kill mortality rates of snakes should be proposed in the context of ensuring that future generations of park visitors will be able to experience the same opportunities as are currently available at that site. Furthermore, because FRSP exists in relative isolation from other large parcels of mesic hardwood forest, the public should be informed of the unique nature of the community interactions occurring on this site

(especially when compared to the modified habitats that are more common in the region). Continued involvement with visitors to FRSP will help ensure that they have some awareness of the interesting natural histories inherent to this community of snakes (*e.g.*, Willson & Dorcas 2004).

Acknowledgments – I thank C. Carter, A. Durso, I. Gross, C. Lennon, M. Thomas, M. Walters, and J. Zigler for their assistance with maintaining and monitoring the drift fence/pitfall trap arrays to collect the various herpetofauna. I am grateful to IDNR for partially offsetting the associated with this project, and to the Illinois Department of Transportation (Effingham Office) for the loan of a car-counter. I am also indebted to R. Janzen for advice, and to G. Lyons and C.M. Moomey for granting permission to conduct research on IDNR property.

Additional outcomes

During the period funded by this grant award, research on this system has been disseminated in the following venues:

Paper presentations:

Gross, IP, AM Durso, CP Lennon & SJ Mullin. 2012. Why did the Brownsnake cross the road? Understanding how snake populations are impacted by vehicle access within a state park. Midwest Partners in Amphibian & Reptile Conservation, Pioneer, OH.

Gross, IP, AM Durso, CP Lennon & SJ Mullin. 2012. Why did the Brownsnake cross the road? Understanding how snake populations are impacted by vehicle access within a state park. 7th World Congress of Herpetology, Vancouver, BC, CANADA.

Poster presentations:

Gross, IP, CP Lennon, MA Thomas, AM Durso & SJ Mullin. 2013. Patterns of snake (Colubridae: *Storeria*) movement and mortality during seasonal migrations between habitats. Joint Meetings of Ichthyologists & Herpetologists, Albuquerque, NM.

Thomas, MA & SJ Mullin. 2013. Measuring niche overlap in a community of invertebrate eating snakes. Joint Meetings of Ichthyologists & Herpetologists, Albuquerque, NM.

Graduate thesis:

Lennon, CP. 2013. Dietary ecology of an actively-foraging snake species: C*oluber constrictor foxii*. MS thesis, Eastern Illinois University.

Undergraduate honors thesis:

Gross, IP. 2013. Taking the road most travelled: Understanding patterns of snake (Colubridae; *Storeria*) movement and road mortality in a state park. BS honors thesis, Eastern Illinois University.

Radio and web-based programming:

"Nature" on BBC Radio4, airing 11 March 2014; <http://www.bbc.co.uk/programmes/b006sr7c>

http://www.eiu.edu/research.php?story=9

Furthermore, continued research efforts at this site have spawned projects that have received funding in the form of four awards from intramural sources (EIU), include three to student researchers.

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Table 1. Number of individuals representing each snake species observed along Ridge Lake Road, Fox Ridge State Park (Coles Co., IL), from 4 April 2011 to 5 November 2013. Values in parentheses are recapture rates within each sampling year (reported as % of marked individuals observed again within that year).

	Sampling Year		
Taxon	2011	2012	2013
Coluber constrictor foxii	23 (26.1%)	30 (0.03%)	18 (17.0%)
Diadophis punctatus	14 (0.00%)	8 (0.00%)	40 (0.00%)
Heterodon platirhinos	2 (0.00%)	3 (0.00%)	2 (0.00%)
Lampropeltis calligaster	6 (0.00%)	9 (0.00%)	9 (0.00%)
Lampropeltis triangulum	2 (0.00%)	3 (66.7%)	2 (100%)
Nerodia sipedon	2 (0.00%)	7 (0.00%)	1 (0.00%)
Opheodrys aestivus	4 (0.00%)	1 (0.00%)	7 (0.00%)
Pantherophis spiloides	0	4 (0.00%)	4 (0.00%)
Storeria dekayi wrightorum	697 (0.00%)	982 (0.004%)	422 (0.05%)
Storeria o. occipitomaculata	6 (0.00%)	7 (0.00%)	16 (0.00%)
Thamnophis s. sirtalis	9 (22.2%)	7 (0.00%)	20 (0.00%)

Table 2. Range of snout-vent lengths (SVL) and mortality rates based on road encounters for both sexes of each species of snake encountered along Ridge Lake Road (Fox Ridge State Park, Coles Co., IL) from 2011-2103. Sample sizes upon which mortality values are based are shown in parentheses.

	SVL (mm)		% mortality (*n*)	
Taxon	Minimum	Maximum	Males	Females
Coluber constrictor foxii	241	1102	11.4 (35)	9.1 (22)
Diadophis punctatus	99	356	3.9 (26)	2.9 (35)
Heterodon platirhinos	451	741	0.0 (2)	0.0 (5)
Lampropeltis calligaster	223	937	0.0 (10)	0.0 (11)
Lampropeltis triangulum	481	835	100.0 (1)	0.0 (3)
Nerodia sipedon	172	616	50.0 (4)	0.0 (2)
Opheodrys aestivus	130	540	66.7 (3)	0.0 (4)
Pantherophis spiloides	774	1316	0.0 (2)	0.0 (5)
Storeria dekayi wrightorum	81	460	55.7 (815)	46.6 (996)
Storeria o. occipitomaculata	74	214	22.2 (9)	23.1 (13)
Thamnophis s. sirtalis	157	669	5.9 (17)	0.0 (18)

Table 3. Amphibian and reptile species (excluding all snakes), and their relative abundance observed along Ridge Lake Road, Fox Ridge State Park (Coles Co., IL), from 4 April 2011 to 5 November 2013. Relative abundance during study period coded as follows: low = 1-2 sightings; moderate = 3-15 sightings; high = >15 sightings. [* = breeding choruses recorded during at least one activity season during study period.].

Taxon	Relative abundance
Amphibia – Caudata	
Ambystoma texanum	moderate
– Anura	
Acris crepitans	high*
Anaxyrus a. americanus	high*
Anaxyrus fowleri	high*
Hyla chrysoscelis (x *versicolor*)	moderate*
Lithobates catesbeianus	high*
Lithobates utricularius	high
Pseudacris maculata	moderate*
Reptilia – Testudines	
Chelydra serpentina	low
Chrysemys picta marginata	low
Terrapene carolina	moderate
Trachemys scripta elegans	low
– Squamata	
Plestiodon fasciatus	low
Plestiodon laticeps	moderate

Figure 1. A portion of the northern 2.7-km section of Ridge Lake Road in Fox Ridge State Park (Coles Co., IL). The northerly perspective illustrates the road-bed following the ecotone between the mesic upland forest habitat to the east (right side of image), where snakes typically seek hibernation sites in the winter; and the bottomland floodplain to the west (left side of image), where snakes spend most of their activity season.

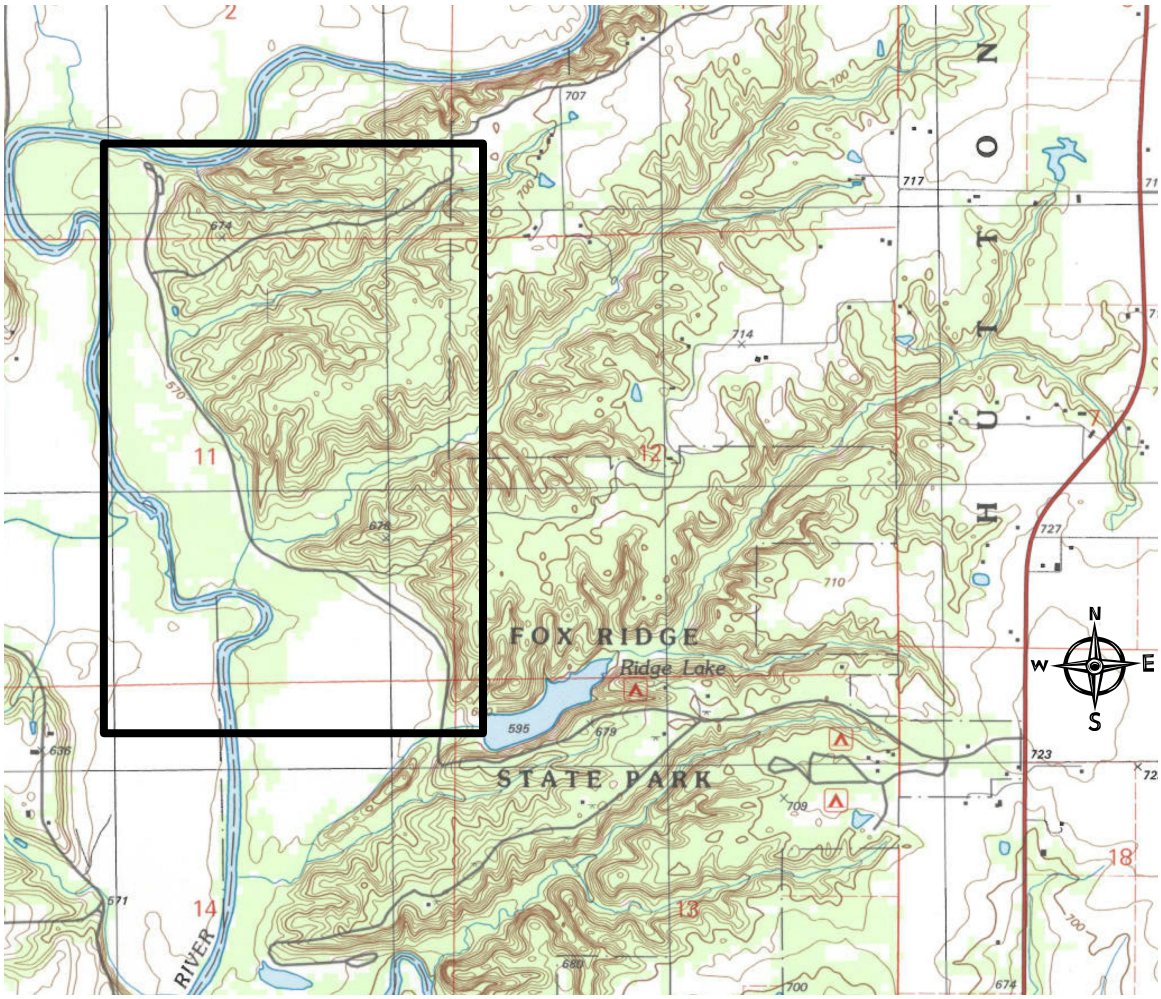

Figure 2. Topographic map of Fox Ridge State Park (Coles Co., IL). The rectangular box identifies the 2.7-km section of Ridge Lake Road running along the ecotone between bottomland floodplain habitat to the west, and upland mesic forests to the east.

Figure 3. Students from the Department of Biological Sciences at Eastern Illinois University installing portions of a drift fence-pitfall trap array along Ridge Lake Road (Fox Ridge State Park, Coles Co., IL).

Figure 4. An adult female of the focal species among the leaf-litter community of snakes at Fox Ridge State Park (Coles Co., IL), the Midland Brownsnake (*Storeria dekayi wrightorum*).

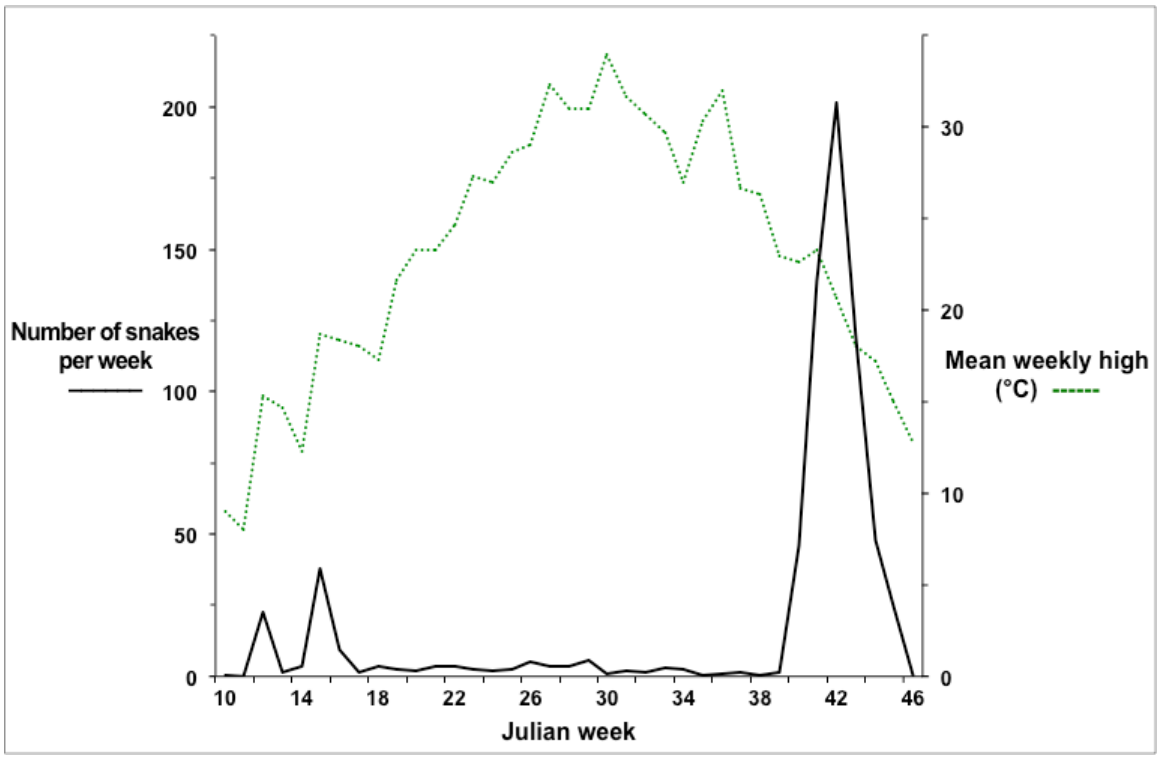

Figure 5. Number of Midland Brownsnakes (*Storeria dekayi wrightorum*) observed at Fox Ridge State Park (Coles Co., IL), and mean high temperature (°C), during each week of the activity season (reported as Julian week). Depicted values represent the mean response for each week calculated across the study period (2011-2013), and temperature values are based on high temperatures averaged over all days within the week.

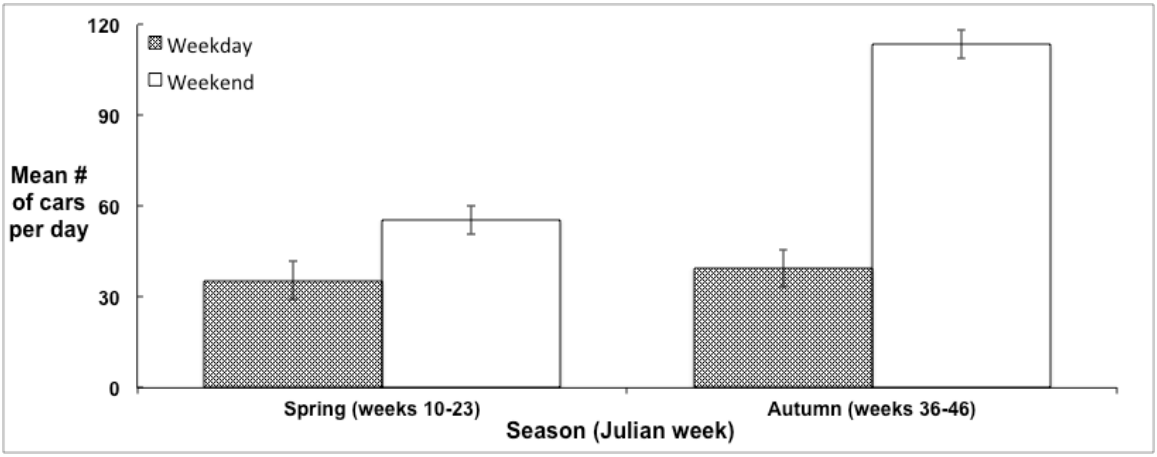

Figure 6. The average (±1 SE) number of cars passing along the northern section of Ridge Lake Road (Coles Co., IL) during each of two seasons in 2011-2012. Because the road dead-ends at the northern extent of the park, each car makes two transits along the road, resulting in twice as much apparent traffic volume.

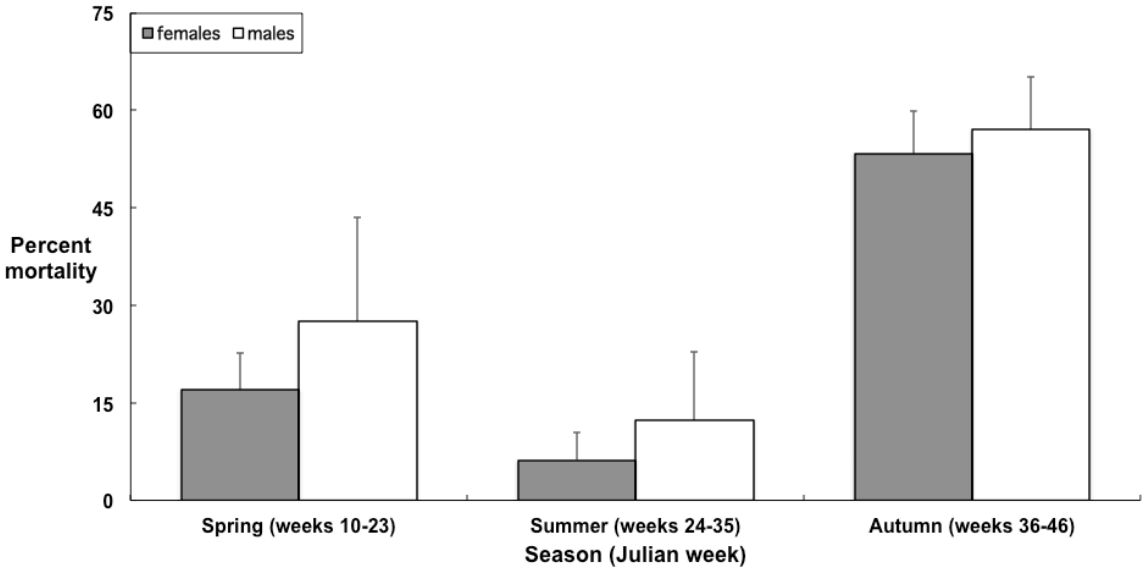

Figure 7. Percent mortality of each sex of Midland Brownsnake (*Storeria dekayi wrightorum*) as a function of season within the activity period at Fox Ridge State Park (Coles Co., IL). Each bar represents a mean (+1 SE) based on values calculated for seasons within each year, from 2011-2013.

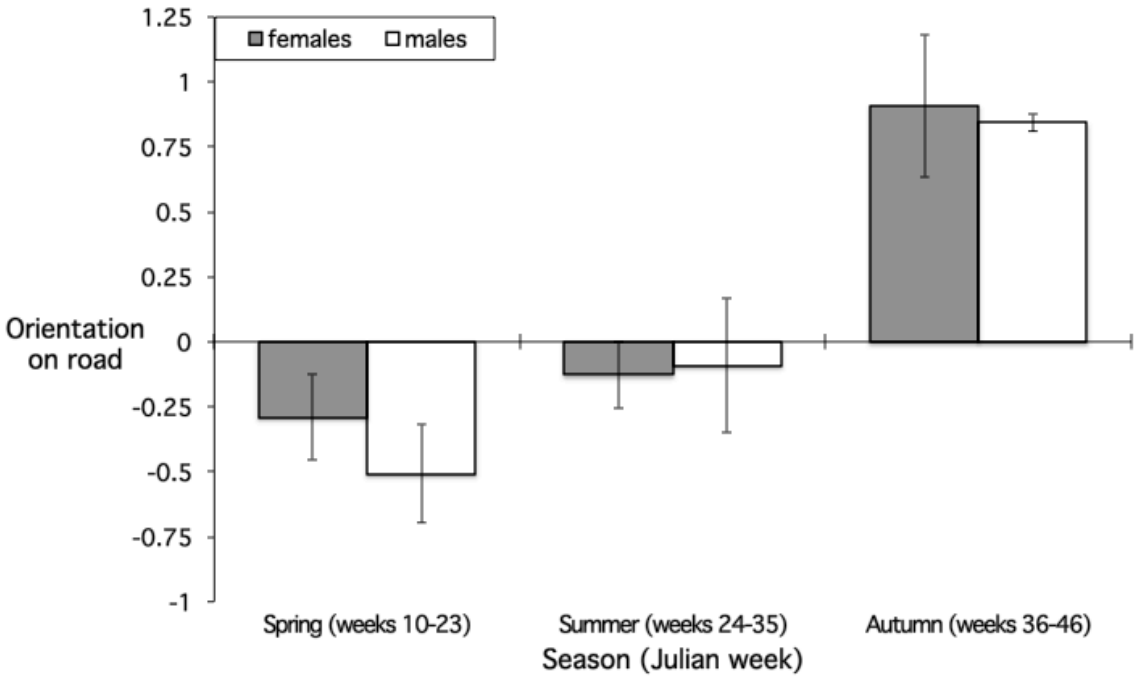

Figure 8. Direction of orientation of live Midland Brownsnakes (*Storeria dekayi wrightorum*) encountered along Ridge Lake Road (Fox Ridge State Park, Coles Co., IL) during each season within the activity period. Negative values represent movement downslope, towards the lowland habitat, whereas positive values represent movement upslope, towards the hibernation sites. Values for each season represent means (±1 SE) based on coding the orientation of each snake observed within that season (*i.e.*, a mean response of 1.0 would indicate that all snakes observed within that season were moving upslope).

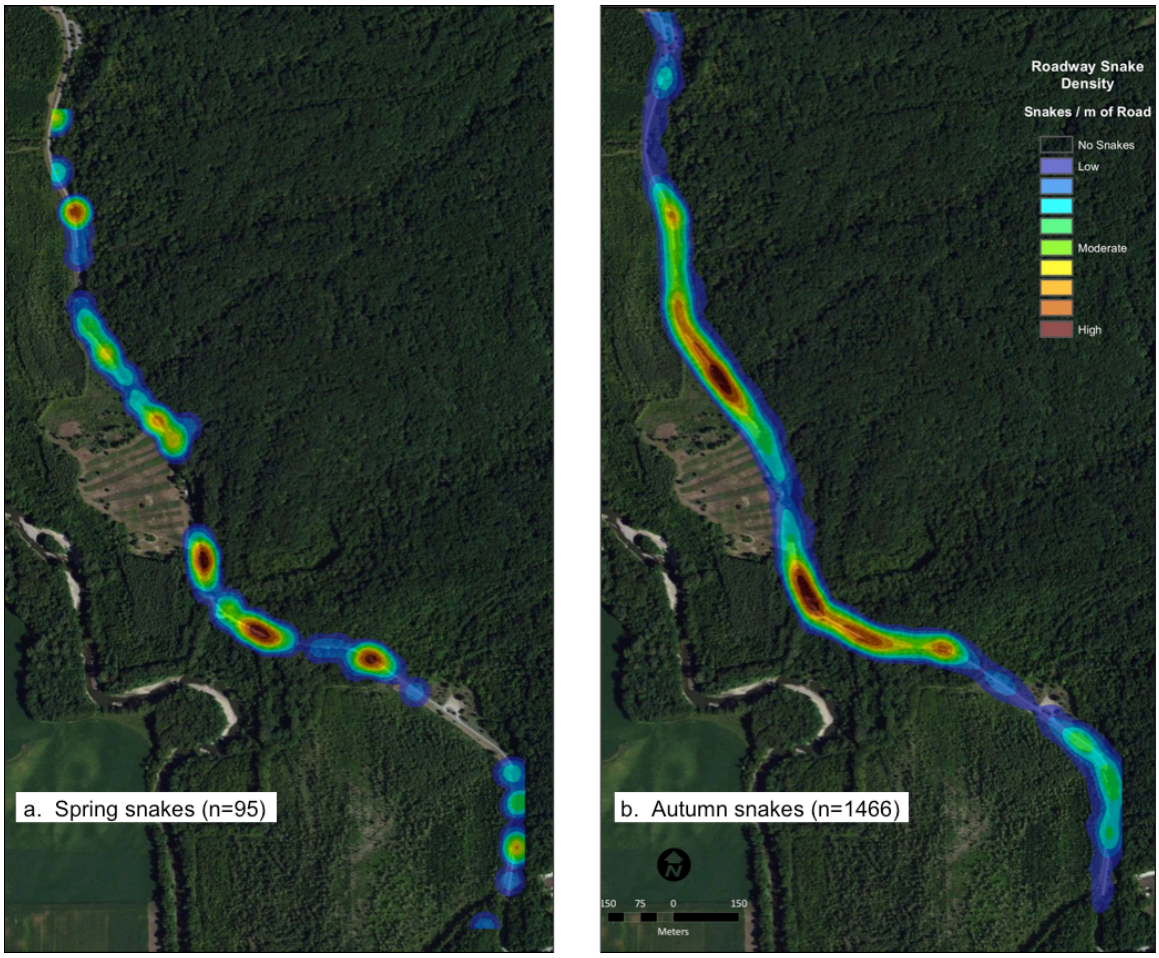

Figure 9. Aerial view of the northern 2.7-km section of Ridge Lake Road in Fox Ridge State Park (Coles Co., IL). Color shading corresponds to the relative number of live Midland Brownsnakes (*Storeria dekayi wrightorum*) encountered along the road from October 2010 to November 2012. Intensity of color is based on a kernel density function within ArcGIS; (a) Spring; and, (b) Autumn.

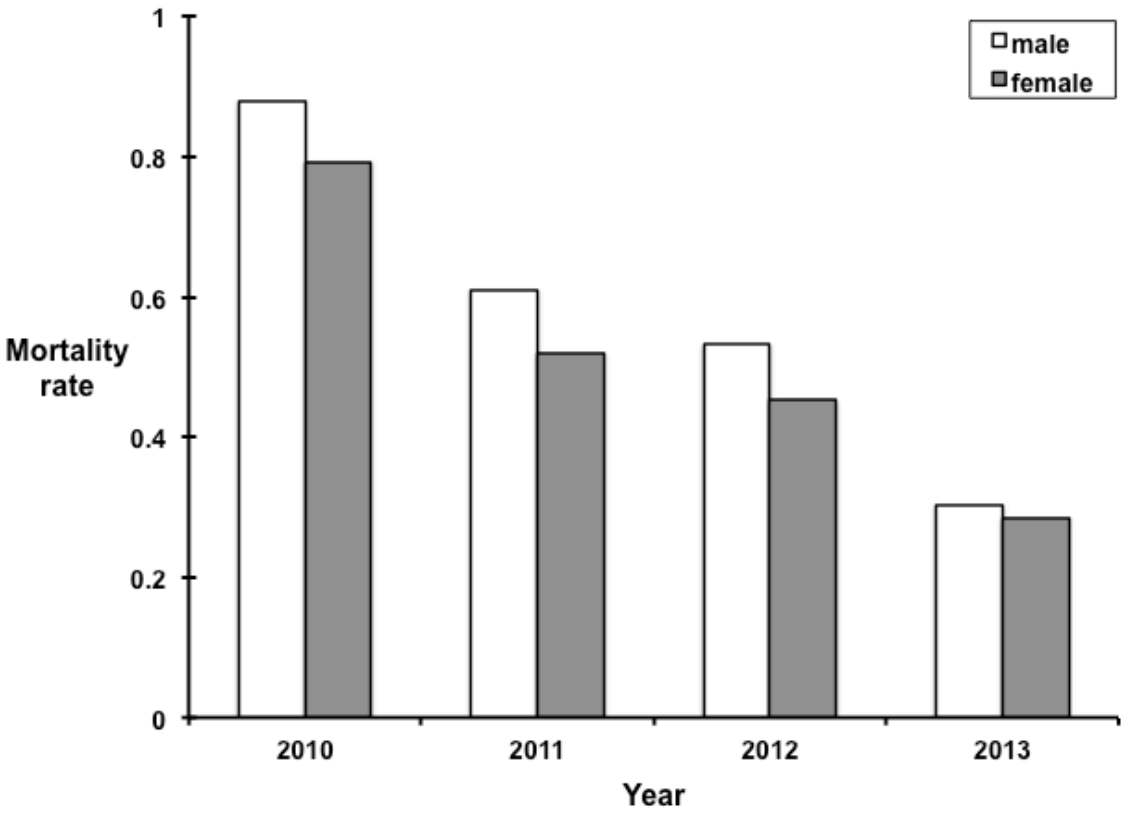

Figure 10. Mortality rate (proportion) for each gender of Midland Brownsnake (*Storeria dekayi wrightorum*) as a function of time as observed along Ridge Lake Road (Fox Ridge State Park, Coles Co., IL). Values shown for 2010 reflect snakes sampled in the Autumn season only (October-November), whereas values for other years represent mortality rates for brownsnakes over the entire activity period within each year.

Project Expenditures – Grant #12-013W

Category/Item	Cost ($)
Student Research Assistance	
Undergraduate Assistant in Summer 2013 (Murphy Walters)	433°°
Commodities (purchased throughout study period)	
250 18" wooden stakes (Moultrie-County Beacon, 401 W. Water St., Sullivan, IL 61951)	60°°
3 pkgs of tin capsules for tissue sample storage (Costech Analytical Technologies, 26074 Ave. Hall, Valencia, CA 91355)	87°°
2 eXplorist 310 handheld GPS units (Magellan GPS, 471 El Camino Real, Santa Clara, CA 95050)	178°°
hardware supplies for constructing fence-pitfall arrays (shovels, staple guns, staples, cable ties, work gloves, hammers, tin flashing, trowels; Rural King Supply, 1475 18th St., Charleston, IL 61920)	250°°
liquid nitrogen to process tissue samples (Gano Welding Supply, 20 Railroad Ave., Charleston, IL 61920)	642°°
Travel (incurred throughout study period)	
20 round trips from EIU campus to study site (20 miles ea. at 0.55¢ per mile)	283°°
TOTAL	$ 1933°°