Seasonal vulnerability of snakes to road traffic at Wheeler National Wildlife Refuge

Jackson S. Schoettle

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SEASONAL VULNERABILITY OF SNAKES TO ROAD TRAFFIC
AT WHEELER NATIONAL WILDLIFE REFUGE

Jackson S. Schoettle

A THESIS

Submitted in partial fulfillment of the requirements
for the degree of Master of Science

in

Biological Sciences

to

The Graduate School

of

The University of Alabama in Huntsville

December 2023

Approved by:

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Dr. Jon Hakkila, Graduate Dean
Snakes are important predators and prey in North American food webs that exhibit seasonal activity patterns in temperate regions. During periods of heightened activity, they will often utilize roads both for traveling from one habitat patch to another and/or for thermoregulation. In this thesis, I explore how human recreational activities impact the diversity and distribution of snake communities by examining the relationships between the seasonality of human recreational activities and gravel road closures for waterfowl management on snake road mortality and activity at Wheeler National Wildlife Refuge in northern Alabama, USA. Many studies have investigated how snakes interact with paved roads, but there is little literature documenting how they may use gravel roads within a protected area, such as a wildlife refuge. We identified a total of 121 snakes (12 species) from our VES surveys and 91 snakes (9 species) from our road surveys. While we identified the most common species within the refuge, we likely underestimated overall species richness. We identified seasonal road trends in detectability across all snake species. While our occupancy values were high, our detection values ranged from 0.29—0.34 for all snakes. We had an abnormally low
number of dead-on road snakes. While this could be due to the nature of the refuge, it could also be due to limitations of our study design. We recommend Wheeler National Wildlife Refuge employ brief seasonal road closures during periods of peak snake activity.
ACKNOWLEDGEMENTS

This study would not have been possible without all the volunteered hours from lab members, friends, and family. I am forever immensely grateful for your time and energy in helping me complete my field work. A very special thank-you to Skylar Hopkins for countless hours of statistical discussion and walking me through R programming. Thank you to the people at Wheeler National Wildlife Refuge for being so accommodating and allowing me to do my research on their property. Their staff helped us install our dataloggers and were always helpful when responding to my many inquiries. I would like to thank my advisor Dr. Matthew Niemiller for all his help, guidance, and patience as I worked my way through my project planning and analysis, and to Dr. Kendall for her advisory role and making sure my teaching would streamline with my field schedule. Finally, I would not be here today if it were not for my family. From an early age, they have nurtured and encouraged my love of nature and animals and have continued their unwavering support throughout this Thesis. From the little kid who watched Steve Irwin every night, thank you for helping me do what I love.
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Chapter 1. Introduction

Snakes play important roles within many terrestrial and aquatic ecosystems as mid-trophic level species (Lind et al. 2005; Bohm et al. 2013). Although snakes and other reptiles in general are often overlooked in many conservation initiatives, they are subject to many of the same stressors, including emerging infectious diseases, persecution, and habitat loss and fragmentation (Langley et al. 1989; Andrews and Gibbons 2005; Clark et al. 2011; Lorch et al. 2016), as charismatic megafauna that receive more conservation support (Gibbons et al. 2000). Habitat fragmentation often involves construction of new roads, which cause high mortality rates for snake species that cross roads between habitat patches or attempt to use warm roads for thermoregulation (Smith and Dodd 2003; Andrews and Gibbons 2005; Fortney et al. 2012; McCardle and Fontenot 2016). Paved roads are especially well-studied, and some structural modifications can be created to allow snakes and other herpetofauna to pass safely under paved roads (Colley et al. 2017). Road closures have also been employed with positive effects on herpetofauna populations (Jochimsen et al. 2004, Jochimsen et al. 2014; Wagner et al. 2017). For example, Shawnee National Forest (managed by the US Forest service) closes a 4 km segment of a gravel road in Union County, Illinois (famously known as “Snake Road”) for 8 weeks biannually in spring and autumn which allows the snakes to have safe passage to and from their winter hibernacula (Palis 2016). In contrast, it is less clear how snakes interact with gravel roads, and whether interventions can be used to protect snake populations. Mediating snake road morality remains an underexplored option for improving snake population persistence around the
The Tennessee River Valley in northern Alabama is a biologically diverse region in the southeastern United States noted for its exceptional richness of freshwater fish, mussel, crayfish, and turtle species as well as significant diversity of many other terrestrial and aquatic groups (USFWS 2007). Historical records of snakes are infrequent and sporadic in this region (Steen et al. 2012; Guyer et al. 2019) and there is a substantial knowledge gap related to the richness and abundance of snakes in the Tennessee River Valley, in particular, which flows through southern sections of the Southwest Appalachians, Interior Plateau, and Southeastern Plains ecoregions (Knight et al. 2013). The distributions of several species, particularly small woodland snakes, are not well known as they are especially challenging to sample due to their cryptic behavior, camouflage, and relatively short active seasons (Kery 2002; Gu and Swihart 2004; Richardson et al. 2006; Steen 2010; Bartman et al. 2016). The less that is known about a population or species, the harder it becomes to detect trends and effectively manage (Crawford et al. 2020). This is especially true in the southeastern United States, where snakes and reptiles in general are rarely the primary focus of land and habitat management initiatives (Steen et al. 2010). Snake populations likely are heavily influenced by human activity and therefore are distributed differently across the landscape. Moreover, certain species likely are more susceptible to road mortality than others. For example, more active, active diurnal species such as *Coluber constrictor* and *Pantherophis spiloides* may experience higher rates of road mortality. Additionally, species that are more abundant will inherently be more at risk of road mortality as well (Hartmann et al. 2011).
Wheeler National Wildlife Refuge (NWR) is a 35,000-acre refuge containing a plethora of terrestrial and aquatic habitats including wetlands (both temporary and permanent), riparian systems, croplands, upland forests, bottomland forests, and agricultural lands (USFWS 2007; Cantrell and Wang 2018). While primarily managed for waterfowl, much of the refuge is likely important to other species, including snakes. Recently, human development has gradually expanded closer to the refuge’s borders. The Huntsville-Decatur-Madison area that surrounds Wheeler NWR is one of the fastest growing regions in not only the state, but the country (USFWS 2007; Ayala-Silva et al. 2009). Now the most populous city in Alabama, the population of Huntsville has experienced a 19.4% population growth rate since 2010 (City of Huntsville Data 2020). When expanded to include the entirety of Madison and Limestone counties, the estimated population now exceeds 700,000 people (City of Huntsville Data 2020). Pressures from this continued urbanization include clearing land for residential development, agricultural development, flood control projects, and transportation corridors (USFWS 2007; Ayala-Silva et al. 2009). Wheeler NWR shares borders with Redstone Arsenal, a Department of Defense military installation which includes the Marshall Space Flight Center, a center for the National Aeronautics and Space Administration (USFWS 2007; Cantrell and Wang 2018). Preserves surrounded by urban and suburban areas like Wheeler NWR are prime areas for management practices due to both specialist and generalist species seeking refuge (Cagle 2008).

While Wheeler NWR does not experience direct urbanization, it is subject to human traffic and recreational activity, including wildlife observation, birding, fishing, hiking, and hunting (Sexton et al. 2012). Wheeler NWR has approximately 650,000
visitors a year (USFWS 2007), and it is unclear how this level of human visitation impacts the resident snake communities. While populations of snakes, such as *Thamnophis* sp., can endure higher levels of human activity (Patrick and Gibbs 2009; Row *et al.* 2012), other snake species may be less tolerant of human disturbance (Andrews and Gibbons 2005; Willson *et al.* 2006; Bohm *et al.* 2013). There is also evidence that males of several species move more than females (especially during breeding season) putting them at increased risk of contact and mortality on roads (Rouse *et al.* 2011). Additionally, there are roads throughout and daily vehicle traffic in several sections of the refuge. Previous studies have demonstrated that road mortality is both positively associated with increased traffic and is a significant cause of snake mortality (Smith and Dodd 2003; Shepard *et al.* 2008; Jochimsen *et al.* 2014; McCardle and Fontenot 2016; Wagner *et al.* 2017). Wheeler NWR already closes some roads during certain times of the year to benefit waterfowl populations. By studying how human and road activity impact snake diversity, abundance, and mortality at Wheeler NWR, management recommendations can be developed that can benefit snake populations, such as seasonal road closures to reduce human-snake interactions during periods of high snake activity.

This study aimed to update the current list of snake taxa occurring in north-central Alabama, and specifically at Wheeler NWR, and generate management-relevant information on relative abundance, habitat use, seasonality, and potential threats to local populations. This study takes updated knowledge about current distributions and life habits to propose management techniques and practices beneficial to herpetological fauna within the refuge. While many studies have investigated snake interactions with paved
roads, this study attempts to address the gaps in literature by investigating how snakes interact with gravel roads within a protected area. I also aim to investigate the relationship between human recreational activities and snake road mortality and activity at Wheeler NWR in northern Alabama, USA.
Chapter 2. Materials and Methods

Study Area

Wheeler NWR offers a unique site to study human impacts on wildlife. Established in 1938 for waterfowl conservation, Wheeler NWR encompasses 35,000 acres within Madison, Limestone, and Morgan counties of northern Alabama (USGS 2007; Cantrell and Wang 2018). The Tennessee River bisects Wheeler NWR flowing from east to west and separates the refuge into north and south sections (Cantrell and Wang 2018). While both sections contain similar habitats, the northern section is marked by noticeably more human traffic and recreation. Most trails, roads, and the boundary with Redstone Arsenal fall on the northern half of the refuge.

All surveys in this study occurred within four primary areas within the northern section of the refuge: Blackwell Swamp/Rockhouse Road, Penney Bottoms, Beaverdam Peninsula, and Arrowhead Landing (Figure 2.1). Blackwell Swamp/Rockhouse is the largest area of the northern Wheeler NWR field sites. This site was split into the Blackwell Swamp Loop and Rockhouse Road loops. The Blackwell Swamp Loop is heavily vegetated mixed-hardwood forests surrounding a large swamp in the center. The Rockhouse Road Loop runs along the northern bank of the Tennessee River (Wheeler Lake). The northern half of the area is heavily forested and opens into Buckeye Pond in the center. Recreational human activities impacting this site include fishing, biking, horseback riding, birding/wildlife watching. The northern section of Rockhouse Road is closed for waterfowl from mid-October to mid-February. Penney Bottoms is a mixture of wetlands and hardwood forests that open into some agricultural fields. Recreational human impacts in this site include fishing, hunting, biking, and birding. It ends with a dike along Limestone Bay with a water control structure. This site typically is closed to vehicle traffic from mid-October to mid-February and from June through September. Beaverdam Peninsula is located on the edge of Limestone Bay north of Penney Bottoms. The center of the peninsula consists of agricultural fields. The edge near the water has some hardwood forest buffers. This is fishing hotspot on the refuge. This loop is closed to vehicle traffic from mid-October to mid-February for waterfowl. Arrowhead Landing
begins with agricultural fields with some hardwood forests mixed closer to Limestone Bay. Much of this site runs directly along the northern bank of the Tennessee River. It leads into the Eagle’s Nest Landing and White Springs Dike areas which contains some grassland habitat and are more heavily forested. These subsections are closed to vehicle traffic year-round. Common recreational activities in this area include boating, fishing, biking, birding, and running.

Table 2.1 Primary habitats, dominant human recreational activities, and road survey distance for four primary study areas in the northern section of Wheeler National Wildlife Refuge, Limestone-Madison cos., Alabama, USA.

<table>
<thead>
<tr>
<th>Area</th>
<th>Road Survey Distance (in km)</th>
<th>Primary Habitats</th>
<th>Popular Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arrowhead Landing</td>
<td>13-27 km</td>
<td>Agriculture fields, hardwood forests, grassland, mixed forests</td>
<td>Boating, Fishing, Biking, Birding, Running</td>
</tr>
<tr>
<td>Beaverdam Peninsula</td>
<td>5-6 km</td>
<td>Agriculture fields, hardwood buffers</td>
<td>Fishing</td>
</tr>
<tr>
<td>Blackwell Swamp</td>
<td>29-35 km</td>
<td>Hardwood forests, mixed forests, agriculture fields</td>
<td>Hunting, Fishing, Biking, Horseback Riding, Wildlife Viewing</td>
</tr>
<tr>
<td>Penney Bottoms</td>
<td>6-8 km</td>
<td>Wetlands, hardwood forests, agriculture fields</td>
<td>Fishing, Hunting, Biking, Birding</td>
</tr>
</tbody>
</table>
Visual Encounter Surveys

Visual encounter surveys (VESs) were conducted to assess snake diversity inhabiting the four primary study areas on Wheeler NWR. The locations of 47 VES sites across the four survey areas were randomly generated. All sites were chosen within proximity (≤250m) from a road (Figure 2.2). Between May 2022 and May 2023, each station was visited and surveyed six times. During each visit, up to four surveyors searched available habitats within a 150-m radius of the VES site center for a total of one-person hour of search effort. Surveys consisted of visual searches of terrestrial and aquatic habitats and included searching beneath logs, rocks, and other cover objects, which were returned to their original positions to minimize disturbance.
Figure 2.2. All VES locations of Wheeler National Wildlife Refuge, Limestone-Madison cos., Alabama, USA. There are 47 total locations across the refuge.

Road Surveys

Between May 2022 and May 2023, 157 road surveys were conducted across the four survey areas in the northern part of Wheeler NWR (Figure 2.3). To follow snake seasonal activity patterns in the southeastern U.S. (Schwiff et al. 2007; Jochimsen et al. 2014), road surveys were conducted daily in the late spring and summer (May–August 2022) decreasing to 2--3 times a week in the fall and winter (September–December 2022) and the following spring (February–May 2023). This amounted to 33 trips to Arrowhead, 33 to Beaverdam, 61 to Blackwell Swamp/Rockhouse and 29 to Penney Bottoms. Road surveys consisted of driving slowly (~16 kph/10 mph) searching for snakes both on and along the margins of the road. For the snakes observed alive on the road, the direction of
travel and activity was noted. Turtles and other herpetofauna observed on the road also were recorded. Animals were identified to the species level and were captured when possible.

![Figure 2.3](image)

**Figure 2.3.** All Road Survey routes and Traffic Logger locations of Wheeler National Wildlife Refuge, Limestone-Madison cos., Alabama, USA.

**Individual Snake Data Observations**

For each observed individual, we recorded the species, condition (alive versus dead) and life stage (adult versus juvenile). Their movement and activity patterns (basking, foraging, hiding under an object, etc.) as well as GPS location also were recorded. If snakes were moving on a road, their direction of travel was documented. Additionally, snake activity at the time of observation was noted (basking, swimming, etc.) for both VES and road surveys. If a nonvenomous snake could be captured, it was restrained temporarily in a snake bag and massed using a Pesola spring scale (nearest 0.3 g). Any physical abnormalities such as injuries were noted. Photographs were taken of
the snake with a 15.24 cm mechanical pencil for reference. These photos were used later to measure snout-vent-length (SVL) and relative-tail-length (RTL) in the program ImageJ (version 1.53, LOCI). After processing, each snake was released at their point of capture. Due to safety limitations, viperids were not handled and only observational data were taken.

**Environmental Data Collection**

At the start of each road survey and station VES, several environmental variables were recorded. A Kestrel handheld weather station (Model 5500, Kestrel Instruments) was used to measure air temperature (± 0.5°C), relative humidity (± 2%), and wind speed (larger of 3% of reading). A 5” Hanna digital soil thermometer (Model HI98331) was used to measure soil temperature. A soil probe (Kelway Instruments) was used to measure soil pH (±0.3 pH). Sky condition (overcast, partly cloudy, clear) and precipitation status (yes or no) were noted.

Prior to the field season, TRAFx G4 VEH (TRAFx Research, Canada) counters were installed at the Arrowhead Landing, Beaverdam Peninsula, and Blackwell Swamp/Rockhouse Road survey areas to record vehicular traffic during the field season (Figure 2.3). Daily road activity was recorded by taking the total number of cars sensed at the site and dividing that number by two since each car would trigger the counter when both entering and exiting the refuge.

Land cover data (NLCD 2014) were taken and used to generate relative LCD for a 100m buffer radius surrounding each VES station in ArcGIS Pro (ESRI, Version 10.0). The land cover variables included water, open development, low development, barren, deciduous forest, evergreen forest, mixed forest, shrub, herb, pasture, crops, permanent wetlands, and ephemeral wetlands.
**Statistical Analyses**

I quantified snake occupancy and detectability at VES stations and on roads using occupancy models built with the package Unmarked (Fiske and Chandler 2011) in R version 3.0.0 (R Core Team 2023). Before including model covariates, I visually checked for covariations by creating a series of plots, and when two variables were correlated, I eliminated the variables that was *a priori* expected to be less important to snake ecology or that had limited variability and thus limited power to explain variation in snake presence. This left two environmental variables (air temperature and wind speed) that were included that could impact snake detection and two land cover covariates (LCD Deciduous and LCD Water; NLCD 2014) that were included as covariates that could impact snake occupancy. All numerical variables were scaled to standardize the data. Time spent at each VES site during each survey was multiplied by the number of surveyors included and used as a measurement of search effort. For road surveys, total mileage driven was used as an effort measurement.

I also quantified overall snake detection and occupancy on roads using two similar occupancy models. One model included all four study areas and did not include road traffic data because one locality (Penney Bottoms) did not have a traffic counter installed. The second model included only the three study areas with traffic data. Therefore, these models included two or three environmental variables (air temperature, wind speed, and traffic intensity) that could impact snake detection and no covariates that could impact snake occupancy because road localities had no land cover data.

Using the models described above, we compared the estimated occupancy and detection probabilities for all snake species between VES stations and roads. We also ran
individual occupancy models for five snake species (*Agkistrodon contortrix, Coluber constrictor, Nerodia erythrogaster, Pantherophis spiloides,* and *Thamnophis saurita*) that represented both the most frequently observed species and covered a wide variety of ecological niche to compare species-level variation in occupancy. For species-level models, we did not include any covariates because data and therefore model power were limited for any individual species.
Chapter 3.  Results

Visual Encounter Surveys

While conducting 282 VES surveys across the 47 stations at the four study areas between May 2022 and May 2023, we observed 121 individual snakes, representing 12 species. The most observed species were *Nerodia erythrogaster* and *Coluber constrictor* (Table 2.1; Figures A.2 and A.3). Based on single-species occupancy models without covariates, occupancy probabilities varied from 0.67–0.99 and detectability varied from 0.18–0.44 among snake species (Figures A.7 and A.8).

After controlling for sampling effort, relative snake abundance had distinct seasonal peaks in spring (May) and fall (September), with relatively little snake activity in the summer (Figures 3.1 and 3.2). Snake community composition and structure were highly similar across localities, although communities were relatively difficult to characterize at Beaverdam due to low sample sizes (Figure 3.3).

When considering the probability that any snake species was found at any given VES station, we estimated that the overall occupancy probability was 0.94 (95% CI: 0.67–0.99) and the overall detectability was 0.30 (95% CI: 0.18–0.44). None of the environmental covariates were significant predictors of overall occupancy or detectability (Table 3.1). However, there was a trend towards snakes being less likely to occupy stations where a relatively high proportion of the surrounding 150m radius area was water (p=0.075). There was also a trend towards snakes being less detectable on days with relatively high wind speeds (p=0.09).

Road Surveys

While conducting 157 road surveys across the four survey areas between May 2022 and May 2023, we observed 91 individual snakes, representing nine species (Table 2.1). Of these, only nine were roadkill (9.89%). The most observed species were *Nerodia erythrogaster* and *Coluber constrictor* (Table 2.1). Based on single-species occupancy models without covariates, occupancy probabilities varied from 0.18–1.0 and detectability varied from 0.03—0.17 among snake species (Figures A.6-A.11).

When considering the probability that any snake species was found at any given road, we
estimated that the overall occupancy probability was 99%, but due to the limited number of roads surveyed, the 95% confidence interval was so broad that it included 0 and 1. The overall detectability R (95% CI: 0.26-0.43). None of the environmental covariates were significant predictors of detectability (Table 3.3), including traffic numbers.

**VES and Road Comparison**

Across all snake species, snakes were equally likely to occupy VES stations as roads, and given that snakes were present, we were equally likely to detect them in VES stations versus on roads (Figures A.6-A.11). Seasonal trends in relative snake abundance were also similar between VES stations and roads. However, there were some species-specific differences in road use by snakes.

**Table 3.1.** Summary of snake encounters arranged by species and survey encounter type. AOR stands for “Alive on Road” and DOR stands for “Dead on Road.”

<table>
<thead>
<tr>
<th>Species</th>
<th>VES Encounters</th>
<th>AOR</th>
<th>DOR</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Agkistrodon contortrix</em></td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td><em>Agkistrodon piscivorous</em></td>
<td>8</td>
<td>7</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td><em>Carphophis amoenous</em></td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td><em>Coluber constrictor</em></td>
<td>22</td>
<td>20</td>
<td>1</td>
<td>35</td>
</tr>
<tr>
<td><em>Lampropeltis getula</em></td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td><em>Nerodia erythrogaster</em></td>
<td>41</td>
<td>25</td>
<td>1</td>
<td>42</td>
</tr>
<tr>
<td><em>Nerodia sipedon</em></td>
<td>12</td>
<td>11</td>
<td>1</td>
<td>16</td>
</tr>
<tr>
<td><em>Opheodrys aestivus</em></td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td><em>Pantherophis spiloides</em></td>
<td>9</td>
<td>10</td>
<td>2</td>
<td>15</td>
</tr>
<tr>
<td><em>Storeria dekayi</em></td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td><em>Thamnophis saurita</em></td>
<td>11</td>
<td>7</td>
<td>3</td>
<td>17</td>
</tr>
<tr>
<td><em>Thamnophis sirtalis</em></td>
<td>9</td>
<td>1</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>121</strong></td>
<td><strong>82</strong></td>
<td><strong>9</strong></td>
<td><strong>212</strong></td>
</tr>
</tbody>
</table>
### Table 3.2. Occupancy model output for VES data.

<table>
<thead>
<tr>
<th>Covariates</th>
<th>Estimate</th>
<th>SE</th>
<th>z</th>
<th>P(z)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Occupancy Intercept</td>
<td>2.738</td>
<td>1.031</td>
<td>2.656</td>
<td>0.00791</td>
</tr>
<tr>
<td>LCD Water</td>
<td>-0.974</td>
<td>0.548</td>
<td>-1.777</td>
<td>0.07551</td>
</tr>
<tr>
<td>LCD Deciduous Forest</td>
<td>1.211</td>
<td>1.53</td>
<td>0.792</td>
<td>0.42846</td>
</tr>
<tr>
<td>Detection Intercept</td>
<td>-0.86706</td>
<td>0.31998</td>
<td>-2.71</td>
<td>0.00673</td>
</tr>
<tr>
<td>Air Temperature</td>
<td>0.07311</td>
<td>0.14125</td>
<td>0.518</td>
<td>0.60477</td>
</tr>
<tr>
<td>Wind Speed</td>
<td>0.23021</td>
<td>0.13607</td>
<td>1.692</td>
<td>0.09067</td>
</tr>
<tr>
<td>Traffic</td>
<td>0.00577</td>
<td>0.00735</td>
<td>0.786</td>
<td>0.786</td>
</tr>
</tbody>
</table>

### Table 3.3. Occupancy model output for Road data for all four field localities.

<table>
<thead>
<tr>
<th>Covariates</th>
<th>Estimate</th>
<th>SE</th>
<th>z</th>
<th>P(z)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Occupancy Intercept</td>
<td>10.5</td>
<td>93.8</td>
<td>0.112</td>
<td>0.911</td>
</tr>
<tr>
<td>Detection Intercept</td>
<td>-0.659</td>
<td>0.199</td>
<td>-3.317</td>
<td>0.000909</td>
</tr>
<tr>
<td>Air Temperature</td>
<td>0.128</td>
<td>0.205</td>
<td>0.624</td>
<td>0.532543</td>
</tr>
<tr>
<td>Wind Speed</td>
<td>-0.286</td>
<td>0.212</td>
<td>-1.348</td>
<td>0.177734</td>
</tr>
</tbody>
</table>

### Table 3.4. Occupancy model output for Road data including traffic as a covariate. This includes three localities since one (Penney Bottoms) did not have a traffic counter installed.

<table>
<thead>
<tr>
<th>Covariates</th>
<th>Estimate</th>
<th>SE</th>
<th>z</th>
<th>P(z)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Occupancy Intercept</td>
<td>8.97</td>
<td>51.2</td>
<td>0.175</td>
<td>0.861</td>
</tr>
<tr>
<td>Detection Intercept</td>
<td>-0.9073</td>
<td>0.246</td>
<td>-3.687</td>
<td>0.000227</td>
</tr>
<tr>
<td>Air Temperature</td>
<td>0.0406</td>
<td>0.257</td>
<td>0.158</td>
<td>0.874258</td>
</tr>
<tr>
<td>Wind Speed</td>
<td>-0.3581</td>
<td>0.267</td>
<td>-1.341</td>
<td>0.179868</td>
</tr>
<tr>
<td>Traffic</td>
<td>0.385</td>
<td>0.243</td>
<td>1.585</td>
<td>0.112967</td>
</tr>
</tbody>
</table>
### Table 3.5. Occupancy predictions, standard error and confidence intervals for VES and Road data.

<table>
<thead>
<tr>
<th>Survey Method</th>
<th>Prediction Value</th>
<th>SE</th>
<th>Lower</th>
<th>Upper</th>
</tr>
</thead>
<tbody>
<tr>
<td>VES</td>
<td>0.9392378</td>
<td>0.05884069</td>
<td>0.6720189</td>
<td>0.9914976</td>
</tr>
<tr>
<td>Road without Traffic</td>
<td>0.999716</td>
<td>0.002666628</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Road with Traffic</td>
<td>0.9998729</td>
<td>0.006509389</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

### Table 3.6. Detections predictions, standard error and confidence intervals for VES and Road data

<table>
<thead>
<tr>
<th>Survey Method</th>
<th>Prediction Value</th>
<th>SE</th>
<th>Lower</th>
<th>Upper</th>
</tr>
</thead>
<tbody>
<tr>
<td>VES</td>
<td>0.2958662</td>
<td>0.06666161</td>
<td>0.1832901</td>
<td>0.440309</td>
</tr>
<tr>
<td>Road without Traffic</td>
<td>0.3408664</td>
<td>0.04466162</td>
<td>0.2594093</td>
<td>0.4329488</td>
</tr>
<tr>
<td>Road with Traffic</td>
<td>0.2875544</td>
<td>0.05041262</td>
<td>0.1994732</td>
<td>0.3953225</td>
</tr>
</tbody>
</table>
Figure 3.1. All snake encounter locations of Wheeler National Wildlife Refuge, Limestone-Madison cos., Alabama, USA. This includes encounters from both VES and Road Surveys.

Figure 3.2. Plot showing Snakes per mile broken down by month for each locality. Note: there were no surveys conducted in January 2023.
Figure 3.3. Plot showing Snakes per VES trip broken down by month for each locality. Note: There were no surveys conducted in January 2023.

Figure 3.4 Snake road encounters by Locality.
Figure 3.5. Plot showing the detection probability and associated confidence interval for all snakes.
Figure 3.6. Plot showing the occupancy probability and associated confidence interval for all snakes.
Chapter 4. Discussion

Through VES and road surveys, I documented 12 of the 27 species that may potentially inhabit Wheeler NWR. Some undetected species, like queensnakes (*Regina septemvittata*) can be assumed to be heavily cryptic or low in population. It will thus take a considerable search effort to establish occupancy. For example, two detected species *A. contortrix* and *O. aestivus* only had one observation each throughout our entire study. Like *R. septemvittata*, these species are also thought to be cryptic and rare on the refuge property. Other undetected species, such as ring-necked snakes (*Diadophis punctatus*) and timber rattlesnakes (*Crotalus horridus*), are common throughout the Tennessee river valley but may be rare in Wheeler NWR due to a lack of suitable habitat. A study that aims to sample all habitat types within the refuge could help detect these species. Our study only randomly established our VES points, so we could have missed some key habitat patches. While we did not detect many species thought to be living on the refuge, we think our data accurately reflects the relative abundance of the most common species on the refuge.

While none of our covariates were significant (*p*>0.05), we did identify two moderately strong trends. The first was that proximity to water was negatively associated with snake occupancy. This trend is interesting considering our most encountered species was *N. erythrogaster*, an aquatic species commonly associated with water. We attribute this discrepancy to the multiple species being affected differently. For example, some species like *C. ameonus* and *C. constrictor* are more terrestrial and likely have negative or neutral associations with open water. More data with multiple field seasons would allow for stronger single species analysis allowing the factoring of potential confounding
covariates due to the varying ecology between species. Some species, such as *S. dekayi* were exclusively found near or in forests while other species like *P. spiloides* are generalist that are found in a variety of habitats. This is likely true of many land cover variables, since our study documented many species representing a wide range of ecological niches. Snakes were less detectable as wind speed increased. Another study found average wind speed to be marginally significant as well, though there were better covariates to explain detection (King and Meik 2023).

Occupancy values for the pooled species model were all near 1. This is expected with cryptic taxa (King and Meik 2023). Our primary interest was in the detection predictions. Snakes have notoriously low detection rates, so an absence of detection does not necessarily indicate an absence of occupancy. For example, we found a mudsnake (*Farancia abacura*) before official surveying began (Niemiller *et al.* 2021). However, we did not observe this species during the entirety of the survey. We know mudsnakes occupy parts of the refuge, but their rarity and cryptic nature makes detecting them an immense challenge. This is consistent with other studies of cryptic taxa, including snakes (Durso *et al.* 2013). Despite observing multiple individuals, our detection rates for Eastern Ribbonsnakes (*Thamnophis saurita*) were still very low (0.03-0.04). Considering these low values for a well-established snake in the area, it is possible our survey efforts were not enough to detect some of the more rare and ecologically cryptic snakes in the area. For example, there have been sparse reports of Diamond-backed Watersnakes (*Nerodia rhombifer*) on the refuge (Niemiller *et al.* 2022), but our survey efforts did not yield a specimen. Thus, while we have a good idea of the relative abundance of each species, we believe our study underestimates the overall species richness on the refuge.
Additionally, while we did conduct a few night surveys, most of our surveys (98%) took place during the day. Consequently, our detection numbers are likely biased towards diurnal species.

Overall, road-killed snakes were much less abundant throughout the study than expected (just nine total). It is possible that this was a low year for roadkill and thus our low roadkill numbers represent a year with low activity. However, low rates of road-killed snakes may be due to the nature of our study area. It may take upwards of 8-16 hours for roadkill to be scavenged (DiGregorio et al. 2011). Wheeler NWR is home to several potential bird and mammal species that may scavenge roadkill, such as vultures, hawks, raccoons, etc. We rarely visited the same sites in back-to-back days; therefore, there were typically at least 24 hours between site visits and considerable opportunity for road-killed snakes to be scavenged before detection. In addition, our study focused on more narrow gravel roads rather than paved roads. Snakes are at a higher risk of vehicle collision on paved roads (Fortney et al. 2012).

There was a correlation with detectability on VES surveys and detectability on roads for individual species. *Nerodia. erythrogaster* was our most encountered species for both survey types. This species also had the highest detectability of all single species models for both road (0.15) and VES (0.17) surveys. This indicates that more numerous species were more likely to be found during both survey methods than less numerous species. While not reflected in the roadkill numbers, we did notice a difference in response to vehicles by different taxa. Mainly, some taxa such as *C. constrictor, N. erythrogaster,* and *T. saurita* would often flee to cover upon noticing an approaching vehicle. *Coluber. constrictor* and *N. erythrogaster* had the lowest DOR rates of any species where we
found at least one DOR individual (5% and 4%, respectively). Despite this, they had the highest road detectability of all the species we for which we ran models (0.12 and 0.15 respectively). However, *P. spiloides* would consistently stop in an attempt at crypsis when encountered on roads. Additionally, smaller bodied species (like *S. dekayi*) are less likely to utilize roads than larger bodied species (Rouse *et al.* 2011). While we believe risk may vary by taxa, our low number of roadkill limits our ability to conclude this.

While not significant, we did notice a relatively high proportion of road-killed *T. saurita* (30% of all road encounters DOR) compared to other commonly encountered road species (5% of *C. constrictor* and 17% for *P. spiloides*). While more research is warranted, we think this may be due to *T. saurita* being of a large enough size to attempt crossing a road (as opposed to smaller species like *C. ameonus*) but is still small enough to not be seen by traffic. Species like *C. constrictor* and *P. spiloides* are larger and thus more likely to be seen while on the road. Interestingly, both species had higher detection probabilities than *T. saurita*, indicating they are more commonly found on roads despite less DOR detections.

Seasonal road closures to protect herpetofauna during periods of movement/vulnerability have been implemented with positive results (Palis 2016). To minimize road mortality and negative interactions with the public, we recommend Wheeler NWR consider short road closures (~2 weeks) in mid-May and mid-September based on our seasonality data. These are periods of peak snake movement to and from their winter hibernacula. Snakes with hibernacula near roads are at a much higher risk of mortality during these periods (Shepard *et al.* 2008; Fortney *et al.* 2012). Additionally, these time periods are peaks of viper activity. Closing roads during these activity peaks
would limit visitor interaction with venomous snakes, such as *A. piscivorous* and *A. contortrix*. Wheeler NWR already conducts seasonal road closures for some areas to protect avian fauna (USFWS 2007). However, we only propose this measure for the most active snake areas. For example, Rockhouse Road and Penney Bottoms had much more snake activity overall, so they would likely benefit from such proposed closures. Beaverdam Peninsula, however, experienced low activity overall, and therefore benefits to road closures may be more minimal. While decreased and highly enforced speed limits have been shown to reduce mortality risk (Schwiff *et al.* 2007), the narrow roads and already slow posted speed limit (15 mph) on Wheeler NWR may make this hard to enforce further.

**Conclusions and future directions**

We were unable to document direct evidence of significant impacts of vehicular traffic and human activity on snake populations at Wheeler NWR. Moreover, we did not detect variation among species in responses of snakes to levels of road traffic. However, we did make significant progress towards updating historical records of the northern Alabama by providing over 200 observations of 12 species during our 13-month study. While not an extensive list, we have established the commonly encountered species living within Wheeler NWR. We also provided data on snake seasonal activity. Lastly, we provided information on how snakes use gravel roads within a National Wildlife Refuge and their associated risks.

Future studies should aim to conduct a longer study (multiple field seasons). Larger sample sizes efforts would lead to stronger single species analysis. When possible,
it is recommended that multiple researchers are employed per survey to increase the percentage of snakes measured. This could potentially allow for inclusion of individual traits such as sex and life stage. Moreover, a more diverse array of sampling approaches, such as minnow traps, coverboards, drift fences, etc. may be warranted to detect rare species. There are a variety of primarily aquatic or fossorial species documented within the Tennesse River Valley. Using attenuated methods (like minnow traps for aquatic species) to catch rare species in combination with standard methods should yield a more accurate representation of the true species richness within Wheeler NWR.
Works Cited


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Langley WM, Lipps HW and Theis JF (1989) Responses of Kansas motorists to snake models on a rural highway. Transactions of the Kansas Academy of Science 92:


Appendix A.

Figure A.1. Map showing *Agkistrodon piscivorus* (Cottonmouth) encounter locations of Wheeler National Wildlife Refuge, Limestone-Madison cos., Alabama, USA. This includes encounters from both VES and Road Surveys.
Figure A.2. Map showing *Coluber constrictor* (Eastern racer) encounter locations of Wheeler National Wildlife Refuge, Limestone-Madison cos., Alabama, USA. This includes encounters from both VES and Road Surveys.
Figure A.3. Map showing *Nerodia erythrogaster* (Plain-bellied water snake) encounter locations of Wheeler National Wildlife Refuge, Limestone-Madison cos., Alabama, USA. This includes encounters from both VES and Road Surveys.
Figure A.4. Map showing *Pantherophis spiloides* (Eastern ratsnake) encounter locations of Wheeler National Wildlife Refuge, Limestone-Madison cos., Alabama, USA. This includes encounters from both VES and Road Surveys.
Figure A.5. Map showing *Thamnophis saurita* (Eastern ribbonsnake) encounter locations of Wheeler National Wildlife Refuge, Limestone-Madison cos., Alabama, USA. This includes encounters from both VES and Road Surveys.

Figure A.6. Plot showing occupancy probability and associated confidence interval for VES surveys. Five species of snake were included: Watersnake (*Nerodia erythrogaster*), Ribbonsnake (*Thamnophis saurita*), Ratsnake (*Pantherophis spiloides*), Racer (*Coluber constrictor*), and Cottonmouth (*Agkistrodon piscivorus*).
Figure A.7. Plot showing detection probability and associated confidence interval for VES surveys. Five species of snake were included: Watersnake (*Nerodia erythrogaster*), Ribbonsnake (*Thamnophis saurita*), Ratsnake (*Pantherophis spiloides*), Racer (*Coluber constrictor*), and Cottonmouth (*Agkistrodon piscivorus*).

Figure A.8. Plot showing occupancy probability and associated confidence interval for Road surveys. Five species of snake were included: Watersnake (*Nerodia erythrogaster*), Ribbonsnake (*Thamnophis saurita*), Ratsnake (*Pantherophis spiloides*), Racer (*Coluber constrictor*), and Cottonmouth (*Agkistrodon piscivorus*).
Figure A.9. Plot showing detection probability and associated confidence interval for Road surveys. Five species of snake were included: Watersnake (*Nerodia erythrogaster*), Ribbonsnake (*Thamnophis saurita*), Ratsnake (*Pantherophis spiloides*), Racer (*Coluber constrictor*), and Cottonmouth (*Agkistrodon piscivorus*).

Figure A.10. Plot showing occupancy probability and associated confidence interval for Road surveys with traffic included as a covariate. This excludes the Penney Bottoms field station which did not have a traffic counter. Five species of snake were included: Watersnake (*Nerodia erythrogaster*), Ribbonsnake (*Thamnophis saurita*), Ratsnake (*Pantherophis spiloides*), Racer (*Coluber constrictor*), and Cottonmouth (*Agkistrodon piscivorus*).
Figure A.11. Plot showing detection probability and associated confidence interval for Road surveys with traffic included as a covariate. This excludes the Penney Bottoms field station which did not have a traffic counter. Five species of snake were included: Watersnake (*Nerodia erythrogaster*), Ribbonsnake (*Thamnophis saurita*), Ratsnake (*Pantherophis spiloides*), Racer (*Coluber constrictor*), and Cottonmouth (*Agkistrodon piscivorus*).