Ecological Studies of the Smooth Earth Snake and Redbelly Snake, and Niche Modeling of Forest Species in Eastern Kansas

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# Table of Contents

**Chapter I. Ecological Studies of the Smooth Earth Snake and Redbelly Snake in Eastern Kansas**

Acknowledgments...........................................................................................................................................3  
Introduction...............................................................................................................................................4  
Methods....................................................................................................................................................6  
Results....................................................................................................................................................8  
Discussion...............................................................................................................................................11  
  Specific Proposal Questions Addressed by New Work.................................................................16  
  Northeast Kansas Habitats ..................................................................................................................16  
  Reproduction.......................................................................................................................................30  
  Isozymes and Adaptation in *Storeria occipitomaculata* ..............................................................31  
  Population Density............................................................................................................................31  
  Mortality ...............................................................................................................................................32  
  Longevity.............................................................................................................................................34  
Conclusions.............................................................................................................................................34  
Literature Cited .....................................................................................................................................36  
Figures ....................................................................................................................................................46-62

**Chapter II. Niche Modeling of Forest Species in Eastern Kansas**

Introduction.............................................................................................................................................62  
Methods..................................................................................................................................................63  
Results..................................................................................................................................................64  
Discussion.............................................................................................................................................67  
Literature Cited.....................................................................................................................................67
Chapter I. Ecological Studies of the Smooth Earth Snake and Redbelly Snake in Eastern Kansas

William H. Busby and George R. Pisani

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Introduction

The Smooth Earth Snake (Virginia valeriae) and Redbelly Snake (Storeria occipitomaculata) remain the two most poorly known snakes ecologically in northeast Kansas and adjacent Missouri. Kansas Department of Wildlife, Parks and Tourism (KDWPT) identifies these two snakes as threatened species. Urban development is perhaps the greatest threat to the habitats utilized by both species in northeast Kansas. This trend is not new (see for example Ahrens 1997), but is continuing, particularly in the greater Kansas City area in Douglas, Johnson, Leavenworth, and Wyandotte counties (Pisani and Busby 2011). This four-county area contains much of the historic habitat for Smooth Earth Snake and Redbelly Snake in Kansas. As habitat is lost to urbanization, little is being set aside for natural areas conservation. Kansas ranks last among the 50 states in percent public land ownership with less than 1% (NRCM 1999). This situation points to a heightened need to enlist public support for conservation in general. A recent KDWPT report indicates public support for wildlife conservation (VanScoyok 2013).

Both species are of small size and do not readily disperse beyond a distance of a few hundred meters. The principal issue is simply mobility—they are small and their locomotion is limited. Other similar-sized snakes behave much the same (Pisani 2009b, Gray 2011). Thus, they have limited ability to re-invade habitats that putatively have been restored but are disjunct from other populations of either species.

Populations of both species are located at the western limits of their ranges which are centered in eastern North America. While these forest-associated species have limited habitat available on the western periphery of their range, eastern populations occur in more heavily forested regions with greater precipitation and more stable climate regimes. This increased environmental uniformity is generally associated with larger populations and perhaps more consistent availability of the prey that make up the specialized diets of these snakes (Pisani and Busby 2011, Gray 2011, Semlitsch and Moran 1984).

Vital to the conservation of these and similar species more generally entails protection of dwindling historical habitats such as (in Kansas) old-growth deciduous hardwood forest. In an extensive review of management practices in mixed hardwood forest, Werner and Raffa (2000) noted that “Loss and fragmentation of natural habitats due to anthropogenic disturbances such as logging, agriculture, altered fire regime, and urban development, are suspected to be primary causes of a rapid decline in the earth's biodiversity ..., with species extinction estimated to be 400 times the natural rate...” These trends are glaringly apparent in northeast Kansas, and balancing conservation with economic growth and suburban development will entail ongoing effort to integrate these goals in order to both preserve the state’s biota and enhance the natural-environment experience of its people.

This study addresses issues and strategies listed in Table 1 that are contained in the Kansas Comprehensive Wildlife Conservation Plan (CWCP), and adds to in information presented in the final report of our previous study (Pisani and Busby 2011).
Table 1. Issues and strategies in the Kansas Comprehensive Wildlife Conservation Plan that are pertinent to this study.

<table>
<thead>
<tr>
<th>Issues</th>
<th>Strategies which together address issues</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of data on species present, and habitat needs</td>
<td>Conduct wildlife surveys.</td>
</tr>
<tr>
<td></td>
<td>Conduct studies of habitat needs of species in forest habitat</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Urbanization and agricultural activities are changing these habitats</td>
<td>Conduct studies of habitat needs of species that inhabit the area.</td>
</tr>
<tr>
<td></td>
<td>Promote the use of best management practices in forests and adjacent lands</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Lack of knowledge and understanding of deciduous forests and</td>
<td>Conduct studies on habitat quality and quantity.</td>
</tr>
<tr>
<td>deciduous floodplains leads to poor management decisions</td>
<td>Provide technical assistance and financial incentives for landowners to implement best management practices</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Specific questions presented in our proposal and addressed by our study are:

<table>
<thead>
<tr>
<th>Question</th>
<th>Background</th>
</tr>
</thead>
<tbody>
<tr>
<td>What is the extent of seasonal habitat use and niche dimensions of these species?</td>
<td>Pisani (2009b) found that Smooth Earth Snakes in one population moved to open grassland after emerging from hibernation sites in deciduous woodland. We investigated seasonal activity in both species at a different site with contrasting environmental features.</td>
</tr>
<tr>
<td>What is the association of Smooth Earth Snake and Redbelly Snake with ants?</td>
<td>Snakes in the genera <em>Virginia</em> and <em>Storeria</em> have an association with ants, especially large-bodied ones of the genus <em>Formica</em> (Cervone 1983; Noble and Clausen 1936; Pisani 2009a). This relationship also has been observed (but not documented in detail) for Redbelly Snake in one of the populations we have studied most intensively.</td>
</tr>
<tr>
<td>What is diet of each species and what are the implications of food availability on season activity and movement?</td>
<td>In other parts of its range, the Redbelly Snakes has been reported to eat predominantly slugs of several genera, and to occur in wooded regions of at least moderate annual rainfall (Smith 1963). In the course of our current SWG study we have noted that in northeast Kansas the species’ presumed range closely approximates that of the slug <em>Philomycus carolinianus</em> and to a lesser extent that of the more widespread and smaller <em>Deroceras laeve</em> (Leonard 1959, Branson 1962). Seasonal movements in Smooth Earth Snake may be tied to its earthworm diet (Pisani 2009b).</td>
</tr>
<tr>
<td>Are sympatric Ringneck Snakes (<em>Diadophis punctatus</em>) potential predators on juveniles and subadults of both GCN species?</td>
<td>Though Fitch (1999) commented on the occurrence of small vertebrates in the diet of Ringneck Snakes from other parts of the country, he reported the species in his eastern Kansas study area to consume just earthworms. This seeming anomaly should be further investigated, as Gilhen (1984:138) reported a closely related subspecies of Ringneck Snake to consume a Redbelly Snake juvenile, and O'Donnell et al. (2007) report extensive predation on immature gartersnakes of two species by another race of Ringneck Snake; they also cite vertebrate consumption by the subspecies that occurs in Kansas.</td>
</tr>
</tbody>
</table>

The approach of this study was to continue field research initiated in 2009 on Smooth Earth Snake and Redbelly Snake in a four-county area (Douglas, Johnson, Leavenworth, and Wyandotte) supplemented with field work and input from cooperators in adjacent counties (Pisani and Busby 2011). In this second phase of the study, we focused more on continued monitoring of established shelter transects in Douglas County, and less on searching for new snake records. We concentrated on the ecology and natural history of *Storeria occipitomaculata*,...
a poorly known species in Kansas, noting relationships and ecological differences/similarities to the better-studied *Virginia valeriae* (Pisani 1971, 2005, 2009a, 2009b).

## Methods

### Sampling

Transects of artificial shelters (primarily corrugated tin, though some utilized both tin and plywood) were continued for sampling (Pisani 2009b, Pisani and Busby 2011). Our rationale remains the same: Smooth Earth Snake and Redbelly Snake are among the earliest snakes to egress from hibernation in spring, and tins, especially when warmed even modestly by sunlight, offer an attractive microclimate to them. Earliest captures of both target species during our ongoing study has been in early- to mid-March. Typically, as arboreal leaf cover emerges the tins hold their attractant value as they are shaded from direct insolation but generally are warmer than ambient ground temperatures by 10 am. Since both snake species are semi-fossorial, shelters are attractive to them (Pisani 2009b; Mesha 2010, 2008).

In spring 2013, additional shelters of scrap carpet (30 cm x 46 cm, commercial tight weave) were deployed alongside selected transects known earlier to provide records of Smooth Earth Snake and Redbelly Snake. Carpet shelters were deployed upside down and effectively trapped soil moisture better than tin or wood as evidenced by condensation beneath them. Snakes were not found beneath carpet during subsequent sampling, though earthworms were found more frequently than beneath tin or wood. In a very few instances, *Formica* ants established small nests beneath carpet.

Pitfall traps and drift fences (Busby and Parmelee 1996) were not used for two significant reasons:

1. Given the widespread localities we sampled, and concomitantly reduced time spent at any one locality, shelters hold less danger of mortality to these GCN target species than would traps. Mortality in pitfall traps can be considerable (Enge 2001), and we wished to avoid adding to the mortality of these GCN species.
2. Though favored by some authors (c.f., Semlitsch and Moran 1984), the method’s success is highly variable. In a similar study of Redbelly Snakes (Cahoe and Troelstrup, Jr., 2004), less than 5% of captures were with the fences/traps deployed. Similar results (also noting trap disadvantages for small snakes) were obtained by Fogarty and Jones (2003) and Harner and Geluso (2011).

We also have used opportunistic collecting, though our over-arching goal of not destroying known or potential habitats have limited our use of extensive leaf-litter raking, rock slope raking, and other destructive methods.
Public Cooperation and Outreach

As previously, we received (and continue to) excellent contributions of records/photos from persons finding what they believe (on reading field guides) may be Smooth Earth Snakes and Redbelly Snakes and searching online for positive identification information. Pisani established the site in 2009 at [http://people.ku.edu/~gpisani/SWGform.html](http://people.ku.edu/~gpisani/SWGform.html) and optimized it for search engine tracking. Several persons contributing sightings via the site have become regular contacts looking for the two species and reporting new sightings. These persons either have their own Kansas Scientific Collecting Permits or have been added to ours and reported by us in our annual summaries. Members of the general public have been advised that both species are legally protected; in all such contacts, we have visited the persons and verified the identity of the snake(s), weighed and measured them and collected scat samples as available, and released them on-site.

Drought Effects

This study period coincided with a major drought (Figure 1). Drought in the plains states is not an uncommon event (Figure 2). What has changed from the perspective of native, moisture-dependent species is anthropogenic modification of surface and subsurface hydrology, as well as loss, fragmentation, and degradation of native habitats which generally maintained a superior barrier to the dehydrating effects of wind and sun than do most current anthropogenically derived habitats. Some of these points as they relate to loss of accumulated thatch and the ecological consequences thereof were addressed by Nekola (2002). Similar deleterious effects on forest herbaceous-layer habitats were confirmed by Gilliam (2007).

Our study was strongly impacted by the prolonged drought through 2011, 2012 and much of 2013. Capture rates of all snakes species, and especially Smooth Earth Snake and Redbelly Snake, dropped off sharply during this period compared to 2009-2010. The prey base of both target species appeared to be greatly reduced during the drought, with likely concomitant reductions of some snake populations. Earthworms, the sole prey of Smooth Earth Snakes in Kansas (Pisani 2009b), were not recorded on the surface at any of our sampling stations during 2013 until late September. Pulmonate mollusks (slugs and snails), known to be the principal prey of Redbelly Snakes (Gray et al. 2013, Gilhen 1984, Pisani and Busby 2012a, Brown 1979) were not recorded at all during 2011 and at just two sites in 2012 despite increased sampling effort.

Earthworms escape drought by burrowing (Chan 2001, Bohlen et al. 1995), making them unavailable to most snake predators which in general lack the cranial osteology to make their own deep burrows (Dowling 1959, Pisani unpublished data). Thus, the snakes must utilize soil interstices and burrows of insects (ants, cicadas) or other animals.

Slugs (eggs, juveniles, adults) are able to withstand considerable percent-water-loss by weight, but in prolonged drought those unable to locate moist refugia die during drought (Slotsbo et al. 2011, Thompson et al. 2006, Prior et al. 1983, Lake 2003), and population recovery thereafter is highly variable. Snails are somewhat more drought-tolerant by virtue of their ability to seal themselves within the shell and remain hydrated.
These recent drought conditions are believed to have affected an entire guild of specialist-feeding (on worms and pulmonate mollusks) snakes in northeast Kansas, a hypothesis that is being studied further by Pisani.

**Results**

This study focused on the ecology and natural history of *Storeria occipitomaculata* and examined relationships and ecological differences/similarities to *Virginia valeriae*. In several study tracts the species have been found within the same overall area; however, in tracts such as that studied by Pisani (2009a, b) Redbelly Snakes are absent. Wherever we have encountered *V. valeriae* we have seen just one ecological relationship that differs from those described in Kansas earlier (Pisani 2005, 2009a, b). Pisani (2009b) observed *V. valeriae* to shift habitat use from woodland hibernation habitat to active-season grass habitat adjacent to woodland. At one of our principal study sites (Rice Woodland) there was no adjacent grassland habitat similar to that studied by Pisani (2009b) on McColl Tract located about 18 miles to the north.

Potential hibernation resources seemed equivalent; Rice Woodland had more abundant mound nests of *Formica* ants, whereas McColl was close to woodland rock substrate with abundant interstices (Pisani unpublished). During periods of moisture, surface-feeding earthworm abundance at McColl shifted rapidly; worms became unavailable in woodland but were abundant in adjacent grass thatch. At Rice Woodland, during the peak moisture year of 2009, worms were abundant through the activity season of *V. valeriae*. Consequently, the population of *V. valeriae* on Rice had available all necessary resources during 2009 and early 2010.

**Table 2.** General features (similarities and those differences of potential significance to *V. valeriae* and *S. occipitomaculata*) of soil units at Rice Woodland and Pisani’s (2005, 2009a, b) McColl site.

<table>
<thead>
<tr>
<th>Rice Woodland resembles McColl in:</th>
<th>Rice Woodland differs from McColl in:</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Elevation: ~1,000 feet *</td>
<td>- Leaf litter (deeper in Rice, which is in a surviving band of old growth forest)*;</td>
</tr>
<tr>
<td>- Mean annual precipitation: 31 to 47 inches *</td>
<td>- Amount disturbed forest (more surviving old-growth trees on Rice)*;</td>
</tr>
<tr>
<td>- Frost-free period: 175 to 215 days *</td>
<td>- Mean annual air temperature: 55 to 59 degrees F (McColl 52 to 55 degrees F)* (significance to target species possible but questionable)</td>
</tr>
<tr>
<td>- Slope: 3 to 7 percent (3 to 8 percent on McColl)*</td>
<td>- Capacity of the most limiting layer to transmit water (Ksat): McColl very low to moderately low (0.00 to 0.06 in/hr); Rice very low to moderately high (0.00 to 0.20 in/hr)*</td>
</tr>
<tr>
<td>- Depth to water table: More than 80 inches*</td>
<td>- Soil parent material: McColl—Residuum weathered from limestone and shale (Rosendale-Bendena silty clay loams and Oska silty clay loam); Rice—Fine-loamy residuum weathered from sandstone (Sibleyville loam and Basehor complex)*.</td>
</tr>
</tbody>
</table>

*Data from NRCS Websoil database, http://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm
* Data from our study
Even within the narrow limits of Rice Woodland there are soil differences that seem to correlate with the sample stations at which we have found the greatest abundance of both target species. For example, neither species has been found where soils experience a high frequency of flooding. Our investigations are ongoing and will include in 2014 some new tracts unavailable earlier.

As noted above, the regional drought from late 2010 through September 2013 greatly reduced our observed numbers of both species despite increased effort during equivalent seasons. At our most consistently monitored transect, East Rice, both Smooth Earth Snake and Redbelly Snake captures were lower during 2011-2013 compared to 2009-2010 (Table 3, Figure 3). This was especially true for Redbelly Snake, which was observed only twice at East Rice since 2010 and not at all in 2013. With the onset of considerable rainfall late in the 2013 season, we have observed at several study sites a resurgence of earthworms at the surface, and a subsequent resurgence of records of adult *Virginia valeriae*. On March 13, 2014 we captured 3 young-of-2013 *Virginia valeriae* in two different localities within the same general area searched in 2013. Though data are insufficient to allow thorough evaluation of breeding success for *V. valeriae*, this suggests that at least some females were able to reproduce successfully—and by implication feed, and accumulate lipids to yolk mature follicles—during the 2012-2013 drought period. *Virginia valeriae* may be a more resilient species than *Storeria occipitomaculata* (in March 2014 we observed none of this species at the same tract) as its predominant prey (surface-feeding earthworms, per Pisani 2009b) is able to escape drought by burrowing and resume surface activity (and hence availability to snakes) when moisture conditions improve.

Several new records were reported from new sites in northeast Kansas (Table 3, Figures 4 and 5). A first record for Redbelly Snake in Johnson County was reported to us in 2013 by Danny Stevens (Figure 5). He provided photos of specimen captured in 2010 in his suburban yard in Overland Park near a riparian corridor (Windham Creek Park). In Miami County, a Redbelly Snake was captured and verified by us in May 2012 in a wooded area 3 miles south of Louisburg. A Smooth Earth Snake was captured and verified by us on the east edge of Camp Naish north of Edwardsville, Wyandotte County, in May 2012 and again in October 2013. Lastly, a Smooth Earth Snake was captured and photographed at Marais des Cygnes National Wildlife Refuge by refuge staff in June 2013 in bottomland forest.

We have compiled files of verified museum records of both species in Kansas and have examined, and performed vegetation surveys in, habitats at verified localities. These data along with annual transect-sampling records have been provided separately to KDWPT. We additionally have maintained searchable databases (accompanied by photos) of all live individuals of both target species captured by us or (non-transect specimens) by contributors through our outreach effort.

Low capture numbers of Redbelly Snake have in our northeast Kansas study areas hindered exploration of the species’ population ecology. In the Discussion therefore, we have integrated our data with a thorough examination of relevant literature. We feel it is valid to apply these inferences to Kansas populations, since in no instance during our investigations have we found that life history data from Kansas Redbelly Snake study contradicts data from studies in other parts of the species’ range.
Table 3. Summary of Redbelly Snake (RBS) and Smooth Earth Snake (SES) observations from northeast Kansas during this study (Aug 2010 through 2013) or reported during the study period.

<table>
<thead>
<tr>
<th>Species</th>
<th>County</th>
<th>Location</th>
<th>Long (d-d)</th>
<th>Lat (d-d)</th>
<th>Precision (m)</th>
<th>Date</th>
<th>Collector</th>
</tr>
</thead>
<tbody>
<tr>
<td>RBS</td>
<td>Johnson</td>
<td>10006 W 126th Terrace, Overland Park</td>
<td>-94.70158</td>
<td>38.89903</td>
<td>200</td>
<td>8/1/2010</td>
<td>Danny Stevens</td>
</tr>
<tr>
<td>RBS</td>
<td>Douglas</td>
<td>East Rice shelter transect, station 22</td>
<td>-95.17828</td>
<td>38.81032</td>
<td>5</td>
<td>4/13/2012</td>
<td>Pisani</td>
</tr>
<tr>
<td>RBS</td>
<td>Franklin</td>
<td>Timber Lakes Camp transect, stn 12</td>
<td>-95.3935</td>
<td>38.55453</td>
<td>20</td>
<td>5/3/2012</td>
<td>W. Busby, G. Pisani</td>
</tr>
<tr>
<td>RBS</td>
<td>Franklin</td>
<td>Timber Lakes Camp transect, stn 16</td>
<td>-95.3914</td>
<td>38.55494</td>
<td>20</td>
<td>5/17/2012</td>
<td>G. Pisani, W. Busby</td>
</tr>
<tr>
<td>RBS</td>
<td>Miami</td>
<td>30100 Metcalf Road</td>
<td>-94.67734</td>
<td>38.58061</td>
<td>20</td>
<td>5/28/2012</td>
<td>E. Shaefer</td>
</tr>
<tr>
<td>RBS</td>
<td>Douglas</td>
<td>West Rice shelter transect, stn 11</td>
<td>-95.18476</td>
<td>38.81019</td>
<td>5</td>
<td>4/17/2012, 5/01/2012</td>
<td>G. Pisani, W. Busby</td>
</tr>
<tr>
<td>SES</td>
<td>Wyandotte</td>
<td>Camp Naish border</td>
<td>-94.8347</td>
<td>39.07690</td>
<td>20</td>
<td>5/20/2012</td>
<td>W. Horner (G. Pisani)</td>
</tr>
<tr>
<td>SES</td>
<td>Douglas</td>
<td>Rice East shelter transect</td>
<td>-95.17917</td>
<td>38.80944</td>
<td>5</td>
<td>5/28/2013</td>
<td>Busby</td>
</tr>
<tr>
<td>SES</td>
<td>Linn</td>
<td>Marais des Cygnes NWR</td>
<td>-94.633</td>
<td>38.2299</td>
<td>100</td>
<td>6/20/2013</td>
<td>Patrick Walker, Tim Menard</td>
</tr>
<tr>
<td>SES</td>
<td>Wyandotte</td>
<td>Camp Naish border</td>
<td>-94.8347</td>
<td>39.07690</td>
<td>100</td>
<td>10/14/2013</td>
<td>W. Horner (G. Pisani)</td>
</tr>
<tr>
<td>SES</td>
<td>Douglas</td>
<td>Wall Woods shelter transect</td>
<td>-95.20350</td>
<td>38.80499</td>
<td>30</td>
<td>9/29/2013</td>
<td>Mike Zerwekh</td>
</tr>
<tr>
<td>SES</td>
<td>Douglas</td>
<td>Wall Woods shelter transect</td>
<td>-95.20325</td>
<td>38.80510</td>
<td>30</td>
<td>9/29/2013</td>
<td>Mike Zerwekh</td>
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<tr>
<td>SES</td>
<td>Douglas</td>
<td>Rice East shelter transect</td>
<td>-95.17786</td>
<td>38.80991</td>
<td>20</td>
<td>9/29/2013</td>
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<tr>
<td>SES</td>
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<td>Rice East shelter transect</td>
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<td>10/10/2013</td>
<td>Pisani</td>
</tr>
<tr>
<td>SES</td>
<td>Douglas</td>
<td>Nitcher shelter transect</td>
<td>-95.20360</td>
<td>38.80430</td>
<td>20</td>
<td>11/9/2013</td>
<td>Pisani</td>
</tr>
</tbody>
</table>
Discussion

Species Characteristics

Because Smooth Earth Snake and Redbelly Snake are secretive, they potentially have wider distribution in the Osage Cuestas physiographic province and adjoining areas of eastern Kansas where both reach the extreme western edges of their ranges in the U.S. Their small size and secretive nature makes these species difficult research targets.

Conservation of both species in Kansas optimally entails conservation of the unique Kansas habitat-mosaic characteristic of the Eastern Tallgrass Prairie biome in a manner that maintains corridors of continuity through developed areas. Key native habitats for one or both snake species include:

- Tallgrass prairie
- Mesic old-growth deciduous forest
- Forest edge habitats and open woodlands, probably including now-defunct savanna
- Wet prairie and marshy habitats that support pulmonate mollusk populations on which the Redbelly Snake feeds, especially where bordering riparian and palustrine woodland
- Riparian and palustrine woodland

Factors that cumulatively reduce habitat diversity (especially intensive agriculture and urban development) lead to considerably reduced abundance of specialist species. For example, in a study in North Carolina *Storeria dekayi* (a prey generalist) were most frequently encountered in suburban neighborhoods and other developed areas whereas *S. occipitomaculata* were captured more frequently in undeveloped habitats (Wilson and Dorcas 2004). A detailed analysis of this effect was performed by Cagle (2008).

It is important to note that use of historic (from preserved museum specimens and records) occurrences of Redbelly Snake and Smooth Earth Snake need not accurately reflect the current distribution and population levels of either species in Kansas. Early records are so few, and often with low site specificity, that they do not seem to misrepresent current status of these species, but we cannot be certain. In Johnson and Douglas counties alone, the growth of urban and suburban development in the past 25 years has drastically altered the natural landscape in ways that impact the overall plant and animal diversity. These impacts generally are detrimental (see discussion of this phenomenon in Cagle 2008). Among these impacts are roads, which impact a variety of wildlife including small snakes. This topic is dealt with below under Mortality.

Quoting from McKinney (2002) in reference to Missouri:

About 50% of the US population lives in the suburbs, with another 30% living in cities (USCB 2001). Over 5% of the total surface area of the United States is covered by urban and other built-up areas (USCB 2001). This is more land than is covered by the combined total of national and state parks and areas preserved by the Nature Conservancy. More ominously, the growth rate of urban land use is accelerating faster
than land preserved as parks or conservation areas by the Conservancy ... Much of this growth is from the spread of suburban housing. It is estimated, for example, that residential yards occupy 135,000 acres in the state of Missouri (MDC 2002). This residential landscape represents nearly 1% of the total area of Missouri and is nearly three times the area occupied by Missouri state parks.

In general, the current distribution of Redbelly Snake in Kansas represents the distribution of old-growth mixed-species forests with strong deciduous hardwood components that provide high levels of foliar calcium to the uppermost (organic) soil layers by late-season leaf-fall. These forest remnants, as documented by Jordan and Black (2012), "supply microhabitat and microclimate condition capable of supporting a diversity of mollusks [slugs and snails]". These mollusks in turn represent the sole documented food species for Redbelly Snake, and the success of the snake is intimately bound to the abundance of its food supply. Additionally, like Redbelly Snake terrestrial mollusks—especially small individuals such as new-hatched ones—are highly susceptible to natural and anthropogenic disturbances, as shown for mollusks by Douglas et al. (2013).

**Smooth Earth Snake (Virginia valeriae)**

**Taxonomy.** Powell et al. (1992) show the general distribution of the subspecies of Smooth Earth Snake in the eastern USA. The Western Smooth Earth Snake (V. v. elegans) is found in Kansas. The taxonomy of the valeriae group is presently undergoing revision (Pisani and Walker, in preparation), and it is anticipated that the western subspecies will be elevated to species status. Pending publication, we here use the standing taxonomy for the species.

**General Distribution, Abundance and Habitat.** The Smooth Earth Snake is found in east-central Kansas and is known from approximately 100 records (Figure 6). Pisani (2009b) documented the seasonal use of different habitats by Smooth Earth Snake and Northern Brown Snake (closely related to Redbelly Snake) in a Kansas population, and Pisani and Busby (2011) provide additional information about the species’ habitat, distribution, and ecology. This study has not discovered any differences in the species’ biology from that reported in these sources. Therefore, in this report we dwell mainly upon our studies of Redbelly Snake with reference to Smooth Earth Snake where we have found new population structure and/or ecological insights.

**Redbelly Snake (Storeria occipitomaculata)**

**Taxonomy and Color Variants.** General characteristics of Storeria occipitomaculata in Kansas (color, scutellation) appear in Collins et al (2010). Dorsal coloration is polymorphic, with variants occurring in the same litter (Bechtel 1978). The brown and gray morphs (Figure 7) (which may appear in a range from ash-gray through black, with variably-colored mid-dorsal stripe) occur in our samples in a 1:1 ratio. In addition to dorsal coloration, the brown and gray morphs differ in subtle biochemical characteristics (Grudzien and Owens 1991) that may represent complementary cold-temperature survival adaptations within populations (see below—Reproduction). Color variants ranging from albino through melanistic, as well as amelanistic have been reported from other parts of the range (Spencer, 1915; Watkins-Colwell 2002).
Redbelly Snake (*Storeria occipitomaculata*) occurs as scattered populations within its restricted range in eastern Kansas. The species in North America consists of three subspecies (Conant and Collins 1991):

- Northern Redbelly Snake, *Storeria o. occipitomaculata*
- Black Hills Redbelly Snake, *Storeria occipitomaculata pahasapae*
- Florida Redbelly Snake, *Storeria occipitomaculata obscura*

Only the nominate subspecies is found in Kansas.

**Post-Pleistocene Distribution.** Because small snakes are poorly represented (for various reasons—all related to small and fragile bone structure) in the fossil record, the pre-glacial distribution of Redbelly Snake and similar-sized species is undefined. Fontanella *et al.* (2007) examined molecular lineages of *Diadophis punctatus* and concluded that for central US forms re-invasion of habitats following retreat of the glacial ice was relatively rapid and began ca 7,000 years ago. *D. punctatus* is largely sympatric with *V. valeriae* in the central USA, and it is therefore not improbable that the latter also followed this pattern. In the east and northeast where *D. punctatus* is largely sympatric with *S. occipitomaculata* these authors indicate that refugia for small snakes may have existed along the edge of the ice, with similarly rapid re-colonization afterward, possibly beginning ~16,000 years ago. Studies of late-glacial and post-glacial riparian vegetation (Baker *et al.*, 1993; Morris *et al.* 2010) show a species-diversity reflective of habitat that would support these small snake species. There also is increasing evidence that terrestrial snails and slugs rapidly recolonized habitat as ice retreated (Pinceel *et al.* 2005).

Since both *V. valeriae* and *S. occipitomaculata* are viviparous, they may have been more successful at re-colonization than the oviparous *D. punctatus* which rely upon habitat temperatures more for embryogenesis. The rapid advance of agriculture post-settlement would logically alter large expanses of landscape, with concomitant fragmentation of habitat supportive of both Smooth Earth and Redbelly Snakes.

The historic distribution may additionally reflect that of the slugs (Figures 8–9) and land snails known to be the principal components of Redbelly Snake diet (see Rossman and Myer 1990, Gilhen 1984, Pisani and Busby 2012). For example, the slug *Philomycus carolinianus* in Illinois was described (Baker 1939) as being widespread and “a forest-loving species usually found in moist woodlands.” Baker goes on to describe what is essentially undisturbed old-growth forest, a habitat type today of very restricted occurrence in Illinois (IDNR 2011).

**General Present Distribution, Abundance and Habitat.** The range of Northern Redbelly Snake extends nominally through the eastern U.S., though populations are often widely separated (Figure 10). This is especially so in the post-Pleistocene “Prairie Peninsula” areas of the east-central USA, which through much of recorded settlement have been increasingly and intensively cultivated, reducing the forest habitat needed by Redbelly Snake. In Kansas, the Redbelly Snake is confined to forested regions near the eastern border of the state and is known from approximately 70 records (Figure 11), many of these from the same handful of sites. Suitable forest habitat is rare and highly fragmented. As is the case elsewhere in much of its range, native habitat has been greatly reduced by agricultural development (KARS 2002).

The effects of anthropogenic conversion of old-growth deciduous forest for agriculture should not be underestimated. Recent reviews (Werner and Raffa 2000, Kappes 2006, Douglas *et al.* 2013) consistently point to such conversion as having led to reduced abundance and
diversity (along with population fragmentation) of gastropod mollusks. These studies, by implication, connote the same for predators such as Redbelly Snake that are closely bound to these mollusks.

In our studies, Redbelly Snake has been restricted to woodland or woodland edge habitats in or near riparian areas. During exceptionally wet years, Redbelly Snake would be expected to utilize other adjacent habitats if those supported populations of snails and slugs. Indeed, Semlitsch and Moran’s (1984) study of Redbelly Snake in an environment more uniform than that in Kansas found that the snakes in their population moved to different habitats as a function of prey availability. Geluso and Harner (2011), refining data from Harner and Geluso (2011) noted that Redbelly Snakes only were captured in moist grassland habitat that was within 500 m of the varied wooded habitats they examined. The species had not been recorded in a similar survey 30 years earlier.

Several recent studies (Price et al. 2011, Knutson et al. 2002, Harner and Geluso 2011, Russell et al. 2002) have documented a high association between Redbelly Snake populations and predictably moist habitat that is within 400 m of woodland. This is not unexpected given the prey preferences noted elsewhere in this report.

The apparently patchy distribution and relatively low population densities of *Storeria occipitomaculata* makes detailed ecological study at best difficult, and what studies have appeared either involve very localized populations (Blanchard 1937) and/or artificial confinement within seasonally natural habitat (Semlitsch and Moran 1984). Thus, aside from ongoing studies by Kansas Biological Survey, much knowledge of the species in Kansas is inferential from isolated reports throughout its range (Pisani and Busby 2011, 2012a). As stated above, we feel it is valid to apply these inferences to Kansas populations.

Even in eastern portions of its range, Redbelly Snake is not encountered in large numbers. In Michigan the species is considerably more abundant than in Kansas (Duellman pers. comm.), yet an early study by Blanchard (1937) found just 157 over a 7-year period (annual captures ranging from just 9-36, average of 22) within an established conservation tract. More recently (Gray 2011) a study in known Ohio habitat of the species resulted in 22 captures out of 636 total captures (all snake species). Numbers encountered in hibernacula when those were excavated are highly variable and range from 2 (Carpenter 1953) to 158 (Lang 1969) with no indication of what governs aggregation size.

A typical statement of occurrence in Massachusetts is (from MassWildlife 2009:23): “This is probably our most mysterious small snake in terms of life history and behavior. Herpetologists often note that it can be found in abundance at one site, and yet appear entirely absent from numerous similar sites nearby.” In Iowa (LeClere 2013, IAGAP 2007, Kane et al. 2004), the species utilizes a variety of local habitats that support its documented prey base [gastropod mollusks (Rossman and Meyer 1990, Pisani and Busby 2012)].

Features of Critical (as well as Suitable) Habitat for Redbelly Snakes in Kansas are:

1. Native Deciduous Hardwood forest or woodland, preferably of high quality (large trees, undisturbed understory, deep leaf litter and humus layer that that retain
moisture and food for prey of the snakes), especially those in sites oriented such that they experience lower evapotranspiration (e.g. slopes with easterly or northerly aspect) and dominated by oaks and hickories (Pisani and Busby 2011). The type and overall condition of the forest may be less important than indication that the site has been forested for many decades—preferably since European settlement.)

2. Forested areas that show evidence of minimal disturbance to the understory and soil (e.g., as for occasional timber management per Smith 1940). Such sites will lack heavy erosion and cultivation and will not show indication of prolonged grazing.

3. Wetland and riparian habitats adjoining such forested tracts.

4. Abundant populations of terrestrial gastropods (slugs and snails).

5. Winter refugia (hibernacula) for the snakes; these may include rocky substrates that provide deeper (below maximal frost line depth—generally deeper than 50 cm) rock crevices and soil interstices as well as soils that contain large colonies (mounds 35cm or more in base diameter) of mound-building ants (*Formica, Pogonomyrmex, etc.*) used by Redbelly Snake, Smooth Earth Snake and other species as hibernacula (Carpenter 1953, Lang 1969, Pisani 2009a).


**Kansas Distribution and Abundance: Correlations between a specialized predator and its prey.** Kansas and adjacent Missouri records of Redbelly Snake occurrence are ecologically associated, with the species in western Missouri being found in far fewer localities than central and eastern Missouri, and then only in the Elk River Hills (SW Missouri) and Wooded Osage Plains (west-central Missouri) ecoregions (Figures 12-13). Thus, the very few recorded localities for western Missouri *S. occipitomaculata* are directly comparable to its limited Kansas distribution. Figure 8 shows much the same distribution of the slug *Philomyces carolinianus*, which as noted above and elsewhere in this report, is a principal prey of *S. occipitomaculata*.

This specialization limits its abundance elsewhere as well, and even in areas where it is more widespread the occurrences of local populations are described as “spotty” (Trapido 1944). Records displayed in the Kansas Herpetofaunal Atlas (KHA) map and from our research (Figure 14) show an essentially riparian distribution, largely within the Osage Cuestas ecoregion. This distribution closely parallels that of the native slug *Philomyces carolinianus* in Kansas (Figure 8, Branson 1962).

*Storeria occipitomaculata* also preys upon the smaller native (Branson 1962) slug *Deroceras laeve* which is more widely distributed and less habitat-specific than *Philomyces carolinianus*, due in part to transport in horticultural products (Figure 8). Semlitsch and Moran (1984) studied confined (in native habitat) populations of *Storeria occipitomaculata* in South Carolina and observed activity to be closely keyed to activity of prey (slug) species. Much less is known about the distribution and ecology of Kansas land snails, which collectively are another major food resource for *Storeria occipitomaculata*.

Thompson *et al.* (2006), in a study of water relations of slugs, noted that “Although *P. carolinianus* was more tolerant to desiccation [than *Deroceras laeve* or *Lehmannia valentiana*],
it is distributed primarily in relatively stable undisturbed habitat.” This is an additional parallel between the distributions of *Philomycus carolinianus* and *S. occipitomaculata*.

As the general physiologies and ecological requirements of terrestrial snails and slugs differ (Leonard 1959, Pilsbry 1948), they may serve as somewhat complementary seasonal food sources for *S. occipitomaculata* as well as its congener *S. dekayi*. Thompson *et al.* (2006) summarized the ecology of these gastropods as follows:

> “Even though slugs are closely related to snails, loss of the shell has lessened the need for calcium salts, so slugs can live in a wider range of habitats than most snails, including low calcium environments such as agricultural fields and suburban gardens (South, 1992). However, without a shell, slugs are more susceptible to desiccation. Slugs compensate for their poor control over water loss by having increased mobility and burrowing more easily into soil as well as having greater tolerance to body water losses than do snails.”

Cumulatively, these data strongly suggest that observations of established populations of gastropods in a habitat can serve as a reliable indicator of the value of that habitat to *S. occipitomaculata*. This has important implications for Kansas habitat assessments, as gastropod occurrence may, in certain habitats and/or seasons, be easier to locate than the snakes.

**Specific Proposal Questions Addressed By New Work**

*What is the extent of seasonal habitat use and niche dimensions of these species?*

In general, the current distribution of Redbelly Snake in Kansas represents the distribution of old-growth mixed-species forests with strong deciduous hardwood components that provide high levels of foliar calcium to the uppermost (Organic) soil layers by late-season leaf-fall. These forest remnants—as documented by Jordan and Black (2012) "supply microhabitat and microclimate condition capable of supporting a diversity of mollusks [slugs and snails]". These mollusks in turn represent the sole documented food species for Redbelly Snake, and the success of the snake is intimately bound to the abundance of its food supply. Additionally, like Redbelly Snake terrestrial mollusks—especially small individuals such as newly-hatched ones—are highly susceptible to natural and anthropogenic disturbances, as shown for mollusks by Douglas *et al.* (2013).

Our primary study sites differed from that of Pisani (2009a, b) in that no tallgrass habitat adjoined the wooded tracts where we found *V. valeriae*. Our recaptures of marked *V. valeriae* were not nearly as many as the 2009b study, but all captures-recaptures were within woodland boundaries. In Pisani’s (2009b) study, woodland leaf litter was thin, and the soil became noticeably drier during summer; this restricted access of snakes to earthworm prey. Worms were abundant in the moist microclimate beneath nearby grass thatch, and snakes (including *V. valeriae*) no doubt moved seasonally to exploit the resource. Several of Pisani’s marked *V. valeriae* were recaptured. Distance moved was minimal but snakes plainly traversed small linear distances to grass habitat as woodland resources diminished.
In our wooded sites, worms were evident beneath shelters during 2009 to early 2010. They were not evident during the sustained drought years, but in 2013 were evident beneath carpet shelters during fall periods of sustained rainfall. This coincided with resumed V. valeriae activity in transects.

**What is the association of Smooth Earth Snake and Redbelly Snake with ants?**

Observations of September-November 2013 activity of *Virginia valeriae* and *Storeria dekayi* in several of our study tracts supports the association with ants (*Formica subsericea*) noted by Pisani (2009a). Our surveys of 3 principal study tracts showed a resurgence of *V. valeriae* observations, with all observations being correlated with the snakes’ presence at ant nests in which the ants had become dormant for the season as described by Pisani (2009a) for a different population.

In addition to the effects on snakes noted above, the extended drought also was characterized by greatly reduced [at the surface] activity of the *Formica* ants regularly observed through our earlier funded study. As drought persisted through 2011, ant reproduction beneath shelter tins was absent or diminished when compared to earlier years. At the same site in 2012, *Formica* ants began normal activity in late March and early April. But by mid-April activity was less; by May it was greatly reduced, and none of the ant reproduction usually observed beneath shelters was apparent through the rest of 2012. The winter of 2012-2013 saw increased moisture from snow, and *Formica* ants were very evident beneath shelters through 2013, with many larvae [and later pupae] being tended.

Post-drought observations of *Virginia valeriae* and *Storeria dekayi* have uniformly been in association with the sizable mound nests of these ants (*Formica subsericea*). From late September through early November 2013, we began to see, as noted above, adult *V. valeriae* and adult plus one juvenile *S. dekayi* beneath shelters. These snakes were in association with the type of ant nests reported by Pisani (2009a); in one instance (fall 2013) an adult male *V. valeriae* rapidly entered an ant tunnel after being scale-clipped and released by Pisani.

Beyond the importance of the ant association to successful hibernation of these snakes (Pisani 2009a), we hypothesized in 2013 as part of our new study that the lower depths to which these ants excavate nests could serve as a refugium from drought for both the snakes and possibly for hatchling gastropods. Nest excavations and instrumentation to explore this hypothesis were beyond the scope of our funding, but intriguing references and subsequent inferences were obtained from literature sources.

Because of their agricultural importance, most nest studies have been done on Harvester Ants (*Pogonomyrmex*), and most investigators (e.g., Foster 1999, 2004) have not sampled soil at the lower reaches of nests.

Laundré (1990) investigated soil moisture recharge and retention beneath mound nests of Harvester Ants (*Pogonomyrmex*) in semi-arid habitats of northwestern Idaho. He observed that at depths between 60 and 100 cm, higher levels of moisture were found below mounds than in adjacent control areas, and that under ant mounds, approximately 1.3 cm more water was added to the soil between 60 and 100 cm during spring recharge. The increased supply of moisture was
temporary, as extra water under mounds was lost during dry summers and moisture conditions returned to pre-recharge levels as quickly as in control areas. Nagel (1969) recorded similar soil moisture characteristics beneath nests of *Pogonomyrmex occidentalis* in Kansas. She observed that “Soil beneath the mound was as much as 10% wetter than vegetated soil at equal depths during droughty periods.”

Ant nests may extend to great depth. Homburg and Sandor (2006) reported nests of Iowa Western Harvester Ants (*Pogonomyrmex occidentalis*) to extend as deep as 6m in deep soils. Nests also may be active for many years if habitat supports adequate food and water resources for ants. Homburg and Sandor (2006) noted that colonies persist until a queen dies, with a mean period of 43.5 years for *P. occidentalis*.

Though *Pogonomyrmex* are not sympatric with either of our study species, Wali and Kannowski (1975) studied mounds of 9 species (4 genera) of mound building North Dakota prairie ants and found similar physical characteristics of nests, suggesting that size and general excavation characteristics of ant species result in similar nest microhabitats. Scherba (1959) observed very similar results when investigating Illinois nests of *Formica ulkei*, a species ecologically similar to *F. subsericea* in our study areas. His study area consisted of eighty acres of mixed oak-hickory forest located on the Valparaiso terminal glacial moraine approximately 28 miles southwest of Chicago. Quoting from Scherba:

> The moisture content of this series of mound nests differed from that of the adjacent soil in the following ways:
> 2. At the 5 cm level, the mean weekly moisture content of the [adjacent] soil, measured once per week, is significantly higher than that of the nest, while at the 30 cm depth, the nest moisture content is significantly higher than that of the [adjacent] soil....
> 5. Mound nests have a striking ability to withstand drought. An opportunity to observe this was presented from August 13 to September 3, 1953, when a 22-day drought occurred in the Chicago region. Maximum air temperatures were raised in excess of 90°F for ten consecutive days and crop damage was severe. Weekly moisture observations during this period indicated that both nests and soil at a depth of 5 cm lost approximately 34 percent of their moisture content in three weeks. However, at a depth of 30 cm, the soil lost 29 percent of its moisture while the mound nests lost only 10 percent.

Nagel (1999) mentioned in passing that *Formica subsericea* is a species found more in older tracts of replanted native grass than her primary study area. This is the ant species, and one of the types of habitat, studied by Pisani (2009a); in that paper he cited Noble and Clausen (1936) who found snakes (*Storeria*) hibernating at a depth of 36 inches (90 cm) which is within the depths reported by the others (Laundré 1990; Nagel 1969; Scherba 1959)) as remaining more moist than adjoining soil during drought conditions.

The association with ants requires further investigation, as it may be an important predictor of habitat use, especially during hibernation and extreme drought. Thus, mound-building ants could be an important component of critical habitat for Redbelly and Smooth Earth snakes.
What is diet of each species and what are the implications of food availability on season activity and movement?

Pisani (2009b) found only earthworm setae as prey remnants in scat samples from V. valeriae in his study area. This was consistent with prior records for V. valeriae Pisani (2009b and references therein). Since 2009, we have obtained and examined scats from 50% of our S. occipitomaculata captures and 30% of V. valeriae captures. Our recent findings for V. valeriae prey show nothing to alter Pisani’s (2009b) conclusion that Smooth Earth Snake feeds exclusively upon surface-feeding earthworms of both native and introduced genera. Based upon our Kansas studies (Pisani 2009b, Busby and Pisani 2011), Smooth Earth Snake utilizes a wider range of habitats than does Redbelly Snake, which may reflect a wider occurrence across habitats of earthworms vs. gastropods. Drought of course affects earthworms as well as gastropods. Earthworms have been limited or absent during the most recent drought (per our field notes); though worms may burrow to considerable depth to escape drought, small snake species in northeast Kansas (save for Worm Snake, Carphophis vermis) lack the skull structure to forcibly burrow in soil, and so are incapable of following them.

Storeria occipitomaculata is, in dentition and behavior, exceptionally specialized for a diet of terrestrial gastropods (Rossman 1990, Rossman and Meyer 1990, doAmaral 1999, Ducey et al. 1999), though in captivity (and very rarely in the wild—Hamilton and Pollack 1956) some individuals have taken earthworms (Gloyd 1928, Ditmars 1936). When gastropods are scarce in the wild, they undoubtedly may consume earthworms or even other invertebrates, though our examination of scats from 11 Kansas individuals (m:f = 5:6; SVL 107-285 mm) revealed a single worm seta in one scat and 3-4 small setae in another. These may represent predation, or may have been incidentally ingested; we have not examined soil samples to assess the occurrence of setae from earthworm death and decomposition. We found no invertebrate exoskeletal parts.

Snails and slugs must rely upon crevices, or burrows of other animals to escape prolonged dry conditions. Though some terrestrial gastropods are known to burrow, they seem restricted to doing so in loose soils and not to any depth sufficient to survive extended drought (Boss 1974, Dourson and Dourson 2006, AMS 2008, Jokinen 1978). We have found no references to indicate that Kansas gastropods burrow to escape drought, and so in the absence of deep and moist refugia it is probable that drought mortality is considerable.

The principal prey species known to be consumed by Storeria occipitomaculata in natural habitats are the slugs Philomyclus carolinianus and Deroceras laeve. However, other slug species (native or introduced) such as Arion circumspectus also are eaten (Axtell, 1947; Gray et al., 2013), and the recorded preferences may simply reflect natural availability through time along with the seasonal observations of investigators. Per the studies of Rossman and Myer (1990) and doAmaral (1999), land snails also are an important component of the Redbelly Snake diet. In one study of prey preference by Black Hills Redbelly Snakes (Backlund 2010), captive snakes fed preferentially on the terrestrial snail Oreohelix cooperi. In this study, during one pre-drought year (on 5 August 2011) we were fortunate to observe an extensive hatch of [unidentified] snails that preceded by several weeks the expected birth period of Redbelly Snakes. This timing could (if regular) be an important food resource for neonate S. occipitomaculata.
There are no published observations of the food preferences of neonate Redbelly Snakes, though we can validly infer from their small size that newly-hatched snails and slugs are critical resources. Douglas et al. (2013) investigated the effects of anthropogenic disturbance in shaping both species diversity and community structure of land snails, especially what they termed micro-snails (those less than 0.5mm diameter), and there are striking parallels to the distribution and habitat of Redbelly Snake in Kansas and range-wide. Douglas et al. (2013) further stated that “Because of the convergence between traits of micro-snails and old-growth forests, it would appear that micro-snails would have a preference for the more natural conditions of undisturbed ecosystems.” Though encounters of neonate and juvenile Redbelly Snakes are even fewer than those of adults, neonate survival—and potential convergence with micro-snail (and slug) abundance—is by extension a determinant of Redbelly Snake population success.

**Are sympatric Ringneck Snakes potential predators on juveniles and subadults of Smooth Earth and Redbelly snakes?**

Though still not entirely resolved, we must advance a tentative yes to the question, particularly during severe droughts when prey for several snake species is severely restricted in abundance. As noted in our proposal, Gilhen (1984:138) reported a closely related subspecies of Ringneck Snake to consume a Redbelly Snake juvenile, and O’Donnell et al. (2007) report extensive predation on immature gartersnakes of two species by another race of Ringneck Snake; they also cite vertebrate consumption by the Kansas subspecies. Blanchard et al. (1979) kept 12 adults of the closely-related *D. p. edwardsii* in captivity and made observations of food choices/consumption (Table 3).

**Table 3. Results of feeding trials with Ringneck Snake (*Diadophis p. edwardsii*) in captivity (Blanchard *et al.* 1979).**

<table>
<thead>
<tr>
<th>Item</th>
<th>Total trials</th>
<th>Percent accepted as prey</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earthworms</td>
<td>18</td>
<td>39%</td>
</tr>
<tr>
<td>hatchling smooth green snakes, <em>Opheodrys vernalis</em></td>
<td>19</td>
<td>42%</td>
</tr>
<tr>
<td>newborn red-bellied snakes, <em>Storeria occipitomaculata</em></td>
<td>12</td>
<td>25%</td>
</tr>
<tr>
<td>hatchling five-lined skinks, <em>Eumecies fasciatus</em></td>
<td>27</td>
<td>63%</td>
</tr>
<tr>
<td>eggs of red-backed salamanders, <em>Plethodon cinereus</em></td>
<td>16</td>
<td>63%</td>
</tr>
</tbody>
</table>

*In Blanchard’s Michigan population, this subspecies predominantly eats these salamanders.*

Fitch (1999) reported earthworms as prey of northeast Kansas *Diadophis punctatus arnyi*, the Prairie Ringneck Snake. Quoting from Fitch (1999), “*the local population feeds upon earthworms almost to the exclusion of other kinds of prey.*” However, Fitch (1975), in his extensive ecological study of *D. p. arnyi*, recorded one hatchling Glass Lizard (*Ophisaurus attenuatus*) among the 224 prey items of the subspecies that he examined. And, Henderson (1970), working with Fitch on feeding and digestion of *D. p. arnyi*, mentioned in passing that he fed captives on earthworms and *Acris*. Henderson’s snakes did not accept the lizards he offered (native *Eumeces*, locally-purchased *Anolis*). Gehlbach (1974) referred to the same subspecies in Texas as “*thoroughly ophiophagous,*” and noted they readily consumed the snakes *Virginia*...
**striatula** (Rough Earth Snake), *Sonora episcopa* (Great Plains Ground Snake), *Tantilla atriceps* (Mexican Blackhead Snake), and *T. gracilis* (Flathead Snake) in captivity. All are similar in size and semi-fossorial behavior to Redbelly Snake and Smooth Earth Snake. He also stated (Gehlbach 1974:144) “Although arnyi commonly eats earthworms in Oklahoma, Kansas, and Missouri ... I have rarely seen it do so in Texas.” Ditmars (1936) reported an adult Redbelly Snake consumed by a [New York or New Jersey] Ringneck Snake (*Diadophis*).

During summer of 2012, Pisani also took radiographs of 160 KUMNH specimens of Prairie Ringneck Snake (*Diadophis punctatus arnyi*) from Douglas and Jefferson counties. He anticipated that any vertebrate prey in the stomach would thus be revealed. No remnants of vertebrate prey could be discerned.

This work is ongoing. Given the literature cited here, it is possible that *Diadophis* in Kansas could be a significant predator on at least juveniles of both GCN species during periods of ecological stress and earthworm absence, such as drought.

**Northeast Kansas Habitats**

**General Habitat Considerations**

Eastern Kansas historically is a habitat landscape that is transitional (ecotonal) between Tallgrass Prairie and Deciduous Woodland. Within this biotically rich zone are populations of plant and animal species that occupy a fragile mosaic of habitats more typical east or west of eastern Kansas. Though rightly regarded as peripheral, these populations increasingly are found to add crucial survival value to their species. The great potential importance—involving maintenance of genetic diversity and adaptability to marginally supportive microhabitats (Huey 1991)—of peripheral populations to ultimate survival of wide-ranging species has been discussed recently by several authors for diverse taxa (c.f., Channell and Lomolino 2000; O’Donnell and Rayburn 2009). This value is of particular significance when human influence poses a threat to animal survival (Channell and Lomolino 2000), as seems likely for northeast Kansas populations of *S. occipitomaculata*. Cagle (2008) used Mantel correlation tests to demonstrate the complex changes in distributions of generalist and specialist snake species along urban-agricultural-natural borders and associated habitat gradients. Several factors that cumulatively reduce habitat diversity (especially intensive agriculture and urban development) lead to considerably reduced abundance of specialist species (Kjoss 2000 and references therein).

**Relevant Forest and Land Use History**

Prior to intensive agricultural development, northeastern Kansas was dominated by tallgrass prairie on gently rolling hills. Forest was limited mainly to riparian zones and north-facing slopes which were less susceptible to fires, most of which presumably followed prevailing southerly winds. Based on public land surveys in the 1850s, Kindscher *et al.* (2005) estimated that land-cover in counties within our study area (Leavenworth, Wyandotte, Johnson, Douglas, Franklin, and Miami) were 75-94% tallgrass prairie, with most of the remainder being forest. The majority of this wooded area, particularly on uplands, was oak-hickory forest, woodland or savanna. Current land-cover is dominated by agriculture and much of the original forest has been
converted to agriculture for crop or livestock production. While the amount of forested land is currently similar to or greater than that in the 1850s, much of the current forest was formerly prairie and is now dominated by successional tree species and not by oaks and hickories. In other cases, original oak-hickory forest was partially cleared and used for grazing for a time, abandoned, and has now grown back to oak-hickory forest.

As noted above, the current distribution of Redbelly Snake in Kansas represents the remnant distribution of old-growth mixed-species forests with strong deciduous hardwood components that provide high levels of foliar calcium to the uppermost (organic) soil layers by late-season leaf-fall. As elaborated on later in this document, calcium supply is critical to the ability of habitat to support a diversity of mollusks [slugs and snails] which in turn represent the sole documented food species for Redbelly Snake. These mollusk and snake populations are intimately bound to the abundance of their supply of essential resources. Additionally, like Redbelly Snake terrestrial mollusks—especially small individuals such as new-hatched ones—are highly susceptible to natural and anthropogenic disturbances, as shown for mollusks by Douglas et al. (2013).

Over the course of the past 150 years, forest habitat was concentrated in riparian zones; based upon our observations and those of earlier authors, this was the main habitat used by *S. occipitomaculata*. While forested riparian zones were originally narrow, linear, and embedded in an extensive expanse of grassland, they also tended to be connected along streams, so that genetic exchange occurred among populations. In contrast, today habitat is highly fragmented and populations are likely genetically isolated from one another. Documenting any such isolation would be important to understanding population threats to this species, but is beyond the scope of our present funding.

**Optimum Habitats**

Optimum habitats for both species are those which:

1. Support abundant (or at least adequate) populations of prey during the snakes’ activity seasons;
2. Contain abundant winter hibernation refugia such as fragmented rock substrate in wooded areas, soils well-tunnelled by other animals, and/or nests of deep-burrowing, larger species of ants (c.f., Pisani 2009a and references therein);
3. Contain accessible refuges from seasonal, or prolonged regional, drought.

Because the earthworm prey of *V. valeriae* (Pisani 2009b) is more widely distributed across landscapes than that of *S. occipitomaculata*, the former is able to thrive in a broader range of habitats (Pisani and Busby 2011, Pisani 2009b).

Optimum habitat for *S. occipitomaculata*, which feeds almost solely upon several species of gastropod molluscs (Brown 1979, Pisani and Busby 2011; Pisani and Busby 2012), consists of largely riparian ones that offer continual support to gastropods as well as sufficient hibernation resources. These include palustrine woodlands, old-growth deciduous woodland adjacent to moist riparian habitats, and adjacent patches of palustrine grass (Busby and Pisani 2011; Pisani and Busby 2012; Geluso and Harner 2011). Those habitats in eastern Kansas generally are
lacking or ephemeral, and the species utilizes riparian woodland and adjacent long-established upland forest. *S. occipitomaculata* is known to “return to the same [hibernation site] in successive winters” (Lang 1969), and den mortality may be considerable during winter.

Neither is a highly vagile species, though individuals may move surprising distances for small snakes (e.g., 70-100 m over 5-7 days) (Blanchard 1937, Pisani 2009b and references therein). This is highly significant to conservation goals, as shall be discussed in detail below.

**Available Calcium, Terrestrial Mollusks, and Implications for Snake Habitat**

Earlier studies have, as noted elsewhere in this report, emphasized the importance of a stable population of slugs and snails as the sole documented prey of Redbelly Snake populations. However, no herpetological studies have actively investigated the inter-related environmental variables that are essential to these gastropod mollusks, despite the obvious importance of prey species to this specialized snake. We therefore began to examine studies of ecological factors that determine gastropod abundance in the belief that data from these would allow us to more accurately define Critical Habitat for Redbelly Snake and to better understand its basic ecology.

We have identified extractable calcium in the uppermost (3-6 cm) organic (Oe, Oi, Oa—SSGTC 2008) soil horizons (Figure 14) as a major indicator of land snail/slug density and species diversity in a given habitat, and by extension as a major component of Critical Habitat for Redbelly Snake. We believe this has great relevance for the distribution, abundance, and population stability of Redbelly Snake, in Kansas and elsewhere.

This relationship between gastropod abundance and available (e.g., extractable as Ca$^{+2}$) Calcium is well established. Beier *et al.* (2007) observed increasing trends in snail community richness and abundance, as well as increased canopy tree basal area, along a gradient of increasing soil calcium. Slugs and (especially) snails are critically dependent on extractable calcium in their habitats (Beyer and Saari 1977, Fournié and Chetail 1984). Calcium is incorporated into the shell of snails, and is utilized by both snails and slugs in a broad range of critical metabolic processes (Fournié and Chetail 1984). Beyond importance to soft tissue metabolic needs, calcium is critical to shell development in snails (Beyer and Saari 1977) and to production of defensive mucus in the slug genus *Deroceras* (Fournié and Chetail 1984). Among slugs, which have a reduced internal shell, calcium is more important to the Limacidae, the family to which *Deroceras* and *Philomycus* belong (Fournié and Chetail 1984)—both of which are important prey for Redbelly Snake (Busby and Pisani 2011 and references therein).

Though limestone-derived soils through eastern Kansas hold abundant calcium, snails and slugs derive most of their needs from thin organic soil horizons (Figure 14) at or within 6 cm of the surface (Hotopp 2002, Beyer and Saari 1977). Except on very acidic soils (pH < 4.5), soil calcium values in the Organic horizons of deciduous temperate forests are dependent primarily on litter-fall from the dominant tree and understory plant species present, and not on edaphic factors (Beyer and Saari 1977). Calcium return-rates from litter-fall in these forests exceed litter-fall rates for N, K, P and Mg (Table 4). Even earthworm biomass in forest habitats depends upon available calcium in these few horizons (Reich *et al.* 2005).
Table 4. Loss of nutrients from litter-fall in temperate zone forests (from Chabot and Hicks 1982).

<table>
<thead>
<tr>
<th>Reference</th>
<th>Region</th>
<th>Type</th>
<th>Leaf litter, g m⁻² yr⁻¹</th>
<th>Leaf litter, as % of total</th>
<th>Nutrient return rate, g m⁻² yr⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>119</td>
<td>Eurasia</td>
<td>Deciduous</td>
<td>343.4</td>
<td>58.9</td>
<td>3.60  1.87  7.36  1.03  11.34</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Evergreen</td>
<td>307.9</td>
<td>49.7</td>
<td>2.92  1.36  2.00  0.73  2.97  7.31</td>
</tr>
<tr>
<td>24, 26</td>
<td>New York</td>
<td>Deciduous</td>
<td>301.8</td>
<td>1.86  0.37  1.51</td>
<td>7.36  1.03  11.34</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Evergreen</td>
<td>277.1</td>
<td>1.36  0.20  0.73</td>
<td>2.97  0.50</td>
</tr>
<tr>
<td>78</td>
<td>South Carolina</td>
<td>Deciduous</td>
<td>428.4</td>
<td>85.3</td>
<td>2.97  9.94  2.22</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Evergreen</td>
<td>418.3</td>
<td>81.4</td>
<td>1.49  2.02  0.68</td>
</tr>
<tr>
<td>103</td>
<td>Scotland</td>
<td>Deciduous</td>
<td>—</td>
<td>6.40  0.40  3.75</td>
<td>7.00  1.60</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Evergreen</td>
<td>—</td>
<td>5.30  0.25  1.55</td>
<td>4.70  0.65</td>
</tr>
<tr>
<td>16</td>
<td>North Temp Zone</td>
<td>Deciduous</td>
<td>240.0</td>
<td>75.0</td>
<td>2.36  0.35  1.30  3.41  0.61</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Evergreen</td>
<td>260.0</td>
<td>70.3</td>
<td>2.63  0.37  0.53  1.91  0.27</td>
</tr>
</tbody>
</table>

Other investigators (Dauer et al. 2007; Bard 1945; Killingbeck 1986; Binkley and Giardina 1998), concentrating upon mineral availability and energy flow in mature forest habitats, demonstrated convincingly that the requisite extractable calcium in the O-horizons is derived largely from leaf-fall of a limited (in Kansas habitats) number of tree species (Table 5). Many of these tree species are common in forests inhabited by Redbelly Snake in northeast Kansas (Pisani and Busby 2011).


<table>
<thead>
<tr>
<th>Species</th>
<th>Average foliage calcium (% dry weight)</th>
<th>Reference*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hackberry</td>
<td>3.7</td>
<td>2</td>
</tr>
<tr>
<td>Basswood</td>
<td>2.9</td>
<td>1</td>
</tr>
<tr>
<td>Hop Hornbeam</td>
<td>2.6</td>
<td>1</td>
</tr>
<tr>
<td>Bitternut Hickory</td>
<td>2.2</td>
<td>1</td>
</tr>
<tr>
<td>Red Elm</td>
<td>2.1</td>
<td>1</td>
</tr>
<tr>
<td>Black Cherry</td>
<td>2.1</td>
<td>1</td>
</tr>
<tr>
<td>Sycamore</td>
<td>2.0</td>
<td>3</td>
</tr>
<tr>
<td>White Ash</td>
<td>2.0</td>
<td>4</td>
</tr>
<tr>
<td>Norway Maple</td>
<td>1.9</td>
<td>3</td>
</tr>
<tr>
<td>Pignut Hickory</td>
<td>1.8</td>
<td>1</td>
</tr>
<tr>
<td>Shagbark Hickory</td>
<td>1.8</td>
<td>1</td>
</tr>
<tr>
<td>Sugar Maple</td>
<td>1.5</td>
<td>1</td>
</tr>
<tr>
<td>White Oak</td>
<td>1.5</td>
<td>1</td>
</tr>
</tbody>
</table>
As discussed at length by Gilliam (2007), the herbaceous layer in temperate hardwood forests is also a major contributor to foliar litter, adding as much as 20% of litter volume in some deciduous forest habitats. Gilliam further noted that litter from these herbaceous plants is generally of higher nutrient content than tree foliage. Presently, there are no studies of the calcium contributed by the herbaceous component of forests to the O-horizons, especially in Kansas.

Considerable leaf-fall calcium is exchanged in the complex process of decomposition prior to being used by slugs and snails. In mixed deciduous hardwood forests such as those known to be used by Redbelly Snake, fungi and surface-feeding earthworms are the principal initiators of this process (Cromack et al. 1977, Jacob et al. 2009), establishing a pronounced web of connections among these plant, fungal and animal species (Figure 15). Fungi are primary agents of foliar-litter decomposition, and also are calcium concentrators that in turn pass calcium to foraging slugs and snails (Kappes 2006, Speiser in Barker 2001) (Table 6). These mollusks also consume moist senescent and decomposing plant material (the largest component of their diet) as well as fungi (the second largest) (Barker 2001), adding to calcium intake from foliar litter in the process.

### Table 6. Calcium on forest floor (O-horizon), North Carolina hardwood forest (adapted from Cromack, et al. 1977)

<table>
<thead>
<tr>
<th>Component</th>
<th>Calcium (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deciduous forest floor</td>
<td>15,620-17,220</td>
</tr>
<tr>
<td>Fungal hyphae</td>
<td>76,900-86,300</td>
</tr>
<tr>
<td>Fungal rhizomorphs</td>
<td>26,800-35,200</td>
</tr>
<tr>
<td>in gastropod mollusks from the habitat</td>
<td>178,400-324,200</td>
</tr>
</tbody>
</table>

Introduced European slugs, mainly of the genus *Arion*, are increasingly common in North America (Pinceel et al. 2005, Thomas 2010), and are less dependent upon O-horizon calcium than are the Limacid slugs (Brady and Pearce 2007, Beyer and Saari 1977) most often recorded as Redbelly Snake prey. *Arion* spp differ physiologically from native species and are independent of O-horizon calcium supply (Brady and Pearce 2007, Beyer and Saari 1977). In one example of this Brady and Pearce (2007) noted the scarcity of the native *Deroceras* beneath oaks (*Quercus*) in their study area; the distribution of *Arion subfuscus* was independent of calcium levels, whereas *Deroceras laeve*, and *D. reticulatum* [Limacidae] were most abundant under trees high in calcium, such as white ash, black locust, and tulip poplar. Redbelly Snake also eats *Arion* (Gray et al., 2013), and it presently is not apparent how, or if, the spread of introduced terrestrial mollusks will affect Redbelly Snake populations. Furthermore, prior studies have shown that land snail communities are often characterized by varying species responses to edaphic biotic and abiotic factors (Beier et al. 2012).

Terrestrial mollusks are organisms with low dispersal capabilities, and therefore local or regional populations are susceptible to natural and anthropogenic disturbance (Douglas et al., 2013). The trophic dependence of Redbelly Snake on these mollusks suggests therefore that snake populations may be expected to respond similarly.
Unfavorable Habitats and Detrimental Management

While defining Critical and Optimum habitats for these species plainly is a desirable outcome, as part of our funded study of these species, we have additionally been able to identify habitat characteristics and land management practices (beyond the obvious ones such as intensive development and/or agriculture) that are detrimental to Smooth Earth Snakes and Redbelly Snakes.

There is evidence that small tracts (especially ones intensively managed by mowing) may not support Redbelly Snakes. Studies of snake communities (Kjoss 2000, Kjoss and Litvaitis 2001) in a region of New Hampshire with land use characteristics not unlike those of our core study area found that small (<1.5 ha) habitat patches supported no Redbelly Snakes (or the closely related Brown Snake, *S. dekayi*). They inferred that this seeming anomaly could be due to absence of suitable prey in small patches with significantly lower vegetation heights and, by extension, drier soils and greatly reduced prey abundance. Frequent mowing was also correlated with absence of both species of *Storeria*. Brown Snakes (*S. dekayi*) seem to fare better in urban landscapes than *S. occipitomaculata* (Gray 2011, 2013; Gaul 2008). Wilson and Dorcas (2004) noted that *S. occipitomaculata* was less abundant than *S. dekayi* in developed [i.e., suburban] areas. Since causality was unknown, we initially examined available ecotoxicology literature for insight.

Brown Snakes (*S. dekayi*), though preferentially feeding upon gastropods, take a broader range of prey than do Redbelly Snakes (Gray 2014). Bracher and Bider (1982, cited in Campbell and Campbell 2001) noted that application of the insecticide Aminocarb to a forest community in the Laurentians of southwestern Québec significantly reduced activity of eastern garter, smooth green snake (*Opheodrys vernalis*), and northern redbelly (*S. o. occipitomaculata*). Campbell and Campbell (2001) hypothesized that the snakes could have been adversely affected by the Aminocarb spray through reduced prey availability. It is well-documented that snails and slugs, the principal prey of *S. occipitomaculata*, are major accumulators of various heavy metal pollutants that have long residency in soils, principally lead, cadmium and zinc (Triebskorn and Köhler, 1996; Berger and Dallinger 1993; Janssen and Dallinger 1991).

However, a 2-year study of herpetofaunal effects of differing maintenance methods in 5 treatment units along a power line right-of-way (ROW) in Centre County, PA (Yahner et al. 2001), for example, showed that *S. occipitomaculata* was:

- Found *exclusively* in the mixed short-vegetation habitats of the ROW as opposed to the adjacent deciduous forest;
- Absent (as were the other 4 snake species) from the Hand-cutting management unit, which was a mixed oak-shrub vegetation;
- Present in reduced number in the High-volume Basal Spray (shrub-forb vegetation) and Mowing+Herbicide (grass-shrub-forb) units than in the Stem-foliage Spray or Foliage Spray (alone) units (both grass-shrub-forb).

For details of species composition of these units, see Yahner et al. (2001). Yahner sampled from June through October 1998 and March through October 1999, and did not indicate
sampling frequency within months. It therefore is not clear if \textit{S. occipitomaculata} used the ROW for hibernation as well as later-season activity, but clearly the landscape configuration played a greater role in the species’ activity than did two types of herbicide application. Gastropod abundance also was not sampled.

The effects of commonly used herbicides on gastropods, and subsequently predators upon them, has not been well-explored, and though caution in their application is certainly warranted we conclude that their effects on Redbelly and Smooth Earth Snakes simply cannot presently be discerned. The topic merits further investigation.

We believe that a better explanation for the results noted by Wilson and Dorcas (2004) involves the complex inter-relations involved in soil calcium availability discussed above. Kappes (2006) examined the relation between forest management and abundances of snail and slug populations, noting that these were significantly higher in “…\textit{comparatively undisturbed forests than in forests with high anthropogenic disturbance}.” Kappes (2006) further elaborates the effects of forest management on available calcium in these systems.

Past land use can have persistent negative effects on habitat suitability for both species. An example is seen at one our study areas, University of Kansas’ Rice Woodland, where viable populations of Redbelly Snakes and Smooth Earth Snakes occur in mature oak-hickory forest habitat. Adjacent to the east side of the Rice Woodland and separated by a 10-m-wide gravel road, is the Boyd Tract managed by Baker University. The Boyd Tract contains a mix of mid-successional forest and oak woodland, much of which has a history of intensive agricultural use. Though USDA/NRCS soil types are similar (Figure 16), the classification does not take into account erosion or agricultural degradation. We established cover board transects on both tracts, since slope and aspect on Boyd is a close mirror image of that on Rice. To date we have found no Redbelly Snakes or Smooth Earth Snakes on Boyd, though both are found on Rice less than 50m away. It is unlikely that the lightly-traveled county road separating the tracts poses a true barrier to dispersal, as dead Redbelly Snakes have been occasionally salvaged from the road surface. It appears that the Boyd Tract does not provide suitable habitat for these snakes even 30+ years after cessation of agricultural use.

Another form of habitat degradation is hydrological modification and soil erosion. The prey base of both snake species is associated with moist soil environments. Intensive agricultural use often results in soil erosion. Loss of topsoil reduces organic matter and soil moisture-holding capacity. Hydrological alteration can result from stream channelization, down-cutting of streambeds associated with rapid soil runoff due to land clearing, and re-routing of runoff associated with road construction. Such land use changes often result in reduced soil moisture levels that may reduce snake habitat quality. Evidence of erosion and hydrological modification are present at many of our study sites where off-site land management has influenced runoff pattern on site. Examples include streambed erosion due to downstream channelization, downstream and upstream landuse, and reduced streamflow due to stream capture by road ditches. The degree to which these changes degrade snake habitat is unknown, but reversing these changes, where feasible, may provide an opportunity for meaningful habitat improvement.
With the onset of a high rainfall period in fall 2013, we examined hydrology of the adjoining edges of these 2 tracts in greater detail than previously. The general landscape suggests that overall drainage is from the higher hillsides of Boyd to the west-northwest lowland of Rice. County road maintenance deepened a drainage channel along the Boyd side of the road, diverting flow across to Rice and directing it north to flat, open pasture land. The site lends itself to future management improvement study.

Competing conservation-oriented land management practices can inadvertently prove deleterious to both species. The population of *Virginia valeriae* studied by Pisani (2005, 2009a, b) was set back when the landowner, seeking to control small-scale invasion of woody plants into the thick habitat of native prairie grasses, hayed the entire grassland in the same year that an early spring controlled burn was done. These decisions unfortunately coincided with the onset of the 2011-2013 extreme drought across Kansas. The complete loss of the accumulated grass thatch (used by *V. valeriae* and other species as spring and summer feeding habitat) was removed by the burn, and the subsequent drought and August haying combined to expose the soil surface to extreme insolation and desiccation. Following these management practices, no *V. valeriae* or other species formerly common (including the formerly ubiquitous Ring-neck Snake) were seen on the site through 2011; the diverse community documented by Pisani (2009a, b) was no longer evident.

At Pisani’s urging, 2012 management was changed such that the second haying of the management plan left a 50-75 m buffer strip along the woodland used by diverse snake species as fall-winter habitat and hibernacula. However, the persistent drought led to minimal grass recovery and no replenishment of the thick thatch that both retained soil moisture and sustained the surface-feeding earthworms used by *V. valeriae* and other species as food (Figure 17). During 2013 there was some recovery of trophically generalist snakes such as *Thamnophis sirtalis* and *Diadophis punctatus*. But trophic specialists like *V. valeriae*, *Carphophis vermis*, and even the less-specialized *Storeria dekayi* were not seen. The study is ongoing.

These studies and observations highlight the exceptionally fragile balance of habitat factors that affect populations of *V. valeriae* and *S. occipitomaculata*. Taken collectively with the drought effects noted previously, it becomes apparent that habitat changes (natural as well as anthropogenic) can rapidly reduce the food resources of these small specialist species with concomitant snake abundance effects.

Adults of *S. occipitomaculata* are more resistant to desiccation than adult Ringneck Snakes, *Diadophis punctatus*, or Worm Snakes, *Carphophis vermis* (Elick and Sealander 1972). This may contribute to the species’ ability to survive periodic dry spells in the western extremities of its range, though the resistance also may be of survival value to neonates as these typically are born in August. The ability of individual populations to survive in the absence of acceptable prey due to prolonged drought is unknown and may be more critical. The prolonged Kansas drought from late 2010-2013 will provide us opportunity in subsequent years to assess that. *Carphophis* is able to burrow in dense soil, somewhat enabling it to escape desiccation. *Carphophis* is therefore also capable of foraging on native prairie earthworm species that are fire-adapted subsurface feeders (James 1988). But *S. occipitomaculata* lacks the cranial osteology to burrow
very deeply (Dowling 1959, Pisani unpublished data) and so must utilize existing soil interstices and burrows of insects (ants, cicadas) or other animals.

The effect of controlled burns (woodland and/or grass habitat) is unknown at present. However, there is documentation that burns greatly reduce the abundance and diversity of gastropods in representative grassland habitats (Nekola 2002). That study also documented loss of thatch and the ecological consequences thereof.

Reproduction

We have not observed courtship or mating in Redbelly Snakes or Smooth Earth Snakes. However, the few literature records that exist for other parts of the country are instructive, and were summarized by Pisani (2009b) for Smooth Earth Snake. Both Redbelly Snakes and Smooth Earth Snakes are live-bearers.

*S. occipitomaculata* in Pennsylvania was reported breeding in September (Meshaka 2010); Wright and Wright (1957) cite observations of coitus during spring, mid-summer, and fall, including by a gravid female (verified after preservation) on July 9, 1921. Collins et al. (2010) states “mates spring and fall.” No reference was cited. These observations, combined with those below on fecundity, indicate that *S. occipitomaculata* demonstrates great plasticity in breeding season as part of an overall “r-selection” life history wherein females produce larger litters of smaller-sized young.

Collins et al. (2010) state that Kansas *V. valeriae* “mates in spring and may mate in fall”; no reference was cited. The general species description given by Wright and Wright (1957) do not clarify mating season of this species. However, the commonality of bimodal mating seasons in similar small snake species (Fitch 1999) suggests that it is a reasonable assumption for *V. valeriae* barring contrary evidence.

Seventy-five percent of adult female Redbelly Snakes in our sample were gravid, and contained an average of 7 well-developed embryos (range 4-13, sd 3.5). This is consistent with data of studies elsewhere (Blanchard 1937, Smith and Stephens 2003, Collins et al. 2010). Gravid females ranged from 193-245 mm snout-vent length (SVL) (mean 221 mm, sd 18.1). Again, this is consistent with other studies (see review in Kapfer 2010), though larger than SVL reported by Wilson and Dorcas (2004) in South Carolina.

Young are born at varying times between late July and early September, depending upon a number of conditions affecting gravid females (Smith and Stephens 2003). Young grow rapidly and are 107-125 mm (snout-vent) upon emergence from their first hibernation. This is comparable to (though slightly larger than) lengths in litters recorded by Semlitsch and Moran (1984).

Newborn *V. valeriae* are comparable in length to those of *S. occipitomaculata* but are more robust (Pisani 1971, Bradford 1973, Cervone 1983). The adaptive value of this is not known with certainty, but may serve (in combination with relatively earlier birth in any given year) to
increase their competitiveness for food with similar length neonate *Thamnophis* (more prolific and abundant) and *Diadophis* (far more abundant) which are ecologically similar (Fitch 1999).

Females of both *Storeria occipitomaculata* and *S. dekayi* bear relatively small young; mean offspring size is not correlated with female mass (Brodie and Ducey 1989, King 1993). A high percentage of mature females bear litters in any given year (Blanchard [1937] cited 90%). An additional characteristic of the genus is early female maturation, with some being reproductive 18 months after birth, and a near-doubling of litter size the following year (Fitch 1999, Gray 2014). Thus, the pattern within the genus is for females (especially larger ones) to invest more energy in litter size rather than size of neonates at birth. Through the 1970s this pattern was referred to as *r*-selection, and was supposed to lead to short-lived organisms with high fecundity. The model has been challenged by several authors (see Stearns 1984, King 1993, and references therein). Though King’s (1993) results were somewhat compromised (longer-term, captive gravid females did not thrive in captivity), they clearly indicated that larger females and females in better condition produce smaller (but more, per Brodie and Ducey 1989) offspring.

Applying an adaptationist interpretation (*sensu* Stearns 1984) to data from Kansas *Storeria*, of both species, it would seem that large litters of small young are not *r*-selection (density dependent) but rather are adaptive to accelerated recovery of a small local population when severely depleted by harsh periods of environmental variation. The effects of the 2011-2013 drought on our study populations will allow us to further investigate this.

Sex ratio of Redbelly Snake in our study is 1:1 (m:f).

**Isozymes and Adaptation in Redbelly Snake**

As noted above (Taxonomy—Color Variation) the color morphs of Redbelly Snake are distinguished by a subtle enzyme variation (Grudzien and Owens 1991) of currently unknown significance. LDH2b (lactate dehydrogenase) occurs only in the brown morph; DLR2b (Dihydrolipoamide reductase) and IDH1b (isocitrate dehydrogenase) are found only in the gray (with variants to black) morph. Though physiological ecology of enzymes is poorly explored in reptiles, these enzyme variants seem to play important complementary roles in facilitating muscle-metabolism adaptation (perhaps by facilitating mitochondrial function in muscle, Alfaro and Arnold 2001; Somero 2010; Senthilkumaar and Kalyanarama. 2010) to the frequent sudden cold weather often encountered in a Continental Climate biome.

Aleksiuk (1971) explored the temperature-activity properties of LDH isoenzymes, concluding that they "are more appropriately regarded as adaptations to a variable thermal regime..." Akelsiuk (1971) additionally concluded that they “...are the most probable biochemical basis of the instantaneous cold compensation observed in the standard metabolism of certain reptiles....” These enzyme variations in *Storeria occipitomaculata* in Kansas populations at the west periphery of its range may have high adaptive value throughout the range of the species (see discussion of this effect, in general terms, in Somero 2010). While well beyond the scope of our funded studies, this variation deserves further investigation.

**Population Density**
To date, there are insufficient recaptures of Redbelly Snakes to reliably estimate Kansas population densities. Abundance of the closely-related but more widely distributed and generalist-feeder, *S. dekayi* was estimated (Pisani 2009b) to be 32/ha, and was close to Fitch’s (1999) estimate for *S. dekayi*. Pisani (2009b) estimated the mean probability of capture of *S. dekayi* at 0.0206.

However, *S. occipitomaculata* is a specialist feeder on relatively lower-abundance prey, and thus can be predicted to have lower population sizes than even *V. valeriae*. The corresponding analysis for *V. valeriae* is much lower (19.4/ha, Pisani 2009b) than for *S. dekayi*; confidence limits of the two species overlap and so are potentially instructive with *V. valeriae* having a lower mean probability of capture (0.0171). These estimates for *S. occipitomaculata* are consistent with the low density noted in our studies and by others (Blanchard 1937, Cahoe and Troelstrup 2004, Axtell 1947). In a herpetofaunal survey done in south-central New York, Axtell (1947) found *S. occipitomaculata* numbering 119 of 2,967 snakes recorded (4%) vs 17.7% for the closely related *S. dekayi*. Kapfer (2010) studied *S. occipitomaculata* and *S. dekayi* in Wisconsin (well within the range-limits of the species) and reported that *S. occipitomaculata* “...were encountered at more sites than ... *S. dekayi* but in lower densities.”

**Mortality**

Our study over several years strongly suggests that fluctuations of preferred prey (due to environmental extremes) of *V. valeriae* and *S. occipitomaculata* are the most significant causes of mortality in both species. However, because both species are small and secretive, direct observations of mortalities are few. Below, we elaborate on two verified categories of mortality.

**Road Deaths**

“Road cruising” has for many years been one of the more popular herpetological collecting methods, as roads generally provide easily traversed transects through varied habitats (Dodd, *et al.* 1989). The hazards to herpetofauna are many, and the literature was reviewed by Blankenship (2012). *S. occipitomaculata* as well as *S. dekayi* move onto road surfaces for varying reasons that often reflect species abundance at a site as well as seasonal movements in general (Axtell 1947, Cahoe and Troelstrup 2004). Mortality of small snakes is highly variable. For example, McCollister and vanManen (2010) reported Redbelly Snake road mortality as minimal in their wildlife study, while others have noted that mortality may be locally heavy at times (MacKinnon *et al.* 2005, Gross 2013, Price *et al.* 2011). Gross (2013) reported that he

“... was able to locate clusters of snake [Midland Brownsnakes (*Storeria dekayi wrightorum*)] movement where individuals are drawn to cross in association with certain habitat types, topographic cues, or possibly even the scent trails made by other migrating snakes.”

Discovery of road-killed small snakes may more accurately reflect actual populations in an area, as larger snakes often are deliberately killed by motorists (Pisani, unpublished). When active during rains, *S. occipitomaculata* may be found on roads and may suffer vehicle mortality. Axtell (1947) recorded 26.8% of observed *S. occipitomaculata* were road mortalities (DORs) vs.
30.7% of the *S. dekayi*. Though these percentages are nearly the same, the fact that Axtell recorded 4.4 times as many *S. dekayi* as Redbelly Snakes affirms higher road mortality for Redbelly Snakes. Most were seen between the end of July and hibernation with the vast majority in a *ca* 1.5 mile length of heavily-traveled 3-lane highway. DORs often coincided with rains, but the greatest mortality was not correlated with rain; most DOR Redbelly Snakes seemed to be moving from the marsh-side of the road to the cliffs-side.

Taggart (pers. comm.) found 7 *S. occipitomaculata* (with 3 of those dead) on roads during a rainfall in Cherokee County (KS) where the species is far more abundant than elsewhere in the state. Specimens are cataloged in the Museum of the High Plains, Fort Hays. Of 72 verifiable records of *S. occipitomaculata* (including the Taggart ones mentioned above), collected between 1928 and 2013, 10 (14%) were road mortalities.

Road mortality records for *V. valeriae* are less common. In our historic data set just 4 of 92 records (4.3%) were road kills. Gibson and Merkle (2004) recorded some road mortality of *Storeria dekayi* and *S. occipitomaculata* in central Virginia, but none of *V. valeriae*. Ware (2008) reported similar results for *V. v. pulchra* in West Virginia. Overall, available data indicate that road kills do not seem to be a special hazard for these two species in Kansas, though in other areas local mortality may be quite significant.

**Predators**

Potential natural predators are many, as is true for small snakes in general. Known predators include American robin, *Turdus migratorius* (Axtell 1947), ruffed grouse, *Bonasa umbellus*, thirteen-lined ground squirrel, *Spermophilus tridecemlineatus*, large-mouth bass *Micropterus salmoides* (Knapik and Hodgson 1986), American kestrel, *Falco sparverius* (Smith and Stephens 2003 and references therein), Virginia opossum, *Didelphis virginiana* (Hamilton 1951) and several species of small rodents (Fitch 1999).

Though avian predators, being visually oriented, intuitively would seem the most abundant threat to Redbelly Snakes, and indeed are documented (Cahoe and Troelstrup, Jr. 2004; Axtell 1947), predation may only occur in a narrow time span when *S. occipitomaculata* is active on the surface. In the course of our study, we have seen three *S. occipitomaculata* active on the surface, all females and all during the month of June at different sites. McCallum *et al.* (2006) examined tail damage and the use of the tail as a distraction decoy by small snakes; their data suggests that for *S. occipitomaculata* other sources of predation may be more significant in general.

Snakes, especially those species that orient primarily by olfaction, are especially efficient predators on other snake species. Though racers (*Coluber*) are well-known predators on other snakes (Fitch 1999), they are visually-orienting predators (Pisani, unpublished), and would be expected to take either more active snakes (*Thamnophis, Opheodrys* per Hamilton and Pollack 1956) or very abundant ones (Hamilton and Pollack 1956). Hamilton and Pollack (1956) record very low incidence of racer predation on *S. dekayi*, and data from Kjoss (2000, table-5) suggests that Redbelly Snake abundance was not influenced by racer activity in her study area. Axtell (1947) recorded just one Redbelly Snake among prey of racers he examined.
Milk Snakes (*Lampropeltis triangulum*) also are predators upon other snakes as well as diverse other prey (Fitch 1999). They additionally orient primarily by olfaction and often forage beneath thatch, rocks and other shelter. Brown (1979) and Medsger (1922) reported a Redbelly Snake consumed by a Milk Snake, and Gray (2013) photographed a Milk Snake consuming a juvenile *S. dekayi*. Kjoss’s (2000) data suggest a slight influence of Milk Snake abundance on Redbelly Snake abundance. However, Axtell (1947) recorded Redbelly Snakes as 4 of 12 Milk Snake prey items. Overall, the relatively low incidence of Milk Snake predation on *Storeria* spp. may simply reflect relatively low *Storeria* abundance in the habitat of an opportunistic predator.

Racers have not been found in habitats where we have found Redbelly Snakes. Only one Milk Snake has been found in habitat where we have found Redbelly Snakes.

And as noted above, the potential exists for Kansas *Diadophis* to take juveniles of several snake species when worms are scarce during drought years.

We confirmed one instance of house cat predation on an adult Redbelly Snake (Ron Wyatt pers. comm.—locality data in Pisani and Busby 2011). Domestic and feral cats are well-documented predators of various small snake species (Mitchell and Beck 1992).

**Longevity**

Based on information for captive animals, neither Redbelly Snake nor Smooth Earth Snake appear to be long-lived (Table 7). An exceptional record for a captive specimen of the eastern subspecies *V. v. valeriae* of 9 yr 6 mo is also cited. No longevity records exist for wild population specimens.

**Table 7.** Maximum lifespan of Redbelly Snake and Smooth Earth Snake in captivity (from Slavens and Slavens (2003)).

<table>
<thead>
<tr>
<th>Species</th>
<th>Maximum lifespan in captivity</th>
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<tbody>
<tr>
<td>Redbelly Snake</td>
<td>4 yr 7 mo</td>
</tr>
<tr>
<td>Smooth Earth Snake</td>
<td>4 yr 1 mo (Pennsylvania subspecies most closely related to Kansas one)</td>
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</table>

**Conclusions**

This study and literature review adds considerably to knowledge of the Kansas distribution and ecology of these highly specialized species. Additionally, we have corrected several historical records that were misidentifications in museum databases.

Redbelly Snake and Smooth Earth Snake have large ranges in eastern North America, but in Kansas are imperiled components of the State’s overall biotic diversity. Both species occur in
small, scattered populations within restricted ranges in eastern Kansas. In particular, Redbelly Snake is a fragile, diet-specialist species with prey that is particularly vulnerable to drought and to anthropogenic alteration of habitat hydrology. It is important to note that use of historic (from preserved museum specimens and records) occurrences of *Storeria occipitomaculata*, need not accurately reflect the current distribution and population levels of the species in Kansas. In Wyandotte, Johnson and Douglas counties alone, the growth of urban and suburban development in the past 25 years has drastically reduced areas of native vegetation that are critical to overall native plant and animal diversity.

The Kansas distribution of Redbelly Snake appears to be confined to historically forested areas in or adjacent to riparian zones. Favored habitat is old-growth oak-hickory forest, but second-growth oak-hickory forest and other moist habitats that support gastropod prey may also be used.
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Taggart, T. 2008. Kansas herpetofaunal atlas (http://webcat.fhsu.edu/ksfauna/herps/)


**Figure 1.** Kansas drought maps for mid-March—mid-August 2011 through 2013 (from USDA Drought Monitor).
Figure 3. Redbelly Snake (RS) and Smooth Earth Snake (SES) captures at East Rice Woodland, 2009-2013. Sampling effort defined as number shelters x number sampling days ÷ 10.
Figure 4. Locations of Smooth Earth Snake records from our previous study (Pisani and Busby 2011) and the current study (red squares).
Figure 5. Locations of Redbelly Snake records from our previous study (Pisani and Busby 2011) and the current study (red squares).
Figure 6. Kansas records of Smooth Earth Snake.
Figure 7. Color morphs of *Storeria occipitomaculata*.
Figure 8. Kansas distribution of the slugs *Philomyrus carolinianus* (top) and *Deroceras laeve* (bottom) from Leonard 1959.
Figure 10. Distribution of the Redbelly Snake in North America (NatureServe 2014).
Figure 11. Kansas records of Redbelly Snake through 2013.
38. Boston Mountains*
   38a. Upper Boston Mountains*
   38b. Lower Boston Mountains*
39. Ozark Highlands
   39a. Springfield Plateau
   39b. Elk River Hills
   39c. White River Hills
   39d. Central Plateau
   39e. Osage / Gasconade River Hills^n
   39f. Saint Francois Knobs / Basins^n
   39g. Meramec River Hills^n
   39h. Current River Hills^n
   39i. Easter Ozark Border^n
   39j. Black River Hills Border^n
   39k. Prairie Ozark Border^n
40. Central Irregular Plains
   40a. Loess Flats and Till Plains
   40b. Osage Cuestas^n
   40c. Wooded Osage Plains
   40d. Cherokee Plains
   40e. Claypan Prairie^n
47. Western Corn Belt Plains
   47d. Missouri Alluvial Plain
   47e. Steeply Rolling Loess Prairies
   47f. Rolling Loess Prairies
   47h. Nebraska / Kansas Loess Hills^n
   47i. Loess and Glacial Drift Hills^n
   47m. Western Loess Hills
71. Interior Plateau*
    71m. Northern Shawnee Hills*
    71n. Southern Shawnee Hills*
72. Interior River Valleys and Hills
    72a. Wahash / Ohio Bottomlands*
    72d. Upper Mississippi Alluvial Plain
    72e. Middle Mississippi Alluvial Plain
    72f. River Hills
    72g. Southern Ozarkian River Bluffs*
    72i. Western Dissected Illinoian Till Plain*
    72j. Southern Illinoian Till Plain*
    72k. Cretaceous Hills*
    72I. Karstic Northern Ozarkian River Bluffs*
73. Mississippi Alluvial Plain
    73a. Northern Holocene Meander Belts
    73b. Northern Pleistocene Valley Trains*
    73c. Saint Francis Lowlands
    73f. Western Lowlands Holocene Meander Belts
    73g. Western Lowlands Pleistocene Valley Trains
74. Mississippi Valley Loess Plains
    74a. Bluff Hills
    74b. Loess Plains

Numbers are Level III ecoregions. A corresponding number with an alphabetic suffix indicates a Level IV ecoregion within the Level III ecoregion.

Figure 12. Missouri Level IV Ecoregions (Chapman et al. 2002)
Missouri ecoregions with no records of Redbelly Snake

<table>
<thead>
<tr>
<th>Ecoregion</th>
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<tbody>
<tr>
<td>39. Ozark Highlands</td>
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<td>39b. Elk River Hills</td>
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<tr>
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<tr>
<td>40a. Loess Flats and Till Plains</td>
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<tr>
<td>40d. Cherokee Plains</td>
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<tr>
<td>47. Western Corn Belt Plains</td>
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<tr>
<td>47d. Missouri Alluvial Plain</td>
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<tr>
<td>47e. Steeply Rolling Loess Prairies</td>
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<td>47f. Rolling Loess Prairies</td>
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Missouri ecoregions with few records of Redbelly Snake

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<th>Ecoregion</th>
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<tbody>
<tr>
<td>40. Central Irregular Plains</td>
</tr>
<tr>
<td>40c. Wooded Osage Plains</td>
</tr>
<tr>
<td>39. Ozark Highlands</td>
</tr>
<tr>
<td>39f. Saint Francois Knobs / Basins</td>
</tr>
<tr>
<td>39g. Meramec River Hills</td>
</tr>
</tbody>
</table>

**Figure 13.** Missouri records of Redbelly Snake (from Daniel and Edmond 2013) with notes on occurrence by ecoregion (as shown in Figure 10).
**Figure 14.** Soil Horizons (from [http://faculty.yc.edu/ycfaculty/ags105/week02/soilFormation/soilFormation_print.html](http://faculty.yc.edu/ycfaculty/ags105/week02/soilFormation/soilFormation_print.html))

The O-horizons (Organic) typically total less than 6cm depth.
**Figure 15.** Simplified calcium flowchart of Redbelly Snake habitat.
Figure 16. Soil units on University of Kansas Rice Woodland and Baker University Boyd Tract. (NRCS Websoil database, http://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm)
Figure 17. Site of Pisani’s *V. valeriae* study (Pisani 2005, 2009a, b) in 2007 (A), after 2011 haying (B, C), and in 2013 after slight regrowth within buffer strip. (Photos by G. Pisani, ©2012 All rights reserved).
Chapter II. Ecological Niche Modeling of Forest Species in Eastern Kansas

William H. Busby, Narayani Barve, and E. Townsend Peterson

Introduction

As landscapes dominated by human activities expand and see more intense use, natural ecosystems continue a pattern of alteration and contraction. In regions such as the Great Plains of North America, agriculture is now by far the dominant land use, and native vegetation is confined to small, scattered fragments of varying ecological condition. Development pressure on these remnants of native systems continues owing to urbanization, agricultural intensification, energy development, and climate change.

This set of large-scale processes has put pressure on native species that depend on natural habitats. As landscapes have become increasingly modified by human development, many native species have declined. In some cases, populations of formerly widespread and abundant species have shrunk to the point of regional extirpation (Kozol et al. 1986). Other species, especially non-natives, have increased to the point of becoming invasive and damaging to natural systems in other respects. Hence, given the rapid changes affecting natural and human-modified environments, human intervention to manage species and natural resources has become common-place. Fundamental to sound decision-making for species and natural resource management is accurate information not only about the status and distribution of plant and animal species, but also about intrinsic and extrinsic factors affecting those distributions. For many species, such basic information is limited or geographically incomplete; challenges involved in acquiring better data are considerable owing to costs of travel and field surveys, difficulties of land access, and the difficult-to-find nature of many species.

Development of quantitative geographic and ecological models by which to estimate ecological niches and geographic distributions of species is one approach for improving geographic information about biodiversity. Such models have been used in an expanding array of applications, such as illuminating distributions of rare and endangered species (Menon et al. 2010, Theresa et al. 2014), understanding species’ habitat requirements to reduce development impacts (Jarnevich and Laubhan 2011), estimating the geographic potential of invasive species (Ward 2007, Medley 2010) and disease agents (Peterson 2009), and exploring species’ distributions over historical time (Nyári et al. 2010).

These ecological niche models require only occurrence data for the species and raster GIS data layers that characterize relevant environmental parameters across relevant landscapes. Diverse inferential techniques for characterizing an ecological niche from these data streams,
which have been explored in detail to make possible modeling species for which few occurrences are available, such as for cryptic, difficult-to-locate or declining species. These approaches have been summarized in a recent conceptual overview and methodological summary (Peterson et al. 2011).

Here, we apply ecological niche modeling approaches to four reptile and amphibian species (redbelly snake, Storeria occipitomaculata; smooth earth snake, Virginia valeriae; broadhead skink, Plestiodon laticeps; spring peeper, Pseudacris crucifer) in Kansas, each of which is in need of modeling results to complement field-based data. These species, all threatened species in Kansas, all are known from small numbers of occurrences in the study area. We used Maxent to characterize requirements with respect to climate, soil characteristics, and vegetation type, and to predict potential areas of occurrence across an area of ~40,000 km$^2$. The four target species, all more widely distributed in eastern North America (Conant and Collins 1991), are at the periphery of their ranges in eastern Kansas (Collins et al. 2010), and are state threatened species, such that detailed distributional information is crucial.

**Methods**

We accumulated occurrence data for the four species across their distributional areas in eastern Kansas. Sources included specimen collections records in HerpNet, primarily from the collections of the University of Kansas and Fort Hays State University; database records from the Kansas Natural Heritage Inventory; collection records from Kansas Department of Wildlife, Parks, and Tourism; scientific literature (refs); and targeted field surveys by the authors. In light of the limited distributions of the four species in Kansas, and the cryptic nature of the three reptile species, numbers of occurrences that could be obtained were low: Plestiodon laticeps 30, Pseudacris crucifer 82, Storeria occipitomaculata 40, and Virginia valeriae 58.

Occurrence data were filtered based on date of collection and accuracy of the georeference—we used in analyses only localities with a maximum error radius $\leq$1000 m that were collected in or after 1970. To avoid over-representing areas that had been sampled intensively for these species, we overlaid a 0.05° grid on the region, rarefied occurrence data to a single point per grid square, and used a checkerboard to choose two sets of occurrence data for calibrating and evaluating models. Finally, we buffered all of the occurrence data by 2° (~150 km)—the portion of this area that fell within Kansas was used as the calibration area.

We explored diverse sources of environmental data sets for this analysis. Specifically, (1) we obtained 33 data layers describing aspects of soil qualities, by Natural Resources Conservation Service (NRCS; [http://datagateway.nrcs.usda.gov/](http://datagateway.nrcs.usda.gov/)); using the SSURGO soil data viewer ([http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/geo/?cid=nrcs142p2_053618](http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/geo/?cid=nrcs142p2_053618)), we converted the table-based soil database into geospatial data in ArcGIS 10.0. (2) We considered 3 variables related to topography (elevation, slope, aspect), which were downloaded at 30” resolution from [http://topotools.cr.usgs.gov/GMTED_viewer/](http://topotools.cr.usgs.gov/GMTED_viewer/). Finally, (3) we used a land use map (Kansas Biological Survey 2006), originally at 30 m spatial resolution as a categorical variable; we focused on the general forest/woodland class specifically. All data layers were resampled to 90 m spatial resolution. To reduce dimensionality of the soil variables, we used a
principal components analysis, in which the first 16 components explained 95% of the variation, which we retained for analysis, along with 2 categorical variables.

We calibrated models using Maxent 3.3.3 on default settings except for 50% random test points (bootstrapped), one replicate, and 1000 maximum iterations. We thresholded models to binary using least training presence approaches (Pearson et al. 2007, Peterson et al. 2011); in view of the fine-resolution nature of the occurrence data in this study, to take into account existence of some level of error in the occurrence data and their relationship to the environmental data, we modified the ‘least’ training presence approach to permit as much as 5% omission error. We evaluated the robustness of model predictions using partial receiver operating characteristic (ROC) approaches, which take into account differential meanings of omission and commission errors in spatial predictions of species’ occurrences (Peterson et al. 2008). We made a series of models incorporating all possible combinations of soil variables, topographic variables, and land use to explore the relative contribution of each suite of data layers.

Finally, we explored the implications of historical forest cover, with geospatial maps of forest cover as of the 1850s derived from Public Land Surveys (http://www.ksls.com/about_surveys.htm) and recently captured in digital raster formats by the Kansas Applied and Remote Sensing Program. We overlaid our initial model predictions (which did not take into account historical distributions of forest cover in any way) and occurrence data for each species on the forest cover data, to assess whether historical continuity of forest cover might help to explain where these rare species do and do not occur at present. We used cumulative binomial probability tests to assess whether occurrence data fell nonrandomly in suitable areas coinciding with historical forest cover, as opposed to suitable areas that do not fall in areas with historical forest cover.

**Results**

Models developed for three of the four species of reptiles and amphibians made predictions of independent evaluating data sets better than random expectations (Pseudacris crucifer, Storeria occipitomaculata, Virginia valeriae; see Figure 1). For each of these species, 9-11 of the tests (2 reciprocal sets of calibration versus evaluation X 6 combinations of environmental data layers) were statistically significant ($P < 0.05$), lending considerable confidence in the predictive ability of these models. From among the significant predictions, experts reviewed maps and chose the ‘best’ predictions based on their knowledge of the species and landscapes, but blind to historical forest cover patterns. For the fourth species, Plestiodon laticeps, no model predictions performed better than random expectations, such that we did not consider this species further in our analyses—to do so would be irresponsible over-interpretation of models that are not necessarily robust or predictive.

We used available occurrence data to assess whether known occurrences clustered nonrandomly in areas that had forest cover historically. For each of the three species with significant Maxent models (Pseudacris crucifer, Storeria occipitomaculata, and Virginia valeriae), a high proportion of occurrences fell in areas that had been forested historically (Figure 2) and the degree of coincidence is quite surprising. All showed nonrandom coincidence
of occurrences with historical forest cover, regardless of the occurrence data set or the environmental data set on which the models were based (P << 0.05; Figure 2).

Figure 1. Map of eastern Kansas, showing current (green) and historical (orange) forest extents, along with known occurrences of each of the four species that are the focus of this study.
Figure 2. Summary of geographic predictions for each of the four species examined in this study, showing known occurrences, present-day predictions of suitability across the landscape, and the relationship to historical forest cover.
Discussion

Niche-based models were successfully developed for three (*Pseudacris crucifer*, *Storeria occipitomaculata*, and *Virginia valeriae*) of four species examined at the periphery of their range in eastern Kansas. Most combinations (9 of 11) of predictor variables consisting of three sets of environmental data (soil characteristics, topography and natural vegetation type) produced significant models for each of the three species. Furthermore, the predictions of the distribution models were substantially enhanced by comparing recent occurrences to historic (1850s) forest cover. Given that historic forest cover was a minor component of land cover, averaging <20% of land cover in most counties in the study region, these results support the contention that these species are strongly associated with Eastern Deciduous Forest habitat.

That forest distribution 150 years ago correlates strongly with recent species occurrence records may indicate that these species have limited mobility and/or are dependent on old-growth forests sites. The limited mobility of many small anurans and snakes is well documented and may be exaggerated in fragmented landscapes where the matrix habitat is unsuitable or avoided. This is certainly the case for forest-adapted species in the Plains states were landuse is dominated by agriculture and grassland. An association by these species with historic forest sites could be attributable to any number of factors, including a suitable micro-climate, over-wintering sites, prey availability, or predator avoidance. In the study region, forest cover declines sharply along a strong longitudinal precipitation gradient and historic forest cover is associated with moister sites such as riparian zones and north-facing slopes. This tends to accentuate the micro-climate differences between open, upland habitats and bottomland forested habitats. This may accentuate habitat preference by species such as the redbelly snake (*Storeria occipitomaculata*), a gastropod specialist (Rossman 1990, Rossman and Meyer 1990, doAmaral 1999, Ducey et al. 1999). Slugs and snails are more concentrated in moist environments such as forests and riparian zones and avoid open habitats, at least during dry periods.

The ability of niche-based models to predict species distributions provides a useful and cost-effective tool for research and wildlife management. The increasing availability of environmental data coverages, often at finer scales and enhanced accuracy, will continue to make predictive modeling an increasingly valuable methodology in the natural resource field.

Literature Cited


