2016

Assessment of the Efficacy of the Hose-Bridge as a Road-Crossing Structure for Dekay's Brownsnake (Storeria dekayi)

Sarah Elizabeth Manka
Eastern Illinois University

The Graduate School

EASTERN ILLINOIS UNIVERSITY

Thesis Maintenance and Reproduction Certificate

FOR: Graduate Candidates Completing Theses in Partial Fulfillment of the Degree
Graduate Faculty Advisors Directing the Theses

RE: Preservation, Reproduction, and Distribution of Thesis Research

---

Preserving, reproducing, and distributing thesis research is an important part of Booth Library's responsibility to provide access to scholarship. In order to further this goal, Booth Library makes all graduate theses completed as part of a degree program at Eastern Illinois University available for personal study, research, and other not-for-profit educational purposes. Under 17 U.S.C. § 108, the library may reproduce and distribute a copy without infringing on copyright; however, professional courtesy dictates that permission be requested from the author before doing so.

Your signatures affirm the following:

- The graduate candidate is the author of this thesis.
- The graduate candidate retains the copyright and intellectual property rights associated with the original research, creative activity, and intellectual or artistic content of the thesis.
- The graduate candidate certifies her/his compliance with federal copyright law (Title 17 of the U. S. Code) and her/his right to authorize reproduction and distribution of all copyrighted materials included in this thesis.
- The graduate candidate in consultation with the faculty advisor grants Booth Library the non-exclusive, perpetual right to make copies of the thesis freely and publicly available without restriction, by means of any current or successive technology, including by not limited to photocopying, microfilm, digitization, or internet.
- The graduate candidate acknowledges that by depositing her/his thesis with Booth Library, her/his work is available for viewing by the public and may be borrowed through the library's circulation and interlibrary loan departments, or accessed electronically.
- The graduate candidate waives the confidentiality provisions of the Family Educational Rights and Privacy Act (FERPA) (20 U. S. C. § 1232g; 34 CFR Part 99) with respect to the contents of the thesis and with respect to information concerning authorship of the thesis, including name and status as a student at Eastern Illinois University.

I have conferred with my graduate faculty advisor. My signature below indicates that I have read and agree with the above statements, and hereby give my permission to allow Booth Library to reproduce and distribute my thesis. My adviser's signature indicates concurrence to reproduce and distribute the thesis.

Graduate Candidate Signature

Sarah Monka
Printed Name

M.S. Biological Sciences
Graduate Degree Program

Faculty Adviser Signature

Gary Bulla
Printed Name

5/25/16
Date

Please submit in duplicate.

ASSESSMENT OF THE EFFICACY OF THE HOSE-BRIDGE AS A ROAD-CROSSING

STRUCTURE FOR DEKAY'S BROWNSNAKE (Storeria dekayi)

(TITLE)

BY

Sarah Elizabeth Manka

THESIS

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF

MASTER OF SCIENCE in BIOLOGICAL SCIENCES

IN THE GRADUATE SCHOOL, EASTERN ILLINOIS UNIVERSITY
CHARLESTON, ILLINOIS

2016

YEAR

I HEREBY RECOMMEND THAT THIS THESIS BE ACCEPTED AS FULFILLING
THIS PART OF THE GRADUATE DEGREE CITED ABOVE

THESIS COMMITTEE CHAIR	23 May 16 DATE	DEPARTMENT/SCHOOL CHAIR OR CHAIR'S DESIGNEE	5/24/16 DATE
THESIS COMMITTEE MEMBER	5-23-2016 DATE	THESIS COMMITTEE MEMBER	5/23/2016 DATE
THESIS COMMITTEE MEMBER	DATE	THESIS COMMITTEE MEMBER	DATE

ABSTRACT

Various structures have been integrated into roadways to ensure the road does not impede wildlife movements between adjacent habitats. Where traffic volume is low, the costs of installing and maintaining such structures is typically prohibitive. I tested the efficacy of a hose-bridge deployed temporarily on a State Park road in Illinois that allowed the passage of cars over it and small wildlife species to cross through it. I predicted that, during the 4.5-week period of peak migratory movement, road-based mortality of Dekay's Brownsnakes (*Storeria dekayi*) would be less at the site having the hose-bridge, when compared to a similar section of road without a hose-bridge (control). I erected drift fences at both sites to guide snakes to each section of road and collected snakes that successfully crossed the road with an array of cover objects and pitfall and funnel traps. The speed limit on the road varied from 32–48 kph, but cars passing over the hose-bridge slowed to ≤8 kph. Snake mortality at the hose-bridge site was reduced compared to the control site. Mortality at both sites was less than in previous years, which might be attributable to reduced vehicle speed or increased motorist awareness of migrating wildlife. I conclude that the hose-bridge and accompanying signage efficiently decreased the road mortality of *Storeria dekayi* during their fall 2014 and 2015 migrations.

DEDICATION

This thesis is dedicated to my grandparents: Lois and Tom Manka, Elizabeth Ericson, Richard Titus, and Dale Ericson. Thank you for fanning the flame of my passion for the outdoors and education. You have always shown me how to respect the environment. You have taught me perseverance and responsibility. I will always strive to teach others with the same fervor with which you taught me. Thank you for everything.

ACKNOWLEDGMENTS

This thesis would not have been completed without the support, advice, and hard work of a number of people. I would like to thank the following persons for their contributions to this research. First and foremost, I would like to extend my gratitude to my committee members, Drs. Scott Meiners and Ann Fritz, as well as my advisor Dr. Stephen Mullin. Thank you Dr. Meiners for giving me guidance through continual statistics questions and logistic difficulties. I am also grateful for the invitation to participate in his lab group when Dr. Mullin transitioned to Texas. Thank you Dr. Fritz for the words of support, professional guidance, and professional development opportunities. I am also grateful to my advisor Dr. Stephen Mullin. Throughout various challenges, he has shown me that perseverance, flexibility, and intuition can overcome the hurdles that can come with scientific research. I am undoubtedly a better writer thanks to his editorial skills. He has imparted upon me an immeasurable amount of knowledge not only about herpetology, but also about teaching and professional development.

Other faculty and staff whom I would like to thank include Drs. Ruth Chesnut, Barb Carlsward, Gary Bulla, and Britto Nathan; Derrick Douros, Sandra Baumgartner, and Marschelle McCoy. All of these people have guided me through research efforts, thesis notes, teaching, lab management, and piles of important paperwork. I would like to extend my gratitude to past and present members of the herpetology lab group including Cynthia Carter, Alanna Cross, Glen Curry, Andrew Durso, Kylee Gochanour, Iwo Gross, Lindsey Johnson, Danielle Kappel-Sparr, Amelia Missavage, Jena Nierman, Calista Olmstead, Maggie Thomas, Meagan Thomas, and Joseph Zigler. In particular, I would like to thank Joseph Zigler, Jena Nierman, and Kylee Gochanour for dedicating many hours of their time assisting with road monitoring, snake processing, and drift fence construction.

The Illinois Department of Natural Resources employees at Fox Ridge State Park were instrumental in the continuation of snake research at the park as well as the construction of the hose-bridge array, especially when modifications were needed. Funding was graciously awarded to me through teaching and research assistantships from Eastern Illinois University (EIU), a grant from the Illinois Department of Natural Resources, a Student Travel Award from the Society for the Study of Amphibians and Reptiles, a Council on Faculty Research award, and Williams Travel Grant from EIU. Finally, I would like to thank my loving fiancé Alex Worthington, my parents, Laura and Robert Manka, and the remainder of my family for their consistent support, understanding, and for putting everything into perspective when life felt overwhelming.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Introduction

Conservation projects for wildlife have traditionally been focused around charismatic and game species (Holbrook 1974, Landres et al. 1988, Noss 1990). Currently, endangered and game species projects represent a large portion of all conservation projects being overseen by the United States Fish and Wildlife Service (USFWS 2016). Whereas such animals attract attention from the general public, these species are not the only ecologically important organisms in their ecosystems. Invertebrates and small vertebrate species often serve as prey for larger charismatic species and provide multiple ecological services for the system (Gibbons et al. 2000, Losey and Vaughan 2006, Christoffel and Lepczyk 2012).

Conservation projects for game or endangered species include direct animal management as well as habitat manipulations. Direct management strategies for game animals include hunting, relocation, and reintroduction. These techniques have the largest impacts on the focal species, with potential cascading effects on other species within the community (Beazley and Cardinal 2004). In contrast, habitat manipulation for game wildlife can have more widespread impacts on the entire community (Finch and Ruggiero 1993). Although these impacts might be beneficial for some non-game species, most studies only collect data on the effects of the management techniques on the focal organisms. Therefore, specific conservation techniques designed for non-game species are equally important to those developed for game species.

Roads and Wildlife

Habitat alteration is a major cause of population declines in wildlife species (Blaustein et al. 1994). Human developments and the roadways that connect them are an increasingly problematic source of habitat loss and fragmentation. Roadways have direct and indirect negative impacts on wildlife populations. The direct impacts that roads have on animals are easily seen by the public in the form of injury and death from vehicles. However, roads pose many indirect threats to the well-being of wildlife populations. Indirect negative impacts include habitat fragmentation, habitat degradation, and disruption of natural movements (Forman and Alexander 1998, Riitters and Wickham 2003, Crooks and Sanjayan 2006).

As roads are planned, the route is chosen based on the most efficient path to connect the principal destinations. Habitats and the wildlife that occupy them have historically been an afterthought, if even considered, in the planning process (Trombulak and Frissell 2000). Roads serve as major barriers to population connectivity on account of road avoidance by wildlife. Population fragmentation leads to loss of genetic heterozygosity, inbreeding depression, and the possible decrease in a population's overall viability through an extinction vortex (Lacy 1987, Caughley 1994, Findlay and Houlahan 1997). Compared to game species, less concern is given to the habitats of non-game taxa. This bias in consideration can result in unintentional destruction or fragmentation of resources needed to support non-game species. Fragmentation of a habitat decreases usable land area as well as increasing edge exposure. Shrinking land area limits resources available to all of the organisms unable to compensate for the presence of roads. If such physical barriers restrict necessary resources outside of that habitat (e.g., shelter, water, etc.), then it is likely that populations will not survive in that fragment.

Proximity to roads causes degradation to the habitats present in that area (Forman and Deblinger 2000). Increased edge exposure from roads can disrupt normal functions of wildlife. Roads and associated human activities can bring erosion, exotic species, and noise and light pollution to habitats that would otherwise be suitable for area-sensitive wildlife species (Forman 2000, Barber et al. 2010, 2011). Breeding songbirds have lower reproductive success with louder traffic noise when compared to areas with lower traffic noise and further away from roads (Reijnen and Foppen 2006). The birds compete with traffic noise to be heard by potential mates, yet the population does not have connectivity problems associated with the road. In other animals, such as bats, increased road noise can have effects on navigation and hunting success (Siemers and Schaub 2010). Similarly, wildlife populations close to roadways in National Parks are smaller than populations geographically buffered from roads, with noise pollution and road mortality being major contributing factors to the losses (Barber et al. 2011).

Roads and other human developments can transect wildlife migration routes. While some animals can modify their migration patterns, the routes of other species are less likely to be as flexible. Some situations require organisms to cross dangerous barriers, including roads, to complete their migrations (Marchand and Litvaitis 2004, Aresco 2005). This often results in high mortality rates in short temporal windows. During migrations, wildlife populations are transitioning towards necessary checkpoints in their life cycles. If individuals are unable to reach these checkpoints in a timely manner, there could be reverberating effects on the population (Steen and Gibbs 2004, Gibbs and Steen 2005). Roadways are harsh environments for organisms undergoing migrations. Migrating amphibian populations are susceptible to desiccation while crossing roads because of their highly permeable skin. A displacement study found that five of seven amphibian species examined were limited by road noise and road presence to pond systems on the same side of a road (Eigenbrod et al. 2009). No successful road crossings were reported for the five species.

Road-crossing Structures for Wildlife

A variety of road-crossing structures are already in place, or being developed, for use in mitigating the effects that roads have on wildlife (Glista et al. 2009). Each installation has costs and benefits, as well as specifications for the target organism and road. Structures have often been made from existing materials or designs that were originally designed for other purposes. Most wildlife road-crossing arrays are currently being built as permanent structures; however, some are temporary (Aresco 2005). Although many studies of road-crossing structures focus on a specific taxon, some devices allow multiple taxa to safely pass (e.g., Glista et al. 2009, Sparks and Gates 2012).

Permanent road-crossing structures can involve modifications of structures already used to make roadways permeable to humans and abiotic forces. Structures such as culverts, overpasses, and underpasses, are commonly employed for wildlife road-crossing (Glista et al. 2009, Sparks and Gates 2012, Rhodes et al. 2014, Baxter-Gilbert et al. 2015). Culverts were originally designed to allow water to flow under the road to avoid washouts. Previous studies have found that reptile and amphibian corridors often utilize wetland habitats, making culverts potentially promising for these animals (Glista et al. 2007, Langen et al. 2009). Underpasses and overpasses were initially engineered to get vehicles and pedestrians to the other side of the road. However, biologists and transportation officials are now building specific under- and overpasses for wildlife (Corlatti et al. 2009).

Road-crossing structures on high-traffic roads (>4000 vehicles per day [Shepard et al. 2008]) must be suitable to the requirements of sustaining high-volume traffic flow. In these cases, crossing structures are often large, permanent installations. A benefit of these types of crossings is that the large size allows a wide variety of species to utilize the passage. Additionally, the permanence guards against having to close the road multiple times for installation or repairs. Conversely, there are large installation costs, including monetary and convenience costs. There is also a risk that these large investments may not perform as expected. For example, wildlife migration patterns could change such that the crossing location is no longer relevant. It is also possible that the construction design may inhibit or discourage certain animals from using it. A large permanent construction was built to mitigate Florida wildlife crossing two major 4-lane divided highways near the Paynes Prairie State Preserve (Dodd et al. 2004). The structure was successful in decreasing road mortality and increasing culvert use. It was difficult to detect statistical significance in survival rates, however, because of variation between years in construction and environmental stochasticity.

Large animals are not the only casualties of road crossing mortality. Some roads present barriers to the movement routes of small animals (Gibbons et al. 2000, Steen and Gibbs 2004, Aresco 2005, Eigenbrod et al. 2009). If the road supports medium- to high-volume traffic (1000–4000 vehicles per day), it might still be beneficial to build permanent road-crossing structures for these small animals. At this size, expense is less of an issue than with large crossing structures. If migration patterns or human needs change, however, the permanence of structure is unable to adapt to those needs without incurring increased cost or inconvenience.

An alternative to installing a crossing structure would be to completely close the road permanently or during times of high mortality, whichever is appropriate for the system. Currently, the U.S. Forest Service closes one of their access roads in the Shawnee National Forest to protect migrating snakes (U.S. Forest Service 2016). The road is a 4-km long dirt road with low-volume traffic. It parallels an ecotone between low wetlands and limestone bluffs. The area snakes migrate from the lowlands to the west- and south-facing bluff overwintering sites. During fall and spring migrations, the road is closed to vehicles and foot traffic is restricted. This area is home to 26 species of snakes, 6 lizards, 13 turtles, dozens of amphibians, and 5 additional protected vertebrates (Pallis 2016, USFWS 2016). With such a diverse community, the benefits of temporarily closing the road outweigh the costs. Similar thoroughfares with low traffic and high diversity of road-crossing animals could also be closed temporarily or permanently.

Critical migratory habitats might be intersected by medium- to low-volume roads (<1000 vehicles per day), resulting in episodically high road mortality during migration that is low throughout the rest of the year. While these are key windows of activity, human access might be deemed important enough for full closure of the road to be inappropriate. Small, temporary road-crossing structures are a promising solution for such road and habitat combination, as they offer greater flexibility, both spatially and temporally, than their permanent counterparts. Such structures are typically appropriate for small animals, yet are not species specific.

Herpetofauna and Roads

Thermoregulation requirements and movement patterns increase the susceptibility of herpetofauna (amphibians and reptiles) to road mortality (Jochimsen et al. 2004, Barthelmess and Brooks 2010, Garrah et al. 2015). The behavioral ecology of reptiles and amphibians can inform managers in constructing road crossings for these animals (Woltz et al. 2008). The surfaces of roadways absorb solar radiation that, after the sun sets, is slowly released as heat that ectotherms use to regulate their body temperatures (Mccardle and Fontenot 2016). A study on Aesculapian Snakes (*Zamenis longissimus*) showed that mature individuals use road embankments to thermoregulate, while juveniles often thermoregulate and cross on the drivable road surface (Kovar et al. 2014). The adult Aesculapian Snakes use pre-existing drainage culverts to cross the road.

Herpetofauna exhibit reproductive and activity characteristics that predispose them to the negative impacts of roads. Road noise interferes with anuran communication and consequently, reproduction (Eigenbrod et al. 2009). With slow reproductive rates, road mortality can often outpace recruitment to the population from reproduction (Saint Girons 1992). Limited home ranges and migration routes could be further limited or cut off by human development and roadways. For all of these reasons, it is important to study the impacts of roads on herpetofauna as well as possible solutions to negative impacts.

Dekay's Brownsnakes at Fox Ridge State Park

Fox Ridge State Park (FRSP), Coles Co., Illinois, provides recreation to many residents of the surrounding central Illinois area. Park officials actively manage habitats for game fish, whitetail deer, and grassland plant species. Biologists with the Illinois Department of Natural Resources also work in collaboration with Eastern Illinois University to manage and monitor bats, songbirds, and snakes. Research on the snake populations inhabiting FRSP has occurred since 2009. The focal species of some of the studies has been *Storeria dekayi* (Dekay's Brownsnakes; e.g. Gross 2013, Thomas 2014).

Storeria dekayi are small (≤ 40 cm total length) leaf-litter snakes. The species occurs from southern Quebec to Honduras, and from the eastern Dakotas to the Atlantic coast. Their diet mainly consists of slugs and earthworms (Thomas 2014). During the activity season, *S. dekayi* are commonly found in low-lying marsh and grassland habitats, particularly those associated with forest edges. *Storeria dekayi* are often found underneath woody debris during the summer activity season (Hecnar and Hecnar 2011).

Migration habits of *Storeria dekayi* include movements to activity sites in the Spring and to hibernacula in the Autumn. During cold months, the snakes generally hibernate inside of fissures in the soil that occur along sloped terrain (Carpenter 1953). When temperatures warm, *S. dekayi* migrate from the hibernaculum towards their activity sites. *Storeria dekayi* spend the Summer in the grassland and forested-marsh lowlands. During this time, they breed, feed, and grow until Autumn, when snakes begin to migrate towards their hibernacula. This activity reaches its peak at FRSP when daily high temperatures drop below 20 °C (Gross 2013). The pattern of snake movement is spatially and temporally focused. Human activity within FRSP increases in Autumn as hunting, Autumn color observation, and other recreational activities become more popular. The overlap of high activity seasons for both *S. dekayi* and humans causes a dramatic increase in snake mortality rates along the road (Figure 1).

Objectives

The purpose of my research was to assess the efficacy of a hose-bridge as a temporary road crossing structure for snakes. My null hypotheses were that (1) *S. dekayi* road mortality would be similar with or without the implementation of this temporary crossing structure and (2) *S. dekayi* road mortality would be similar at the temporary crossing structure in pre-treatment years and during the experimental period. An increase in road mortality at the hose-bridge or control site would indicate that the structure and associated barrier fencing creates a sink that is ineffective at getting snakes across the road alive. A decrease in road mortality rate would indicate that snakes are effectively guided by drift fences to utilize the hose-bridge as a means to cross the road.

Methods

Study Site

Fox Ridge State Park contains mixed hardwood forests, riparian areas, and meadows. The total area is 835 ha, and it is bordered by the Embarras River to the west. It lies along the southern border of the terminal moraine of the Wisconsin glaciation (Ebinger 1985). Part of the park is a restored agricultural field that is managed as a short-grass meadow through prescribed burns. The rest of FRSP consists of mixed hardwood forest mostly of oak (*Quercus*) and hickory (*Carya*) trees. Park managers currently attempt to control the continual invasion of bush honeysuckle in the open forest floor.

In addition to *S. dekayi*, previous snake studies at FRSP have included *Coluber constrictor*, *Diadophis punctatus*, *Opheodrys aestivus*, and *S. occipitomaculata* (Gross 2013, Lennon 2013, Thomas 2014). The studies have ranged from dietary ecology to population descriptions and conservation. Additional snake species that occur at FRSP include *Heterodon platirhinos*, *Lampropeltis calligaster*, *L. triangulum*, *Nerodia sipedon*, *Pantherophis spiloides*, and *Thamnophis sirtalis* (Gross 2013). The snakes occurring at FRSP have also been observed in conjunction with bird nest-site selection research (Helton 1997). These studies have confirmed that snakes play an important role in the ecosystem function of FRSP.

My study site was along Ridge Lake Road. This road extends northwest from the main park to the hunting areas and horse trails. The road is 2.6 km long, with a speed limit ranging from 24-48 kph. It parallels an ecotone between low short-grass meadow and raised sandstone hills covered in oak-hickory forests. The road is connected to the rest of the park, and therefore only accessible, on one end. The other end terminates in a river access trail, parking lot, and turnaround. Most vehicles utilize the road to access areas for hunting, foraging, horse riding, hiking, nature observations, kayaking, and biking.

Previous observations of *S. dekayi* spring migration at Fox Ridge State Park have found that this migration is not a focused pulse, spatially or temporally (Gross 2013). Additionally, the road transecting the habitat is only accessible by park personnel during the early spring. The Autumn migration in FRSP often occurs during times of high human recreation in the forms of leaf color-change observations and deer-hunting season.

Determination of High-mortality Crossing Sites

Using a Kernel-density function within Geographical Information Systems (GIS) software, Gross (2013) found that the migratory pattern for *S. dekayi* across Ridge Lake Road is clustered around two primary locations hotspots. During the Autumn migration period, these hotspots were associated with valleys or temporary streambeds. Gross (2013) suggested that the snakes were following the low-slope topography to the upland hibernacula habitat. One of the two snake movement clusters was located along the portion of Ridge Lake Road with the proximate association with riparian vegetation near the Embarras River. The second cluster was associated with a drainage rivulet to low-lying wetlands. In addition to being useful navigation routes to upland hibernacula sites, the brownsnakes would be able to forage on soft-bodied invertebrates in the damp soils prior to and throughout fall migrations.

Hose-bridge Deployment

The crossing structure utilized in this study was a hose-bridge manufactured by Turtle Plastics, Inc. (Loraine, Ohio; Figure 2). This hose bridge consists of PVC plastic components, each molded to withstand the force of a vehicle rolling over it (≤ 6350 kg per axle). There are tunnels on the underside of the structure with surface perforations allowing light to reach the road bed. The tunnels ranged from 4–13 cm in diameter. The middle components of the bridge had entrances/exits 16 cm in diameter interspersed by solid footers, which allowed for lateral movement by small wildlife underneath the pieces. In longitudinal-section, the bridge contained two middle components with a ramp on either side. The pieces interlocked together in shape, and were held in position using metal brackets (7 mm in diameter). The total bridge construction used 20 middle pieces and 20 ramp pieces, and measured 6 m long, 2.4 m wide, and 20 cm high. The bridge array was anchored in position by securing it to steel T-bars that were staked into the adjacent roadbed. All hose-bridge components were purchased for $9400°° from Turtle Plastics, Inc. (Loraine, Ohio).

A second control site along Ridge Lake Road was established in similar fashion to the hose-bridge site, excluding the actual structure. A 5-cm strip along the edges of the hose-bridge was painted yellow with high-visibility road paint. Corresponding lines were painted at the control site to match the pattern at the hose-bridge site. Large, high-visibility road hazard signs (reading "Bump") were placed 30 m before the hose-bridge in both directions of vehicle travel. High-visibility A-frame road barricades straddled the ends of the drift fencing where each one met with the road crossings (Figure 3).

Previous research on *S. dekayi* at FRSP has shown that the autumnal migration of that species peaks when the weekly means of daily temperature maxima fall below 20 °C (Gross 2013). I timed the installation of the hose-bridge based on my monitoring of weather patterns, and comparing densities and movement rates of brownsnakes across Ridge Lake Road to those prior records (Figure 1).

At the hose-bridge and control sites, I installed drift fencing to direct snakes to the two crossing locations (Figure 4). Each wing of fencing extended from the road at a ~30° angle relative to the edge of the road bed. The proximal section of each wing, made of plastic silt-cloth fencing, measured ~40 m. Distal sections of each wing extended an additional ~35 m and were constructed using aluminum mesh so as to minimize resistance to water movement during seasonal flooding. The resulting funnel was ~130 m wide at each site. Fences were affixed to wooden stakes at a 30 cm height; to ensure that snakes did not go under the barrier, the bottom 5-8 cm of material was buried. No *Storeria* were observed crawling over or under the fences. The purchase of all drift fencing materials associated with the areas immediately adjacent to both hose-bridge and control sites amounted to $562°°.

Drift fences made of silt cloth extended away from the edges of the hose-bridge on the hibernaculum side of crossings. These were angled slightly outward to reduce the probability of snakes encountering them and turning around. Each fence extended 5 m away from the edge of the hose-bridge. Between these two lengths of fence on this "uphill" side of the hose-bridge, I installed an array of 6 (~150 x 60 cm) covermats, 4 funnel traps, and 5 pitfall traps to capture all snakes that completed the crossing (Figure

5). Pitfall traps were comprised of 18.5-L buckets placed into a trench such that the bucket rims were flush with the ground surface.

Data Collection

I monitored Ridge Lake Road for snake activity starting on 28 and 27 March in 2014 and 2015, respectively. During the activity season (March-September), I surveyed the road daily to check for snakes, and recorded GPS location, mass (±0.1 g), and snout-vent length (SVL; ±1 mm) values of all snakes encountered. Subjects were encountered on the road, under covermats, or in pitfall traps. In addition to those associated with the hose-bridge and control sites, additional covermats and pitfall traps were located along four 100-m long drift fences built parallel to the road (Figure 6). Fences were numbered 4-7 (lowest number being the most southern fence), as established during a previous study that assessed snake migratory patterns (Gross 2013). Each drift fence included seven pitfall traps (one at each end and five evenly spaced, alternating sides of the fence) and four pairs of covermats (one on each side of the fence) evenly spaced throughout the fence. After recording measurements, I marked all subjects using a medical cauterizer (Winne et al. 2006), and released them at site of capture. I also recorded the occurrence of other snake species that I encountered in association with the drift fences. I followed collection and measurement protocols established by Gross (2013) and Lennon (2013) so that I could compare my data to those from 2011–2013. As such, I designated data from 2011–2013 as a temporal control for using the hose-bridge, or "pre-treatment period," to which I compared data gathered during the migrations in 2014–2015, or "experimental period."

The hose-bridge was deployed from 30 September to 7 November, 2014, and 30 September to 8 November, 2015. Daily monitoring of the road, both control and hose-bridge arrays, and all associated drift fences continued throughout the experimental period. All snakes were captured, measured, marked, and released in the direction they were traveling. Snakes found dead on road (DOR) were recorded for location and mortality data. If DOR snakes were not noticeably desiccated, morphology data were taken when possible. The hose-bridge, and the associated arrays of drift fencing at both the hose-bridge and control sites, were removed after a period of 7 days without *S. dekayi* being encountered at either location.

Statistical Analyses

I used logistic regression analysis to analyze the effectiveness of the hose-bridge at increasing the survival rate of *S. dekayi* crossing the road. Additional logistic regressions were used to analyze the effects of weather, location (hose-bridge vs. control), and period (pre-treatment vs. experimental) on the survival rate of *S. dekayi* on the roadway. All logistic regressions were done using RStudio v3.2.3. All locations reported reflect the number identifier for the fence that they were found closest to using GPS data point analysis. GPS location data for all snakes found at the hose-bridge and control sites during the pre-treatment period were reviewed and re-categorized from using fence identifiers to using identifiers that reflect presence at test locations for biologically meaningful comparisons.

In order to visualize fluctuations of *S. dekayi* throughout the year, I plotted the total number of brownsnakes encountered each month on the road, alive and dead. I also plotted the number and mean survival rate of *S. dekayi* encountered at each location (drift fence), including at the hose-bridge and control sites. To visualize the patterns of response to annual weather fluctuations, I plotted mean temperature and precipitation level against the mean monthly survival rate, as well as the number of *S. dekayi* encountered during each month.

Chi-squared analyses were used to describe associations between population movements and independent variables. These analyses were further used to determine the effects of variables identified as being significant from the logistic regressions. The expected assumption of the Chi-squared analysis on snake location was that all snakes would be evenly distributed along Ridge Lake Road. I set the significance level for all statistical comparisons at $\alpha < 0.05$; unless otherwise stated, all values are reported as means ± 1 SE.

Results

The hose-bridge was deployed for 39 days in 2014 and 40 days in 2015. Initial deployment of the hose-bridge in 2014 revealed that modifications were needed. The slope of each side of the bridge was such that undercarriage of several standard vehicles, especially low-clearance sedans, scraped against the top of the hose-bridge. To solve this problem, I constructed wooden ramps to extend the ramp distance, therefore lowering the grade. The ramps were installed during the 2015 field season. Each ramp was constructed from two offset sheets of plywood, supported by 5 x 10 cm boards on the low (road) and high (bridge) sides, with a 10 x 10 cm beam supporting the center section of each ramp (Figure 7). All additional materials needed to construct the ramps cost $\$667^{oo}$.

Hose-bridge and Control Site

Throughout the study years, a total of 201 *S. dekayi* were encountered at the hose-bridge location and 145 *S. dekayi* were encountered at the control location. During the spring and summer activity seasons, only 30 *S. dekayi* were found at the hose-bridge and control sites. The survival rate was 70.0 ± 0.5 % for these snakes.

When comparing the pre-treatment and experimental periods, there was an increase in the mean survivorship of snakes encountered at the hose-bridge site during the Autumn migration from 38.6 % to 40. 0% (Figure 8). I also observed an increase in the mean survival rate for snakes at the control site between pre-treatment and experimental periods, from 49.1% to 54.1%. The mean survival for brownsnakes at the hose-bridge and control sites was 43.6%. The mean survival rate for *S. dekayi* was similar between the hose-bridge and control sites ($df = 1$, $z = -1.31$, $p = 0.19$). The mean survival rate for

S. dekayi during the experimental period was similar compared to the rate at the same site in pre-treatment years (df = 2, z = 0.36, p = 0.72). Survival rates were also similar at the control site when comparing values from 2014 and 2015 to those in pre-treatment years (df = 1, z = 0.88, p = 0.38). The mean number of *S. dekayi* crossing the road at the hose-bridge location during migration decreased from 48 snakes in 2011–2013 to 12 snakes in 2014–2015. Similarly, the average road crossings during migration at the control site decreased from 43 snakes in 2011–2013 down to 18 snakes in 2014 and 2015.

Habitat Factors

A logistic regression revealed that there were differences of *S. dekayi* survival rates between all locations throughout 2011–2015 (Chi^2 = 12.05, p = 0.03, df = 5; Table 2). Within the model, there were differences between the components, Fence 4 and Fence 5, with Fence 4 having the lower survival rate (z = 2.42, p = 0.02; Figure 9). Location also affected the number of snakes encountered on the road throughout 2011–2015 (Chi^2 = 797.85, df = 10, $p < 0.001$). Survival rates were similar between locations during the period of time in which the hose-bridge was deployed ($p > 0.05$).

The mean survival of *S. dekayi* on Ridge Lake Road throughout the five sampling years was 46.0 %. Survival during the months outside of the migration season (March–September) averaged 83.4 % for the entire road. Mean snake survival during the fall migration was 34.7 % in the pre-treatment years. During the experimental period, *S. dekayi* had a mean survival rate of 33.5 % for the entire length of the road.

I recorded the weather statistics for each of the study years (Table 2). The 2014 field season had more precipitation than had occurred on average in the prior 5 years.

Additionally, the soil at the hose-bridge site had high concentrations of densely packed clay particles. The soil at the control site contained clay but had a high concentration of larger sand particles. These conditions resulted in the pitfall traps flooding during that season, with the hose-bridge traps holding more water for a longer time than the control site traps. Consequentially, no *Storeria dekayi* were encountered in either site's pitfall traps during the 2014 migration. Trenches for the 2015 pitfall traps were dug approximately 30 cm deeper than the height of the buckets. I placed cobbles and sand in the extra space to slow water accumulation. During the 2015 field season, seven *S. dekayi* were found in the pitfall traps. The other capture methods did not vary in effectiveness between years.

The mean amount of precipitation for each month of snake activity was compared with average survival rate of *S. dekayi*. There was an effect of monthly precipitation on survival rate ($df = 1$, $z = 6.95$, Chi^2 deviance = 49.68, $p < 0.001$; Figure 10). This regression predicted that for every 1 mm increase in precipitation, survival probability increases by 0.54%. A Chi-squared analysis revealed that the number of snakes encountered did not change with precipitation amount. Average temperature could not predict snake mortality rate or number of snakes encountered.

Discussion

The survival rate of brownsnakes tended to be lower at the hose-bridge site than it was at the control site, but the difference was not so large as to be statistically significant. Whereas the hose-bridge had lower survival than the control site, both sites experienced decreased trends in mortality rates as compared to fall migrations of pre-treatment years (Figure 7). Further years of study could reveal statistically- or biologically-significant trends in reduction of road mortality rates. The decreases in road mortality with only two years of repetition is promising for the use of the hose-bridge as a management technique for this and other wildlife systems.

Possible causes for higher road mortality at the hose-bridge when compared to the control site include stochasticity, detection issues, and determent from crossing the road at that location. Stochasticity could have caused the snake populations to have a migration with fewer individuals and/or that was less focused spatially. Additionally, weather patterns affect both snake behavior and trap efficiency. If snakes were underneath the hose-bridge while I was checking the trap arrays, a live snake would go undetected. This was not a problem with the control site, where numerous snakes were encountered actively basking on the asphalt. Mccardle and Fontenot (2016) reported that detection of snakes on a road surface changes with the temperature of that surface and air-surface temperature differences. Furthermore, patterns and performance efficiencies of snake movements change with temperature (Gerald and Claussen 2007, Garrah et al. 2015). I was unable to check traps and the road at the exact same time or solar position throughout the study. Therefore, surface temperatures of the road might have varied for snake movements and/or thermoregulation across the road during daily monitoring.

A lack of replication might have influenced the efficacy of the hose-bridge. Because I was able to complete only one replicate application of the hose-bridge, inter-annual variation and my need to modify the ramps of the hose-bridge in the middle of my study could have contributed to reduced road mortality at the hose-bridge when compared to the control site. While it is unlikely that the initial construction activity was a factor, the types of modifications done to the hose-bridge and control site might have influenced capture rates and snake movements throughout the road-crossing. For example, the pitfall traps were flooded during the first year. The second year, I engineered a solution that captured snakes. This modification, as well as others, could improve the effectiveness of the measurements over time.

It is possible that the hose-bridge itself was a deterrent for snakes attempting to cross the road. The hose-bridge is a foreign structure under which some snakes might have been unwilling to traverse. Without tracking the exact path taken, however, it is difficult to say what actions the *S. dekayi* took to complete their migration while still avoiding the structure. It is possible that the snakes followed the drift fencing away from the crossing until they were able to cross the open road. Traps were not deployed in the areas where this might have occurred, so I can only speculate about this outcome.

Habitat Factors

The difference in survival rates as a function of location throughout the year at all four fences and test sites indicates that there was an effect of location on survival probability, with Fence 4 and Fence 5 having the largest differences. Snakes encountered at Fence 5 had the highest survival rate, and snakes at Fence 4 had the lowest. Fence 4 preceded the hose-bridge as vehicles traveled from the FRSP entrance to the end of Ridge Lake Road, while Fence 5 was after the hose-bridge crossing. A small parking lot and hiking trail are located between Fence 4 and the hose-bridge. While the parking lot and hiking trail are not largely popular stopping points for recreation, the area is sometimes used as a turnaround for vehicles. This might contribute to a decreased the mortality rate for snakes at the more distant locations.

It is possible that Fence 5 has a higher survival rate because of the surrounding habitat. The road along Fence 5 is bordered by forest edge along an open meadow on one side and a stand of young trees on the other side. This open environment allows for good visibility of the road surface and any possible organisms on it. In contrast, the road along Fence 4 is heavily shaded and often covered in twigs. This results in low visibility and low recognition of twig-like organisms, like snakes. A previous study found that the road mortality of small vertebrates was higher in areas with vegetation close to the road when compared to road sections where the vegetation is farther away from the roadbed (Clevenger et al. 2003). Although this is a possibility, some of the other fences have similar open surroundings, so it is still unclear as to the specific reason why Fence 5 has higher survival rate than the other locations.

There was no effect of the location of *S. dekayi* on survival rate during the experimental period. This result indicates that all snakes crossing the road have an equal chance of surviving the ordeal. Additionally, this indicates that vehicles travelling the road while the crossing structures are deployed have an equal probability of hitting a snake no matter their location on the road at any one moment.

Irrespective of the presence of the hose-bridge, the amount of monthly precipitation was a predictor of mortality rate for brownsnakes along Ridge Lake Road. My results indicated that an increase of precipitation leads to a decrease in mortality. A study on snake road mortality in south Florida found similar correlations with precipitation (Bernadino and Dalrymple 1992). This pattern could be caused by a combination of two biological factors. The first possible explanation is that *S. dekayi* are ectotherms. Precipitation often leads to a drop in temperature and sun exposure. Through the process of evaporation, precipitation will lower the surface temperature of a roadway. The lower surface temperature is less beneficial for thermoregulation, meaning that the road surface would be a less attractive stopping point for snakes migrating across it.

The second possible explanation of decreased road mortality with increased precipitation is the decrease in human activity during rain events. Popular recreational activities in Fox Ridge State Park include hunting, picnics, foraging, observation of fall leaf color change, and hiking. While still enjoyed during rainy weather, outdoor activities such as these experience an increase in patronage when it is not raining. In a previous study at Fox Ridge State Park, it was found that *S. dekayi* experienced higher mortality rates during the same days (weekends) that high numbers of vehicles were utilizing the park (Gross 2013). An increase in vehicle presence leads to an increase in the probability of a snake crossing at any one moment to be struck and killed by a vehicle. Encounter rates of brownsnakes were not correlated with amount of monthly precipitation, suggesting that the relationship between snake mortality and precipitation levels was attributable to decreased human activity at FRSP during rain events (and not related to changes in the abundance of brownsnakes crossing the road).

Detection Problems

Because of the decrease in number of snakes encountered at the test sites between the pre-treatment years and experimental period, it is possible that not all of the live snakes that used the hose-bridge or control crossings were captured. Snakes could have escaped from, or avoided, some of the traps. While the cover mats are attractive to snakes (as opportunities for both shelter and thermoregulation), individuals could travel over or under the mats to continue migration. If the snakes continued on before I made my daily checks, there would be a lower count of live individuals. Utilization of different trap types may be an appropriate change for this and other studies where organism monitoring is of a high priority.

My results indicate that flooded pitfall traps might have decreased snake capture rates, resulting in a bias against capturing live snakes. The percolation drain built under the 2015 pitfall traps increased drainage. Snakes were captured in the pitfall traps during the 2015 experimental period, suggesting that the pitfall traps are an effective capture mechanism for snakes in road-crossing studies. Yet while planning and constructing pitfall traps, researchers must be cognizant of weaknesses such as soil type, climate, length of deployment, and target organisms. Proper drainage is important to the efficacy of pitfall traps as is the need to minimize risk of desiccation and predation of capture specimens (McDiarmid et al. 2012, Willson and Gibbons 2009).

Camera traps with time-lapse capabilities would be a useful addition to this study. Because snakes are ectothermic, they do not trigger contemporary infrared-triggered wildlife cameras. Therefore, time lapse settings would need to be used to capture images of snakes. It would be advantageous to view both sides of the road-crossing structure. Such a layout would allow researchers to see reactions to, estimate time within, and calculate organisms using the structure. Images captured may also reveal possible weaknesses in the construction. Additional cameras could be used to observe human user behaviors. Human behaviors, such as road use and trap interference, are a high concern in management techniques that are meant to decrease human-caused mortality. Camera traps were not used in this study because of my concern about the security of the equipment.

Suggestions for Hose-bridge Modifications

Prior to deployment in the second year of my study, the hose-bridge was modified to improve transit by low-clearance vehicles. The modifications increased the ramp length to lower the slope of ascent and descent. To achieve this same outcome, the height of the hose-bridge could have been lowered. Doing so, however, would have reduced the tunnel diameter used by the snakes, possibly affecting the study. Another possible modification to the hose-bridge design would be to increase the length of the plateau. This would ensure that only one axle of a standard vehicle would be ascending or descending at any one moment.

Comparisons with Other Road-crossing Structures

While further years using the hose-bridge could decrease road mortality of snakes in FRSP, it is possible that other road crossing structures could be similarly or more effective. The lower mortality rate at the control bridge suggests that increased signage during migration season may be a sufficient solution for this system. Increased signage alone would be less expensive, more easily modified, and possibly as effective as these initial hose-bridge deployments. It is possible, however, that repeat park visitors would become acclimated to the signage and disregard it. Conversely, repeated seasonal deployment of the hose-bridge will not be affected by driver acclimation.

The roadways within FRSP are responsible for minimal mortality rates of organisms other than the snakes (with *S. dekayi* experiencing the highest losses). Additionally, the number of *S. dekayi* found on the road at FRSP remained at a low level until the Autumn migration, with mortality rates reflecting the same pattern. Therefore, park and state officials do not find it cost-effective to install permanent road crossing structures for snakes alone. If road construction were needed in locations of high snake mortality, however, it could be practical to build some road modifications that would increase road permeability and driver awareness. Such structures could include modified rumble strips and culverts. If incorporated into road construction, small permanent road crossing structures would possibly decrease road mortality of *S. dekayi*. Similar structures were successful at decreasing road mortality of amphibians, reptiles, and small mammals (Clevenger et al. 2001, Glista et al. 2009, Taylor and Goldingay 2004).

Management and Conservation Implications

Other species of snakes migrate across roads and experience high mortality. Unlike *S. dekayi*, some of these snakes are rare and protected species. In the agricultural landscape of central Illinois, endangered Eastern Massasaugas *(Sistrurus catenatus*) experience high road mortality while migrating (Shepard et al. 2008). Furthermore, other snake species, as well as turtles at that site, suffered high mortality rates during specific months. Road mortality of turtles was highest in May and June; colubrid snakes experienced the highest mortality rates during April and October; and *S. catenatus* mortality rates were highest from mid-August to mid-September. Reptile road mortality was focused spatially on a portion of the roadway that was associated with a lake. *Sistrurus catenatus* mortality was not associated with climatic changes, leading Shepard et al. (2008) to conclude that the road mortality of this endangered species occurred during migration, mate-searching, or neonate dispersal. Death at any of these life-history stages could have major impacts on population size, genetics, and future. Having road mortality with spatial and temporal correlations, as well as being a species of special concern, the Eastern Massasauga population in Clinton County, Illinois, would make a good system for the use of the hose-bridge as a mitigation measure. Another population of *S. catenatus* in Missouri would also be a promising assemblage to test the hose-bridge (Seigel 1986). It is also possible that other populations of *S. catenatus* would be good candidates for this temporary, affordable, and easily modified system to be utilized.

The hose-bridge would be an appropriate solution to small aquatic turtle mortality on roads where they move from one pond to the next (Aresco 2005, Gibbs and Steen 2005). It is possible that the hose-bridge could be deployed when turtles are nesting in areas that are separated from the water by a roadway (Wood and Herlands 1997). The hose-bridge is an effective device to increase road permeability to organisms using it. Throughout the experiment only one snake was found dead underneath the hose-bridge in 2014. Evidence at the time suggested that the hose-bridge was nudged a short distance by the underside of a vehicle, and that the snake was consequently killed by the bridge shifting over it. All other snake mortality at the hose-bridge occurred on the road surface around the structure. This incident being the only occurrence of snake mortality during transit under the hose-bridge suggests that this device is a safe passageway for all organisms that are willing to enter the structure, move within its borders, and continue to the other side of the road.

The hose-bridge is an efficient option for a temporary road-crossing structure for many systems. It would be suitable for small organisms that require lighting throughout the crossing. The hose-bridge is simple to install or move if needed. It is therefore appropriate for wildlife with spatially or temporally dependent migrations. The range of tunnel sizes allows organisms of varying sizes to access the other side of the road. Combined with the maneuverability, low cost, low maintenance, ease of use, temporary nature, and ease of modifications; the hose-bridge is an effective mitigation structure for decreasing road mortality of *Storeria dekayi* at Fox Ridge State Park.

Effective wildlife road-crossing structures are engineered to address the specific needs of the target species and systems. Placement of road-crossing structures should incorporate road characteristics, areas of high road-mortality, and behavioral and physiological characteristics of the target animals (Forman and Alexander 1998, Clevenger et al. 2003, Woltz et al. 2008). Relatively few studies have assessed the proximal behaviors of wildlife in response to road-crossing structures (reviewed in Taylor and Goldingay 2010). Analyzing these responses would inform managers of the appropriate road-crossing structure to utilize in their system. For example, many wildlife species, such as green frogs (*Lithobates clamitans*), will not enter a road-crossing structure that is not permeated by light (Woltz et al. 2008). Road-crossing structure characteristics – permanence, light permeability, substrate composition, heat conductivity, dimensions, and placement – need to be tailored to the requirements of the many wildlife species within the system that are affected by the road. With these considerations, road-crossing structures have the potential to decrease the effects of roads on wildlife while still providing connectivity between, and within, human developments and natural resources.

Literature Cited

Aresco, M. J. Mitigation measures to reduce highway mortality of turtles and other herpetofauna at a north Florida lake. Journal of Wildlife Management 69, 549-560 (2005).

Barber, J. R., Burdett, C. L., Reed, S. E., Warner, K. A., Formichella, C., Crooks, K. R., Theobald, D. M., & Fristrup, K. M. Anthropogenic noise exposure in protected natural areas: Estimating the scale of ecological consequences. Landscape Ecology 26, 1281–1295 (2011).

Barber, J. R., Crooks, K. R. & Fristrup, K. M. The costs of chronic noise exposure for terrestrial organisms. Trends in Ecology and Evolution 25, 180–189 (2010).

Barthelmess, E. L. & Brooks, M. S. The influence of body-size and diet on road-kill trends in mammals. Biodiversity Conservation 19, 1611-1629 (2010).

Baxter-Gilbert, J. H., Riley, J. L., Lesbarreres, D., & Litzgus, J. D. Mitigating reptile road mortality: fence failures compromise ecopassage effectiveness. PLoS One 10, 1-15 (2015).

Beazley, K. & Cardinal, N. A systematic approach for selecting focal species for conservation in the forests of Nova Scotia and Maine. Environmental Conservation 31, 91-101 (2004).

Bernadino, F. S., Jr., & Dalrymple, G. H. Seasonal activity and road mortality of the snakes of the Pa-hay-okee wetlands of Everglades National Park, USA. Biological Conservation 62, 71-75 (1992).

Blaustein, A. R., Wake, D. B., & Sousa, W. P. Amphibian declines: judging stability, persistence, and susceptibility of populations to local and global extinctions. Conservation Biology 8, 60-71 (1994).

Carpenter, C. C. A study of hibernacula and hibernating associations of snakes and amphibians in Michigan. Ecology 34, 74-80 (1953).

Caughley, G. Directions in conservation biology. Journal of Animal Ecology 63, 215-244 (1994).

Christoffel, R. A. & Lepczyk, C. A. Representation of herpetofauna in wildlife research journals. Journal of Wildlife Management 76, 661–669 (2012).

Clevenger, A. P., Chruszcz, B., & Gunson, K. Drainage culverts as habitat linkages and factors affecting passage by mammals. Journal of Applied Ecology 38, 1340-1349 (2001).

Clevenger, A. P., Chruszcz, B., & Gunson, K. Spatial patterns and factors influencing small vertebrate fauna road-kill aggregations. Biological Conservation 109, 15-26 (2003).

Corlatti, L., Hacklander, K., & Frey-Roos, F. Ability of wildlife overpasses to provide connectivity and prevent genetic isolation. Conservation Biology 23, 548-556 (2009).

Crooks, K. R. & Sanjayan, M. Connectivity conservation: Maintaining connections for nature. Conservation Biology Series–Cambridge 14, 1-20 (2006).

Dodd, C. K. Jr., Barichivich, W. J. & Smith, L. L. Effectiveness of a barrier wall and culverts in reducing wildlife mortality on a heavily traveled highway in Florida. Biological Conservation 118, 619-631 (2004).

Ebinger, J. E. Forest types of Fox Ridge State Park, Coles County, Illinois. Transactions of the Illinois State Academy of Science 78, 183-190 (1985).

Eigenbrod, F., Hecnar, S. J., & Fahring, L. Quantifying the road-effect zone: threshold effects of a motorway on anuran populations in Ontario, Canada. Ecological Society 14, 23-26 (2009).

Finch, D. & Ruggiero, L. Wildlife habitats and biological diversity in the Rocky Mountains and northern Great Plains. Natural Areas Journal 13, 191–203 (1993).

Findlay, C. S., & Houlahan, J. Anthropogenic correlates of species richness in southeastern Ontario wetlands. Conservation Biology 11, 1000-1009 (1997).

Forman, R. T. T. Estimate of the area affected ecologically by the road system in the United States. Conservation Biology 14, 31-35 (2000).

Forman, R. T. T. & Alexander, L. E. Roads and their major ecological effects. Annual Review of Ecology and Systematics 29, 207-231 (1998).

Forman, R. T. T. & Deblinger, R. D. The ecological road-effect zone of a Massachusetts (U.S.A.) suburban highway. Conservation Biology 14, 36-46 (2000).

Garrah, E., Danby, R. K., Eberhardt, E., Cunnington, G. M. & Mitchell, S. Hot Spots and Hot Times: Wildlife Road Mortality in a Regional Conservation Corridor. Environmental Management 56, 874–889 (2015).

Gerald, G. W. & Claussen, D. L. Thermal dependencies of different modes of locomotion in neonate brown snakes, *Storeria dekayi*. Copeia 2007, 577-585 (2007).

Gibbons, J. W., Scott, D. E., Ryan, T. J., Buhlmann, K. A., Tuberville, T. D., Metts, B. S., Greene, J. L., Mills, T., Leiden, Y., Poppy, S., & Winne, C. T. The Global Decline of Reptiles, Déjà Vu Amphibians. Bioscience 50, 653–666 (2000).

Gibbs, J. P. & Steen, D. A. Trends in sex ratios of turtles in the United States: implications of road mortality. Conservation Biology 19, 552-556 (2005).

Glista, D. J., DeVault, T. L. & DeWoody, J. A. A review of mitigation measures for reducing wildlife mortality on roadways. Landscape and Urban Planning 91, 1–7 (2009).

Glista, D.J., DeVault, T. L., & DeWoody, J. A. Vertebrate road mortality predominantly impacts amphibians. Herpetological Conservation and Biology 3, 77-87 (2007).

Gross, I. P. Taking the road most travelled: understanding patterns of snake (Colubridae; *Storeria*) movement and road mortality in a state park. Eastern Illinois University Honors Thesis (2013).

Hecnar, S. J. & Hecnar, D. R. Microhabitat selection of woody debris by Dekay's brownsnake (*Storeria dekayi*) in a dune habitat in Ontario, Canada. Journal of Herpetology 45, 478-483 (2011).

Helton, M. N. Adaptive significance of re-nesting following nest abandonment in the Blue-Gray Gnatcatcher (*Polioptila caerulea*). Eastern Illinois University Master's Thesis (1997).

Holbrook, H. L. A system for wildlife habitat management on southern national forests. Wildlife Society Bulletin 2, 119-123 (1974).

Jochimsen, D. M., Peterson, C. R., Andrews, K. M., & Gibbons, J. W. A literature review of the effects of road on amphibians and reptiles and the measures used to minimize those effects. Idaho Fish and Game Department (2004).

Kovar, R., Brabec, M., Vita, R., & Bocek, R. Mortality rate and activity patterns of an Aesculapian snake (*Zamenis longissimus*) population divided by a busy road. Journal of Herpetology 48, 24-33 (2014).

Lacy, R. C. Loss of genetic diversity from managed populations: interacting effects of drift, mutation, immigration, selection, and population subdivision. Conservation Biology 1, 143-158 (1987).

Landres, P. B., Verner, J., & Thomas, T. J. W. Ecological uses of vertebrate indicator species: a critique. Conservation Biology 2, 316-328 (1988).

Langen, T. A., Ogden, K. M., & Schwarting, L. L. Predicting hot spots of herpetofauna road mortality along highway networks. Journal of Wildlife Management 73, 104-111 (2009).

Losey, J. E. & Vaughan, M. The economic value of ecological services provided by insects. BioScience 56, 311-323 (2006).

Marchand, M. N. & Litvaitis, J. A. Effects of habitat features and landscape composition on the population structure of a common aquatic turtle in a region undergoing rapid development. Conservation Biology 18, 758-767 (2004).

Mccardle, L. D. & Fontenot, C. L. The influence of thermal biology on road mortality risk in snakes. Journal of Thermal Biology 56, 39-49 (2016).

McDiarmid, R. W., Foster, M. S., Guyer, C., Gibbons, J. W., & Chernoff, N. Reptile Biodiversity: Standard Methods for Inventory and Monitoring. University of California Press (2012).

Noss, R. Indicators for monitoring biodiversity: a hierarchical approach. Conservation Biology 4, 355-364 (1990).

Palis, J. G. Snakes of "Snake Road". Bulletin of the Chicago Herpetological Society 51, 1-9 (2016).

Reijen, R. & Foppen, R. U. U. D. Impact of road traffic on breeding bird populations. Pp. 255-274 in The Ecology of Transportation: Managing Mobility for the Environment (ed. J. Davenport and J. L. Davenport). Springer (2006).

Rhodes, J. R., Lunney, D., Callaghan, J., & McAlpine, C. A. A few large roads or many small ones? How to accommodate growth in vehicle numbers to minimize impacts on wildlife. PLoS One 9, 1-10 (2014).

Riitters, K. H. & Wickham, J. D. How far to the nearest road? Frontiers in Ecology and the Environment 1, 125-129 (2003).

Saint Girons, H. Stretegies reproductrices des Viperidae dans les zones temperees fraiches et froides. Bulletin de la Societe Zoologique de France 117, 267-278 (1992).

Shepard, D. B., Dreslik, M. J., Jellen, B. C., & Phillips, C. A. Reptile road mortality around an oasis in the Illinois corn desert with emphasis on the endangered Eastern Massasauga. Copeia 2008, 350-359 (2008).

Seigel, R. A. Ecology and conservation of an endangered rattlesnake, *Sistrurus catenatus*, in Missouri, USA. Biological Conservation 35, 333-346 (1986).

Siemers, B. M. & Schaub A. Hunting at the highway: traffic noise reduces foraging efficiency in acoustic predators. Proceedings of the Royal Society of London: Biological Sciences 278, 1646-1652 (2010).

Sparks, J. & Gates, E. An investigation into the use of road drain- age structures by wildlife in Maryland, USA. Human and Wildlife Interactions 6, 311–326 (2012).

Steen, D. A. & Gibbs, J. P. Effects of roads on the structure of freshwater turtle populations. Conservation Biology 18, 1143-1148 (2004).

Taylor, B. D. & Goldingay, R. L. Wildlife road-kills on three major roads in northeastern New South Wales. Wildlife Research 31, 83-91 (2004).

Taylor, B. D. & Goldingay, R. L. Roads and wildlife: impacts, mitigation and implications for wildlife management in Australia. Wildlife Research 37, 320-331 (2010).

Thomas, M. A. Aspects of the trophic ecology of an invertivorous snake community. Eastern Illinois University Master's Thesis (2014).

Trombulak, S. C. & Frissell, C. A. Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology 14, 18-30 (2000).United States Fish and Wildlife Service. Fiscal year 2017 president's budget justifications and performance information. Department of the Interior (2016).

United States Forest Service. Shawnee National Forest. U.S. Department of Agriculture, http://www.fs.usda.gov/shawnee (2016).

Willson, J. D. & Gibbons, J. W. Drift fences, coverboards, and other traps. Pp. 229-245 in Amphibian Ecology and Conservation (ed. C.K. Dodd, Jr.). Oxford University Press (2009).

Winne, C. T., Willson, J. D., Andrews, K. M., & Reed, R. N. Efficacy of marking snakes with disposable medical cautery units. Herpetological Review 37, 52-54 (2006).

Woltz, H. W., Gibbs, J. P., & Ducey, P. K. Road crossing structures for amphibians and reptiles: informing design through behavioral analysis. Biological Conservation 141, 2745-2750 (2008).

Wood, R. C. & Herlands, R. Turtles and tires: the impact of roadkills on Northern Diamondback Terrapin, *Malaclemys terrapin terrapin*, populations on the Cape May Peninsula, Southern New Jersey, USA. Proceedings: Conservation, Restoration, and Management of Tortoises and Turtles—An International Conference 46-53 (1997).

Tables

Table 1. Mean survival rate and number of *Storeria dekayi* encountered by drift fence location along Ridge Lake Road throughout 2011–2015 activity seasons in Fox Ridge State Park (Coles County, Illinois).

Location (Fence)	Mean Survival Rate	Mean number of *S. dekayi*
4	0.439	590
5	0.527	279
6	0.462	299
7	0.481	447
Control	0.503	145
Hose Bridge	0.388	201

Table 2. Logistic regression results for effect of location encountered on survival rate of *Storeria dekayi* at hose-bridge and control site during 2014–2015 fall migrations at Fox Ridge State Park (Coles County, Illinois). Statistics reported as (A) entire model and (B) model components.

A.

	Df	Chi^2	Residual Df	Residual Chi^2	p
NULL			1960	2708.4	
Location	5	12.053	1955	2696.3	0.034*

B.

Location	Estimate	Standard Error	Z value	p
Intercept (Fence 4)	-0.245	0.083	-2.96	0.003*
Fence 5	0.353	0.146	2.42	0.016*
Fence 6	0.091	0.143	0.64	0.523
Fence 7	0.169	0.126	1.34	0.179
Control	0.259	0.186	1.40	0.163
Hose-Bridge	-0.210	0.167	-1.26	0.208

Table 3. Monthly mean numbers and survival rates of *Storeria dekayi* encountered during each month (2011–2015) along Ridge Lake Road at Fox Ridge State Park (Coles County, Illinois); as well as average monthly temperature (°C) and precipitation (mm). Monthly precipitation and temperature values for the final month are averaged from precipitation and temperature values up to the last day of encountering a snake during that field season.

Month	Number of *S. dekayi*	Survival rate of *S. dekayi*	Average Monthly Precipitation (mm)	Average Monthly Temperature (°C)
March	67	0.896	39.90	24.946
April	281	0.797	151.94	23.825
May	73	0.836	96.01	25.741
June	78	0.923	144.07	25.344
July	85	0.941	96.39	35.556
August	37	0.892	31.44	30.741
September	158	0.342	91.49	22.354
October	2035	0.363	75.13	19.752
November	82	0.110	8.81	13.333

Figures

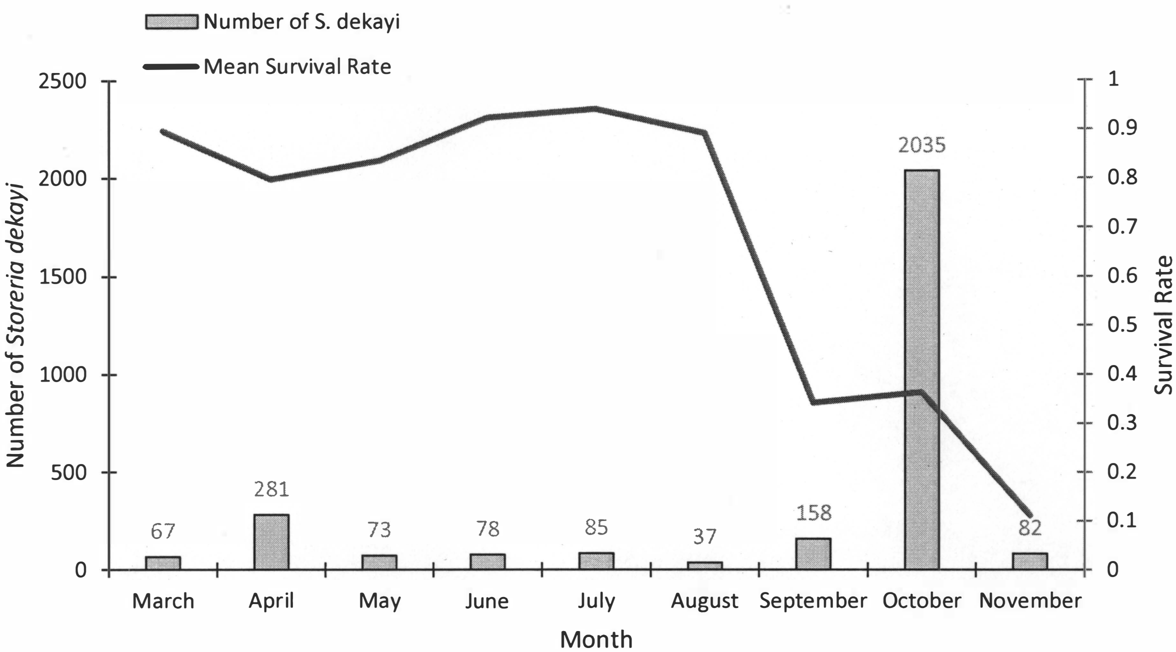

Figure 1. Total number and mean survival rate of *Storeria dekayi* surveyed during each month throughout 2011–2015 along Ridge Lake Road in Fox Ridge State Park (Coles Co., Illinois).

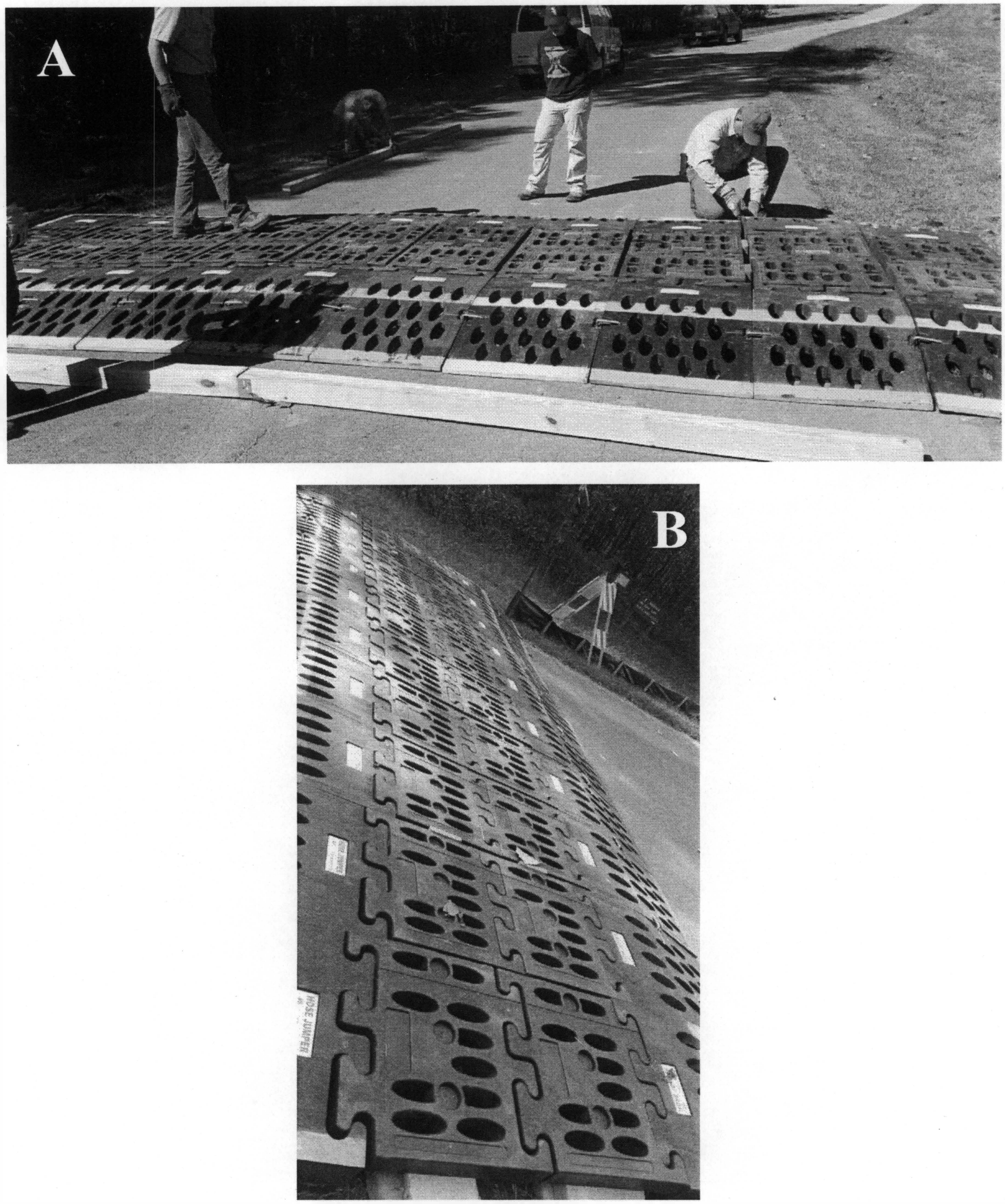

Figure 2. Hose-bridge from Turtle Plastics Inc. tested as a road-crossing structure for *Storeria dekayi* along Ridge Lake Road in Fox Ridge State Park (Coles Co., Illinois). (A) During construction, illusrating size relative to road and vehicles. (B) Hose-bridge construction and drift fencing complete.

Figure 3. Hose-bridge and associated traffic signage to warn approaching vehicles of bump caused by hose-bridge presence and road-crossing movements of snakes at control site along Ridge Lake Road in Fox Ridge Sate Park (Coles Co., Illinois).

Figure 4. Drift fences built at both hose-bridge and control sites to direct flow of Dekay's Brownsnakes migrating across Ridge Lake Road to hose-bridge and control sites, respectively. Located in Fox Ridge State Park (Coles Co., Illinois)

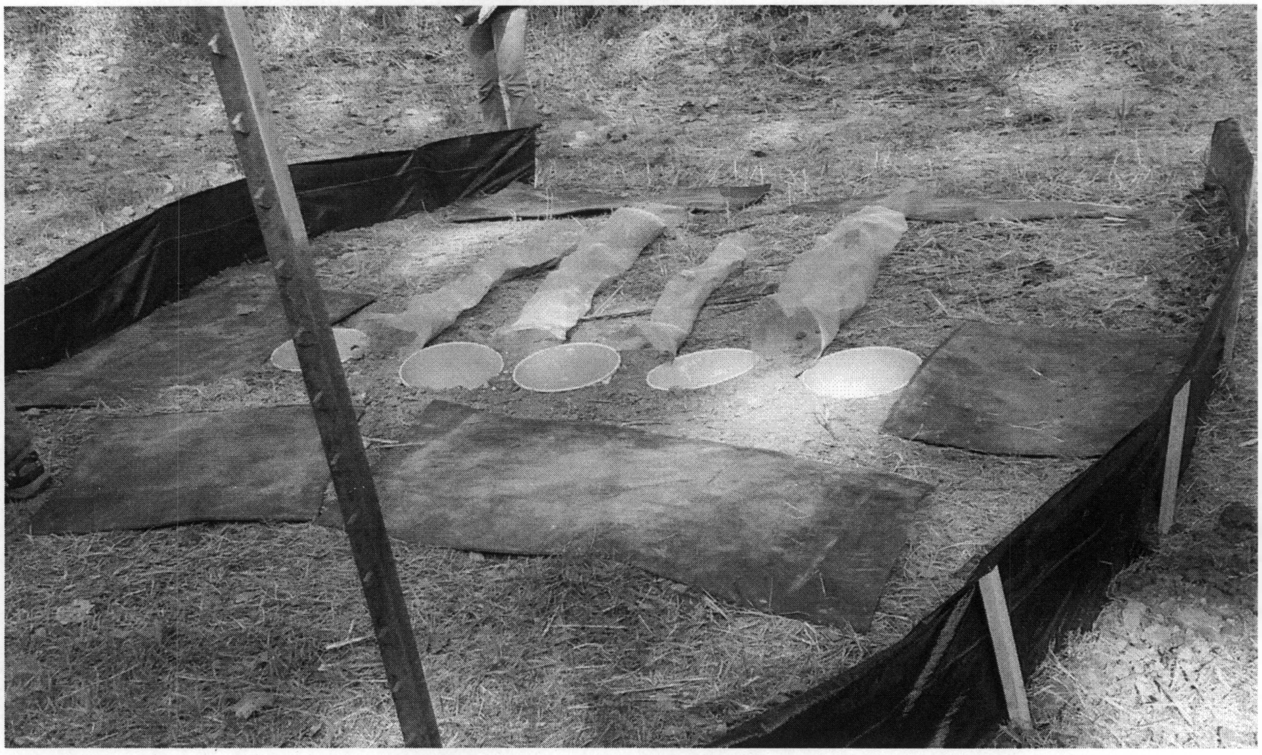

Figure 5. Image of configuration of covermats, pitfall traps, and funnel traps at control and hose-bridge sites along Ridge Lake Road in Fox Ridge State Park (Coles Co., Illinois).

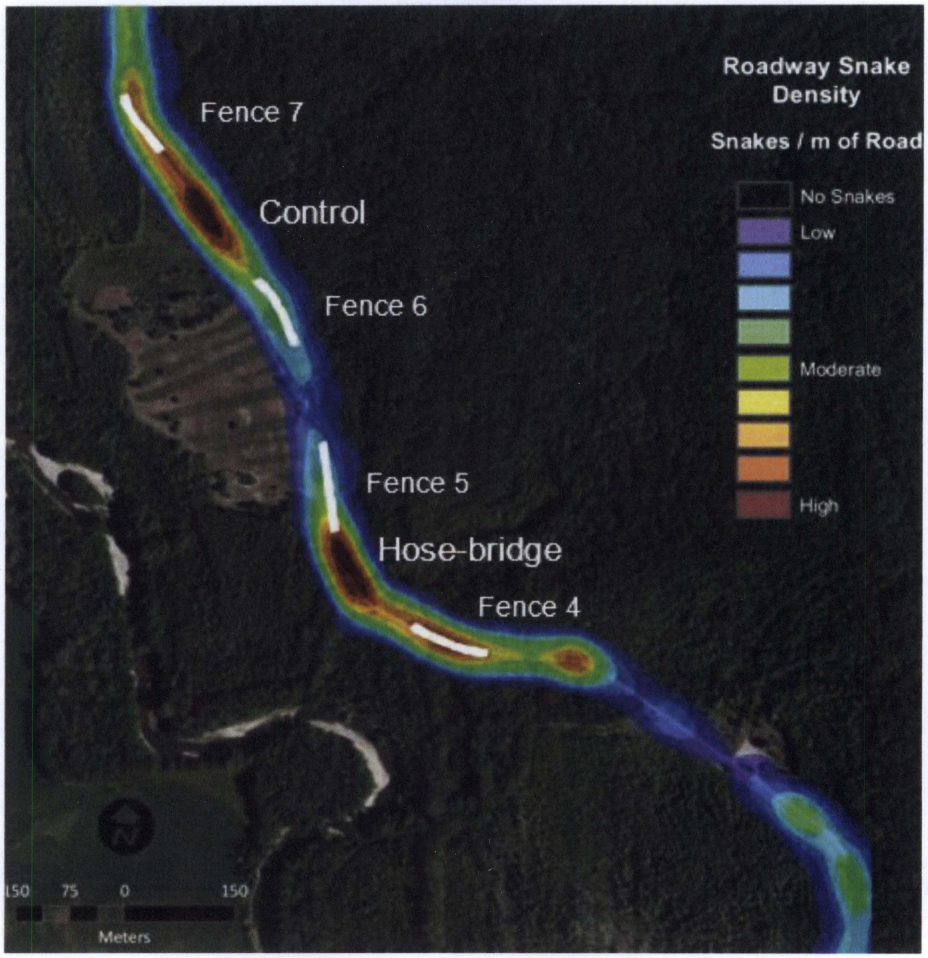

Figure 6. Location of each drift fence and density of roadway snake captures (2011–2015) along Ridge Lake Road in Fox Ridge State Park (Coles Co., Illinois). Drift fence locations and test sites are arranged such that the lowest (numerically) fences are the most southern, while greater (numerically) fences are the most northern. Hose-bridge and control sites are located in the center of respective high snake density areas. Fences are highlighted as white lines along Ridge Lake Road.

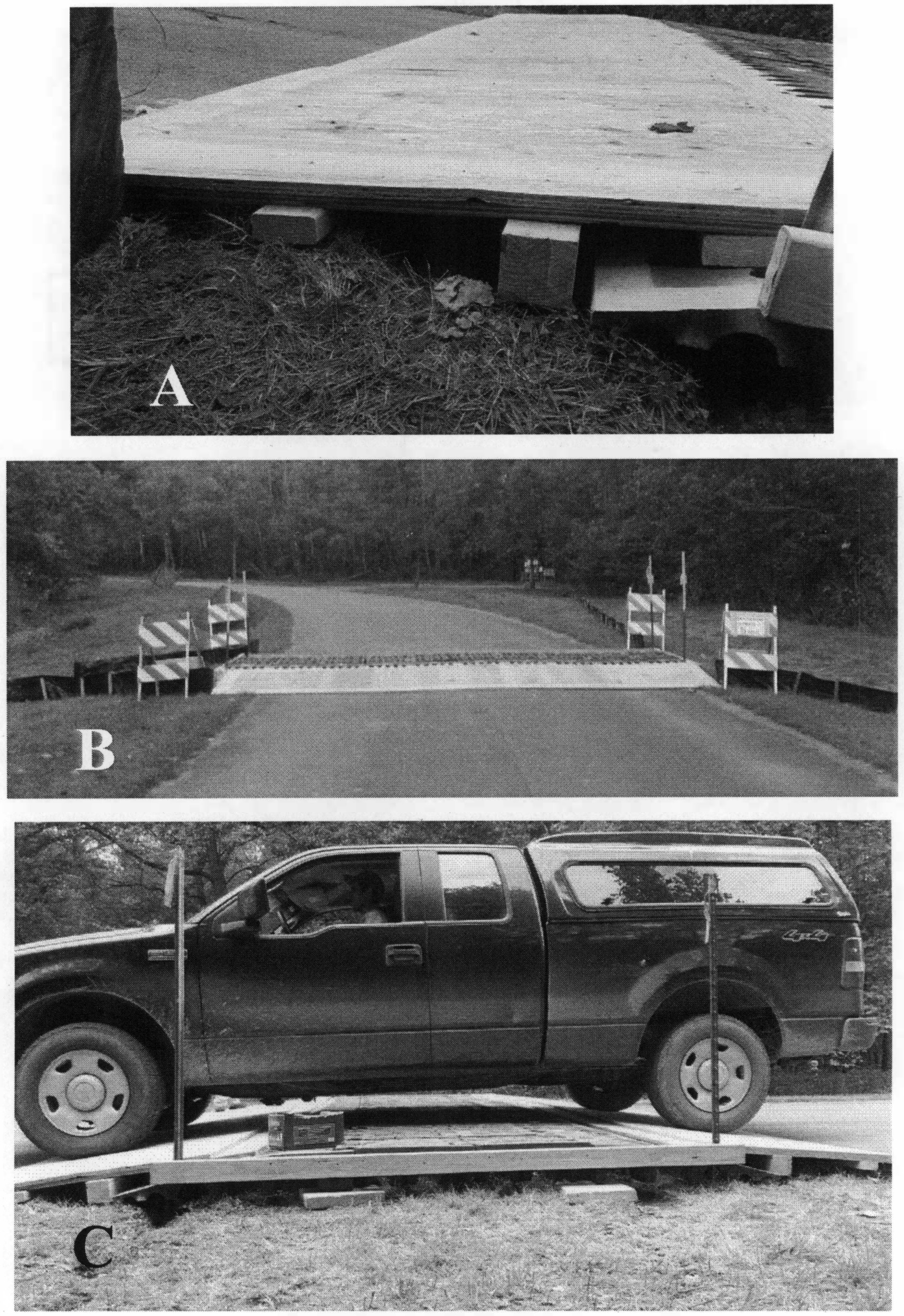

Figure 7. Images of modifications to the hose-bridge in 2015 on Ridge Lake Road in Fox Ridge State Park (Coles Co., Illinois). (A) Detail of cross section of ramp constructed to improve vehicle mobility while crossing. (B) Overall ramp construction view as approaching vehicle. (C) Vehicle traversing the hose-bridge structure with ample clearance provided by ramps.

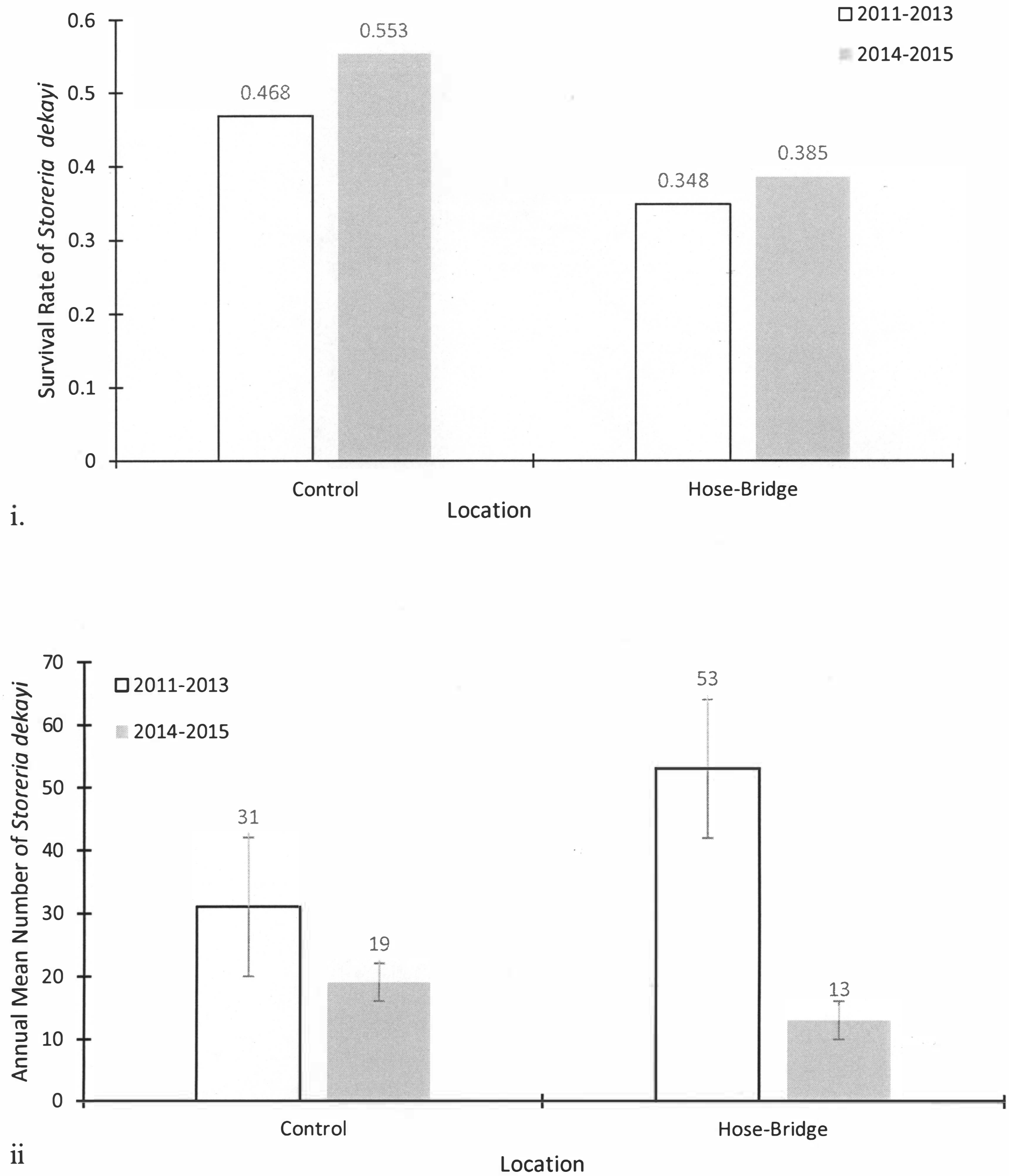

Figure 8. Hose-bridge and control site (i) survival rates and (ii) annual average number of individuals encountered of *Storeria dekayi* during Autumn migrations prior to (2011–2013) and during (2014–2015) hose-bridge deployment on Ridge Lake Road in Fox Ridge State Park (Coles Co., Illinois).

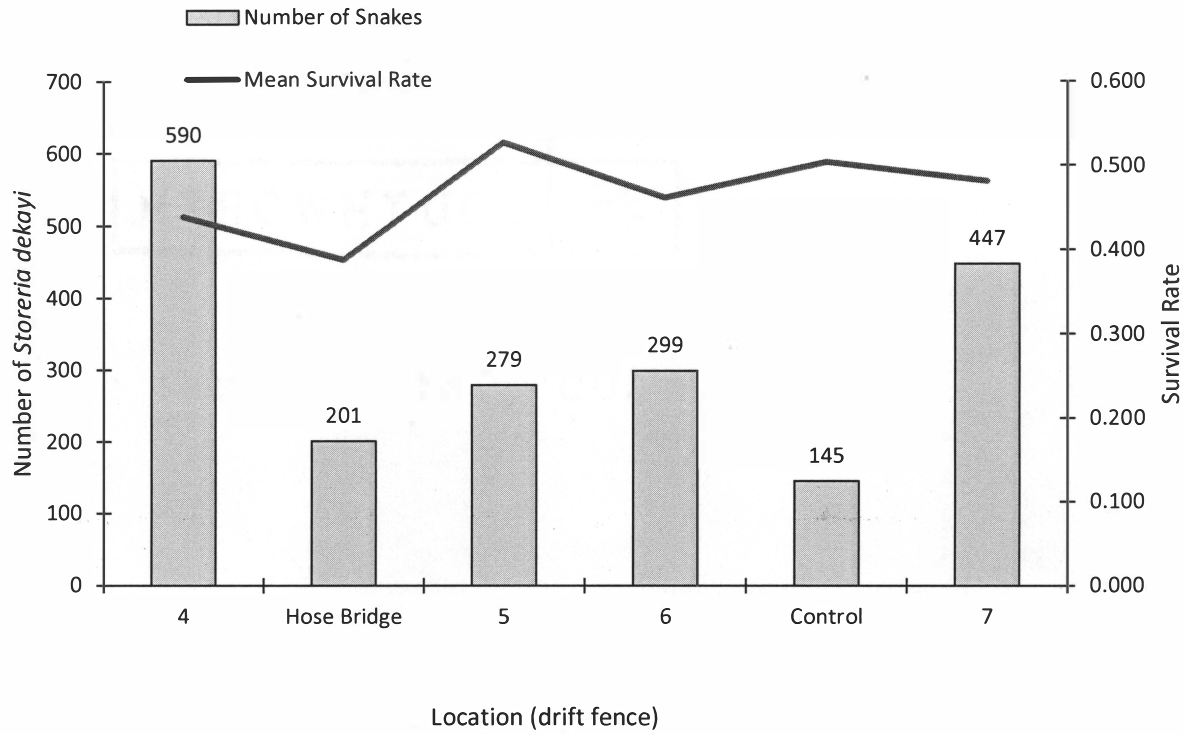

Figure 9. Relationships between the drift fence location along Ridge Lake Road, mean survival rate and number of encountered individual *Storeria dekayi* in years 2011–2015 in Fox Ridge State Park, Coles Co., Illinois. Drift fence locations and test sites are arranged such that the left and lowest (numerically) fences are the most southern, while right and greater (numerically) fences are the most northern.

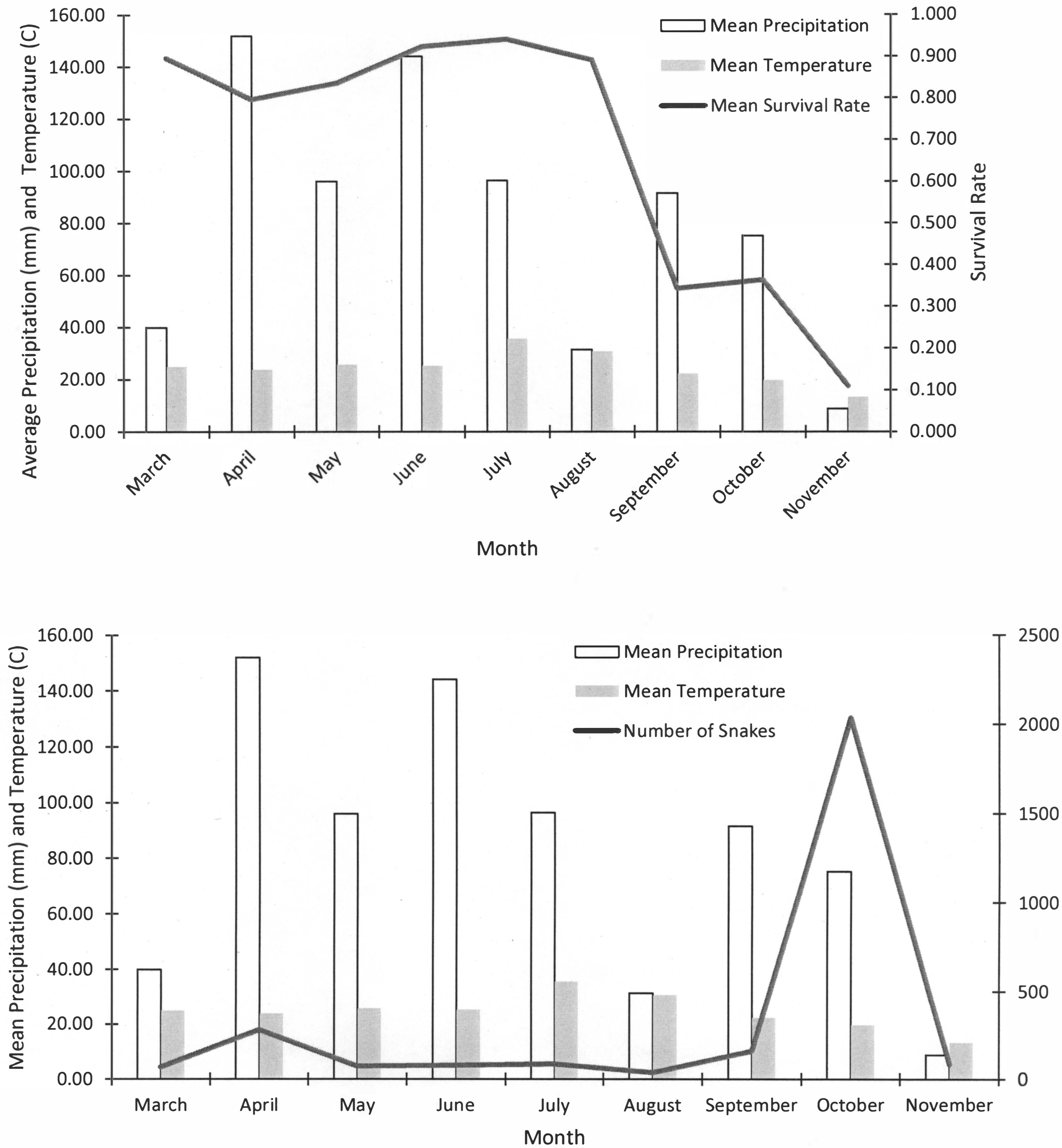

Figure 10. Mean precipitation and temperature of each month for Fox Ridge State Park (Coles Co., Illinois) plotted against (i) mean survival rate of *Storeria dekayi* crossing Ridge Lake Road and (ii) number of *Storeria dekayi* found on the roadway.