EFFECTIVENESS OF WILDLIFE MITIGATION TREATMENTS ALONG THE NELSONVILLE BYPASS

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16. Abstract

The Nelsonville Bypass is a 9 mile stretch of U.S. Route 33 that runs through the Wayne National Forest, an area high in species diversity and home to several threatened and endangered species. The motorist safety, economic and conservation values of building effective mitigation features that reduce vehicle-wildlife collisions along the bypass have been nationally recognized. Mitigation features include: high and low fencing to reduce wildlife trespass into the right-of-way (ROW), uni-directional jump outs for wildlife exit from the ROW, underpasses and ecopassages to maintain habitat connectivity across the highway, high-mast lighting to lure bats above traffic flow, and replacement of wetlands and bat roosting habitat. Our two-year study employed road surveys, continuous monitoring of jump outs and wildlife passages, population estimations, detailed mapping of fence structures and breaches, and radio telemetry of an endangered target species. Road surveys of the bypass and control highways revealed that the mitigation structures reduced deer-vehicle collisions, but collisions still occurred on the bypass. Although, generally well-constructed, we identified several ways in which the mitigation features could be made more effective. Placement of fencing near the outer boundary of the ROW made it vulnerable to damage from erosion and tree falls, and isolated high-quality habitats within the ROW. Placement of the fence within 30-50 ft. of the roadway on less rugged terrain away from the forest would likely reduce costs of construction and maintenance while allowing wildlife access to habitat within the ROW. We also recommended regular maintenance inspections and mowing on both sides of the fencing. Jump outs were effective uni-directional exits, but wildlife, particularly deer, were not compelled to exit the expansive area within the ROW fencing. Placement of the fence with jump outs closer to the road would reduce habitat within the fence and combined with traffic noise may increase jump out use. Large wildlife underpasses and crossings were well used by a variety of mammal species. Smaller mammals used the small wildlife ecopassages. Reptiles and amphibians avoided the use of underpasses and road mortality rates of amphibians were high on Ohio State Route 78 (tributary road) near wetlands. Placement and passage design were contributing factors to high amphibian mortality. Radio-tracking of rattlesnakes discovered that snakes easily trespassed the small wildlife fencing and used the habitat within the ROW, likely because it was warmer than the surrounding forested habitat. No road mortality or attempted road crossings by rattlesnakes were detected. Finally, while bats foraged near the lights, most species were detected with equal frequency at different heights under the lighting. Our report details these findings and provides additional recommendations to improve design and construction of wildlife mitigation features both along the Nelsonville Bypass, and for future design of mitigation features for roadways in high-density wildlife areas.

17. Key Words

Nelsonville Bypass, RT 33, Wildlife Mitigation, Vehicle-wildlife Collision, Deer, Amphibians, Reptiles, Ecopassages, Wildlife Underpasses, Wayne National Forest, Habitat Connectivity, Conservation

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EXECUTIVE SUMMARY

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The Ohio Department of Transportation (ODOT) constructed several mitigation structures to minimize vehicle-wildlife interactions along the U.S. 33 Nelsonville Bypass (NVBP) bisecting the Wayne National Forest (WNF). Two primary objectives motivated the design and construction of the wildlife mitigation features. The first objective was to reduce the impact on wildlife living in the WNF by minimizing road mortality, maintaining population connectivity across the bypass, and reducing the impact of habitat loss. The second objective was to reduce large wildlife-vehicle collisions as a matter of safety in an area known to possess a substantial white-tailed deer population. The purpose of this research was to provide ODOT with a study of the effectiveness of the wildlife mitigation structures, including their design and implementation, and functionality. Based upon literature reviews and preliminary surveys by the investigators, the research team developed several hypotheses that related to the overall research objective. The hypotheses included:

1) High fencing constructed along the NVBP reduced the number of wildlife-vehicle collisions. This was evaluated through historical records of vehicle-wildlife collisions and comparisons of roadkill between the NVBP and control sites.
2) Wildlife use the ecopassage / underpass crossings to traverse and jump outs to egress the NVBP right-of-way (ROW) while minimizing ingress, and thus reducing wildlife-vehicle contact.
3) Reptiles, amphibians and other small wildlife use the small wildlife underpasses / ecopassages and culverts as a mechanism to traverse the NVBP and its tributaries to avoid wildlife-vehicle contact and minimize fragmentation of their populations.
4) The low wildlife (snake) fencing excludes snakes? from the ROW and directs them to wildlife ecopassages, reducing road mortality and maintaining population connectivity across the NVBP.
5) The barrier fencing along Ohio State Route 78 (SR 78) funnels migrating amphibian species to ecopassages, allowing them to migrate between terrestrial and aquatic habitats.
6) High-mast lighting along the NVBP lures feeding bats to heights above the flow of traffic, reducing animal-vehicle collisions while simultaneously providing lighting for interchanges.

Researchers conducted roadkill surveys, wildlife-vehicle crash analyses, fencing permeability surveys, population estimation, radio-telemetry and behavioral observations to identify wildlife use of the ROW and to evaluate the effectiveness of the mitigation features in reducing animal-vehicle collisions and wildlife mortality along the NVBP. Infrared and motion sensitive camera traps were installed to continuously monitor use of underpasses, jump outs, and ecopassages to test the hypothesis that wildlife were using these structures as designed and intended. Reptiles were monitored using radio-telemetry and box traps along the snake fence to

evaluate fence and ecopassage effectiveness, in addition to camera monitoring. Amphibian responses to barrier fences and ecopassages were monitored using break-beam sensor activated cameras, pitfall traps, nightly surveys, road mortality surveys, and road crossing behavior studies. Acoustic detection equipment monitored bat activity in areas with high-mast lighting.

More than 103 vertebrate species were detected in our combined studies (Table ES-1) and at least 80 species were found dead on the road (Table ES-2). Animal-vehicle collisions accounted for 17.5% of the reported traffic accidents on the NVBP. Although higher than the statewide and Athens-Hocking two-county average, 17.5% is much lower than the 49% and 56% of the reported crashes that were wildlife-vehicle accidents in our two control sites. White-tailed Deer were the primary species in reported accidents, however, many wildlife species were struck without accident reporting due to no or minimal vehicular damage. Other wildlife species that had lower collision rates on the NVBP than in our control sites, included the Virginia opossum, raccoon and eastern cottontail (Table ES-2). The reduction in accidents relative to control sites suggests that the high wildlife fencing and accompanying jump outs along the NVBP reduced deer-related traffic crashes during the first three years of the NVBP being open. Because the high fencing was mostly placed on the outer perimeter, deer trespassed into the ROW in sections where tree falls, vandalism and erosion had created openings in the fence. Deer also made use of interchanges to enter and exit the ROW. Frequently, deer entered the ROW and remained there to access the forage, especially during June-July when the ROW vegetation provided abundant high-quality browse. Another peak in deer ROW use was during the reproductive (rut) season (October-December), when male deer travel extensively in search of mates. Although deer did use jump outs to exit the ROW, they often were not compelled to exit the ROW and remained in the ROW to browse. However, the deer extensively used the large wildlife underpasses and bridges to access habitat on the two sides of the NVBP, which likely contributed to relatively low percentage of deer-vehicle accidents along the NVBP segment.

Numerous white-tailed deer, coyotes and other mammals used the two large animal underpasses that were not shared with off-road vehicles (ORVs) (Table ES-1). The volume of wildlife moving through the large underpasses indicates that these crossings are a successful mitigation strategy for mammals. Placement of the fence and openings compromised the fence and jumpouts as a mitigation strategy. Efficacy can be increased by regular (semi-annual) inspection and maintenance to repair openings. The location of the fence along the ROW boundary increases damage from tree falls, makes inspection and maintenance challenging, and isolates high-quality foraging habitat from deer. Thus, deer actively entered the ROW and avoided using the jump outs on many occasions.

The low snake fence was permeable to snakes that could readily trespass into the ROW through holes, over vegetation, and across tree falls. The fencing suffered extensive damage from washouts on steep slopes and corrosion in areas with acidic soils, overgrowth, and tree falls that knocked down the fence. Where the fence was intact and nearby vegetation removed, both snakes and turtles were frequently deterred alongside the fence, suggesting the barrier could direct animal movement.

Reptile and amphibian use of the small ecopassages as detected by cameras was minimal. No snakes or turtles used the small wildlife ecopassages under the NVBP, however, large numbers of small mammals used these corridors successfully. Amphibian ecopassages along SR 78 were used by less than 0.2% of the amphibians that attempted to move from uplands to wetlands and between wetlands. The limited success of the amphibian ecopassage was due to suboptimal design parameters, and most of the mortality occurred in areas between upland and wetland habitats.

The ROW may have created open habitat that provided benefits for the rattlesnake population. However, these benefits are contingent on ROW habitats not increasing mortality rates. If rattlesnakes are attracted to the ROW and subsequently killed by vehicles, humans, or other predators, then these features constitute an ecological trap. In particular, snake fencing should not inhibit access to ROW areas that provide high-quality basking habitat.

This study found little evidence that high-mast lighting is effective at mitigating mortality of bats along the roads. With the possible exception of Big Brown Bats, activity of most bat species and species groups increased the most at the level of traffic under high-mast lights, suggesting these bats are foraging at heights where they are at risk of traffic collisions regardless of the height of adjacent highway lighting.

The findings and conclusions of this study should assist ODOT in developing preliminary design policies and guidelines for roadway wildlife mitigation structures for engineers and planners. The policies should include the involvement of ecologists, biologists, and other wildlife experts to identify potential impacts to various wildlife species like those studied herein. Although we provide recommendations regarding mitigation structure placement and construction, any new strucutres installed based on our recommendations should be empirically studied to evaluate function, impacts on wildlife, feasibility, and maintenance to evaluate their effectiveness. Our findings corroborate that roadway cuts create edge and open habitats that are attractive to a variety of species because they provide forage and thermoregulatory opportunities that may simultaneously increase the likelihood of animal-vehicle collisions

Our primary recommendation is that wildlife mitigation structures should not be placed along the outer perimeter of the ROW, but within 30-50 ft. of and parallel to the travel lanes, thus allowing wildlife access to the ROW habitats but preventing access to the travel lanes. At the exterior edge of the ROW, damage from tree falls and erosion in rugged terrain compromised the fence and increased the difficulty and cost of repair. Furthermore, vegetation adjacent to the fence can be more easily maintained on the flat area near travel lanes. Vegetation maintenance is critical for fencing success as arboreal wildlife can use vegetation as a bridge to trespass over fencing. Our second recommendation is that wildlife passages targeting amphibians and reptiles be much larger (Clevenger and Huijser 2011, Gunson et al., 2016) and maintain a clear line-of-sight to the opposite side.

PROJECT BACKGROUND

The *National Environmental Policy Act of 1969* (NEPA) and subsequent laws and regulations outline a public process designed to identify, assess, and mitigate the possible impacts of agency actions on potentially affected portions of the human environment. This process, known as the "NEPA process" or the "environmental process," is required for all public agency activities involving Federal nexus, including a majority of roadway projects undertaken by the ODOT. Key requirements of the environmental process affecting the development of ODOT highway projects include developing and analyzing several alternatives for each proposed action, identifying potential impacts; avoiding and minimizing them if possible, and proposing mitigation for those that cannot be avoided or minimized. The process is conducted in the public venue and with a high coordination among public agencies and affected groups. Such a process for the NVBP ended in the publication by ODOT in June 2005 of a Final Environmental Impact

Statement (EIS) entitled "US 33 Nelsonville Bypass City of Nelsonville, Hocking and Athens Counties, Ohio (FHWA-OH-EIS-04-01-F)". The EIS cover page included the following statement:

> *This project consists of a proposal to upgrade a nine-mile (14.5 kilometer) section of existing US 33 to a four-lane controlled access highway between Haydenville in Hocking County and New Floodwood in Athens County. The purpose of this project is to provide US 33 macro-corridor service to statewide, regional, and local traffic. Offering macro-service in the project area will meet project needs of providing system linkage; improving safety; enhancing economic development in the region; and improving level of service (LOS) and deficiencies by better controlling access to US 33 and separating through and local traffic. The preferred alternative minimizes impact to the human and natural environment while meeting the project's purpose.*

Consultation between the WNF, ODOT and the Ohio Department of Natural Resources, Division of Wildlife resulted in recommendations concerning the nature, impact and strategies for mitigation that were incorporated into the highway construction process. Because the proposed roadway bisected the WNF, wildlife-vehicle crash prevention became a key mitigation component of the highway construction. The area harbored a substantial White-tailed Deer population, a prominent source of costly wildlife-vehicle interactions, but also populations of federally endangered Indiana Bats and Ohio endangered Timber Rattlesnakes, all potentially threatened by the NVBP construction and the high-speed traffic it would facilitate. A key set of mitigation strategies were adopted to minimize wildlife-vehicle interactions, including wildlife fatality, vehicle damage, and human injury. ODOT worked closely with agencies, particularly the U.S. Forest Service to develop, design and incorporate several mitigation treatments to protect wildlife into the construction of the NVBP Project. Evaluation of the effectiveness of specific mitigation treatments and the overall impact of the integrated mitigation program for this project may provide relevant and useful insights for current and future ODOT project development activities in areas with significant or vulnerable wildlife populations.

The construction cost associated with the development of environmental mitigation strategies has long been a controversial issue relative to the effectiveness of these strategies. Considering the vast roadway network in the United States (over 4 million miles and over 250 million registered vehicles), interactions between vehicular traffic and wildlife are numerous (USDOT 2017). Utilizing the National Highway Traffic Safety Administration's Fatality Analysis Reporting System (FARS), Langley et al. (2006) determined that nationwide there was an average of 165 people fatally injured each year on the roadways between 1995 and 2004 due to wildlife-vehicle collisions. A more recent investigation into the FARS database indicates that annual fatalities peaked in 2007 at 223. In 2012, a total of 174 persons nationwide were fatally injured due to wildlife-vehicle collisions (FARS, 2014). Considering the decreasing vehicle miles traveled across the nation, the number of fatalities per vehicle miles traveled has not differed between 2007 and 2012 and is approximately 0.07 fatalities per billion vehicle miles traveled. The National Safety Council annually estimates the average economic cost and average comprehensive cost per fatality at $1,420,000 and $4,459,000, respectively for 2011, which would amount to a $247,000,000 economic cost and a $775,800,000 comprehensive cost for the 174 fatally injured individuals. Huijser et al. (2008) estimate the total cost per year for deer-vehicle collisions across the nation is $8,388,000,000. To further complicate the issue of wildlife-vehicle interactions, collisions with animals are unlikely to be reported if the damage to the vehicle is less than $1,000, therefore most small animal collisions go unreported. Only in cases where damage costs are high or drivers are severely or fatally injured are wildlife-related collisions reported. Furthermore, targeting of small wildlife by vehicles, particularly snakes, is a well-documented phenomenon (Langley et al. 1989, Ashley et al. 2007) and most amphibians are small and never noticed by drivers. We are unaware of any studies that have documented the economic impact through loss of ecological services or potential tourist revenue as a consequence of wildlife loss. Although rarely if ever considered, wildlife-vehicle crash impacts on local animal populations add to the justification for mitigation because the WNF has a significant role in the southeastern Ohio tourist and wildlife economy. Therefore, the total economic cost associated with wildlife-vehicle collisions is difficult to pinpoint. The goal of this study was to identify the effectiveness of mitigation structures placed along the NVBP and evaluate if the structures reduce wildlife-vehicle interactions, and when possible determine the impact of the road on wildlife populations. Ohio University researchers used various mechanisms to evaluate the effectiveness of the wildlife mitigation structures installed along the NVBP to provide guidance for ODOT in the development and improvement of future treatments.

ODOT constructed several mitigation structures to replace habitats lost during roadway construction and to minimize wildlife-vehicle interactions including exclusionary fencing to prevent wildlife from trespassing the ROW, escape devices to allow ROW egress in the case of a trespass, and ecopassages to provide safe passage across the ROW. These structures included:

- Large cross-sectional area ecopassages (underpasses) for larger wildlife movement through the highway corridor,
- Small cross-sectional area travel ways with integrated directional barriers (fencing) for small mammals, reptiles and amphibians through the NVBP corridor and along SR 78,
- 8-ft. tall highway corridor fencing to exclude large fauna from ROW,
- Low fencing to exclude snakes, turtles and smaller wildlife from the ROW,
- 2-ft. tall curved plastic fencing to exclude snakes from the SR 78 roadway,
- One-way jump out structures to allow safe egress from the ROW way by large fauna,
- High-mast lighting to move prey-seeking bat activity well above traffic,
- Bat roosting structures to off-set losses of tree-bark roosting habitat, and
- Constructed wetlands for amphibians to replace areas drained or removed during NVBP installation.

The construction of a 600-ft. wide by 9 mi. long highway corridor through a primarily forested landscape introduced risks for the resident species by altering the composition of the available habitat and erecting barriers that redirected their movement. Assessment of the function, operation and relative effectiveness of the structures that were designed and constructed to reduce risks to wildlife must be assessed within the local environmental context. The structure, placement and size of the mitigation features dictates their functionality as determined by the size and locomotor capabilities of the targeted wildlife species. For example, fencing with a 6-in. square mesh will not redirect the travel of a small mammal or snake. Therefore, the effectiveness of mitigation measures to reduce wildlife risks from a vehicle can only be assessed within the environmental context for which they are designed and placed.

For a thorough background on the ODOT NVBP project development process and the integration of the transportation project with wildlife mitigation strategies refer to Chapter 1. For an in-depth description of the environmental setting of the NVBP and surrounding WNF, refer to Chapter 2. Thorough descriptions of the mitigation features can also be found in Chapter 2.

RESEARCH CONTEXT

The main objective of this research was to assess the effectiveness of wildlife mitigation measures installed along the NVBP bisecting the WNF, and to provide recommendations for improvements including design, functionality, placement and implementation of the wildlife mitigation treatments. Based upon literature reviews and surveys by design staff, the research team established several hypotheses to evaluate to address the research objectives. The hypotheses are as follows:

1) High fencing constructed along the NVBP reduced the number of wildlife-vehicle collisions. This was evaluated through historical records of vehicle-wildlife collisions and comparisons of roadkill between the NVBP and control sites.
2) Wildlife use the ecopassage / underpass crossings to traverse and jump outs to egress the NVBP ROW while minimizing ingress, and thus reducing wildlife-vehicle contact.
3) Reptiles, amphibians and other small wildlife use the small wildlife underpasses / ecopassages and culverts as a mechanism to traverse the NVBP and its tributaries to avoid wildlife-vehicle contact and minimize fragmentation of their populations.
4) The low wildlife (snake) fencing excludes animals from the ROW and directs them to wildlife ecopassages, reducing road mortality and maintaining population connectivity across the NVBP.
5) The barrier fencing along SR 78 funnels migrating amphibian species to ecopassages, allowing them to migrate between terrestrial and aquatic habitats.
6) High-mast lighting along the NVBP attracts bats and lures them to heights above the flow of traffic, reducing animal-vehicle collisions while simultaneously providing lighting for interchanges.

To accomplish the research objectives and evaluate the hypotheses, the Ohio University research team completed the following sub-objectives:

1) Regular roadkill surveys conducted on the NVBP and control sites to quantify wildlife-vehicle interactions and evaluate the overall effectiveness of the mitigation structures.
2) Camera traps monitored wildlife jump outs, fencing and underpasses to document egress, ingress, and lack of use by deer or other large animals.
3) Deer pellet counts documented the use of ROW habitat by deer, and also allowed for estimates of deer population density.
4) Small wildlife (snake) fencing and crossings were monitored with camera traps, box traps, and radio-telemetry to determine the fence's ability to exclude snakes and other wildlife from the ROW and direct them toward the 4-ft. diameter ecopassages.
5) The effectiveness of fencing along SR 78 to direct mole salamanders and other amphibians to ecopassages and away from the ROW was determined using pitfall and camera traps. Pitfall traps monitored ability of the fence to direct amphibians to the ecopassages while high resolution cameras documented crossing through the ecopassages.

6) Bat sonar detection recoding equipment mounted on high-mast lighting monitored activity near high-mast lights and equipment position (low, mid and high) determined concentration of bat activity vertically.
7) Camera traps monitored the 11.67-yd. wide large wildlife underpass, the Butterfly Bridge ecopassage, and the two 4-ft. diameter small wildlife culverts to document successful movement between the two sides of NVBP by wildlife.
8) The 16-ft. wide box culvert ORV/Wildlife crossing was monitored for both wildlife and ORV use to determine the effectiveness of a multiple-use underpass structure shared by wildlife and low volume motorized traffic.

The work plan developed to address the objectives and hypotheses of this research project consisted of the following 13 tasks:

Task 1. Hold Project Start-up Meeting
Task 2. Conduct a Literature Review
Task 3. Conduct an Existing Field Condition Evaluation
Task 3.1 Assemble and modify the Project Area GIS Database using existing datasets.
Task 3.2 Locate and measure all pertinent structures and features of interest in the field
Task 3.3 Conduct background investigations on design and field location decisions
Task 4. Establish the Protocol for the Experimental Plan
Task 5. Conduct Field Monitoring Studies
Task 6. Reduce and Analyze Data
Task 7. Evaluate the Effectiveness of Wildlife Mitigation Treatments
Task 8. Determine Sustainability and Maintenance Plan of the Wildlife Mitigation Treatments
Task 9. Develop Recommendations for Wildlife Mitigation Treatment Improvement
Task 10. Hold Project Review Session
Task 11. Prepare and Submit Quarterly Reports
Task 12. Prepare and Submit Draft and Final Reports
Task 13. Hold Project Wrap-up Meeting

RESEARCH APPROACH

The teams' research approach was subdivided based on the hypotheses presented in the Research Context section of this Executive Summary.

HYPOTHESIS 1: HIGH FENCING EFFECTIVENESS AT REDUCING WILDLIFE-VEHICLE COLLISIONS

The effectiveness of the fencing along the NVBP was evaluated by quantifying the number of vehicle-wildlife interactions as determine by roadkill surveys and a deer-vehicle crash analysis. Furthermore, a camera trap study evaluated fence permeability.

Road Kill Survey

This study included a direct count of animal carcasses found along the NVBP for 12 months and simultaneous carcass counts along two similar road segments in an area that lacked mitigation measures. The two similar road segments were: 1) an 11.53 mi. stretch of U.S. Route 33 south of Athens between the U.S. Route 50 west intersection and the Ohio State Route 681 intersection and 2) a 6.38 mi. stretch of U.S. Route 50 east of Athens beginning at the Holzer Clinic at the end of East State Street in Athens to the Athens County Road 65 intersection (Figure ES-1). This work tested the hypothesis that the number of carcasses along the NVBP was lower than the number of carcasses along the two control segments. If the mitigation structures were successful at reducing wildlife-vehicle interactions, overall and per-mile mortality rates should be lower.

All roadkill encountered was identified to species and the precise location was GPS recorded. Location, date, time, species, and position of the carcass within the road corridor were recorded using Trimble GPS units. We compared carcass counts by species between NVBP and the reference highways (Table ES-2). Location data were imported into ArcGIS and clustering of collisions was evaluated relative to nearby landscape and roadway features.

All three highway segments were surveyed on the same day 2-3 times per week. A two member team consisting of a driver and observer drove about 55 mph; the driver focused on the road while an observer searched the road and ROW for carcasses. Once a carcass was identified, the spotter alerted the driver to pull safely to the right side of the paved road berm. A 30 second GPS point was taken as near as possible to the observed carcass. Reflective, short persistence Day-Glo® green paint was used to mark the road berm to indicate that the carcass had been counted and could be removed by ODOT.

For further detailed information on the road kill survey, please refer to Chapter 3.

Deer Crash Analysis

The research team analyzed the Ohio State Patrol Crash Reports Database for seven years, 2009-2016, for the entire state of Ohio to aid in understanding deer-vehicle collision patterns. The team also compared deer-vehicle crash rates for the NVBP and the two reference sites. Deer-vehicle collision data included date, time of day, road type, road conditions, visibility conditions and location coordinates. Time and season related patterns of deer crashes were developed and compared on statewide, regional, county-wide and individual roadway bases. Road segment traffic data were obtained from ODOT for road segments throughout the state. Data included daily traffic counts for all metered roads, road speed limits, number of lanes and conditions. These data were used with strike data to reveal relationships between deer strikes, speed limits and traffic volumes.

For further detailed information on the deer crash analysis, please refer to Chapter 3.

Fence Permeability Survey

Ideally, the NVBP fencing was impermeable to wildlife and thus all animal movement influenced by the bypass was expected to be outside the ROW and parallel to the fencing. The tall fence was constructed of 8-ft. tall graduated square wire mesh (3 in. x 6 in. for the bottom 3 ft. and 6 in. x 6 in. for the top 5 ft.) connected by wooden posts. The tall exclusion fence was positioned at the outer boundary of the ROW running the entire length of the NVBP, interrupted only at interchanges. This outer perimeter fence was designed to exclude rabbit-sized animals and larger. The fence was to be installed so that the lowest wires were buried or in solid contact with the ground. Where fences crossed drainage channels, combinations of rock and wooden rails were installed to inhibit trespass by animals.

We completed a thorough integrity survey of all fencing in 2015. Team members walked the entire length of the fence twice during the study period. Holes in the fence were documented and georeferenced using GPS units. Fence openings were created by tree fall or land movement, erosion creating openings below the fence, construction flaws that left gaps under the fence, and vandalism. Older holes accumulated wildlife trails parallel to the fence leading to the openings, which frequently were used by wildlife to enter the ROW. Wildlife trails were mapped to better understand wildlife movement across the landscape within and adjacent to the highway corridor. Openings in the fence were measured and the source of damage documented when possible. Camera traps recorded and quantified wildlife use of some holes along the high fence.

For further detailed information on the fence permeability survey, please refer to Chapter 4 as related to deer movement.

HYPOTHESIS 2: WILDLIFE USE OF CROSSINGS AND JUMP OUTS

Trail cameras continuously monitored for 18 months (July 2015 – December 2016) all jump outs and underpasses to test the hypothesis that wildlife were using the mitigation structures for their intended use. Trail cameras were installed at both ends of each underpass / ecopassage to monitor entry, exit and crossing through underpasses, and in strategic locations at jump outs to monitor use and direction of animal movement. Camera locations and camera field-of-view areas were GPS located and made part of the GIS database for the project. Images were regularly collected by downloading from SD cards and then uploaded to a shared drop box. All images were automatically date and time stamped and were individually reviewed by the project team to determine species and behavior near the structure. Images which showed an entrance by an animal on a camera at one end were confirmed as a use if the same animal was shown to exit the underpass on the camera at the other end of the structure. Images revealing an animal near a structure and use events were marked and copied to a separate file with an annotation of the observation.

For further detailed information on the deer movement, population estimates and jump out analysis, please refer to Chapter 4.

HYPOTHESIS 3: REPTILE AND AMPHIBIAN USE OF CROSSINGS AND CULVERTS

Camera traps monitored small wildlife (snake) crossings continuously from July 2015 – December 2016 to test the hypothesis that wildlife were using these underpasses. Each snake ecopassage under the NVBP was monitored with three motion sensitive cameras one at each end of the underpass and one in the middle. The amphibian ecopassages under SR 78 were monitored with break-beam sensor activated cameras to insure detection of small animals that might be missed by the motion sensitive and ambient heat differential detectors of the standard camera traps. Camera traps were placed to quantify the movement of reptiles, amphibians and mammals through these structures, and confirm passage all the way through the tunnel. Data were collected on the number of crossings through the culverts, their use as a shelter or for other purposes (e.g. thermoregulation, foraging), and were analyzed by species, time of day, time of year and temperature.

Because only one small wildlife culvert had snake exclusion fencing, the camera trap data between culverts were examined to determine if the fencing increased use of culverts or not. The numbers of individuals captured along the fence was then compared to camera trap data to determine if animals were successfully redirected to culverts and to identify species that were either unable to find or unwilling to use the culverts.

For further detailed information on the amphibian use of crossings on SR 78, please refer to Chapter 5. For detailed information on the wildlife use of the small wildlife crossings, please refer to Chapter 7.

HYPOTHESIS 4: REPTILE RIGHT-OF-WAY EXCLUSION AND CONNECTIVITY MAINTAINED BY THE MITIGATION STRUCTURES

Reptile Fencing Evaluation

A second low "snake" fence 3 ft. high with 1/4 in. mesh was installed from the Dorr Run interchange west for approximately 1 mile on both sides of the bypass. This snake fence was either congruent with the 8-ft. tall fence or placed closer to the roadway in some locales. The goal of this fence was to prevent reptiles and small mammals from entering the travel lanes and direct them to small wildlife underpasses. Cover boards (Grant et al., 1992) and box traps (Burgdorf et al., 2005) captured animals moving parallel to the snake fence both inside and outside of the ROW. Herpetofauna captured, marked and recaptured on both sides of the fence were used to determine if individuals were trespassing the exclusion fencing. Captures within the ROW also identified which animals took advantage of roadside habitats. Such information helped identify species at risk of road mortality, as some animals may not have been detected in roadkill surveys due to their small size, obliteration by vehicles, removal by scavengers, or fleeing the road after impact. All snakes, lizards, and turtles captured along the fence were sexed, marked, and measured. Fence permeability was further assessed via radio-telemetry of two snake species, Black Racers and Timber Rattlesnakes. Three to four weekly relocations of telemetered snakes were recorded using GPS to identify habitat use and preference inside and outside of the ROW.

For further detailed information on the fence permeability survey and reptile movement, please refer to Chapter 7.

Reptile Habitat Use and Connectivity

Radio-telemetry was used to relocate snakes several times per week to test the hypothesis that the snake fencing effectively prevented snakes from entering the ROW. Radio-telemetry also monitored snake behavior and determined home range sizes. Radio-telemetry was utilized on all adult Timber Rattlesnakes that were captured. Location (using GPS), behavior, body temperature, and habitat use were recorded upon each radio-location. Radio-telemetry data were used to identify hibernacula, determine home range size and movement patterns, and evaluate habitat use in relation to the NVBP. Radio-telemetry also determined if snakes traversed the roadway to maintain population connectivity across the NVBP.

For further detailed information on reptile habitat usage, please refer to Chapter 7.

HYPOTHESIS 5: AMPHIBIAN CONNECTIVITY AS EFFECTED BY THE MITIGATION STRUCTURES

Amphibian populations were monitored to test the hypothesis that amphibians could access the wetland and woodland habitats isolated by SR 78, a tributary to the NVBP, and that the mitigation structures contributed to habitat connectivity for amphibians. The redirected section of SR 78 fragments a complex of wetland and upland habitats for which mitigation, a barrier-ecopassage system, was installed. This barrier-ecopassage system was put in place to facilitate the migration and movement of Mole Salamanders (*Ambystoma* spp.), but several other resident amphibian species were monitored as well. Pedestrian surveys of road mortality documented extensive amphibian mortality on this section of SR 78 (Table ES-2). Behavioral observations were conducted to quantify the probability of successful road crossing in areas where no mitigation structures were present. Surveys quantified the use of amphibian passages with camera traps and pitfall traps. Cameras were placed at entrances to the amphibian ecopassages to take photographs of amphibians using the passages. At the ends of roadway barriers (designed to direct animals toward passages) pitfall traps were placed, which caught animals that may have otherwise crossed the road, which puts them at risk of being hit by a vehicle.

For further detailed information on amphibian habitat usage, please refer to Chapter 5.

HYPOTHESIS 6: HIGH-MAST LIGHTING DRAWS BATS ABOVE ROADWAY

Acoustic bat detectors (SM4 Bat, Wildlife Acoustics, Inc.) were deployed at four locations along the NVBP to test the hypothesis that the high-mast lighting lures bats above the flow of vehicle traffic. Bat detectors were deployed beginning April 28, 2016, and remained operational through December 31, 2016. First, two of the four high-mast lights were turned off to compare bat activity at lit and unlit highway lights to test the hypothesis that highway lighting attracts bats. Second, to test the hypothesis that bats are attracted to highway lights above the flow of traffic, bat detectors were placed at the level of traffic (3 ft. above ground), the height of typical highway lighting (50 ft. above ground), and at the level of the highway lights (100 ft. above ground). Highway lights turn on shortly before dusk and remain on until after dawn. Similarly, bat detectors were programmed to turn on and record bat activity from a half-hour before sunset to a half-hour after sunrise. Detectors were checked every 3-5 weeks to download recorded data and change their batteries.

For further detailed information on the impacts of high-mast lighting on bats, please refer to Chapter 6.

RESEARCH FINDINGS AND CONCLUSION

Through the myriad of techniques and component studies carried out in the evaluation of the mitigation structures for the NVBP and its tributary roadways, the team encountered more than 103 species, including at least 32 mammal, 16 reptile, 17 amphibian and 38 bird species (Table ES-1). The breadth of species impacted by the NVBP and the mitigation structures attests to both the biodiversity of the region but also the multitude of species that are potentially affected by roads, including the small species detected as dead on the road (Table ES-2). Comparing the number of organisms discovered dead on the roadways using vehicle-based surveys at 50-55 mph versus those done on foot, as was done along SR 78, we see a tremendous increase in the diversity of species killed, most of which are too small to detect from a moving vehicle (Table ES-2). Although some of the mitigation structures effectively prevented wildlife mortality, the research team also identified potential improvements in design, placement, and implementation of the structures that could facilitate habitat connectivity for wildlife and reduce wildlife-vehicle collisions.

Below we restate our hypotheses, followed by summaries of our major results.

1) The high fencing in association with underpasses, bridges and jump outs constructed along the NVBP, reduces the number of deer-vehicle collisions relative to control sites.
    a. Wildlife-vehicle collisions represent 17.5% of all collisions reported for the NVBP, whereas at our control sites 49% and 56% of all reported collisions were wildlife related. These data suggest that the fencing and related structures along the NVBP contributed to a reduction in wildlife-vehicle crashes. It should be noted that 17.5% is higher than the annual statewide average of 7.0%, and that in Athens/Hocking County collisions with wildlife average 14.6% of all crashes. These data attest to the higher

deer populations in Athens/Hocking Counties relative to the rest of Ohio. However, the difference in wildlife-vehicle crashes between the NVBP and the control sites suggests that the deer-related wildlife mitigation features constructed as part of the NVBP project were effective at reducing deer-related crashes during the first three years of the NVBP being open to the public.

   b. The roadkill surveys along the NVBP, its tributaries and control sites discovered more than 80 species dead on the road (Table ES-2). Among species with sufficient sample sizes to perform statistical analyses between control sites and the NVBP, a G-test revealed a decrease in wildlife-vehicle mortalities for the white-tailed deer, Virginia opossum, raccoon, and eastern cottontail on the NVBP relative to at least one of the two control sites; an increase in mortality for combined squirrel species (Fox Squirrel and Grey Squirrel) on the NVBP; and no difference in Striped Skunk mortality between the NVBP and the control sites. These findings support our conclusion that the wildlife mitigation structures do contribute to reducing mortality of the larger species, particularly white-tailed deer.

2) Wildlife use the large ecopassage crossings to traverse the NVBP and jump outs to egress the NVBP ROW while minimizing ingress, thus reducing animal-vehicle contact.
   a. Camera trap data at the jump outs indicated that some jump outs were used more heavily than others by deer to exit the ROW, but also that deer were frequently not compelled to exit the NVBP ROW when encountering a jump out. Approximately 21.5% of deer camera trap events showed deer exiting the ROW, with the other camera trap data showing deer browsing, traveling or resting inside ROW. Pellet count surveys showed that deer density inside ROW during the summer activity peak (June-July) in 2016 was 10.5 – 15.5 deer/sq. mi. The wildlife fence limited deer movement where intact and properly installed, as deer movement along the fence outside ROW was greater than movement inside ROW. Gaps in the fence due to tree falls, vandalism, and structural failure (e.g., horizontal wire at culverts) resulted in deer trespass into the ROW. Camera traps revealed that deer were knowledgeable about gaps in the fence and used them for both ingress and egress of the ROW. Repairs resulted in deer returning to the site to obtain access to the ROW, but the fence was able to prevent trespass after the repair.
   b. A high diversity of mammals used the large wildlife underpasses (Table ES-1). Smaller animals (reptiles, amphibians and small mammals) were not detected in the larger underpasses, likely due to the limited detection ability of our cameras across large openings. The high volume of deer, coyotes and foxes that use the large ecopassages indicate that they were used to successfully traverse the ROW, thus reducing the risk of wildlife-vehicle collision.

3) Reptiles, amphibians and other small wildlife use the small wildlife underpasses / ecopassages and culverts as a mechanism to traverse the NVBP and its tributaries to avoid wildlife-vehicle contact and minimize fragmentation of their populations.
   a. Although, small (coyote to shrew size) mammals readily used the two smaller wildlife ecopassages (Table ES-1) on the NVBP, reptiles and amphibians were rarely detected, and none completely traversed under the bypass. One intended goal for the small wildlife ecopassages was to maintain connectivity of the Timber Rattlesnake population potentially fragmented by the NVBP. Radio-telemetry and camera traps failed to detect any rattlesnakes crossing the highway.

b. The amphibian ecopassages on the SR 78, a tributary of the NVBP, were used by <0.2% of the populations of amphibian species detected, suggesting that the ecopassages are not effective. Part of this limitation may be due to design factors, but placement was also a problem as most of the amphibian road mortality was southwest of the barrier-ecopassage structure, where large migrations between the upland forest habitat and wetland habitat resulted in high levels of road mortality.

4) The low (snake) fencing excludes animals from the ROW and directs them to the wildlife ecopassages, reducing road mortality and maintaining population connectivity across the NVBP.
    a. Both capture-mark-recapture and radio-telemetry identified that a variety of snake species, including rattlesnakes, could cross the fencing into the ROW. Tree falls, erosion, vegetation overgrowth and corrosive damage to the fence created holes for trespass into the ROW. In areas where the fence was intact, reptiles and small mammals were redirected by the fence as evidenced by the capture of animals in box traps along the fence.
    b. The ROW may have provided improved habitat by providing quality basking sites that benefit the local rattlesnake population. However, the benefits are contingent on ROW habitats not increasing mortality rates. If rattlesnakes are attracted to the ROW and are subsequently killed by vehicles, humans, or other predators, then these features would function as an ecological trap.
    c. No dead rattlesnakes were discovered during roadkill surveys, suggesting that despite trespassing into the ROW snakes avoided the travel lanes, even though some individuals came as close as 15 ft. to the road surface. Eastern Milk Snakes, Black Racers, Copperheads and Eastern Box Turtles were documented as roadkill on the NVBP in areas with and without snake fencing.
5) The barrier fencing along SR 78 funnels amphibian species migrating among the wetlands and forest habitat to the ecopassages allowing them to migrate between habitats.
    a. Based on high roadway mortality, at least four amphibian species may be experiencing unsustainable mortality rates due to the new roadway (Hels and Buchwald, 2001; Gibbs and Shriver, 2005). The installed amphibian mitigation structure is not effective at facilitating amphibian movement across the roadway due to design deficiencies (Woltz et al., 2008; Patrick et al., 2010). In addition, the barrier-ecopassage system is located northeast of the area where most amphibians were found crossing the roadway.
6) High-mast lighting along the NVBP attracts bats and lures them to heights above the flow of traffic, reducing animal-vehicle collisions while simultaneously providing lighting for interchanges.
    a. This study finds little evidence that high-mast lighting is effective at mitigating mortality of bats along the roads. Excepting Big Brown Bats, activity of most bat species and species groups increased the most at the level of traffic under high-mast lights, suggesting these bats are foraging at heights where they are at risk of traffic collisions. However, without data on the number of bats killed in lit and unlit areas it remains unclear if these differences in activity translate to actual differences in the number of road-killed bats. Only two bats were discovered dead throughout all the roadkill surveys conducted (Table ES-2).

RECOMMENDATIONS FOR IMPLEMENTATION OF RESEARCH FINDINGS

Based on the data and findings presented in this report we found that there has been an impact / reduction in the number of deer-vehicle collisions and in some smaller mammal species. However, many of the mitigation structures would benefit from improvement in their design, placement and installation. We, as biologists and highway engineers and designers, make the following suggestions and recommendations for the improvement of these or future mitigation structures.

- ***Design*** – We recommend that ODOT develop a preliminary design policy for projects to guide engineers and designers in the placement and construction of mitigation structures. The policy should include the involvement of ecologists, biologists, maintenance staff, designers, and other wildlife experts to identify potential impacts on various wildlife species like those studied herein. During the environmental impact assessment of the project, careful evaluation of habitat, potential wildlife species impacted, and their movement patterns should be considered in developing and locating mitigation structures. We recommend an adaptive management policy whereby feedback between engineers, construction contractors and biologists work in concert to develop cost effective solutions to increase safety and minimize wildlife-vehicle collisions.
- ***Placement*** – Many of the shortcomings associated with the wildlife mitigation structures of the NVBP are due to their placement.
    - *High Fencing* **–** The high fencing on the NVBP is placed on the outer edge of the ROW and the road cut. Although this is likely determined by tradition and preventing humans from trespassing into the ROW, the ROW frequently provides habitat and forage sought out by many wildlife species. Thus, wildlife will enter the ROW when and where they can find access to access resources. We suggest placing the fence within 30-50 ft. of the road surface as there are many potential benefits to this practice, including: 1) decreased cost of installation on flatter, less rugged terrain than may be found on the ROW boundary, 2) facilitated maintenance of the fence and vegetation control both inside and outside the fence, 3) decreased damage to fence due to tree falls and erosion in the more rugged terrain at the boundary of the ROW, and 4) wildlife access to habitat and forage within the ROW, but away from travel lanes and possible damage from vehicles that leave the roadway.
    - *Low Fencing* – We recommend that the low small wildlife fencing be integrated with the high fencing (placed closer to the roadway rather than at the ROW boundary), but built such that the large mesh high fencing faces the road and the small mesh fencing faces away from the road. This minimizes the risk of entrapment of animals between the two fences, as was observed with Box Turtles. By placing the low fencing close to the road, maintenance and installation costs will be reduced and allow for small wildlife (small mammals, amphibians and reptiles) to use ROW habitat. Furthermore, because state-endangered Timber Rattlesnakes were discovered in areas where no snake fencing was present, we recommend that the snake fencing be extended along the entire NVBP, to reduce mortality of all snake species.

- *One-way Jump Outs* – Jump outs should be placed in areas with opportunities for wildlife to access the ROW, such as adjacent to intersections. Additional sites for jump outs should be areas where deer traffic was documented to be high. Jump out use varied among the 16 jump out structures. This highlights that the landscape setting and documentation of high deer movement areas and trails should be used to inform the proper placement of jump outs. The high variation in technical specifications and low overall number of jump outs precluded us from drawing robust inferences on the optimal jump out design. Anecdotally, two jump outs that developed cattail wetlands in the landing area outside ROW were never used by deer during this study. Two rare ingress events took place at jump outs with the lowest height (4.0-4.5 ft.), thus we recommend a height >5 ft. for future jump outs. The wing fences intended to direct deer towards the jump outs were not successful because deer rarely exhibited escape behaviors that would have funneled them towards jump outs. Deer simply traveled around the wing fences, and in instances where the jump outs were close to the pavement, the wing fences drove deer within feet of the pavement.
- *Underpasses* – Wildlife ecopassages should be placed in areas of high wildlife usage. Wildlife usage of particular areas can be identified by the number of trails and scat or other telltales of wildlife presence, or in evaluating the location and number of wildlife-vehicle collisions if available. We believe that the three large underpasses were insufficient in number to accommodate deer needing to cross the NVBP along its entire length, and that deer wanting to traverse the highway contribute to fence trespass rates. Refer to Chapter 4 for detailed recommendations for implementation.
- *Amphibian Underpasses and Fencing* – Although amphibians move among wetlands, the most significant amphibian migrations occur between adult terrestrial habitat and wetland breeding habitat. Careful surveys during spring and fall amphibian migrations should guide the placement of amphibian mitigation structures. Unfortunately, we found that the amphibian ecopassages on SR 78 had minimal success, in part because of their placement missed the primary amphibian travel corridor.

- ***Construction*** **–** The research team discovered some construction and material flaws and we recommend the following:
  - The small wildlife fencing was made of substandard material that corroded in acidic soils within two years of installation. We recommend stainless steel fencing in this application.
  - In several locations the deer fencing was not in contact with the ground. We recommend more thorough inspection during construction and upon completion of fencing implementation.
  - The small wildlife fencing was not well integrated with the small wildlife underpasses. We recommend that fencing be placed to effectively funnel wildlife to the underpasses. Furthermore, small wildlife ecopassage #2 at the west end of the NVBP had no fine mesh fencing so many small wildlife species could easily slip through the fencing and into traffic.

    - Jump out landing areas should not form wetlands. Two of the jump outs have landing pads that have developed into wetlands; these two jump outs were not used by deer. We recommend insuring adequate drainage with a sand substrate to prevent wetland formation.
    - Recent findings have suggested that wildlife crossings for reptiles and amphibians should be at least 8 ft. in diameter for the length of the underpasses for the NVBP (Clevenger and Huijser, 2011; Gunson et al., 2016). They further recommend that these underpasses should be between 150-200 ft. apart, thus suggesting the need for many more underpasses. Similarly, the amphibian ecopassages under SR 78 should be larger and more frequent along the span of the amphibian migration corridor.
    - We recommend discontinuing the planting of leguminous plants such as clover and alfalfa in ROW areas because this is high-quality forage that can attract a variety of mammalian herbivores, in particular White-tailed Deer.
- ***Maintenance*** – As with all infrastructure, maintenance is a critical component to the functionality of the wildlife mitigation structures. The research team found many openings in the fences, and a maintenance schedule is not in place. We make the following recommendations for mitigation maintenance
    - Twice annually walk the fence and jump outs to find and repair all holes and damage created by erosion, tree falls and vandalism beginning with those documented in our surveys of the fence. Placing the fencing closer to the roadway would reduce resources necessary for these inspections.
    - Prevent vegetation from growing over the fence to preclude wildlife from climbing over the fence on the vegetation. Vegetation control would be facilitated by placing the fence closer to the roadway, as suggested above.
    - No supplemental planting in the ROW within the fence to re-establish forest vegetation. The open habitat created within the ROW is a limited resource exploited by snakes and other ectothermic vertebrates for thermoregulation.
- ***Monitoring and Further Studies*** – The research team suggests that a study and monitoring program be implemented to evaluate the effectiveness of further mitigation measures. For example, the high-mast lighting had little success in attracting bats to elevations above the flow of traffic. We suggest an empirically-based research program to develop and test alternative mechanisms to minimize traffic related bat mortality. Similarly, construction and implementation of fence segments, particularly small wildlife fencing, closer to the roadway would benefit from thorough survey work of both road mortality, ecopassage use, and habitat use among reptiles and amphibians. Similar study of sections of high fencing along the NVBP or other highways to evaluate effectiveness and cost savings would be useful. Some continued studies are already partly underway: evaluating snake use of habitat in the road cuts and assessing use of alternative designs in amphibian ecopassages for SR 78.

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CHAPTER 1: PROJECT BACKGROUND

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The transportation project development process consists of planning, environmental analysis, design, construction, and operation and maintenance of transportation infrastructure. For transportation projects in regions where animals are common, strategies to integrate the transportation project with the surrounding wildlife and habitats focus on two objectives (Clevenger and Huijser 2011):

- Strategies and mechanisms to reduce wildlife-vehicle accidents and avoid impacting wildlife.
- Strategies and structures that maintain connections between wildlife habitats that are divided or isolated by roadways.

The first objective relates to the broader goal of developing transportation facilities that are safe and functional for motorists and wildlife. In this context, highway agencies have been investigating methods and approaches for reducing wildlife-vehicle collisions (WVCs), particularly collisions between vehicles and large mammals. Early studies (e.g., Allen and McCullough 1976, Bashore et al. 1985, Carbaugh et al. 1975) focused on identifying WVC "hot spots" along roadways. Similar analyses conducted for Ohio (Stoll et al. 1985, Iverson and Iverson 1999, Schwabe et al. 2000) identified the scale, potential economic and human impacts of deer-vehicle collisions. More recently, the Ohio Department of Public Safety revealed that an average of 25,836 deer-vehicle crashes and seven human fatalities due to deer-vehicle crashes occurred annually between 2003 and 2012. Deer-related accidents account for approximately 7.8% of all statewide reported crashes. Additionally, the Ohio Insurance Institute (2013) reported that the average insurance claim exceeded $3,400 per deer-vehicle incident. Incorporating mechanisms to reduce WVCs into Ohio Department of Transportation (ODOT) projects is beneficial for human safety, highway functionality, economic gain and the conservation of wildlife.

The second objective promotes the development of transportation facilities in harmony with the surrounding environment, including native and endangered wildlife populations and their habitats. Specifically, the construction of new infrastructure such as highways can impact the natural landscape by creating physical barriers dividing existing populations, reducing and isolating critical habitats, and altering the connectivity (gene flow) among populations. However, roads cuts can also create habitat that may be limited, e.g., open areas in regions with a well-developed forest canopy. In addition, new highway construction causes indirect effects on habitats: modifying the type and availability of food resources (e.g., roadside vegetation), introducing chemicals to habitats (gas, oil, road salt, etc.), and changing noise and light regimes. Lastly, topographic changes from fill or excavation can alter aquatic and terrestrial habitats and the surface structure of the landscape (e.g., exposing and creating rock faces in road cuts). The National Environmental Policy Act (NEPA) process mandates that ODOT identify and mitigate any adverse effects of proposed transportation projects on environmental and natural resources in the area surrounding the proposed project. Mitigation developed from the NEPA process can often focus on the presence of endangered or threatened species with habitat adjacent to proposed project sites, consistent with laws and requirements in the *Endangered Species Act*.

Several national and international studies have established guidelines to assist in the planning and design of roadways in significant wildlife habitat areas. These studies focus on identifying wildlife habitats, selection and placement of appropriate treatments for wildlife mitigation, effectiveness of certain strategies, and recommended design specifications for common treatments. The 2005 *Safe, Accountable, Flexible, and Efficient Transportation Act: A Legacy for Users* (SAFETEA-LU), a Congressionally-mandated effort, directed the U.S. Department of Transportation to conduct a national study of WVCs. The result of this directive was a full *Report to Congress* (Huijser et al. 2008a) and an accompanying *Best Practices Manual* (Huijser et al. 2008b). The National Cooperative Highway Research Program (NCHRP) also published two research studies on WVC issues. The first, *NCHRP Synthesis 370: Animal-Vehicle Collision Data Collection*, focused on data collection and database development for WVC modeling (Huijser et al. 2007). The second report, *NCHRP Report 615: Evaluation of the Use and Effectiveness of Wildlife Crossings*, reported on a national study of deployment and effectiveness of one mitigation strategy, wildlife crossings (Bissonette and Cramer 2008). *NCHRP Report 615* also included a decision guide and companion website to assist practitioners with selection, placement, and design of wildlife crossings.

The U.S. Federal Highway Administration (FHWA) Office of Planning, Environment, and Realty (HEP) has also created at least two web-based resource guides to assist with the development of wildlife-sensitive highways: *Wildlife Crossings: Keeping it Simple: Easy Ways to Help Wildlife Along Roads* and *Critter Crossings*. Another web-based initiative is the National Deer-Vehicle Crash Information Clearinghouse which provides a repository of tools and techniques for reducing deer-vehicle collisions. In March 2011, the FHWA Federal Lands Highway Office, Central Division published *Wildlife Crossing Structure Handbook: Design and Evaluation in North America*, providing additional guidance on wildlife crossing issues (Clevenger and Huijser 2011). Since these reports, more specific guidelines laid the groundwork for protecting small wildlife with an emphasis on reptiles and amphibians in the *Best Management Practices for Mitigating the Effects of Roads on Amphibian and Reptile Species at Risk in Ontario* (Gunson et al. 2016). Although not available at the time of the planning and design of the mitigation structures along the U.S. 33 Nelsonville Bypass (NVBP), they provide a framework for future projects.

Huijser et al. (2008a) outlined four broad categories as potential strategies and treatments for integrating highway development with surrounding wildlife and habitats by:

- Influencing or changing driver behavior.
- Directing or altering animal behavior, primarily movement patterns.
- Reducing wildlife population size (particularly in urban areas).
- Physically separating animals from the roadway.

Most highways that bisect wildlife habitat, including the NVBP, at a minimum install some mitigation methods to influence driver behavior (e.g. warning signs). The wildlife mitigation strategies and treatments constructed as part of the NVBP project studied in this research project generally seek to physically separate animals from the roadway and direct animal movement through wildlife crossings.

Wildlife mitigation strategies and treatments incorporated in the highway development process can benefit highway agencies, users, and wildlife. With a greater understanding of the issues associated with WVCs and highway development in wildlife habitats, research emerged on the effectiveness of different strategies and treatments in meeting the key objectives of roadway safety and wildlife habitat preservation. Early research on specific wildlife mitigation activities to physically separate wildlife from the roadway focused on the effectiveness of enhanced right-of-way (ROW) fencing in reducing deer-vehicle crashes (e.g., Bellis and Graves 1978, Falk et al. 1978, Feldhamer et al. 1986), concluding that fencing was effective at deterring deer activity from the highway with mixed results for motorist safety. One improvement in the practice of developing wildlife-friendly highways is the evolution from fencing only to fencing with complementary infrastructure, such as grade-separated wildlife passages (i.e., wildlife crossings) and other similar features along roadways. The NVBP includes two such complementary infrastructure pieces: wildlife crossings and one-way jump outs.

Exclusionary fencing as a strategy to mitigate WVCs has many undesirable effects that include reduced access to the ROW for maintenance workers, altered visual aesthetic, fragmented wildlife habitat, and barricaded movement corridors (Huijser et al. 2008a). When barriers divide wildlife habitat, wildlife will frequently trespass the barrier to access isolated habitats, thus reducing the effectiveness of the barrier fencing. Exclusionary fencing can be integrated with wildlife crossings or corridors that allow wildlife to traverse under or over the roadway without risk of WVCs. Wildlife crossings are generally defined as underpasses or overpasses designed for safe passage of wildlife from one side of a highway to the other (Clevenger and Huijser 2011, Glista et al. 2009). Wildlife crossings are typically constructed to increase the permeability of a roadway and decrease habitat fragmentation. Crossings range in size from relatively small structures (small pipes and box culverts) to large structures (large culverts and bridges). In addition, the potential for trespass into the ROW indicates that another mitigation feature that would allow wildlife to exit the ROW while simultaneously preventing additional trespass may be useful. One-way jump outs allow larger wildlife, such as deer, a pathway to exit after trespassing into the ROW.

Measuring the effectiveness of wildlife mitigation structures requires comprehensive, multi-year monitoring to evaluate mitigation performance and the response by wildlife as they adjust to the presence of the roadway and the mitigation features. Wildlife crossings and studies of their use began in the early 1970s when an underpass was constructed to accommodate mule deer migration under I-70 in Colorado (Reed et al. 1975). The broader use of wildlife crossings in recent decades improved the scope and validity of effectiveness studies as wildlife observation techniques and the understanding of wildlife behavior in response to roadways has improved (Bissonette and Cramer 2008). Western states have led the research on the effectiveness of large vertebrate wildlife crossings in Arizona (Bristow and Crabb 2008, Dodd et al. 2012), Montana (Huijser et al. 2007, MDT 2014), and Utah (Cramer 2012). In Canada, large wildlife underpasses in Banff National Park have been studied for nearly two decades (Clevenger 1998, Clevenger and Waltho 2000, Clevenger et al. 2009). Western states and Canada lead in large wildlife mitigation studies because there are larger proportions of protected land and greater diversity of large wildlife (such as elk, moose, deer, sheep and bear) that present a greater risk to motorists. However, some studies have been conducted in the Eastern U.S., including studies in Florida (Walker and Baber 2003), Vermont (Bellis 2008), and Virginia (Donaldson 2005). Furthermore, the concerns for smaller wildlife and the impacts on their populations has led to studies of mitigation features for a greater diversity of wildlife (reviewed in Andrews et al. 2015).

The 2008 *WVC Best Practices* study (Huijser et al. 2008b) estimated that wildlife fencing complemented with appropriately-designed wildlife crossings is 87% effective at reducing WVCs. A review of wildlife crossing research by Glista et al. (2009) and Gunson et al. (2016)

note that the effectiveness of wildlife crossings depends on the location, dimensions, size, shape, relative openness, visibility at the ends, vegetation, and traffic noise.

The coordinated use of wildlife exclusion fencing and passages does keep wildlife away from highways and reduces WVCs. However, the possibility of wildlife inadvertently entering the ROW through interchanges or holes in the fence requires features that will allow animals to exit the ROW while minimizing the opportunity for trespass. In rural settings with low volume roads, cattle grates have long been used as a mechanism to prevent the movement of livestock without requiring an openable gate. While such structures could be effective where interchanges create breaches in continuous fencing, they are not amenable to one-way exit of wildlife from ROWs. One-way exit gates are fence openings with a metal gate or movable barrier that opens but a unidirectional gate prevents return. Escape ramps or "jump outs" are fence openings where the ROW side of the opening has higher elevation than the opposite side with the goal of allowing animals to jump out but preventing their ability to jump into the ROW. The elevational difference can be created by a short incline leading up to the opening on the ROW side and a sharp drop-off away from the highway facilitating one-way exits from the highway. Combined with barrier fencing and funneling fencing to help direct wildlife to the jump out, these structures are a potential way to ameliorate occasional trespass into the ROW and continue to reduce WVCs. Past research on the effectiveness of exit gates and escape ramps has been limited. Early studies of exit gates in Colorado (Reed et al. 1974) and Minnesota (Ludwig and Bremicker 1983) demonstrated that exit gates could be used in conjunction with fencing to reduce WVCs. However, Lehnert (1996) found that only 16.5% of deer that approached an exit gate in Utah used them to exit and found jump outs to be 8-11 times more effective than one-way gates at allowing mule deer to escape the ROW (Bissonette and Hammer 2000). Siemers et al. (2013) reported the preliminary results of an on-going study of escape ramps in Southwest Colorado, finding that 41% of wildlife approaching the ramps used them successfully and that the jump height and ramp slope were key design features influencing usage. They also noted a small number of occurrences where deer used the escape ramps to jump back into the highway ROW.

The NVBP is one of the first large-scale efforts by the ODOT to use a combination of the aforementioned mitigation structures to minimize the WVCs along a high-speed roadway built through the Wayne National Forest (WNF). Completed in 2013, the NVBP includes barrier fencing excluding large mammals from the roadway combined with jump outs to allow egress for individuals that trespass into the ROW. There are three large wildlife underpasses that maintain wildlife connectivity between the north and south sides of the highway. In addition, a 1-mi. section of the NVBP has finer mesh small wildlife fencing to protect state-endangered reptiles and prevent reptile road mortality. This was also accompanied by a small underpass, to allow passage between the two sides of the highway. A second small wildlife underpass also was installed but independent of the small mesh fencing. Along Ohio State Route 78, a collector road to the NVBP with several adjacent wetlands, a barrier-passage system was constructed to divert amphibians moving among wetlands and prevent their crossing of the road surface. Finally, a series of high-mast lighting fixtures were installed to lure insect-feeding threatened bats above the level of traffic. The objective of our study was to determine the use and effectiveness of these installed mitigation structures and assess whether they reduce WVCs and minimize impacts on wildlife, particularly rare and endangered species, affected by the NVBP and its local and collector roads.

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CHAPTER 2: NELSONVILLE BYPASS – STUDY SITE AND MITIGATION FEATURE DESCRIPTIONS

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INTRODUCTION

In this chapter we describe the U.S. 33 Nelsonville Bypass (NVBP) site and the mitigation features built into the right-of-way (ROW), including geological and ecological features that may affect wildlife movement patterns. We evaluate the environmental context at two scales: (1) the general geographic setting encompassing the adjoining Wayne National Forest (WNF) and the Hocking River flood plain, including the town of Nelsonville, Ohio (Figure 2-1); (2) a more restricted consideration of the NVBP ROW and those habitats at the boundary of the WNF and the ROW (Figure 2-2). Finally, we identify and provide detailed descriptions of all the mitigation features built into the NVBP ROW.

It can be assumed that construction of the NVBP isolated a portion of the WNF and altered wildlife movement patterns across the landscape. In particular, the NVBP bisected a large contiguous eastern deciduous forest area to the north from potentially high value food and water resources to the south and east in the Hocking River flood plain. There were few natural or artificial barriers to wildlife movement prior to the construction of the NVBP, and wildlife could presumably move easily between food resources, cover, hibernation sites, overwintering sites, and areas associated with reproduction. Deer and other mammals habituate to trails, which are frequently the most energy efficient pathways between resources. When such trails become blocked, animals pioneer new pathways to maintain connectivity among resources. The construction of the NVBP and its wildlife mitigation structures established two barriers: the roadway, and the wildlife fencing. Although the roadway is a permeable barrier, the abrupt change in habitat associated with road construction combined with high-speed traffic and its associated noise constitute a formidable barrier. The fencing is part of the wildlife mitigation, and includes under-road passageways to maintain connectivity on either side of the roadway.

Evaluating the effectiveness wildlife mitigation features requires an understanding of the landscape and the distribution and availability of smaller scale habitat differences that determine the distribution, abundance, and movement of wildlife. Where animals find cover, food, water, thermoregulatory opportunities etc. is an important component of how they use the landscape. The availability of different habitat types will determine the frequency and distance that animals move. An organism's mechanism of locomotion, combined with spatial and temporal availability of resources, determines the extent of the landscape that is crucial habitat for completing a life cycle. Competition, reproductive state, hunting pressure and prior stress also affect movement among landscape elements. Based on these criteria, the landscape habitat delineation area (Figure 2-1) is described by the following limitations:

- The bank of the Hocking River from the confluence of the first west-flowing perennial tributary just north of Haydenville, downstream to the confluence with Monday Creek.
- The bank of Monday Creek from the Hocking River confluence to where it is crossed by State Route 278, northwest of Carbonhill.
- Along the south side of Route 278 to State Route 595.
- Southwest along the south side of Route 595 through the 595 interchange near the Rocky Boot shipping facility, and along the perennial tributary to the Hocking River.

Because the bypass is mostly within the Wayne National Forest (WNF), we first evaluate the area that encompasses the national forest and the Hocking River. We also present higher resolution detail on the bypass ROW, including the immediately adjacent area. We provide more detail on the habitat within the ROW by identifying 11 road segments. The segments are delineated by the east and west ends of bypass construction zone and the interior boundaries between overpasses. There are 10 overpass structures that vary in size, purpose and distance between bridges, resulting in a mix of long and short sections (Figure 2-2). These segments are used to identify habitat that lies both within and immediately adjacent to the ROW (Figures 2-3 – 2-13). The fencing was built mostly on the outer edge of the ROW. However, in some areas the fencing was placed closer to the roads such that the ROW includes area both within and outside the fencing. Each segment contains areas of vegetation that are maintained (e.g. mowed) and some sections contain vegetation, particularly on steep slopes that are undergoing natural succession. Most of the habitat identified within these sections was altered during the construction of the NVBP and its associated structures and tributaries.

HABITAT MAPPING

We used geographic information system (GIS) mapping to identify the structure and types of habitat in the study area and the NVBP corridor, and to identify potential pathways of movement and the placement of the mitigation structures. ESRI ArcGIS 10.5.1 was used to map habitat and other germane features. The following data resources were used to create the habitat map presented as Figure 2-1.

- 2014 Athens and Hocking Counties Digital Orthoimagery, both true color and color infrared – leaf-off. 3-inch and 6-in. pixel size. Woolpert. OGRIP: http://gis5.oit.ohio.gov/geodatadownload/
- 2014 Athens and Hocking Counties light detection and ranging (LiDAR) – leaf-off. Woolpert. OSIP
- 2000, 2007, 2011 digital aerial imagery
- ArcGIS basemap world imagery, various dates but mostly 2014 through 2016
- Google Earth imagery 1992 through 2016

LiDAR data generated topography to reconstruct slope, aspect and elevation. LiDAR data also generated tree canopy maps, three-dimensional renderings, cross-sections, and soil saturation maps to identify wetlands. LiDAR data sets were overlaid on georeferenced imagery and habitats that were heads-up digitized. Habitat delineations within the bypass fencing were performed at between 1:400 to 1:1500 relative fraction ratios to capture high resolution detail within and near the bypass corridor. Areas further away were digitized at ratios of 1:2000 to 1:4800. Habitat maps were ground-truthed, confirmed or modified at GPS located sample plots during map development.

Habitat mapping polygons, delineated through heads-up digitizing in ArcGIS 10.5.1 using recent high-detail georeferenced aerial imagery, represent the spatial extent of different land covers in the project area. The upper surface distinguishable from an aerial image is the land cover type, and includes (1) natural features, such as bare earth, vegetation, canopy cover, and water; and (2) man-made features, such as pavement and buildings. The upper observable surface canopy layer and its characteristics and composition were used to classify or name predominate habitat cover features (Daubenmire 1959). The aerial platform canopy layer is a product of surface geology, anthropogenic land uses, the composition and productivity of the vegetation as influenced by moisture and soil fertility, and the time since the last disturbance. Thus, the canopy layer can be used to define habitat types using the USDA PLANTS (2011) database, to standardize species information and nomenclature. In addition, field sampling provided direct data on the composition of species and an estimation of the relative importance of each within definable stands (polygons), enabling the use of textures and colors in the aerial imagery to define species-based differences.

The position of a delineated polygon on the landscape is fundamental in determining and naming habitat polygons. Topographic contours created using LiDAR data were overlaid to differentiate, for example, between north- and south-facing slopes, which can support widely differing vegetation communities due to the highly variable moisture regimes that result from opposing solar exposures. The ability to positively identify low-lying sites and flat slopes is also important in the identification of wetland and bottomland habitats.

All delineated polygons were classified according to a hierarchical format with the primary division between (1) Natural Vegetation and Landscape Features, and (2) Anthropogenic Land Cover and Uses, including the types of features comprising that division. Classes were grouped based on the similarity of ecological form and function apparent on the landscape.

Natural vegetation is strongly affected by surface geology (including soils), recent prevailing climatic factors, temperature and moisture regimes, prevailing winds, latitude, the magnitude of solar insulation, disturbance, the competition between species of vegetation, and by faunal influences (particularly pollinators and seed transporters). These factors result in the accumulation of species into limited groups that may be considered at a regional scale as a temporally significant.

GENERAL SETTING OF THE STUDY AREA

The Temperate Deciduous Forest Biome (Braun 1950) characterizes the forest condition in the study area. This biome historically includes most of the area between the Mississippi River and the Atlantic Coast, and southern Ontario to the southern Appalachian Mountains. Precipitation ranges from 28 in. per year in the northwestern section of the biome to more than 60 in. in the southeastern mountains. In the study area, precipitation averages more than 40 in. per year and is well-distributed seasonally. There is distinct seasonality. The dominant plant species of the biome are broad-leaved deciduous trees, although native pine stands occasionally prevail. There are eight recognized forest complexes throughout this biome, four of which are found in the study area (Braun 1950). Topographically induced variability in growing conditions results in forest type complexes that are small and widely distributed.

Generally, older forests develop greater structural complexity and a corresponding increase in habitat diversity. The range of stem sizes increases as shade-tolerant, berry-producing understories become established, which in turn contribute to an increase in surface organic matter. Left undisturbed, older trees will perish and fall, leaving cavities for denning and establishing a “pit-mound” forest floor structure that provides small ephemeral wetlands, which provide breeding sites for amphibians and aquatic insects and water sources for wildlife. Limbs and logs cover the forest floor. The time-driven increase in habitat diversity and structural complexity increases the value of mature forest to native fauna.

There is no primeval (old growth) habitat in this region of Ohio. The entire landscape within the area of the Nelsonville Bypass site has been frequently disturbed over the last 200 years by colonizing Europeans, and over the previous 12,000 years by populations of Native Americans. Fire, climate change, glaciation, timber harvest, mining, land clearing for crops, and surface erosion have all contributed to the disturbance and reestablishment of vegetation. Following disturbances, secondary succession begins the process of recovery and reestablishment. The initial species are a product of the seed bank and the biophysical conditions following the disturbance. Eventually the pioneer community may be replaced via seral successional stages, perhaps ultimately reaching an equilibrium characteristic an old growth eastern deciduous forest. This process is highly dependent on the level of disturbance, its impact on the soils and their nutrients, the surviving seed bank, and the colonization and dispersal capabilities of the equilibrium seral stage species (Curtis and McIntosh 1951). This process requires scores to hundreds (or even thousands) of years.

GEOLOGY, TOPOGRAPHY, AND DRAINAGE

The U.S. Route 33 Nelsonville Bypass was constructed between 2006 and 2013 through a dendritically eroded portion of the of the Allegheny Plateau peneplain. The bedrock plates of the local Allegheny Plateau are composed of Mississippian and Pennsylvanian aged bedrock that dip at about 7 degrees to the southeast. Streams have eroded and incised 300 to 500 ft. gorges into the plate, creating a rugged topography in which most hilltops have a common elevation. Erosion of softer substrates resulted in steep grades, often exceeding a 60%, and riparian habitats that drain into Hocking River and Monday Creek. Long, deeply incised streams tend along an east-west alignment, while short tributaries flow north and south at nearly perpendicular angle to the channels of the major perennial streams. Sandstone and limestone rock outcrops are common, particularly at valley heads and along ridge crests, where a residual hard caprock is encountered.

The southeast-trending NVBP begins at the former alignment of old Route 33 approximately 2,800 ft. east of Haydenville, OH (west end), continues along an 8.26 mi. sinusoidal loop north of the city of Nelsonville, and rejoins former Route 33 approximately 1,200 ft. west of Doanville, OH (east end). While beginning near and ending in Pleistocene-age sediments of the Hocking River Valley, the highway was principally carved through the shallow-soiled Pennsylvanian-aged rocks composed of sandstones, shales, mudstones, siltstones and coal measures. There were approximately 21 ridge-top cuts ranging in depth from 40 ft. to more than 140 ft. The area affected by construction ranges from 200 ft. in width where final grades are near pre-construction elevations to much greater than 200 ft. near interchanges. The average width of the NVBP corridor is 600 ft. Included in the construction project was a 1.8 mi.

realignment of Ohio State Routes 78 and 691 (SR 78 and SR 691) between Buchtel and Hocking College Parkway, which entailed reconstruction of the SR 691 Bridge over the Hocking River (eastern interchange). A second 0.8 mi. segment was constructed west of Nelsonville near the alignment of Dorr Run Road (western interchange). The total land disturbance estimate for the project construction area from 2014 aerial imagery is approximately 925 acres, including the roadway construction area, temporary ingress-egress roads, temporary storage and equipment areas, and borrow pit and disposal areas adjacent to or near the now fenced highway ROW.

HABITAT TYPES

Habitats change over time. Forest outside the ROW will change slowly in the absence of disturbance, while habitats within the ROW will undergo rapid succession unless suppressed by mowing or the use of herbicides. Because within the ROW the surface soil and its associated O-B horizons were completely removed, the initial successional stage will be a largely function of the seed mixes planted. However, within 10-15 years much of the fenced area likely will represent young early successional forest. In 20-40 years, the non-mowed areas will be similar to the present forest edge outside the fence. Our habitat delineation is based on conditions represented in 2014 aerial imagery. Mapped habitats are named simply and described by composition and structure. Figure 2-1 provides a habitat overview of the general study area and Table 2-1 provides area coverage of the different habitat types in the general study area. Figures 2-3 – 2-13 provide more detailed habitat identification within the NVBP ROW, and Table 2-2 provides the specific area coverage of habitat types and structures within the NVBP ROW. Below we describe the habitat types encountered in the study site and their importance to wildlife in the study area.

FOREST HABITATS

Forest predominates in the moist, warm-summer and cool-winter mid-continental climate zone of southeastern Ohio on landscapes that lack disturbance and human suppression. Receiving nearly 40 in. of annual precipitation, forests in southeastern Ohio have full and closed tree canopies with 80-100 percent light occlusion during leaf-on conditions. Forest is the most abundant habitat type mapped for this assessment area, occupying 10,891 acres (Table 2-1). The forests near the NVBP and virtually all forests in the region have been harvested or removed during the last 150 yr. Consequently, forest stands in the study area range from 10-150 years in age and active silviculture is practiced on the WNF. Tree diameters average 18-24 in. near the NVBP. Trees in the 24-in. to 30-in. diameter class were frequently observed near stream corridors and in valleys that presumably had made access for past tree removal difficult; these tree sizes are consistent with older forest stands. Braun (1950) characterizes the forest type found in the study area as a microclimate-driven combination of deciduous oak-hickory and mixed mesophytic forest. Generally, the oak-hickory forest type occurs on ridge tops and south facing slopes above local valley bottom base flow. Mixed mesophytic forest occurs on north facing slopes and on well-drained but well-water lowlands. We identified five forest types in the study area based on position on the landscape, stand age, hydroperiod, and species composition.

Dry Forest

Dry forest is closed canopy forest, located chiefly on south facing slopes and well-drained ridge crests. Dominant species include black oak, white oak, red oak, scarlet oak, chestnut oak, mockernut hickory, red hickory, white ash, big-toothed aspen, and black gum.

Reclaimed mines often support planted stands of sweetgum. Old American chestnut sprouts are often observed in the understory between dogwood and black haw. Acorns are abundant from late summer to mid fall, and through winters during mast years. Low-bush blueberries, huckleberries, and green briar are found in mature stands near ridge tops in mid-summer, and provide cover and forage for wildlife.

Mesic Forest

Mesic, or moist, forest occupies north facing slopes and valley bottoms at higher elevations. Forest canopy composition includes red maple, sugar maple, red oak, bitternut hickory, shagbark hickory, American beech, tulip poplar, American elm, red elm, black walnut, white walnut, and persimmon. Spicebush, blue-beech, ironwood, and redbud are often common in the understory. Mesic forest slopes and upper valley “cove” conditions are usually rich in spring forbs and graminoids, including early sedges and the wide array of pre-canopy herbs. Low-flow seeps and springs frequently are present on southeast-facing (dip) slopes below sandstone outcrops, and are dry period sources of drinking water for wildlife.

Riparian Forest

Riparian areas include the flood plains of streams and rivers. Moisture is generally available for most of the growing season from runoff, shallow groundwater flow from adjacent uplands, and rainfall collection on low gradient and depressional topography. Dominant trees are tolerant of periodic inundation and resilient in the face of flood debris damage. Typical species include silver maple, American sycamore, boxelder, green ash, river birch, and American elm. This forest type not only persists along both the Hocking River and Monday Creek, but along various smaller streams such as Dorr Run, Snake Hollow, lower Coe Hollow, the Purdum Road Hollows and lower Monkey Hollow. Graminoid and succulent forage is generally available from late winter through late fall. A dense understory and proximity to ample water are positive attractants for wildlife during all seasons, and provide a refuge during drought. These areas can also serve as a path of least resistant travel-way through rugged landscapes, such as exist in the study area.

Pine Forest

Pine forest stands scattered throughout the study area are composed of either naturally occurring Virginia pine on xeric, low nutrient ridge tops, or as white pine plantings on mine reclamation sites or nutrient depauperate agricultural sites. Pine forests provide year-round dense shade and cover during the hottest times of the summer and the coldest times of the winter. Understory forbs and forage is typically absent or very low.

Swamp Forest

Swamps are permanent or ephemeral aquatic habitats dominated by trees and extended periods of low soil oxygen during the growing season. Swamps are found in the study area along undisturbed portions of the Hocking River, and particularly within the glacial outwash plains along lower Monday Creek. These forests are dominated by pin oak, swamp white oak, boxelder, black willow, and green ash, including in lowlands not connected to major streams but saturated due to low permeability subsoils. Some swamps are geomorphic fluvial lowlands and abandoned meanders, while others are the result of historic mining, railroad construction and attempted land drainage. Because of the microclimate created by the persistent presence of water near the surface, grasses and forbs are available for wildlife in both early and late winter. Ground cover generally is dense with multiflora rose and poison ivy, provide high-quality cover and refuge during all seasons.

HYDROLOGICALLY MAINTAINED NON-FOREST HABITATS

Persistent and sustained inundation results in long term soil saturation that suppresses forested habitat. Precipitation-driven overland flow concentration, shallow groundwater outflow, and flooding combined with water retention facilitators such as beaver dams, topographic depressions, mining activities, and dam building by humans maintain persistence water and non-forested plant communities. Wetland communities are naturally uncommon in the tilting and highly eroded landform of the project area, however, human activities have greatly changed the number and area occupied by saturated soil, and standing water features comprise approximately 220 ac. of the study area.

Shrub-swamp

Shrub-swamps are the result of impoundments created by highway and railroad construction in the study area. Some non-acid mine high wall pools also have accrued a dominant wetland shrub community. Water levels are usually constant at 6-12 in. for most of the year. Many shrub-swamp stands are 60 to 80 years old, based on stem cross-section growth ring counts. The dominant species is button-bush; however, the following additional species may occur: swamp dogwood, red-osier dogwood, speckled alder, and sandbar willow. Dense low growth forms provide all-season shelter and cover for wildlife.

Marsh and Fen

Marshes and fens differ chemically and hydrologically. Marshes are found in still, standing water and are eutrophic. Fens arise form slowly flowing shallow groundwater discharge, and are oligotrophic. They are dominated by herbaceous vegetation and present a wet-soil-water signature in aerial imagery. Functionally, marshes and fends provide year-round water sources, and grasses and succulent forage for wildlife. Marshes and fens are scattered throughout the study area, and are associated with abandoned mine water discharge. Many are acidic: a yellow or red discoloration is a consequence of acid mine drainage. Most support wetland vegetation as acid concentrations are diluted with distance from the outflow point.

Permanent and Ephemeral Waters

Lentic and lotic surface water provides valuable habitat for all wildlife and ranges from sustained shallow water ponds to ephemeral pools to high velocity rivers and streams. Natural ponds are rare in the steep and highly eroded southeastern Ohio topography, but ephemeral pools are more common on naturally occurring benches. Beaver activity creates and maintains pond environments on small streams. However, the majority of the pools and ponds in the study area are man-made impoundments created by damming small drainage basins, gravel mining in the rich glacial valley deposits in the Hocking River and Monday Creek flood plains, or by strip mining for coal. The forest north of the bypass contains many unreclaimed strip pits and grading basins that retain water. Many are not acidic, and are a valuable water source for wildlife during dry periods.

ANTHROPOGENICALLY MAINTAINED, DISTURBED, AND NON-VEGETATED HABITATS

Disturbed areas represent habitat that is altered on a regular basis through human activity. Mowing, agriculture, and construction all contribute to the disturbance that maintain these areas. Despite a high disturbance regime, some wildlife still use these habitats for forage. Within the study area, 3,492 ac. of highly disturbed habitat belong to this category.

Rough Grass

On disturbed ground, rough grass habitats are dominated by planted non-native and native herbs and grasses, colonizing native species and invasive species. Soils have been profoundly disturbed, graded and contoured into their present position. Soils have an absent or limited O-horizon and are composed of mixed surface soils, newly exposed subsoils, and crushed rock. Typical soil microbial communities and fauna are lacking or absent. After fertilizing and planting, this habitat provides high-quality forage for some years, then is colonized from undisturbed fringes over long periods (years to decades). These areas provide grazing habitat for wildlife, particularly deer. Rough grass dominates the habitat type within the ROW road grades, median, and berms and the recently graded and planted areas south of the bypass and west of Nelsonville, Ohio associated with the Athens-Hocking Reclamation Center landfill.

The species composition of cool-season grasses and legumes within these areas suggests that they provide preferred food sources for 9-10 months (outside of very hard freeze conditions) over the year for deer populations. The high densities of legumes in many of these areas create high-quality forage for herbivorous wildlife.

Scrub Forest

These habitats are comprised of isolated patches that were not disturbed during construction, and include native and invasive scrub species. This habitat characterizes abandoned agricultural fields within the first 10 years of succession after abandonment, and will ultimately succeed into forest habitat. Scrub forest habitats frequently are invaded by invasive exotic species that can form dense stands of multiflora rose, Japanese honeysuckle and privet, all of which are easily observed in aerial imagery. These habitats provide daytime concealment for wildlife within the NVBP ROW.

Successional Scrub

Successional scrub stands are transitional habitats on profoundly disturbed soils, and are dominated by 2-9 ft. tall native and introduced woody species of plants. Canopies are open, allowing herbs and grasses to persist and function as important forage sources. Scrub occurs along both sides of a highway, particularly on road-cut terrace shelves and above steep road cuts, where plants have become established since the finished grade was obtained and no mowing has occurred. Composition includes early successional oligotrophic xerophytes such as Virginia pine, black locust, eastern red cedar, and American sycamore. Some oaks, hickories, wild black cherry, and Japanese honeysuckle also were observed in this habitat during site inspections in 2016. Successional scrub will revert to forest habitat over time.

Agriculture

Three types of agricultural activity in the study area are perennial or seasonal attractors for deer populations: pastures (particularly those with feedlots), hayfields, and rotational row crops (corn and soy beans). Early old-field successional areas were included in this category because the soil in abandoned fields have a rich seed bank and well-represented populations of soil organisms. Most occur in the Hocking River flood plain in the study site.

Residential Landscapes

Residential areas contain well-watered grass, succulent herbs, and well-tended shrubs that provide opportunities for foraging wildlife. Home vegetable gardens are included in this mapping unit. Residential areas are concentrated, high nutrient food sources that entice deer to travel into these habitats, particularly during the winter when natural food sources may be scarce.

Steep Rock Cuts

Steep rock cuts are exposed and barren due to lack of soil and the moisture necessary for vegetation. Some cracks and shelves where organic debris has accumulated may be colonized by grasses, forbs, and woody vegetation. Benches in cut faces are heavily occupied by successional vegetation. However, areas associated with acidic coal and black shale outcrops, which are toxic to most germinating seeds, remain barren.

Rip-rap Beds

Large rip-rap beds were constructed and are common within the ROW. Composed of 6-in. to 24-in. irregular limestone rock fragments, these engineering features are used to control erosion and stabilize steep slopes. Rip-rap beds provide excellent cover and habitat for small wildlife and thermoregulatory habitat for ectothermic species such as reptiles.

Road Pavement

Hard-surfaced major roads within and near the bypass were delineated at the pavement edge.

Municipal and Industrial Land Uses

Municipal and industrial lands include factories, lumber yards, large storage facilities, and other typically barren and hard-surfaced areas. They provide little habitat and sometimes are perilous and devoid of wildlife.

HABITAT MAPPING SUMMARY

The habitat and land cover mapping for the approximately 14,640 ac. study area resulted in the identification and mapping of 11 cover types identified shown in Figure 2-1. We also detail the coverage of the habitat types identified above both in the Figure 2-1 and their surface area on the study site in Table 2-1. Forest habitat dominates the study site to the north and south of the bypass. This is followed by residential and disturbed areas in the town of Nelsonville, Ohio, on the bypass itself, and agricultural area in the Hocking River flood plain (Table 2-1). Figure 2-2 provides an overview of the 11 highway segments used to map the habitat types within the NVBP ROW. We mapped the habitat in the area within the fence and those areas immediately adjacent to the wildlife fence (Figures 2-3 – 2-13). The area within the fencing are dominated by rough grass habitat (217 ac.; Table 2-2). That is followed by successional scrub (62 ac.) and bare rock (52 ac.) on the steep slopes of the road cut and rip rap erosion control features (Table 2-2). Roadway comprised almost 90 ac. of the NVBP ROW (Table 2-2).

MITIGATION FEATURES

Because the NVBP bisected a section of the WNF, ODOT installed several mitigation treatments to minimize vehicle-wildlife interactions and maintain connectivity for wildlife between the two segments of the forest. Below we describe the general applications of the structures and specific details about each of the structures. The mitigation structures were constructed with four general goals for their implementation. These include:

1) *Exclusion Devices - keep animals out of the ROW and away from vehicles*
- High fencing along the bypass corridor to restrict entry into the ROW by large fauna
- Low, fine mesh fencing to prevent reptile and small animal access to the ROW
- High-mast lighting to draw insects and prey-seeking bats above traffic

2) *Escape Devices*
- One-way jump-out structures that provide safe exit from the ROW by large fauna

3) *Permeability Devices*

- Large cross-sectional area underpasses for large and small wildlife movement through the highway corridor
- Small cross-sectional area travel ways for small mammals, reptiles and amphibians through the highway corridor

4) *Habitat Replacement*

- Bat roosting boxes to replace basking habitat of tree nesting bats
- Newly constructed wetlands to replace areas removed during construction

The above structures were designed and constructed explicitly for wildlife mitigation. Some additional road bridges and non-screened drainage culverts traversing under the NVBP that may provide connectivity and safe passage were also investigated. The effectiveness of the mitigation structures to minimize wildlife-vehicle interactions and maintain habitat connectivity was assessed for several wildlife groups: deer and other large animals (Chapter 3 and Chapter 4), amphibians (Chapter 5), bats (Chapter 6), and reptiles and other small animals (Chapter 7).

EXCLUSIONARY DEVICES

Barriers, fences, and the high-mast lighting are exclusionary devices designed to prevent wildlife from entering the highway or lure wildlife away from the highway. Two fencing types were installed along the NVBP to exclude wildlife. The first is the tall fencing installed along the ROW perimeter of the NVBP to exclude larger animals, primarily deer, from the bypass. The second is short mesh wildlife fencing installed primarily to exclude reptiles, but also may be effective for many small animal species. High-mast lighting was installed to light intersections while attracting insects high above traffic, so that bats, which prey on insects, would be lured above traffic.

Tall Wildlife Exclusion Fence

Eight-foot-high wildlife exclusion fence was installed on the NVBP corridor, mostly along the boundary of the ROW and the WNF. The exclusion fence is 8-ft. tall and lines both sides of the bypass from the connection with old U.S. Route 33 near Haydenville to the re-connection with old 33 near Doanville. The fence is composed of 96 in. high-tensile, 12.5 gauge galvanized, woven graduated wire-mesh fence; this fence was stapled to 10-ft. tall, earth-embedded (3-1/2-in.) pressure-treated landscape timber posts and was installed flush with the ground surface. The wire-mesh graduations increase from 3 in. x 6 in. mesh on the lower 3 ft. up to 6 in. x 6 in. mesh for the upper 5 ft. The smaller mesh was intended to create a barrier for intermediate sized animals such as raccoons, coyotes, opossums and other similar sized organisms. Wooden post spacing ranges from 20 ft. or less at corners and other stress points to more than 150 ft. in straight flat runs. Galvanized metal T-posts were placed at approximately 25 ft. intervals in the long runs between wooden posts. Corners and turns were double-braced and guyed. The installation resulted in most posts being rigidly in place, with bottom strands on the ground surface. Fence tension between posts was sufficient to be an effective barrier to wildlife.

The fence is continuous between ROW access gates, one-way jump outs and bridge abutments. The total length of installed fence, including jump outs and their wing fences, is 99,966 ft., as measured from high definition aerial imagery. Fence length is approximately 48,776 ft. along the south side of the bypass and 51,190 ft. along the north side. There are 18 access gates along the fence on both sides of the ROW west of Burr Oak Boulevard in Nelsonville, Ohio. Built into the fence are 16 unidirectional jump outs designed to allow wildlife, primarily deer, exit from the ROW without providing an entry point. Detailed images of fence position and jump outs are provided by road section in Figures 2-3 to 2-13.

The fence mostly follows the rugged topography on the ROW boundary. Therefore, the fence ascends ridge tops, crosses over road cuts, and extends down steep cuts and fill grades into deep stream valleys to cross streams. The rugged terrain resulted in some sections of the fence maintaining poor ground contact. In addition, there are gaps from construction errors, or from rill and gully erosion characteristic of the region (Figures 2-3 to 2-13). Finally, the fence in most cases is located along the boundary with forested habitat, and therefore is vulnerable to tree falls that can collapse the fence.

The tall exclusion fence was installed per plan. However, its effectiveness as a barrier to wildlife movement is reduced by breaches created by erosion and tree falls. Furthermore, there were some instances of human caused damage to the fence where wire had been cut. At either end of the bypass the fence converts from 8 ft. to 4 ft. in height, or to no fence. The 4 ft. fences are easily jumped by deer. There are two major interchanges that create fence gaps across the roadway for automobile travel that animals use too. The eastern interchange at SR 78 and SR 691 has openings along the north and south sides. The north opening is 365 ft. wide and adjoins forest, marsh and swamp land that provides wildlife entrance onto the ROW. The south side opening is 205 ft. wide and opens to the Hocking River riparian forest corridor and extensive agricultural fields beyond. The western interchange at John Lloyd Evens Memorial Highway (formerly Dorr Run Road) has a northern opening 200 ft. wide and a southern opening 400 ft. wide. The north opening is a dead-end road that leads into a 9000-acre forest in the WNF. The south side of Dorr Run Road opens to a 25-acre plot of recently planted rough grass in a residential area and beyond lies the Hocking River riparian forest corridor. Both interchanges offer access points for wildlife onto the NVBP ROW, and heavily used trails are evident (See Chapter 4 for more detail).

Numerous stream crossings that intersect the fence are blocked with site specific gates constructed from treated lumber (2 in. x 4-8 in.). The gates are hinged to a reinforcing rod attached to the fence bottom so that they only open downhill, rising by water flow to accommodate flooding and closing when the water recedes. Since installation, rock and woody debris have accumulated behind the gates, creating openings that allow wildlife access to the ROW. Erosion also excavated the stream channels below gates, sometimes more than 2 ft. The erosion in some cases resulted in deeply incised openings, and wider channels that are no longer effectively blocked and thus provide avenues for wildlife to enter the ROW.

The tall fence was constructed on the outer edge of the ROW. Often, a path was brushed-hogged above a road cut to install the fence or the fence was installed along the toe of fill slopes. In both locations, trees from the remaining forest are next-to or within 50 ft. of the fence. Much of the forest canopy along the bypass is greater than 80 ft. in height and thus trees can damage the fence when they fall. Interior forest trees are less resistant to wind-throw than trees at the edge of the forest and because the NVBP was built through interior forest the trees now on the edge of the ROW are vulnerable to falling, until they grow new roots and branches to increase stability. As a result, many have fallen along the bypass, and several have collapsed the tall fence creating gaps that allow wildlife trespass. Several such incidents have occurred at distances of 200-400 ft. from the highway and along steep slopes, making repair difficult.

Three additional construction details resulted in openings in the fence that provide access to the ROW for wildlife. First, fence posts that initiate the fence adjacent to bridge abutments are not snugly placed against the abutment. The resulting openings are wide enough (>18 in.) that wildlife, including deer, can trespass onto the ROW. Second, west of the Dorr Run Interchange are six culverts greater than 48 in. in diameter that end near the highway. Barriers made of 12-

gauge wire spaced 18-24 in. and placed horizontally across the culvert suspended from fence post on either side are designed to prevent wildlife access. However, smaller wildlife and deer can easily penetrate this fencing. Finally, there are several locations where the tall fence must cross rip-rapped channels; the large size and irregularity of stone placement creates gaps where the fence does not solidly contact the ground and where deer and other wildlife can trespass. These gaps range create 18-42 in. openings above the substrate.

Small Wildlife Exclusion Fence

The small wildlife (reptile) fence begins just west of the Dorr Run entrance/exit ramp confluence with the Dorr Run Road. Fencing was installed west of the Dorr Run interchange and extends for about 1 mile on both sides of ROW. It is composed of 48 in. tall 1/4 in. mesh galvanized wire attached to metal rods inserted into the soil. The upper two-inches of the fence mesh is folded away from the highway at a right angle to restrict climb-over. The fence is buried 3-8 in. to prevent small wildlife from burrowing under the fence. The total length is approximately 11,316 ft. as measured from recent georeferenced aerial imagery. There is 5,468 ft. of fence along the north side and 5,846 ft. along the south side. The location of the reptile fence is shown in Figure 2-14.

The effectiveness of the small wildlife exclusion fencing is discussed in Chapter 7. However, rill and gully erosion has created several gaps under the fence. Additionally, the high sulfur content rock along road-cut banks created acidic run-off that rapidly corroded the fence, resulting in gaps more than 50 ft. long. Several sections of the fence have been dragged downhill by the collected weight of debris and continued erosion.

High-Mast Lighting

There are 16 high mast light fixtures installed along the bypass. Ten of these are near the Dorr Run Interchange. The remaining six are near the Ohio State Route 78/691 Interchange. Lights are arrays of four lamps 100 ft. above the ground. The aim of the high-mast lights is to draw insects above the flow of traffic so that the bats will feed high above traffic. High- mast lighting effectiveness is discussed in Chapter 6.

ESCAPE DEVICES – JUMP OUTS

Sixteen one-way jump out structures were installed along the U.S. 33 Nelsonville Bypass (NVBP). The jump outs were designed to provide a safe exit from the right-of-way (ROW) to animals that trespass into the ROW, while not providing a means of ingress into the ROW. The jump outs were installed mainly for deer, although they can be used by other wildlife.

After an animal trespasses into the 8-ft. tall exclusion fencing zone, the fencing will guide deer and other wildlife to jump out structures. In addition, the structures have wing fences to further guide deer to the escape chutes. Wing fences, also called wing walls, were constructed from the same materials as the 8-ft. exclusion fencing, and these fences are slanted to funnel deer and other wildlife into the escape chutes. Then deer are expected to jump through the escape chute (leaving the ROW) and touch ground on a landing pad (Figures 2-15 and 2-16). The relatively high jump (4-6 ft.) back into the ROW over the jump out wall and soft-landing pad material should discourage deer from trespassing back into the ROW. Soft landing pad materials (sand, soil, and pea gravel) do not provide deer with a compact surface suitable for making high jumps. The jump out wall is composed of number 11-guage twisted wire that holds 4-8 in. limestone rock in place. Wall height varies with installation conditions, and the average jump out wall height is 5.52 ft. high (Table 2-3). Some of the jump outs also have knee bars in the escape chutes to further prevent ingress back into the ROW (Table 2-3 and Figure 2-16). A knee bar is a

2-in. diameter bar that is 18 in. above the jump out wall top. Jump outs have been deployed along western U.S. highways and have been effective at reducing the numbers of wildlife within fenced highway corridors (Beckmann et al. 2011).

The jump outs along the NVBP were planned to be placed between bridges along the segments of the highway, but the final location for each was decided by the construction contractor. Figure 2-2 and Table 2-3 depict and describe the locations of the jump outs along the Nelsonville Bypass. There are between 0 and 4 jump outs located in each of the roadway segments (delineated by movement barriers such as bridges, overpasses, etc.) (Figure 2-2 and Figures 2-3 – 2-13). Five of the jump outs exit north of the road, while 11 exit to the south side of the road. Each jump out is unique (Table 2-3 and Table 2-4) and a complete description of each jump out is included below; individual jump outs are pictured in Figures 2-17 through 2-32.

Jump Out 1 – J1

Jump Out 1 (J1) is the first jump out on the west end of the NVBP. It is located at construction alignment station 39+00, approximately 1,700 ft. from the west end of the southern 8-ft. tall wildlife exclusion fence. J1 is approximately 900 ft. west of the Company Road Bridge that demarcates the end of highway segment 1 and the beginning of segment 2. The jump out wall height is 5.5 ft. There is no knee bar. The wall is 87 ft. from the pavement edge. There are three chutes and two wing fences. There are deer trails around the ends of the wing fences and negligible evidence of grazing within the chutes. Habitat inside the exclusion fence above the jump out is primarily grass with minor woody shrub succession underway. The landing area is within a perennially inundated cattail marsh, with sustained water depths of 4-6 in. Habitat surrounding the marsh is primarily grass and scrub forest. The nearest cover is 120 ft. to the south and blocked by a 4-ft. tall fence. A schematic image of J1 is shown in Figure 2-17.

Jump Out 2 – J2

Jump Out 2 (J2) is located between highway stations 73+00 and 74+00 on the north side of the corridor. The jump out wall is 5.5 ft. tall and 68 ft. from the highway. A guard rail provides separation from the highway for wildlife traveling within the ROW. J2 has two wing walls that create three escape chutes. The landing area is composed of graded fill material and was initially dominated by grass and herbs, but is rapidly succumbing to woody vegetation regeneration. Habitat within the ROW is entirely rough grass, much of which is on north-facing graded slopes, providing high-quality grazing opportunities. Outside the ROW, forest cover is found within 38 ft. of the landing area. There is a seasonal pond within 50 ft. of the landing as well. Company Creek, a west-flowing, acidic perennial channel lays 400 ft. to the north. There is a tree-crushed section of the 8-ft. tall exclusion fence 700 ft. to the east of J2. A schematic image of J2 is shown in Figure 2-18.

Jump Out 3 – J3

Jump Out 3 (J3) is on the south side of the bypass at highway station 105+50. The 5.5-ft. jump out wall is 118 ft. from the highway travel lane and 16 feet below in elevation. There is a single 90-ft. long wing fence that creates two jump chutes. The ROW habitat of J3 is rough grass. The landing area is native soil. J3 is less than 20 ft. away from mature mesic forest outside of the ROW. There are several nearby gaps under the fence suitable for egress by small animals. A tree fall has crushed the fence 240 feet to the west. There is a large wildlife underpass (Wildlife Underpass 1) 200 feet to the east. A schematic image of J3 is shown in Figure 2-19.

Jump Out 4 – J4

Jump Out 4 (J4) is directly across the highway from Jump Out 3 at station 105+50. The jump wall is 84. ft. from the travel lane. J4 has a single wing fence structure with two jump chutes. The 75-ft. wing fence pushes wildlife to within 20 ft. of the travel lanes. The habitat both inside and outside the ROW is rough grass. The graded soil landing pad is 31 ft. from forest cover. A fallen tree crushed the exclusion fence 25 ft. east of the jump out, facilitating two-way wildlife passage. A large wildlife underpass (Wildlife Underpass 1) is located 200 ft. to the east. A schematic image of J4 is shown in Figure 2-20.

Jump Out 5 – J5

Jump Out 5 (J5) is located on the north side of the ROW near road station 131+50. J5 is a two-chute, single wing wall feature. The jump wall is 27 ft. from the pavement edge. The single fence wall extends to within 20 ft. of the active road. A guard rail separates wildlife from the highway at J5. Habitat within the ROW is rough grass and successional scrub. The landing below the wall is reported to have been a sand filled wooden frame, but native herbaceous and woody vegetation have colonized the area. An immediate cover of successional scrub vegetation quickly transitions to mature forest 61 ft. from the landing. This large extensive forest is virtually unbroken for up to 2.5 mi. to the north. A schematic image of J5 is shown in Figure 2-21.

Jump Out 6 – J6

Jump Out 6 (J6) is located on the south side of the ROW at highway station 147+50. Disposition of the jump wall is 99 ft. away from the highway. There are two 80-ft. wing fences creating three escape chutes. J6 is the lowest jump out with a wall height of 4 ft. J6's landing pad is obscured by dense herbaceous vegetation but may have been pea gravel. Mature forest cover is 25 ft. away from the landing. There are also many overgrown roads and recently cleared areas nearby, which are associated with activities of the Hocking-Athens Reclamation Center. There is a tree crushed fence panel 200 ft. to the west of the feature. A schematic image of J6 is shown in Figure 2-22.

Jump Out 7 – J7

Jump Out 7 (J7) is a two-chute, single wing fence that at 8.5 ft. has the greatest jump out wall top to landing height. J7 is a south side jump out located at station 195+50. The jump out wall is 41 ft. from the traffic lanes. The wing fence protrudes more than half that distance toward the highway, leaving only 30 ft. between active traffic and wildlife travel around the wing fences. The landing pad falls off quickly to the south into mature forest (28 ft. away). Approximately 80 ft. farther south is a swamp/marsh pond complex crated by beaver activity in the upper reaches of Dorr Run Creek. A schematic image of J7 is shown in Figure 2-23.

Jump Out 8 – J8

Jump Out 8 (J8) is located at highway station 249+50. It has two wing fences and three chutes. The 5-ft. high jump out wall is 95 ft. from the active highway. Wing fences emerge at 45-degree angles from the jump out wall and extend for distances of 75 ft. and 110 ft. toward the highway. The wing fences leave a walk-around gap of 45 ft. to the travel lanes. The landing area of J8 is perennially inundated by a deep cattail marsh fed by mine seepage from the east. Fifty-seven ft. southeast of the landing begins a stand of reforested mine land with residual pools and sink holes. A large culvert just west of the jump out provides continual flow to create a long marsh that leads to residential areas to the southeast. An 8-ft. tall exclusion fence panel has been collapsed by a tree 100 ft. to the east. A schematic image of J8 is shown in Figure 2-24.

Jump Out 9 – J9

Jump Out 9 (J9) is on the south side of the bypass between highway stations 286+00 and 287+00. There are two wing fences and three chutes with knee bars (Figure 2-16). The distance of the jump wall to the travel lanes is 70 ft. Wing fences are 65 ft. and 75 ft. long, the gap between the wing fence ends to the active travel lane is 25 ft. J9's jump out wall is 5 ft. tall. The landing appears to be native soil and is on a south facing slope. Mature forest is immediately adjacent (45 ft.), but opens to the lawns and gardens of a residential area in Nelsonville, Ohio within 400 ft. There is a tree-crushed section of the tall fence 120 ft. west of J9. A schematic image of J9 is shown in Figure 2-25.

Jump Out 10 – J10

Jump Out 10 (J10) is on the south side of the ROW is at highway station 297+50 in highway segment 6. This is near the bridge over Pleasantview Avenue in Nelsonville. J10 has two wing walls and three escape chutes. The jump out wall is 5.5 ft. tall and J10 has knee bars. The jump wall is set back 51 ft. from the travel lane. The landing pad is fine gravel, but is fully colonized by annual vegetation. Habitat outside the landing area is scrub forest and mature forest is within 50 ft. Residential areas of Nelsonville, Ohio are within 175 ft. There is a gap between the 8-ft. tall fence and the bridge abutment 185 ft. to the southeast. The Pleasantview Bridge provides northern access to the State Prison area and the extensive forest beyond. A schematic image of J10 is shown in Figure 2-26.

Jump Out 11 – J11

Jump Out 11 (J11) is along the south fence line, and has two wing fences, three escape chutes and no knee bar. The jump out wall is 5 ft. in height and is 34 ft. from the travel lanes. Wing fences are short; approximately 16 ft., and walk around clearance between J11 and the active highway is less than 15 ft. The landing substrate is native soil and mature mesic forest is less than 10 ft. from the landing pad. The major habitat within the ROW near the jump out to the west is forest and successional scrub; these are habitats that provide cover, shelter and seasonal forage to deer populations. This habitat continues along the fence to border a 15-ac. area of rough grass. Nelsonville, Ohio residential areas begin approximately 450 ft. to the west. A schematic image of J11 is shown in Figure 2-27.

Jump Out 12 – J12

Jump Out 12 (J12) is at highway station 333+80 on the north side of the NVBP. J12 includes two 70-ft. long wing fences, three jump out chutes, and knee bars. The jump wall is 73 ft. from the travel lane. The wing fences confine the walk around corridor to 30 ft. from the active highway. The habitat within the ROW is primarily rough grass, although areas of successional scrub and scrub forest prevail to the southeast. The landing was pea gravel, but it is becoming heavily vegetated. Outside the ROW, there are extensive areas of rough grass adjacent to extensive mature forest (60 ft. away). Nearby strip mining has left many residual ponds and mine road trails leading down to the rich forage area of Woodlane Creek. A large wildlife underpass (Wildlife Underpass 2) is 370 ft. to the northwest. A schematic image of J12 is shown in Figure 2-28.

Jump Out 13 – J13

Jump Out 13 (J13) is on the south side of the ROW near Burr Oak Boulevard at station 356+00. There are two wing fences, three jump chutes, and knee bars. J13’s jump wall is 66 ft. from the travel lane. The wing fences are 60 ft. in length. The minimum wall height is 5 ft. The landing substrate is gravel. Nearby habitat includes rough grass and a small marsh. Cover is 105 ft. away from the landing pad. Habitat outside the ROW includes rough grass, scrub forest, industrial and residential land uses. There is a fence-abutment gap 290 ft. to the southeast. A schematic image of J13 is shown in Figure 2-29.

Jump Out 14 – J14

Jump Out 14 (J14) is on the north side of the NVBP at highway station 381+50. This jump out includes two wing fences, three jump chutes and a gravel landing pad. The jump out wall is 5-ft. tall and 46 ft. from the active travel way. Wing fences confine the walk around area between the road and the J14 structure to 20 ft. Habitat within the ROW is rough grass and successional scrub. Outside the ROW, mature forest dominates toward Ohio State Route 78 (95 ft. away from the landing pad). A riparian corridor and residual mine roads near the landing pad provide convenient connections to the swamps and marshes near Monday Creek. A schematic image of J14 is shown in Figure 2-30.

Jump Out 15 – J15

Jump Out 15 (J15) is at station 398+50 and has high-mast lighting within 50 ft. of the jump out wall, keeping the jump out brightly illuminated all night. J15 has a two wing wall, three escape chute feature with a jump wall height of 5 ft. J15 is on the south side of the highway. The wall face is 43 ft. from the travel lanes and is close to the eastbound exit ramp for the Ohio State Route 78 interchange. The 45-ft. wing fences constrict the walk around distance to 15 ft. Habitat within the ROW is rough grass and successional scrub. The jump out landing substrate is gravel, but is now well vegetated. Nearby area is mature forest on hills (61 ft. away). Valley bottoms support industrial and residential land uses within 400 ft. of J15. A schematic image of J15 is shown in Figure 2-31.

Jump Out 16 – J16

Jump Out 16 (J16) is the escape feature farthest from the active highway at 139 ft. from the active travel lanes. Unlike the other jump outs, it is concealed by a stand of pine and successional scrub. There is a high-mast light fixture 130 ft. away that keeps the area in filtered illumination throughout the night. J16 is a two-wall, three-chute jump out with a 5-foot wall height and a pea gravel landing pad. It is located at highway station 436+50 and is the eastern-most jump out feature. Habitat outside the ROW is initially rough grass and residential areas commence within 200 ft. and continue to Elm Rock Road. A short crossing of this low use road offers deer access to agricultural fields and the Hocking River riparian area. A schematic image of J16 is shown in Figure 2-32.

PERMEABILITY DEVICES - WILDLIFE UNDERPASSES AND ECOPASSAGES

Constructed wildlife underpasses provide wildlife with the ability to pass safely under the roadway and are a mitigation strategy to maintain habitat connectivity (Andrews et al. 2015, Clevenger and Huijser 2011). As part of the NVBP there are three dedicated large wildlife underpasses: Wildlife Underpass 1, Wildlife Underpass 2, and the Butterfly Bridge. Additional structures that can serve as underpasses for wildlife include road bridges, two dedicated small wildlife ecopassages (Chapter 7), and many major drainage culverts that may provide passage under the U.S. 33 Nelsonville Bypass corridor. There is also a barrier-ecopassage system, with two passages, in place along Ohio State Route 78 (SR 78) to reduce mortality and provide habitat connectivity for amphibians (see Chapter 5).

Wildlife Underpass 1 – UP1

Wildlife Underpass 1 (UP1) is located at highway station 107+10 and divides sections 2 and 3 (Figures 2-4 and 2-5). This is a concrete culvert with a 16-ft. wide travel way and an interior height of 9 ft. The tunnel is 125-ft. long and is open to the sky for a 20-ft. segment between the eastbound and westbound highway lanes. Concrete walls on both ends taper from the top bridge wall to contact the ground. An 18-24 in. gap between the 8-ft. tall exclusion fence and the underpass is found at all four contact locations where the fence contacts the underpass. UP1 is shared between off-road vehicles (ORV) and wildlife, which may impact wildlife use of this passage. ORV traffic is abundant at this location between April 15th and December 15th each year.

Wildlife Underpass 2 – UP2

Wildlife Underpass 2 (UP2) is fully dedicated to wildlife usage and is located at highway station 329+60. UP2 separates highway segments 7 and 8 (Figures 2-9 and 2-10). UP2 spans a 95-ft. highway width and serves as the dividing bridge between highway segments 7 and 8. The passage itself is 125 ft. across. The underpass is a pair of box-culvert structures with a 35-ft. wide, level tunnel floor and an arched ceiling starting from 7 ft. tall at the edges and increasing up to 9 ft. tall in the middle of the tunnel. A 20-ft. wide opening provides light between the eastbound and westbound highway lanes. An arc of 3-5 ft. diameter, closely spaced boulders is placed around each end to prevent use of the structure by ORVs (Figure 2-33). There is also a bat roosting structure on the ceiling of UP2. The structure allows wildlife to travel between the woodland valley corridor to Monday Creek to the north and the Nelsonville, Ohio residential neighborhoods to the south.

Butterfly Bridge – BB

The Butterfly Bridge (BB) at highway station 117+50 was originally identified as a gas pipeline crossing (Figure 2-5). The BB divides highway sections 3 and 4 (Figures 2-5 and 2-6). The BB structure is a standard concrete bridge constructed over highways at other locations in the bypass roadway. High exclusion fencing attaches directly to abutment sides with no observed gaps. There are two 145-foot spans over a 52-foot wide perpendicular, level travel way. Heavily rip-rapped 45-degree slopes, 45-ft. wide descend from both abutments to the travel way. The ground to bridge clearance is approximately 25 feet, making for clear visibility from one side to the other. There is a bat roosting structure on the ceiling of the BB passage.

Small Wildlife Ecopassage – SWE

Two Small Wildlife Ecopassages (SWEs) were built along the NVBP to facilitate the movement of reptiles and other small animals. The passages are 4-ft. diameter corrugated steel culverts designated as herpetofauna crossings. However, these structures could be used by any wildlife small enough to fit through the tunnels. The ecopassages are 170 ft. long, and in the median, the circular culverts open into a 4-ft. wide rectangular box culvert that spans the width of the median. The ceiling of the box chamber is an elevated metal grate that provides natural light at the middle of the passage. One of these structures was installed in the Dorr Run area and is paired with a snake fence (Small Wildlife Ecopassage 1), and the other ecopassage was installed 2.6 mi. west and beyond the extent of snake fencing (Small Wildlife Ecopassage 2). Further detail concerning the SWEs can be found in Chapter 7.

Amphibian Barrier-Ecopassage System

A barrier-ecopassage system is in place along the SR 78 tributary to facilitate amphibian migrations. The system consists of two 60 ft. long ecopassages connected by 250 ft. of fencing on each side of the road (total 500 ft. of fence). The ecopassages are made of treated concrete with semi-circular entrances that are 20 in. wide at the bottom and 16-in. tall in the center. Small perforations run the length of the ecopassages allowing light to penetrate the tunnel. The barrier fencing is 2-ft. tall above ground, with 4 in. buried into the ground. The barrier fencing and ecopassages are made by ACO Polymer Products, Inc.

HABITAT REPLACEMENT

Bat Roosting Boxes

Bat boxes were placed on the ceiling of the Butterfly Bridge and Wildlife Underpass #2. These structures were installed to replace roosting habitat for bats. The forest removal required for the NVBP construction dramatically reduced roosting habitat for bark nesting bats. Shagbark hickory and other tree species with loose, flaking bark are frequently used as roosting sites for bats. To provide new roosting habitat in the ROW, 4 ft. x 8 ft. bat roosting boxes were installed on the underside of the structures.

Constructed Wetlands

During construction of the NVBP, 4.903 ac. of wetlands and 32,975 linear feet of streams were impacted (ODOT 2015). Wetlands and streams are hydrologically maintained features, and include ephemeral ponds and emergent wetlands that are essential breeding habitats for many amphibian species. To recoup the loss of the impacted wetlands, ODOT constructed 7.09 ac. of new wetland and preserved 20.89 ac. of wetland beside SR 78 (ODOT 2015). The 7.09 ac. of new wetland are spread between four wetlands constructed to the southeast and east of the SR 78 ROW. These wetlands were intended to provide wildlife habitat and maintain landscape hydrologic function. Maps with locations of the constructed wetlands are referenced in Chapter 5.

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CHAPTER 3: WILDLIFE-VEHICLE COLLISIONS

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INTRODUCTION

For the U.S. 33 Nelsonville Bypass project, the Ohio Department of Transportation (ODOT) constructed numerous structures specifically to mitigate for adverse impacts of the new highway on the wildlife residing in and around the Wayne National Forest (WNF) adjacent to the highway. Many of the structures were installed for the specific purpose of mitigating the impacts of the new highway on white-tailed Deer (*Odocoileus virginianus*). The U.S. 33 Nelsonville Bypass included the following deer-related mitigation structures:

- Construction of 8-ft. tall “exclusion” fencing along the highway right-of-way (ROW) boundary (normally such fences are 4-ft. tall);
- Construction of 16 one-way jump out structures to allow deer to exit the ROW boundary. Jump out structures are built with a soft landing area outside the ROW that is 3 to 6-ft. lower than the highway side of the structure to promote usage and discourage jumping into the right-of-way; and
- Multiple underpass structures constructed specifically to allow wildlife, including deer, to cross the highway ROW without having to cross through roadway traffic.

The primary purpose of these features was to reduce the possibility of collisions between highway traffic and deer by excluding deer from the roadway or providing an opportunity for deer that did enter the roadway area to exit safely. Ultimately, if these features were successful in accomplishing this purpose, there would be fewer deer-vehicle collisions on the U.S. 33 Nelsonville Bypass (NVBP), as compared with other roadways in similar environments without the mitigation structures. Our analysis examines traffic crash data and roadkill data from the NVBP compared with two other nearby highways as well as statewide averages, where appropriate. For the purposes of this study, it is assumed that the wildlife mitigation treatments listed above are working together as a “system” of mitigation structures; this study cannot isolate the effect of a specific structure or treatment on the frequency or rate of deer-vehicle collisions along the NVBP. The performance of specific wildlife structures in functioning as they were expected are examined in other Chapters of this report (See Chapter 4 for details about effectiveness of deer mitigation).

METHODOLOGY

DATA SOURCES

This section describes the sources of data used in these analyses. Data used in this analysis includes traffic crash data, traffic volume data, deer population data, and roadkill data from our surveys.

TRAFFIC CRASH DATA

Traffic crash data used in this study consisted of statewide traffic crash data and highway segment-specific data. Statewide traffic crash data for the time period 2001 through 2015 was obtained from the Ohio Department of Public Safety (ODPS) “Ohio Annual Crash Facts” report, available from the ODPS website. This report contains details of traffic crashes statewide and by county, including the frequency and severity of traffic crashes. For deer-vehicle crashes, the ODPS report includes crash totals statewide and by county, as well as the number of deer-vehicle crashes in each month of the year. For highway segments, traffic crash extracts were downloaded from the ODPS "Crash Reports" website. Extensive post-processing was required following the data download to ensure compatibility with ArcGIS software, which was used to extract the total crashes and the total deer crashes by month for each of the three highway segments studied in detail in this analysis. Segment-specific data were analyzed up to and including December 2016.

TRAFFIC VOLUME DATA

Traffic volume data used in this analysis consisted of statewide data on vehicle-miles traveled (VMT) and annual average daily traffic (AADT) data for individual highway segments. Both types of data were obtained from the ODOT Office of Technical Services (OTS). The statewide VMT data were obtained from "Daily Vehicle Miles Traveled (VMT)" reports, published annually by the ODOT OTS. The daily VMT report provides data on daily VMT for each county and statewide totals by functional classification. Reports from the years 2001 to 2015 were obtained from the ODOT OTS website.

Individual highway segments examined in this analysis included the NVBP (Athens and Hocking Counties, Ohio) and two other similar highway segments in Athens and Meigs Counties. For this research, traffic count data were needed for the period between 2011 and 2016. Traffic counts for individual highway segments were obtained through a special website maintained by ODOT OTS known as the Traffic Management Monitoring System or TMMS. TMMS provides historical traffic count data for locations around the state, including the highway segments under detailed examination in this research study. Traffic counts and the resulting AADT data on major roadways in Athens, Hocking, and Meigs Counties were collected in 2015 as part of ODOT's three-year rotation of statewide traffic counts. Some observed traffic counts from other years besides 2015 were also available at some locations in TMMS; these data were used where applicable. Where observed traffic counts and AADT data were not available, researchers used traffic growth rate data obtained from the ODOT OTS website to develop an estimate of AADT. Growth rates ranged from 0.8 percent between 2012 and 2013 to 3.6 percent between 2014 and 2015, assuming a functional classification of Rural Principal Arterial for all locations. The only instance where ODOT growth rates were not used was the growth of traffic on the bypass between 2015 and 2016, which was assumed to grow at 3.8 percent based on data from a weigh-in-motion (WIM) station located on the bypass. To be consistent with traffic forecasting guidelines found in the *Ohio Certified Traffic Manual*, researchers rounded all AADT values to the nearest 10 to avoid any implied precision. It should be noted, however, that the AADT values reported in this analysis are researcher estimates and not certified estimates from the ODOT OTS.

Each individual highway segment was divided into multiple sections reflecting different traffic volumes, where appropriate. The NVBP consisted of three sections with the boundary of each section based on the two interchanges and the project limits. For the other highways, the individual sections were defined based on ODOT traffic count locations. The AADT volumes used in this analysis are shown in Table 3-1 (NVBP), Table 3-2 (Control Section #1), and Table 3-3 (Control Section #2). Figure ES-1 shows a map of the NVBP and control sections. The AADT for each section was multiplied by the length of each section (in miles) and the number of days in the year to obtain the annual VMT for each section. The individual section VMT values were then added together to calculate the total VMT for each highway segment being studied. This process was repeated for each year of crash data examined in the analysis.

DEER POPULATION DATA

The research team investigated trends in the statewide white-tailed deer population, as well as at the level of the two counties overlapping the NVBP, Athens and Hocking Counties. Estimates of absolute abundance of white-tailed deer do not exist for Ohio, or any other state for which the population numbers in the hundreds of thousands, as implementing a monitoring protocol annually would be cost-prohibitive. Instead, for determining white-tailed deer population trends and investigating potential correlations with the number of vehicle crashes involving deer, researchers used deer harvest data from the Ohio Department of Natural Resources (ODNR), Division of Wildlife (DOW). More specifically, the buck harvest data are a reliable indicator of population trend, despite gradual changes in hunter demographics, number of hunters (decreasing), as well as means of harvest (switching from gun hunts to bow and muzzleloader) (Michael Tonkovich, ODNR, pers. comm.). Researchers obtained yearly White-tailed Deer harvest data from ODNR for period 2001-2014 summarized at county level; the actual harvest data were standardized by calculating densities of harvested bucks at county level (individuals per square mile), and this data were used as a proxy for the actual trend in the white-tailed deer population. Standardization was necessary for contrasting the deer population to the deer-vehicle crash data.

ROADKILL DATA

To supplement the crash analysis, the research team conducted roadkill surveys to systematically record the number of animals struck and killed by vehicular traffic on the highway segments of interest. The entire length of the NVBP project area, along with two reference areas were routinely driven to locate, identify, and document deceased animals in the highway corridors. The control site selection was based upon similar traffic volumes, vehicular speeds, adequate wildlife habitat, landscape coverage, and visually detectable wildlife presence. Every effort was made to try to maintain vehicle speed during the surveys at 55 mph. Limitations included the speed at which the vehicle traveled (driving slower may have contributed to spotting more animals), construction barrels/activity, roadside vegetation (animals just out of sight under tall grass), and animals that might have been hit that made it just off the shoulder and/or over the guardrail just out of sight). Carcass removal by predators was expected to be a limitation as well, but the research team found that to be negligible. The roadkill surveys were conducted over the time period of March 30, 2015 through March 24, 2016. The survey was suspended from April 29, 2015 – May 28, 2015 due to construction and road maintenance on multiple sections of the NVBP and control areas. In total, 92 individual surveys were conducted during the survey period.

Throughout the project, any deceased wildlife (including mammals, reptiles, amphibians, and birds) found along the NVBP or the control sections were logged with a Trimble Juno 3B handheld GPS unit. The wildlife was identified in terms of species, and when known, by sex, and an estimated time since death was logged. If an animal was not readily identifiable, or decomposed beyond recognition, a photograph was taken to seek help from other experts on the identification. The process entailed two or three people in the vehicle, to ensure at least one person was tasked with the primary function of spotting the deceased wildlife. Once spotted, the vehicle pulled over to a safe distance off the side of the road. One occupant logged the data point with the GPS unit, while another occupant used neon green spray paint to tag the location of the animal, and indicate that the animal had already been documented. This was done to eliminate the animal being logged more than once.

Once the survey was completed, the research team used GPS Pathfinder Office software to post-process and differentially correct the data. After differential correction, an accuracy of 6.6-16.4 ft. was achieved with the data. At that point, each corrected file was then exported to a shapefile, a common format for use in GIS software.

RESULTS

DEER CRASH ANALYSIS – STATE AND REGIONAL

This section presents a brief analysis of deer crash data for the State of Ohio and the Southeast Ohio region. The analysis focuses on the frequency and severity of deer-related collisions as well as crash rates where appropriate. A brief discussion of the trends in Ohio's deer population is also presented for additional context. The purpose of this analysis is to identify broader trends in deer-vehicle crashes for the state and region and to provide more context for the more detailed deer-vehicle collision analysis of the NVBP to be presented in later sections.

Statewide Deer-Vehicle Crash Trends – Frequency and Severity

Table 3-4 presents a summary of the annual total crashes, deer-vehicle crashes, and percentage of deer-vehicle crashes in the State of Ohio for the 15-year period between 2001 and 2015, as obtained from the ODPS publication *Ohio Traffic Crash Facts Book* for the respective years. Between 2001 and 2015, an average of 25,536 traffic crashes occurred annually in the State of Ohio in which the most harmful event was a collision with a deer as noted by the crash report. The highest frequency of deer-vehicle crashes was noted in the year 2003 (31,729) while the lowest frequency was noted in 2014 (19,705). Collisions with deer account for approximately 7.8% of all crashes in the State of Ohio, ranging from 6.97% of all crashes in 2015 to 8.45% of all crashes in 2006.

Also presented in Table 3-4 is the frequency of deer-related crashes that were classified as fatal and injurious (the remainder of crashes being classified as property damage only, not shown in Table 3-4). Between 2001 and 2015, an average of 6.33 deer-vehicle crashes per year resulted in at least one fatality, while an average of nearly 950 deer-vehicle crashes per year resulted in at least one injured person. Based on these frequencies, the probability of a deer-related crash in the State of Ohio resulting in a fatality is 0.025%, or approximately 1 in every 4,000 deer-related crashes. The probability of a deer-vehicle crash in the State of Ohio resulting in an injury is approximately 3.72%, or approximately 1 in every 27 deer-related crashes. The percentage of deer-related crashes resulting in a fatality or injury has not varied substantially between 2001 and 2015.

Statewide Deer-Vehicle Crash Trends – Seasonality

In addition to the analysis of the frequency and severity of Ohio deer crashes, another relevant aspect of this analysis is the seasonal patterns of deer crashes. Figure 3-1 shows the average monthly frequency of deer crashes for the period 2001 to 2015 (total of 180 months of data) as well as the 15-year average for each individual month. Based on 15 years of deer crash data, approximately 2,120 deer-related crashes occur in an average month in the State of Ohio. The months of October, November, and December are substantially higher than average, corresponding to the breeding period, known as "rut," when deer are most active. Approximately 50% of all deer crashes in an average year occur during this three-month period. The months of

January and May are approximately average in terms of the frequency of deer crashes. The other seven months are substantially below average.

Regional Deer-Vehicle Crash Trends – Frequency

The NVBP project includes mileage in both Athens and Hocking Counties. Therefore, this analysis of crash data combines the data from the two counties to ensure that the experiences of both counties are included when comparing with other locations. Table 3-5 presents historical data on the total crash frequency, the deer-vehicle crash frequency, and percentage of deer-related crashes for Athens and Hocking Counties combined for the time period between 2001 and 2015. Also presented in Table 3-5 for comparison purposes is the percentage of deer-related crashes for the State of Ohio. Based on the 15-year average, the annual frequency of deer-related crashes in Athens and Hocking County is approximately 342 per year. On average 15.1% of all traffic crashes in Athens and Hocking County are deer-related, compared to 7.8% statewide. In other words, a crash in Athens or Hocking County is nearly two times as likely to involve a deer as compared to the statewide average.

Deer Population Trends – State and Regional

Examining trends in deer populations is also relevant when investigating deer-vehicle collision trends. For the purposes of this analysis, the density of deer per square mile (statewide or county) is used to normalize the data and provide a direct comparison between geographies. As previously discussed, annual buck harvest data from the ODNR were used as an indicator of the overall deer population. There was a wide variation in the number (and density) of bucks harvested across Ohio, ranging from 0.278 bucks harvested/square mile (Cuyahoga County, 2002) to 6.589 bucks harvested/sq. mi. (Harrison County, 2009). Figure 3-2 shows the annual density of buck harvest per square mile for the State of Ohio, Athens County, and Hocking County for the period between 2001 and 2014. Due to the way these data were assembled, an error of the estimate for the statewide buck harvest density also was calculated and shown in Figure 3-2. The data presented in Figure 3-2 indicate that the density of deer harvested for Athens and Hocking counties is substantially higher than the statewide density. On this basis, it can be reasonably concluded that the potential for deer-related crashes is higher in Athens and Hocking counties (two counties that are generally rural in nature) as compared to Ohio as a whole.

Crash Rates Analysis

For a roadway segment-based analysis, it is customary to calculate the crash rate in terms of the number of crashes per 100 million vehicle-miles traveled (VMT). Using this metric allows for geographic regions or specific highway segments to be compared side-by-side accounting for both the volume of traffic and the extent of the roadway system. Figure 3-3 shows the crash rate per 100 million VMT for deer-related crashes for the State of Ohio as well as Athens and Hocking County combined for the 15-yr. period between 2001 and 2015. The statewide rate of deer crashes per 100 million VMT steadily decreased over the 15-yr. period analyzed from 29.51 crashes per 100 million VMT in 2001 to 17.87 crashes per 100 million VMT in 2015. The crash rate for Athens and Hocking County combined also decreased between 2001 and 2015, although the decrease was not uniform. A large decrease in the deer crash rate was noted between 2001 and 2006 with a noticeable peak in 2009. Starting in 2011, there was a steady increase in the deer crash rate for Athens and Hocking Counties, but a decrease was noted in 2015. However, for all 15 years presented in Figure 3-3, the deer crash rate per 100 million VMT was higher for Athens and Hocking County combined as compared to the statewide average. Individually, Athens County has consistently had a higher deer crash rate per 100 million VMT than Hocking County;

however, both counties are consistently above the statewide average over the 15-yr. period examined in this analysis.

DEER CRASH ANALYSIS – U.S. 33 NELSONVILLE BYPASS AND CONTROL SEGMENTS

This section presents a detailed crash analysis of the NVBP and two other highway stretches of similar nature. The two additional highway segments were located along U.S. 50 east of Athens and along U.S. 33 south of Athens, passing through areas very similar in roadside landscape, context, and character as the NVBP route. Consequently, these two segments were considered "control" sections for the purposes of this analysis with the only differences between the NVBP and the control sections being that the NVBP has the deer-related wildlife mitigation structures (jump outs, crossings, and 8-ft. tall fence) and the control sections do not. Examining the crash experience in the three sections while controlling for other factors such as traffic volume and roadway length provides evidence as to the extent of the deer-related wildlife mitigation structures in improving safety for motorists and wildlife.

Definition of Bypass and Control Segments

Prior to presenting the crash analysis, the exact locations of the highway segments being examined in this analysis should be defined to ensure consistent treatment of these segments in subsequent analyses. Table 3-6 presents the detailed description of the three highway segments examined in this analysis (the NVBP and the two control sections), with the start and end points defined by geographical references and the statewide milepost for each route. The length of each segment in miles (defined as the difference in the statewide milepost values for the start and end of each segment) is also presented in Table 3-6. Statewide milepost data for each endpoint was obtained via the ODOT "DESTAPE" roadway information files available on the website of the ODOT Division of Planning, Office of Technical Services, Transportation Information Mapping System. A map showing the three highway segments examined in this analysis is displayed in Figure ES-1.

For the purposes of this analysis, the NVBP is assumed to start at a location at the west end of the bypass project at U.S. 33 state milepost 178.41, approximately 725 ft. east of the Purdum Road overpass in Hocking County. This location was selected as the start of the NVBP segment as this was the location of the start of the 8-ft. tall right-of-way fencing. Similarly, the endpoint of the NVBP segment at the Elm Rock Road (TR 36) underpass was selected as this was the location of the end of the 8-ft. tall fencing. The speed limit is 70 mph and there is access control along the segment in the form of two diamond interchanges at Dorr Run Road (TR 346) and Ohio State Route 78 (SR 78). It should be noted that the NVBP project construction limits were extended further than the Elm Rock Road (TR 36) underpass and therefore official descriptions of the bypass length are greater than 8.14 miles; however, the extents selected for this analysis were selected to account for the influence of the deer-related wildlife mitigation features, all of which are included in this segment of the roadway. Other new sections of U.S. 33 beyond Elm Rock Road (TR 36) underpass toward Athens, as well as the new SR 78 sections and other access roadways did not have the deer-related wildlife mitigation features and thus were not included in this analysis.

Control Section #1 was located along U.S. 50 east of Athens, starting at the intersection of U.S. 50 and SR 329 (milepost 183.27) and ending at the intersection of U.S. 50 and Vanderhoof Road (Athens CR 65, milepost 189.65). The total length of Control Section #1 was 6.38 miles. Control Section #1 is a four-lane roadway with a barrier or grass median throughout the entire length of the analysis segment. The speed limit is 60 miles per hour and there is approximately one access point per mile along the segment.

Control Section #2 was located along U.S. 33 geographically south of Athens (east of Athens for the purposes of roadway inventory), starting at a location approximately 250 ft. east of the intersection ramp from Richland Avenue (milepost 199.772) and ending at the intersection of U.S. 33 and Ohio State Route 681 in Meigs County (milepost 211.302). The total length of Control Section #2 was 11.53 miles. Control Section #2 is a two-lane undivided roadway except for a 1.6-mile section of four-lane divided roadway at the west end of the segment and a 0.5-mile section of four-lane divided roadway at the east end of the segment. The speed limit is 55 miles per hour throughout and there is approximately one access point every three miles along the segment.

Crash Analysis

This section presents the analysis of traffic crash data for the NVBP and the two control sections. Metrics that are used for the crash analysis are the total crash rate per 100 million VMT for the segment, the deer-related crash rate per 100 million VMT for the segment, and the percentage of crashes on the segment that are deer-related. For all three segments, analysis for the three-year period starting January 1, 2014 through December 31, 2016 is presented. For the two control sections, an additional analysis of the three-year period starting January 1, 2011 through December 31, 2014 is also presented. Following typical practices for crash analyses, each individual year of data are presented as well as the three-year average.

Bypass Section

Table 3-7 presents the deer-vehicle crash analysis results for the NVBP segment for the three-year period between January 1, 2014 and December 31, 2016. Even though the Bypass was officially opened for traffic on October 1, 2013, the three-month period between October 1, 2013 and December 31, 2013 was not included in this analysis because the traffic volumes on the NVBP for this period could not be estimated with reasonable certainty. The values presented in Table 3-7 indicate that approximately 18% of all traffic crashes on the NVBP between 2014 and 2016 were deer-related. Approximately 22% of crashes during the years 2014 and 2015 were deer-related, with the percentage decreasing to approximately 9% of all crashes being deer-related in 2016. The three-year average annual deer-vehicle crash rate on the NVBP was approximately 15.66 deer-related crashes per 100 million VMT.

Control Section #1

Table 3-8 presents the deer-vehicle crash analysis results for Control Section #1 (U.S. 50) for the six-year period between January 1, 2011 and December 31, 2016. Crash data from the U.S. 50 control section indicate that approximately 55% of all traffic crashes along this segment of U.S. 50 are deer-related, with this value being consistent between the two three-year periods examined in the analysis. The deer crash rate during the time from 2014 to 2016 was on average 61 annual deer-related crashes per 100 million VMT, a decrease of approximately 7 annual deer-related crashes per 100 million VMT from the three-year period between 2011 and 2013. A similar decrease in the total crash rate per 100 million VMT was also noted between the two three-year periods examined in the analysis.

Control Section #2

Table 3-9 presents the deer-vehicle crash analysis results for Control Section #2 (U.S. 33) for the six-year period between January 1, 2011 and December 31, 2016. Crash data from the U.S. 33 control section indicate that approximately half of all traffic crashes on this segment of U.S. 33 are deer-vehicle crashes, with this value decreasing slightly between the two three-year periods examined in the analysis. The deer-related crash rate increased by approximately 10 annual deer-related crashes per 100 million VMT between the two three-year periods examined in the analysis. This crash rate increase corresponded to an increase in the crash rate for all crash types along this highway segment.

Roadkill Survey

Table 3-10 reports a summary of the data obtained from the road kill survey conducted on the three highway segments as part of this research study. The data reported in Table 3-10 include the total number of crashes, the total number of deer-related crashes, and the number of deer roadkill observed during the survey period. The primary purpose of the roadkill survey is to determine if the actual number of crashes (represented by the observed roadkill) was different than the number of crashes reported to the police and available from ODPS data extract. It is reasonable to expect that not all deer-vehicle crashes will be reported to authorities; however, if the ratio of unreported crashes to reported crashes is consistent for the three highway segments examined in this analysis, there will be no effect of unreported crashes on the deer-related crash rates presented in Tables 3-7, 3-8, and 3-9. The ratio of roadkill observed to deer-vehicle crashes reported was approximately 3 to 1 for the NVBP and Control Section #1, indicating that for every reported deer-related crash, there were two additional unreported crashes. The ratio for Control Section #2 is approximately 2 to 1, indicating one additional unreported deer-vehicle crash for every reported deer crash on this highway segment. For practical purposes, the lower ratio on Control Section #2 does not substantially impact the outcome of the traffic crash analysis because the NVBP deer-vehicle crash rate is still lower than the control section crash rates when accounting for unreported crashes.

DISCUSSION AND CONCLUSION

DEER CRASH ANALYSIS – STATE AND REGIONAL

This section presents the analysis of trends in deer-related crashes and deer populations for the State of Ohio as well as Athens and Hocking Counties. The results of this preliminary analysis provide context for the analysis to be presented in the following section, focused on the specific characteristics of the NVBP and two other nearby highways. The following conclusions can be drawn concerning statewide and county level data:

- Deer crashes account for approximately 7.8% of all crashes in Ohio.
- The deer crash rate in Ohio has decreased steadily between 2001 and 2015 and was approximately 17.87 crashes per 100 million VMT in 2015.
- A vast majority of deer-related crashes result in property damage only, with less than four percent of deer-related crashes resulting in human injury or fatality.
- Approximately 50% of deer-related crashes occur during the months of October, November, and December, corresponding to the deer rut season.
- The density of deer in Athens and Hocking county (measured in terms of the buck harvest per square mile), is approximately 1.5 times higher than the statewide average density of deer. As a result, the proportion of traffic crashes involving deer, the deer-vehicle crash rate per 100 million VMT, and the probability that a traffic crash involves a deer in these two rural counties are all approximately double the corresponding statewide averages.

DEER CRASH ANALYSIS – U.S. 33 NELSONVILLE BYPASS AND CONTROL SEGMENTS

This report presented an analysis of deer-related traffic crashes on the NVBP, two comparable highway segments in Southeast Ohio, and the State of Ohio. Traffic crash and traffic volume data were obtained from the applicable state-level agencies supplemented by data from a roadkill survey conducted by the research team. The primary purpose of this analysis was to determine if the NVBP project, which included several deer-related wildlife mitigation features constructed as part of the project, had fewer deer-related crashes than other locations.

Table 3-11 reports a summary of the crash analysis presented in this report. The three-year averages for the period 2011 to 2013 (before the NVBP opening) and the period 2014 to 2016 (after opening) are presented. The statewide and Athens/Hocking County data also are presented in Table 3-11 for comparison purposes; however, these data are only from 2014/2015 and do not include any data from the year 2016. The results presented in Table 3-11 indicate that the deer-vehicle crash rate on NVBP is approximately equal to the statewide average in terms of annual deer crashes per 100 million VMT. This crash rate is substantially lower than the crash rate for Athens and Hocking Counties as well as the two control sections (in Athens and Meigs Counties). The percentage of deer-related crashes on the U.S. 33 Nelsonville Bypass is 17.5%, which is higher than the statewide and two-county average. However, the percentage of deer-related crashes on both control sections was substantially higher than the NVBP, with deer being involved with between 49 - 56% of all reported crashes on the control sections.

Based on the analysis described in this report (summarized in Table 3-11), there is strong evidence to suggest that the deer-related wildlife mitigation features constructed as part of the NVBP project were effective at reducing deer-related crashes on this portion of U.S. 33 during the first three years of the entire bypass being open to the public. The deer-related crash rate per 100 million VMT on the NVBP was approximately equal to the statewide average even though the probability of being involved in a deer-related crash is nearly double in Athens and Hocking Counties as compared to Ohio as a whole. The roadkill survey conducted as part of this research study found no evidence to suggest that unreported deer-related crashes would have a meaningful impact on this conclusion. It should be noted that these findings assume that all three elements of the deer-related wildlife mitigation features (exclusion fencing, jump outs, and underpasses) are working together as a “system” and therefore nothing in this analysis is able to distinguish between the relative contributions of each individual mitigation feature in reducing deer-related crashes.

CHAPTER 4: DEER

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INTRODUCTION

White-tailed deer (*Odocoileus virginianus*) were one of the focal species of the mitigation structures implemented along the Nelsonville Bypass (NVBP). Deer-vehicle collisions are a significant source of economic loss and a threat to motorist safety in the Eastern United States, including Ohio. The goals of mitigation aimed at reducing the risk of deer-vehicle collisions include: facilitating movement between habitats bisected by the NVBP (via large animal underpasses), preventing white-tailed deer from entering the right-of-way (via 8 ft. exclusion fencing), and providing exit from the right-of-way in cases when deer become entrapped inside the wildlife fence (via one-way jump outs; see Chapter 2 for detailed descriptions of the mitigation structures). Ultimately, if these features were successful in accomplishing this purpose, there would be fewer deer-related traffic crashes on the U.S. Highway 33 Nelsonville Bypass, as compared with other roadways in similar contexts without the above-listed features (see Chapter 3 for a statewide, regional and local analysis of deer-vehicle crashes).

The mitigation structures have been embedded in a complex landscape setting within the Wayne National Forest (see Chapter 2 for a detailed description of the habitat and landscape context of the NVBP), which required a multitude of observational approaches for determining their effectiveness: camera trapping, roadkill surveys, direct observations of the status of mitigation structures, deer trail mapping, and evaluation of the deer population abundance within the right-of-way (ROW) habitat. We pooled together all these methodological approaches to evaluate:

1) the use of habitat by deer and the status of mitigation measures (trail mapping and wildlife fence gap monitoring)
2) the deer population using the new ROW habitat along the NVBP
3) the actual use and effectiveness of the mitigation features for White-tailed Deer. The effectiveness of individual mitigation structures examines:
   - The effectiveness of the tall exclusion fencing at preventing deer from accessing the ROW
   - The use of the one-way jump outs for exiting the ROW
   - The use of the underpasses, which allow deer to access forested habitats on both sides of the highway

A prerequisite for understanding the effectiveness of the mitigation structures is to place them in the context of deer ecology and behavior. Deer move to obtain resources from their environment. They move from locations that provide shelter and cover to those that provide food and water as a survival imperative. Their highly evolved skill for finding a pathway to food and water is tested when an artificial object, such as the NVBP is constructed. The NVBP was constructed in a west to east alignment. This alignment presumably severed connections between large forested areas north of the city of Nelsonville that provide continual shelter and cover but only seasonal forage, from the perennial forage areas within the Hocking River Valley and Nelsonville's residential areas. Deer learn the distribution and location of vital resources within their landscape. They move between the various resources with daily and seasonal periodicity. In so doing, they habituate to the best routes that by frequent foot contact have suppressed vegetation and compressed linear depression in the soil; creating a visible trail. Deer leave other clear signs of their presence and use of an area, such as scat piles, beds (compressed vegetation delineating a sleeping site), broken and bent vegetation, scrapes (earth disturbance created by bucks as the wallow during rut), and rubs (eroded bark on small trees created by buck scratching the velvet from their antlers). These deer use characteristics can be observed in the field and mapped to assess behavioral responses to anthropogenic landscape alterations.

Deer use their senses to locate food and water and continually test for the most efficient routes to access these resources. Much of the unpaved areas within the fenced NVBP ROW have planted grasses and herbs which are an attractive food source for White-tailed Deer. Prior to construction of the new highway deer utilized the perennially available feeding opportunities along the Hocking River and Monday Creek, the locations of large agricultural areas, residential areas and riparian forest. The high-quality forage opportunities provided by more than 300 acres of the vegetated margins within the fenced ROW entice deer to continually test the effectiveness of the exclusion fence.

DEER SOCIAL STRUCTURE AND DISPERSAL MOVEMENTS

White-tailed deer populations have a social structure that is structured around groups of females (Porter et al. 1991). While there is substantial variation in white-tailed deer density across its North American range, from <1 to 78 individuals / 0.39 sq. mi. (Kammermeyer and Marchinton 1976), genetic analyses revealed that such social groups are family groups, ranging in size from 2 to 10+ individuals, which occupy a well-defined territory. Within the group territory, older individuals occupy home ranges at the center of the group, while younger individuals occupy home ranges at the periphery of the social group (Mathews 1989). The family groups are highly philopatric, with aging individuals moving closer to the ancestral range, and new individuals taking their place at the periphery. The family group territories are very well defined, and in many cases they do not overlap other groups (e.g., in areas will less human impact, such as the Adirondacks; (Porter et al. 1991)); however, white-tailed deer in highly impacted areas (e.g., suburban areas), do not show the same degree of territory partitioning, and family groups overlap highly, presumably due to greater access to food resources, as well as less natural predation or hunting pressure (Comer et al. 2005). Adult bucks are also part of these female-centered family groups during summer, but the structure breaks down during rut season, when males leave the family groups, and travel singly or in small groups, of up to five individuals (Hirth 1977).

Given that female-dominated social groups show high fidelity to their territory, the dispersal role (one-way movements away from the natal territory to another territory) is assumed by males. Across a wide range of densities, <5% of females in the population dispersed to other territories (Porter et al. 1991, Campbell et al. 2004), but this fraction of the population may be altered by scarcity of habitat, in particular in agricultural landscapes; for example, up to 40% of females dispersed in an agricultural landscape in central Illinois (Nixon et al. 2007), and dispersal movements can be of up to 28-31 mi. before settling into new, unoccupied ranges (Nixon et al. 1991). This information is relevant to the NVBP, and raises interesting questions about the number of social family groups in the area before the NVBP was developed, and how the NVBP altered the social structure.

HOME RANGES

Home ranges of individual deer overlap within a family group territory and they can range widely based on geographic location. For example, male and female white-tailed deer in the Adirondacks had similar home range size during both summer (males = 576 ± 58 ac.; females = 546 ± 47 ac.) and winter (males = 371 ± 79 ac.; females = 326 ± 44 ac.). In Northeast Minnesota, (Nelson and Mech 1981) found that female home ranges averaged 205 ac. in summer and 158 ac. in winter. In Randolph County, West Virginia, female white-tailed deer had larger home ranges during winter (329 ± 30 ac.), compared to summer (247 ± 20 ac.) and fall (245 ± 25 ac.), and deer can move several miles between their summer and winter ranges (Campbell et al. 2004). At the other end of the spectrum, female deer inhabiting suburban environments have small home ranges: in Irodequit, New York, 90% Maximum Convex Polygon summer ranges were 52.9 ± 8.4 ac., while winter ranges were 55.4 ± 6.7 ac. (Porter et al. 2004). Overall, females show high fidelity to the same home range in successive years (Tierson et al. 1985), and related females share more of their home ranges than do non-relatives in all seasons (Nixon et al. 1991).

SEASONAL MOVEMENTS

Seasonal movements in white-tailed deer are related to food and shelter availability (Williams et al. 2012). For deer in agricultural Illinois landscapes, adult males vacated areas used by females to rear fawns and moved to habitats dominated by row crops during summer (June-September). In other seasons both males and females favored early successional (<60 yr. old) upland forests and forage crops, avoided flood-prone forests, and used row crops as they occurred (Nixon et al. 1991). In a landscape in central New York, similar from a land cover standpoint to Southeast Ohio, winter movements of deer are a direct result of energetic needs, and animals move between forest (which provides shelter, but has poor nutrition woody browse), agricultural land (which provides waste grain as a nutritional resource), and habitat edges (which contain palatable forbs and shrubs) (Williams et al. 2012). During spring and summer, all habitat types provide nutritional resources, but female deer are more likely to stay within forest habitat during parturition and immediately post-parturition.

The magnitude of movements between winter ranges and ranges used during rut vary greatly based on habitat heterogeneity. In the upper peninsula of Michigan, males traveled father than females (average 9.3 versus 7.4 mi. per day, respectively). However, in heterogeneous habitat (mix of cropland and forest), such seasonal movements were on average 1.9 mi. greater compared to white-tailed deer inhabiting contiguous forest habitats (Verme 1973).

DAILY MOVEMENTS

Daily, fine-scale movements have been recorded in many studies using GPS collars. Males greatly increase their movements during the rut season (Kammermeyer and Marchinton 1976). Webb et al. (2010) found that male white-tailed deer in central Oklahoma had average daily movements of 4.6 ± 0.2 mi. during rut, which is 20% higher than movements post-rut (3.8 ± 0.2 mi.). In contrast, females move less during rut, and maintain locations close to the center of their home ranges (Hölzenbein and Schwede 1989). Thus, females may increase the likelihood to be located by a searching male if they ‘advertise’ a constant location via vocalizations or scent marking. Webb et al. (2010) also found that daily movements in females were greatest during post-parturition (2.09 ± 0.06 mi.), and that peak movement occurred at sunrise and 2 hours prior to sunset. Deer moved up to 1,312 ft. within a single hour, and longer hourly movements occurred in the early morning. Diurnal and nocturnal movements were similar across both males and females during the spring season (656-820 ft./hr.); females had shorter diurnal movements during summer (328-377 ft./hr. versus 440-482 ft./hr. during nighttime) (Webb et al. 2010).

METHODOLOGY

USE OF HABITAT BY DEER AND THE STATUS OF MITIGATION STRUCTURES

To assess the reaction by deer to the bypass opportunities and restrictions, a field study was conducted between February 2015 and October 2016 to map deer trails and locate openings in the exclusion fencing (gaps) that deer may be using to enter the highway ROW. These surveys were conducted both simultaneously and separately by several individuals and compiled into a single database. The primary field method entailed walking obvious deer trails, locating and measuring the unintended gaps in fences and other structures, and field mapping them. Wildlife trail mapping was conducted using field sketching and location by GPS. Trails were mapped both inside the ROW and outside the ROW where access was available.

Field sketching involved drawing an approximation of a trail location on a prepared map while observing objects visible on the map and at the field location. This method was used for short trail sections that could be easily observed, for fall risk locations, for private property where trails could be observed through the fence and for other physically blocked locations. Precision for trail locations mapped in this manner is lower than for GPS methods, for a given instance. We noticed over the sampling period that trail locations through an area varied slightly over time due to small changes in habitat configuration because of woody vegetation growth, soil erosion, snow blockage and the use and closure of access gaps. Deer use a path of least resistance to travel at the time they move through an area.

GPS capture was used for deer trails and deer access gaps. GPS data collection employed Trimble field data collectors including: Juno 3B and 3D units, GeoXT GPS/GNSS receivers, and GeoXH GPS/GNSS units with GLONASS and Omnistar. GPS field data were post-processed to obtain 3.3-6.6 ft. position accuracy for the Juno units and 0.7-3.3 ft. accuracy for the GeoX units. Post-processed positions were exported to GIS shapefiles and used to analyze patterns and produce explanatory graphics using ArcGIS 10.5.1. Trails were collected as continuous line features. Gaps discovered in the wildlife exclusion fence were collected as 30-second residence point features. The data recorded about each gap during GPS point collection included, the cause and characteristics of the gap, whether the gap had evidence of use by wildlife, and the dimensions of the gap.

Location data for trails and gaps were used with other mapping features to assess the mitigation features. These other mapping features include:

- Georeferenced true and IFR imagery with 12-in. and 6-in. pixilation from 2011, 2014 and 2016.
- Habitat mapping layers (see Chapter 2).
- As-built fence mapping
- As-built mapping of jump outs and underpasses
- Topographic data generated from OGRIP LiDAR
- Drainage trace maps created from topographic data
- As-built road and bridge mapping
- Highway and municipality data from various public sources including ODOT TIMS data and the OGRIP data.

DEER POPULATION USING RIGHT-OF-WAY HABITAT ALONG THE NELSONVILLE BYPASS

White-tailed deer use habitats within the NVBP ROW for activities such as feeding, traveling, sleeping, and mating. The need for evaluating the actual number of animals using the ROW arose from observations of deer inside the ROW throughout the study period. In general, monitoring ungulate populations, particularly those inhabiting forest habitats, is difficult to implement using direct observation methods (e.g., directly observing animals during surveys). Thus, estimating ungulate abundance relies on indirect methods, such as track surveys, camera trapping, or pellet counts. Camera trapping and track surveys can only provide relative abundance and probability that a habitat type is occupied by a given species or by a community of species. Estimating relative abundances relies on the assumption that higher animal densities will result in higher camera visitation, or higher number of tracks. While this index is useful in drawing comparisons between different regions, it is difficult to place it in the broader context, such as determining what proportion of the white-tailed deer population is involved in deer-vehicle collisions, and evaluating the performance of mitigation structures.

Currently, the most effective method for monitoring ungulate populations trends and estimating densities is by counting pellet groups deposited (Acevedo et al. 2010). The pellet count method can take many forms of sampling (Acevedo et al. 2008, Camargo-Sanabria and Mandujano 2011), and can yield absolute abundances, a much more effective metric for answering the main questions of the NVBP project: rate of road mortality and effectiveness of mitigation structures. More generally, the pellet count method can take two forms: (1) *single visits* in plots or transects, which rely on fecal pellet decay rates derived empirically, and estimate the Fecal Standing Crop (FST), and (2) *multiple visits* with resampling in the same area, which lead to estimating ungulate abundance using Fecal Accumulation Rates (FAR) (Alves et al. 2013). For single visits (FST method), several options for counting pellets are available, all relying on counting all pellets encountered; plots (circular or square plots), strip transects (transects of a fixed width and length), and line transects (transects of a fixed length, but with variable width based on the type of microhabitat encountered: e.g., wider in habitats with good visibility and narrower in habitats with low visibility). For multiple visits (FAR method), either plots or strip transects of fixed area can be used and resampled periodically.

We estimated the abundance of deer inside the ROW via pellet counts performed using the FAR method. We considered >6 pellets to form a "pellet group" (Figure 4-1). Pellet counts were implemented inside ROW by revisiting 50 164 ft. x 6.6 ft. strip transects evenly distributed between the Eastbound and Westbound habitats. The transects also were distributed proportionally to the three main types of microhabitats within the ROW: herbaceous vegetation, regenerating woody vegetation, and forest (Table 4-1).

The project team (project co-PI, Dr. Viorel D. Popescu, and three undergraduate students: Devon Cottrill, Nicole Dake and Jeffrey Roush) identified >100 potential locations for placing transects using GIS based habitat mapping conducted by Robert L. Wiley (see Chapter 2), and verified them in the field. After the field assessment, the team narrowed down to 50 locations spaced evenly along the Nelsonville Bypass, which were found suitable for surveying and detecting scats. We avoided travel corridors such as animal trails (also mapped by Robert L. Wiley) because of the high likelihood that pellet groups could be trampled and misidentified.

Once the team identified the general area for the transect we used a random start location to mark the start of the transect, a random direction (random numbers generated in Excel), and laid down a 164-ft. measuring tape. We marked the start and end of the transect using wooden posts with flagging. The actual survey was done by two people walking slowly at an even pace holding the ends of a 6.6 ft. stick, , and counting pellet groups on a 3.3-ft. wide strip on each side of the 164-ft. measuring tape. Each transect was revisited by the same team two more times during summer at an interval of approximately 1 month. Pellet groups were counted using the same methodology.

Each transect was visited three times during Summer 2016:

- 30 May – 3 June — Transect placement and initial survey
- 25 – 27 June — First revisit
- 25 – 28 July — Second revisit (NOT USED IN ANALYSES)

To determine the abundance of white-tailed deer in the NVBP ROW, *we used the initial and first revisit only*. The reason for not using the second revisit is that detection of pellet groups decreased, particularly in the herbaceous vegetation habitat because of vegetation growth. The general framework is that with each revisit, the number of pellet groups counted will increase if the animals return and use the transect areas for feeding, travel, etc. While there was an overall increase in the number of pellets counted during the first revisit (conforming to expectations), the second revisit had the lowest number of pellet groups; this indicates that detection of pellet groups was lower, which introduced bias in the data.

Based on the protocol used in this study, white-tailed deer density ($\boldsymbol{D}$) can be calculated based on the formula:

$$\boldsymbol{D} = \frac{\textbf{\textit{number of pellet groups accumulated per mi}}^{\mathbf{2}}}{\textbf{\textit{accumulation time}}(\textbf{\textit{days}})\ \textbf{\textit{x daily defecation rate}}\ (\textbf{\textit{pellet groups per days}})}$$

- The ***number of pellet groups accumulated per mi²*** was obtained by summing the total number of accumulated pellet groups, dividing it by the total area covered by transects (50 transects x 164 ft. x 6.6 ft. = 54,120 sq. ft.), and converting it into an index of accumulated pellet groups/sq. mile
- The ***accumulation time*** was 25 days (period between initial and first revisit)
- The ***daily defecation rates*** for White-tailed Deer were extracted from existing literature, and ranged between 15 and 25 pellet groups/day (Rogers, 1987).

USE AND EFFECTIVENESS OF MITIGATION FEATURES FOR DEER

Use of ROW habitat and effectiveness of mitigation measures were inferred from camera trapping implemented between July 2015 and December 2016. During this time frame, jump outs (N=16) and underpasses (N=3) were monitored continuously; cameras were also placed at potential fence crossing sites, including several holes in the fence created by fallen trees or erosion. Animals were recorded entering or exiting the ROW. Recording continued after damage to the wildlife fence was repaired as well. In June 2016 the effort was supplemented with an additional 11 cameras located in between the jump outs along the exclusion fence. We used a combination of X-Series Wireless Buckeye camera traps (Buckeye Cams, Athens, OH) and Moultrie M-999i camera traps (Moultrie Feeders, Birmingham, AL).

Photograph Tagging Methodology

Processed photographs were uploaded into Picasa to study wildlife activity around the highway mitigation structures. Each photograph was tagged according to the trigger event. An event was defined as an initial PIR (Passive InfraRed) triggered photograph and its two to four subsequent burst photographs when applicable. A single event could not exceed twenty minutes or change trigger tags. Events were then identified as to what type of activity occurred in relation to the ROW. Deer were recorded interacting with the jump outs and if they exited or entered the ROW via the structure was recorded. Instances where deer rejected use of the structure were also documented. All activity, even if structures were not used, were designated by inside or outside the ROW to monitor activity on either side of the fence line.

Statistical Analyses

(1) We evaluated the effectiveness of the jump outs for allowing white-tailed deer to exit the ROW using a sign test under the null hypothesis that the median percentage of deer events recording deer exiting ROW via jump outs was 50%. (2) We evaluated the effectiveness of the wildlife fence for preventing deer access to the ROW using an Exact Two-Sample Fisher-Pitman permutation test under the expectation that the number of deer events captured at cameras was equal on both sides of the fence. (3) We assessed the predictors of deer movement at the landscape level using data from cameras at jump outs and between jump outs, under the design modified after June 2016, which monitored deer use inside and outside ROW with equal intensity. Thus, we used camera data that recorded movement inside and outside the ROW between June and December 2016, which captured the two large peaks in movement: end-May – early-July and rut season (October through early-December). The increased sample size allowed us to use predictive models to determine use of habitat inside and outside ROW, and landscape scale predictors for deer presence and movement. We used generalized linear mixed effects models (Pinheiro and Bates 2000) with a categorical variable denoting whether observed data was inside or outside ROW (*ROW_IN / ROW_OUT*), and *%Developed*, *%Forest* and *%RoughGrass* land cover within 820, 1,640, and 3,280 ft. buffers centered on camera locations as fixed effects. We tested several random effect structures to capture latent variation in terms of time (*Month of the year*) and space (*Camera location*); based on Akaike Information Criterion (AICc, (Burnham and Anderson 2002)) the best random effect structure combination was *Camera-within-Month* (1|Camera/Month). We further used function '*dredge'* in package '*MuMIn*' in program R 3.3.2 (R Core Team 2017) to run all possible model combinations, while retaining the variable *ROW_IN / ROW_OUT* in each model. Last, we performed model selection (Burnham and Anderson 2002) to evaluate the contribution of the three land cover types to explaining differences in deer movement along the NVBP.

RESULTS

USE OF HABITAT BY DEER AND THE STATUS OF MITIGATION STRUCTURES

For purposes of this analysis, the NVBP roadway was divided into segments. Segments were defined by exclusion fencing ends and bridges (See Chapter 2). Bridges were used because they present long travel risk areas that lack both food and any cover. Deer most often move in response to browse availability (although they move long distances without grazing during rut and hunting season). They usually prefer location where cover is quickly accessible. It is likely that bridges 100 feet long and greater serve as forging barriers only used in circumstance of extremity. Observation of bridge approaches, particularly after precipitation did not reveal muddy tracks on cement berms or tracks in mud in unpaved areas near bridge ends. We speculate that deer rarely used bridges to access segments if ingress and egress routes were available within the segments. We also found no evidence of deer crossing the travel way between north and south grassed areas within segments. It is probable that deer frequently cross the highway; a likelihood supported by observations of carcasses in the roadway during the roadkill survey period. We speculate that deer can cross everywhere, and that most crossings are quick and leave little trace.

Table 4-2 presents a list of gaps that may provide deer access to ROW habitat. Gap segment location, gap type, gap description, side of the ROW, highway station and location are also reported (Table 4-2). Gaps are mapped on the ROW in Figure 4-2 and Figures 2-3 - 2-13.

Fence Gaps

Gaps are openings in the exclusion fence system through which a deer can ingress or egress the ROW. The presence of these gaps, along with trail mapping, provide inferences for jump out use and non-use. The gaps inventory includes all gaps recorded during the field survey conducted between March 2015 and October 2016 that are large enough for a deer to pass through (Figure 4-2 and Table 4-2). Deer can and do squeeze through vertical gaps as narrow as 16 in. Deer can crawl under fences if gaps are at least 18 in. They can jump 4-ft. impediments. While the time we record the fence gaps is certain, the time that the gaps became usable to deer is uncertain. Natural processes that form gaps are ongoing. There are likely new gaps that have formed since field work ceased. Construction-caused gaps may have been patched (efforts were made to maintain the fence line in 2016), but if so, even those were in use by deer for several years before closure, leading to the development of distinct deer trails. Vegetation has had several years to infest fences, making some gaps obscure. Gaps were often found by following deer trails to them.

We estimate that more than 98% of the exclusion system fencing is properly installed and functional. There is 99,966 ft. of the tall woven-wire fencing lining the NVBP ROW. The 80 deer accessible gaps identified range from a few feet in width to a few yards in width. The total length of all gaps is less than 300 feet, throughout. Thus, these gaps account for less than 0.3% of the total fence length. Additional gaps are the roadway connections at the ends and at the interchanges. The total open width of these is approximately 1,400 ft.; 1.4% of the exclusion area.

Deer Trails

Approximately 74 miles of deer trails were mapped within the NVBP ROW and near the outside of the NVBP ROW between February 2015 and September 2016. Not all trails were able to be mapped, only the well-worn trails. The locations of these trails show how deer repeatedly responded to the impediments presented by the exclusion fencing. They depict use and non-use of observed gaps and jump outs. Trails suggest deer trespass into the ROW to access high-quality forage. Deer trail mappings are identified in Figures 2-3 through 2-13 for individual segments of the NVBP.

DEER POPULATION USING RIGHT-OF-WAY HABITAT ALONG THE NELSONVILLE BYPASS

The initial survey of the 50 transects yielded a total number of 29 pellet groups (maximum = 8 pellet groups/ strip transect) (Table 4-3). A total of 11 pellet groups accumulated between the initial visit and the first revisit (40 pellet groups recorded during the 25-27 June survey; Table 4-3). The second revisit was not included in the analysis because of low detection of pellet groups due to growing vegetation. The density of pellet groups was 22 pellets/ 2.5 ac.

Using the formula for estimating density via Fecal Accumulation Rate (FAR) method, the overall density of white-tailed deer was between 10.5 to 15.5 individuals per sq. mi. depending on the daily defecation rate used in the calculation (for 25 and 15 pellet groups/day, respectively). Extrapolating to the entire NVBP ROW, which includes 0.772 sq. mi. of potential

White-tailed Deer habitat, we estimate that during the month of June 2016, between 8 and 12 White-tailed Deer were using the NVBP ROW.

USE AND EFFECTIVENESS OF MITIGATION FEATURES FOR DEER

Yearly and Seasonal Deer Movement Patterns Inferred from Camera Trap Data

The total number of camera trap photos was >500,000 during the monitoring period. We observed two activity peaks in White-tailed Deer use of the NVBP: end-May – early-July, and rut period (October – November) (Figures 4-3 and 4-4, Table 4-4). The first peak was associated with attempts to access fresh food resources inside the ROW (300+ acres of rough grass habitat within the ROW). The second peak is associated with the reproductive period (rut), when males dramatically increase their movements as they search for available females. In 2016, the rut season accounted for 30% of all deer events recorded by camera traps.

In addition to cameras associated with each mitigation structure (jump outs, bridges, and underpasses), we installed 11 additional cameras (provided by Dr. Popescu's Conservation Ecology Lab at Ohio University) between jump outs. As such, starting in June 2016, the camera trapping design was modified to monitor deer activity inside and outside the ROW simultaneously (at jump out locations, the cameras monitoring the use inside the ROW also recorded events of deer exiting the ROW via jump outs). This new, balanced design allowed us to determine the magnitude of habitat use inside and outside the ROW, thus effectively assessing the efficacy of the wildlife fence, in addition to evaluating the use of jump outs and underpasses. Adding the extra camera locations also allowed us to increase the sample size and perform statistical analyses on the camera trap data.

Daily Movement Patterns Inferred from Camera Trap Data

Camera trap data corroborated existing knowledge on the timing of daily movement. Deer movement showed two activity peaks: early morning (1-2 hour before sunrise), and early evening (1-2 hours after sunset) (Figure 4-5). Early morning saw a highest deer activity captured at camera traps (4,095 events; 59% of all nighttime movement), compared to evening movements (2,912 events; 41% of all nighttime movement).

Effectiveness of Underpasses and Bridges

Underpasses and bridges (Butterfly Bridge) showed extremely high use throughout the study period, and maintained connectivity of deer social groups located north and south of the NVBP. Wildlife trails radiate in many directions on both sides of the Butterfly Bridge. They were by far the most effective mitigation structures associated with NVBP (locations UP02, UP01 and BB02 in Figure 4-6 accounted for 65% of all deer moving in the NVBP area; N = 3,155 events), and are critical for reducing deer-vehicle collisions. In comparison, all jump outs cameras and additional cameras installed along the wildlife fence after June 2016 accounted for only 35% of all deer movements (1,696 events).

Effectiveness of Jump Outs

Jump outs performed relatively well, facilitating evacuation from the ROW, but their performance was highly dependent on the landscape context, and to a lesser degree on the technical specifications (Figure 4-7). Observations using motion-detection cameras demonstrated that only about 30% of deer that approach the jump outs and use them to exit the ROW, and most of the uses occur during rut. Nearly 70% of deer encountering the jump outs graze near the structures, showing no stress responses, and move on along the highway in the ROW. The low sample size (only 16 jump out of varying design) precluded us from identifying an effect of jump out height or presence of knee bar; the only clear effect was related to landing area: the two jump outs that developed a small wetland in the landing pad were not used at all during the study. Similarly, the lack of control sites did not allow us to determine whether the *wing fences* associated with each jump out played the intended role as a mitigation structure. Camera observations lead us to believe that the intended use ('funneling' the animals towards the jump out opening) was not met: deer moved freely in the area between the wildlife fence and the pavement, they were not 'intercepted' by the wing fences, and the wing fences may have brought deer closer to the traffic at some jump out locations.

Using the deer events at jump outs only, we determined that a median 21.5% of all deer events recorded inside the ROW were deer exiting the ROW (95% Confidence Interval = 8 – 47%; sign test under the null hypothesis that percentage is 50%, df = 7; *p-value* = 0.021). This suggests that deer often traveled or browsed in the area within the camera focal range inside the ROW, and that they were not actively seeking to exit the ROW. Instead, the ROW was incorporated in the deer home ranges during the two peak activity seasons (end-May – early July, and rut period), and jump outs offered a way to exit the ROW (like the existing fence gaps or interchanges that allowed deer to access ROW), as part of their daily or seasonal movement activity. *Therefore, we consider jump outs as having mixed success as a mitigation strategy*, and their effectiveness can likely be increased if continuous efforts are placed into maintaining and repairing the fence to reduce deer access to the ROW.

Effectiveness of the Wildlife Fence

Using all the deer events at jump outs that were not related to exiting ROW (thus just movement resulted from traveling or browsing), we determined that *the wildlife fence limited deer movement to some extent*. Under the expectation that the number of deer events captured at cameras was equal on both sides of the fence, we found that there was significantly more deer movement outside the ROW compared to inside the ROW (Exact Two-Sample Fisher-Pitman Permutation Test; Z = -3.5969, *p-value* <0.0001). The caveat for this analysis is that not all jump outs monitored until June 2016 had equal success in capturing movement inside and outside the ROW, as they were focused more on evaluating deer movement and behavior inside the ROW, and determining correct use of jump outs.

Predictors of Movement Inside and Outside the ROW

We found that movement outside the ROW was greater than movement inside ROW (Figure 4-8). Overall, the median number of events per month recorded outside the ROW was 39, compared to 11 events inside the ROW. Notably, there was large month-by-month variation outside the ROW (Interquartile range = 91 events), and much lower variation inside the ROW (Interquartile range = 26 events). This suggests that, to some extent, the wildlife fence may have reduced deer access to resources within the ROW; likely explanations are that either accessing ROW resources required almost four times more movement to find and use existing gaps in the wildlife fence, or that deer simply used resources outside the ROW to a larger extent, or both.

The level of movement outside and inside the ROW was positively associated with the percent *Developed* land within each of the three buffer zones (the error bars overlap the vertical 0 line very little) (Figure 4-9). Percent *Forest* and percent *RoughGrass* within the same buffers were poor predictors of deer events captured at camera traps (Figure 4-9). Overall, these are coarse metrics, valuable for broad scale predictions; the exact locations of potential mitigation structures may need to rely on more detailed mapping of microhabitats, trails and corridors used by White-tailed Deer.

DISCUSSION

USE OF HABITAT BY DEER AND THE STATUS OF MITIGATION STRUCTURES

Deer accessible openings are caused and characterized by several conditions including construction oversights, erosion, tree fall, and functional necessity.

Construction Oversights

Best construction practices for fence installation result in the lowest fence wires placed on or in the soil. End posts are within a few inches of abutments and if not, there are fence fillers in gaps. Stream crossings are properly screened to prevent wildlife from crawling under. All fence posts are solidly buried and attached to fencing material. Cases where these best practices were not met account for approximately 40% of the recorded gaps in the deer exclusion fencing.

The majority of fence installation errors were bottom gaps due to ground surface irregularity. The change in the slope surface grade is sometimes greater than can be accommodated by the wire fence rolls, resulting in triangular-shaped gaps at the bottom of the fence. Extra effort is required patch such gaps and in some instances the gaps were not patched.

Stream-fence crossings are difficult to block without causing erosion or diversion of water to undesired locations. Blocking devices composed of a lattice of treated dimensional lumber suspended from a rod do not work well over channels filled with 24-in. and greater size rip-rap. A deer can easily stoop through a 24-in. gap. Some of the gaps created by stream-fence crossings observed were 36-42 in. The difficult problem of stream crossings is likely to exacerbate with time. Hinged lattice structures are causing undermining of the channel bottom as they trap water-carried debris, creating dams. The dams are flanked by runoff water as it finds unarmored soil adjacent to the rip-rap channel and erodes. A second problem with the hinged lattice structures occurs as they become propped open by flood-carried large woody debris.

There are several large culverts (48-in to 72-in diameter) installed to direct flows from larger natural streams under the highway. The ends of the culverts emerge near highway edges and are apparently insufficiently covered to allow fence posts to be inserted over them. Resulting gaps were closed using number 4-gauge wire strung horizontally from the ground to post top at 18-24 in. intervals. Deer walk through these with ease. In several locations the wires have been distended from large animals pushing their way through. We camera-trapped one of these locations and collected many observations of deer and coyote entering the ROW through this loose closure.

The deer exclusion system includes the concrete wall structures at bridges. End fence posts must be sufficiently close to the abutment wall to exclude deer. This distance is generally less than 16 in. to exclude adult deer through these vertical gaps. There remain seven locations where the last fence post-to-wall gaps exceed 16 in. There was also a single finding of detachment of the fence from the post. It is uncertain whether this was a construction omission or intentional removal at some later time.

Erosion

Fences have been installed across the faces of road cuts and other steep, treeless graded slopes. Rill and gully erosion on these initially-barren slopes have undermined the high fences at hundreds of locations. A few of these have achieved depths of 2-3 feet, offering ROW access to deer and other large wildlife. The installation of water bars and diversions across these slopes may have prevented much of this erosion while vegetation was becoming established. If unattended the problem will worsen over time.

Erosion of fence support posts was noted in two locations. Post-grading water courses are sometimes inadvertently directed at posts, particularly where natural streams, blocked by grading re-meander into posts. This problem may also increase with time.

Tree Fall

The most prevalent cause of new fence gaps is tree fall. The high fence, particularly along the north side is installed within 5-20 ft. of the forest. Natural falling of old trees and wind-throw from newly exposed forest interior trees has resulted in fence crushing at 42 locations. Trail mapping suggests that most of these provide deer access to and from the right-of-way. Many of these occurrences cannot be seen from the roadway due to frequent fence placement at distant toes of slopes or above high road cuts. It is likely that this fence breaching problem will continue. Placing the exclusion fence closer to the roadway, away from the forest, would reduce this problem.

Construction Functional Necessity

The largest openings that provide deer access are the necessary openings for connection to other roads at ends of the bypass and at interchanges. Old US Route 33 is bounded at the ROW edges by four-foot fencing, or no fencing. This condition does not exclude deer, and allows entrance from the connections. The west connection to Old US Route 33 is 270 ft. wide. The east connection is 185 ft. wide. The conditions of these connections are not conducive to deer use. Grazing is minimal due the narrow grassy areas along the connection and there is little cover available for deer. One small, infrequently used deer trail was observed on the west end. Jump out 1 in that segment had a camera trap in place for 20 months and failed to observe a single jump out and only a single passing deer. No trails leading to or from the bypass were observed on the east end. The east end connection includes an approximately 800-ft. long ramp and bridge with very narrow berms along the travel way.

The interchanges offer great access opportunities for deer to forage within the ROW. The western Dorr Run interchange has a north opening to extensive forest of 200 ft. outside the pavement and a south opening of 355 ft. outside the pavement to the Hocking River riparian corridor. The Ohio State Route 78 interchange has a northern gap of 275 ft. outside the pavement that opens to extensive marshes and riparian forests along Monday creek and 160 ft. on the south that opens to the Hocking River riparian corridor. Deer trails through these areas are frequent and well-established. Camera traps have recorded hundreds of deer observations during the sampling period.

DEER ABUNDANCE IN THE NELSONVILLE BYPASS RIGHT-OF-WAY

The survey timing (accumulation period) coincided with the highest usage of the ROW by deer outside the rut season (evaluated by 18 months of camera trapping). This is likely due to new vegetation growth, which attracted deer to the ROW in search of food resources. These results can also be correlated with the number of deer-vehicle crashes within the NVBP during the month of June 2016 to evaluate the mortality rate during a period of high use of the ROW by White-tailed Deer. The deer crashes are known to peak in November, the rut season, when deer behavior changes dramatically; males tend to travel longer distances in search of females, a behavior which both increases the likelihood of encountering roadways, making them more susceptible to collisions with vehicles.

Deer densities can vary greatly both spatially (even across small distances based on habitat conditions) and temporally; for example, the 2014 deer densities in Athens and Hocking County, estimated by the Ohio Department of Natural Resources (ODNR) based on the yearly deer harvest data, are 24.0 and 26.7 deer/ sq. mi. (Michael Tonkovich, ODNR, pers. comm.); we obtained results that are roughly half of those reported by ODNR. The landscape setting of the NVBP ROW, which is heavily forested, is less likely to support high deer densities because closed canopy forests contain less food resources. It is likely that a large proportion of the animals inhabiting the area adjacent to the ROW were attracted by the abundance of high-quality forage within ROW, and actively sought to access it (evidence based on the many trails that penetrate the wildlife fence through gaps near culverts, erosion at the base of the fence, etc.).

While we intended to conduct another revisit during the rut season, we decided against it for several reasons; first, the time demands for such a survey (3-5 days for 3 people) were not compatible with the students' class schedule; second, we had conversations with several deer biologists (Dr. David Williams and Dr. William Porter, Michigan State University and Dr. Bradley Cohen, University of Georgia), which suggested that rut season is not suitable for this type of evaluation because animals (especially males) drastically change their behavior by traveling a lot more in search of mates. The best time for evaluating deer populations via pellet counts is late-winter/early-spring, before plants start growing, when detection of scat is not hindered by vegetation, and deer spend more time within overwintering grounds. We suggest a deer population survey in the broader area (within 2 miles from the NVBP ROW) be implemented in late-winter/early-spring in the future.

The data on deer density are complementary to the camera trapping data collected during the same period at jump out locations and between jump outs, which only provide relative abundances of 'deer events' outside and inside the ROW. The camera trapping setup was modified in June 2016 to provide complementary images of inside and outside ROW simultaneously at 16 jump outs + 10 locations between jump outs. Deer density, and the actual location of the transects with high number of deer pellets, as well as high pellet accumulation rates, are also useful when evaluating the likelihood of deer-vehicle collisions (from road mortality surveys), and contribute to understanding the overall use of the mitigation structures along the NVBP (underpasses, jump outs), as well as the problems that reduce the mitigation efficacy (points of entry resulting from erosion, felled trees, human-cut holes, etc.).

TIMING OF DEER MOVEMENTS AND EFFECTIVENESS OF MITIGATION FEATURES FOR DEER

Overall, the temporal patterns of movements and spatial use observed in the NVBP area corroborate existing knowledge on white-tailed deer ecology and behavior. On a yearly basis, we observed two peaks of movement. One peak in June-July, associated with fresh browse within the ROW and one peak in October-December, associated with the reproductive period (rut). On a daily basis, there are two peak deer activity periods: 1-2 hours before sunrise and 1-2 hours after the sunset.

The wildlife fence had limited success in preventing deer from entering the ROW; while deer were not able to jump over the 8-ft. wildlife fence, deer frequently entered ROW using: (1) the interchanges, (2) gaps in the fence from soil erosion or tree fall, and (3) culvert areas. Deer actively sought these gaps to access food resources inside the ROW and during the extensive movements associated with the rut season. These gaps were used continuously until they were repaired (deer continued to show up at the location of the former gap for months after the repair). However, the combined analysis of deer events inside and outside the ROW, showed an overall higher number of deer events outside the ROW, suggesting that the wildlife fence may prevent deer from entering the ROW to some extent, and this may be reflected in the lower number of deer crashes recorded in the NVBP segment, compared to the control segments (see Chapter 3 concerning deer-vehicle collisions)

Underpasses and bridges were the most successful mitigation measures, allowing deer to move between the north and south side of the NVBP (accounted for 65% of all camera trap data).

Jump outs allowed deer to evacuate the ROW, but deer behavior inferred from camera trapping suggests that they were used not consistently used: 9-35% of observed deer events recorded at jump outs inside the ROW were exits via jump outs (with a median of 21.5%). Comparing features among jump out was not feasible due to low sample size, but we did detect that jump outs with unsuitable landing pads were not used by deer.

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CHAPTER 5: AMPHIBIANS

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INTRODUCTION

Hundreds of thousands of amphibians are killed on roads each year, which reduces population sizes, disturbs population connectivity, and eliminates populations (Dodd et al. 2004, Glista et al. 2008, Langen et al. 2009). The problems created by roads will continue to increase, as over 13,000 additional miles of road are constructed each year in the United States (United States Department of Transportation 2011). Among amphibian species, few individuals survive to become adults, but reaching adulthood is essential for population persistence (Scott 1990, Vonesh and De La Cruz 2002, Price et al. 2012). Migratory species that require high adult survival to maintain populations are often heavily impacted by roadway mortality (Ashley and Robinson 1996, Trombulak and Frissell 2000, Bouchard et al. 2009) as individuals will cross roadways during migrations (Russell et al. 2005).

To reduce roadway impacts, mitigation measures are increasingly being used. Mitigation measures most often take the form of barriers and ecopassages (Nelson et al. 2006, Andrews et al. 2015). Barriers limit access to roadways and often direct animals toward ecopassages, which are corridors designed to conduct animals safely over or under the roadway. Despite the increase in roadway mitigation, evaluation of the effectiveness of mitigation measures remains understudied (Aresco 2005, Patrick et al. 2010, Andrews et al. 2015). Little is known about amphibian use of ecopassages (Patrick et al. 2010, Pagnucco et al. 2011), and even less is known about the effectiveness of barrier-ecopassage systems in reducing amphibian mortality and maintaining connectivity among amphibian populations (Beebee 2013).

Our research project investigated roadway mortality and the use of a barrier-ecopassage system by amphibians along a two-lane highway. The objectives of our research project were:

1. To obtain population estimates of Mole Salamander species and other amphibian species.
2. To observe road crossing behavior of migratory amphibians at the site.
3. To assess the incidence of amphibian road mortality.
4. To assess the effectiveness of barriers, ecopassages, and the barrier-ecopassage system.

We conducted our research along Ohio State Route 78 (SR 78), which was constructed as part of the Nelsonville Bypass, in Athens County, Ohio. This location has a barrier-ecopassage mitigation system in place. At this site, we assessed mortality and structure effectiveness within the framework of population sizes to quantify the impacts of each on several amphibian populations. In addition, we observed and analyzed road crossing behavior. Based on our results we provide feedback concerning impacts of the new road on amphibian populations, the effectiveness of the mitigation structures, and potential mitigation improvements.

STUDY SITE

The Nelsonville Bypass, completed in 2013, includes 8.8 miles of new four-lane divided freeway (US 33) and two interchanges. One of these interchanges is the U.S. 33/SR 78 /SR 691 interchange, for which 1.63 miles of new two-lane highway (SR 78) was constructed. The Ohio Department of Transportation included wildlife mitigation measures along the roadway, as this bypass bisected the Wayne National Forest. These mitigation measures must be reviewed for effectiveness and possible improvement.

A barrier-ecopassage system is in place along the SR 78 section (Figure 5-1), which bisects a landscape that includes many wetlands (Figure 5-2). An acid mine drainage (AMD) treatment system was also constructed at this location in 2009, and a series of mitigation wetlands were constructed in 2009-2010. Thus, this is an important site to study many mitigation strategies for amphibian conservation (Mitchell et al. 2008, Langen et al. 2009, Price et al. 2012).

The barrier-ecopassage system at this site consists of two 60 ft. long ecopassages connected by 500 ft. of barrier fencing (Figure 5-3). The ecopassages are made of treated concrete with an aperture size of 16 in. x 20 in. (Figure 5-4). There are small perforations running the length of the ecopassages to allow some light into the tunnels (Figure 5-4). The curved plastic fencing is 2 ft. tall and is buried 4 in. in the ground (Figure 5-4). The barrier fencing and ecopassages are made by ACO Polymer Products, Inc.

STUDY SPECIES - AMPHIBIANS

Southeastern Ohio is home to many species of amphibians, including: frogs, toads, and salamanders. There are 29 species of amphibian that can be found in Athens County, Ohio (Table 5-1) (Pfingsten et al. 2013). Eighteen of these species are migratory (Petranka 1998, Pfingsten et al. 2013). Migratory amphibians will travel from upland habitats to wetland habitats to breed or find suitable overwintering habitat. Migrating amphibians are directed in their movements and generally do not hesitate to cross roadways (Russel et al. 2005, Bouchard et al. 2009), thus are of conservation concern. In Ohio, amphibians typically migrate in the spring (March-June) and fall (September-November) (Pfingsten et al. 2013), and are most active on rainy nights (Gibbs 1998, Bouchard et al. 2009, Pfingsten et al. 2013).

METHODOLOGY

POPULATION ESTIMATES

To assess populations, we used a variety of sampling techniques, including:

(1) DIP NETTING – Dip netting surveys were conducted in spring of 2015 (March-June) in 12 wetlands (Figure 5-2, numbered wetlands). Three surveys were conducted in each wetland unless it dried up before they could all be performed; a total of 52.13 hours was spent dip netting wetlands. Surveys were completed using a standard aluminum-frame dip net that measured 11.8 in. x 15.4 in. with 1/8 in. mesh and a fiberglass handle. A dip net sweep was classified as pulling the basket of the dip net across the substrate on the bottom of the wetland for 3-ft. length (Gunzburger 2007) and all suitable habitats within a wetland was surveyed.

(2) MINNOW TRAPPING – Rectangular Promar® collapsible minnow traps were placed in wetlands where water levels were sufficient to submerge trap openings (Figure 5-5). The double-opening minnow traps measured 10 in. x 10 in. x 17 in. and are constructed of maroon 1/8 in. polyethylene mesh. Each trap has a zippered opening to assist in safely removing captured individuals. To keep the top 1-2 in. of the traps above water floats were used (Olson et al. 1997, Dodd 2010). Minnow traps were deployed in 11 wetlands in the spring of 2015, five wetlands in the fall of 2015, 10 wetlands in the spring of 2016, and three wetlands in the fall of 2016. There were a total of 1,536 minnow trap nights in the spring of 2015, 345 minnow trap nights in

the fall of 2015, 1,590 minnow trap nights in the spring of 2016, and 320 minnow trap nights in the fall of 2016.

(3) SPOT LIGHT SURVEYS – Surveys were conducted on rainy nights along the roadway to capture migrating amphibians. Head lamps were used to detect amphibians and individuals were captured by hand (Dodd 2010). Surveys were conducted on 27 nights in the spring of 2015 and 46 nights in the spring of 2016. There were also 10 survey nights in the fall of 2015 and 7 nights in the fall of 2016.

(4) CALL SURVEYS – Amphibians were identified to species based on their calls. The number of animals detected within a five-foot radius by sound and/or sight were recorded during five-minute samples. Surveys were conducted at least one hour after sunset (Heyer et al. 1994, Gunzburger 2007, Dodd 2010). Call surveys were completed at four wetlands in the spring of 2015 and at nine wetlands in the spring of 2016. In the spring of 2015 6 hours of call surveys were completed, and in the spring of 2016, 30.5 hours of call surveys were completed.

(5) PITFALL TRAPPING – Pitfall traps are five-gallon buckets buried in the ground so that they are level with the surface (Figure 5-5). Twelve traps were placed along a 500-ft. barrier, which guide animals to the traps, in an area of high amphibian movement along SR 78. Pitfall traps contained some soil and a sponge at the bottom to prevent desiccation of amphibians. The bottoms of buckets were perforated to allow excess rainwater to drain and to prevent drowning of captured animals (Heyer et al. 1994, Dodd 2010). Traps had plywood covers that were 3 in. off the ground and held in place by a rock to block sunlight, mediate trap conditions, and prevent predation on trapped animals (Enge 2001). Traps were checked daily February 22-June 24, 2016 and September 5-November 14, 2016. Traps were checked a total of 195 times for a total of 2,340 trap nights (195 nights times 12 traps).

All adult animals captured using dip net, minnow trap, spot light, and pitfall trap methods were measured, weighed, sexed, and marked using a batch marking technique (Figure 5-5) (United States Geological Survey 2001, Ferner 2007). Adult animals captured or detected were used to generate population estimates. Population size estimates were generated via mark-recapture methods and area-density methods (Heyer et al. 1994, Dodd et al. 2010). The programs Microsoft Excel and R (R Development Core Team, 2008) were used to process data and estimate population sizes from collected data. Adult breeding population estimates were calculated for eight amphibian species; seven of these estimates were calculated using simple Lincoln-Petersen and Chapman methods, for the Spring Peeper the population estimate was calculated by multiplying animal density by suitable habitat area. Spring Peeper suitable breeding habitat was identified as water less than 12 in. deep with vegetation present for egg deposition; suitable habitat was identified in the field and mapped into ArcMap to calculate area size (Figure 5-6).

Population estimates allow us to compare the number of amphibians found dead on the roadway and the number found using the ecopassage to the breeding population size.

ROAD CROSSING BEHAVIOR

We assessed roadway crossing behavior by watching individuals crossing the road. We recorded time of day, air temperature, angle of crossing, time to cross, distance traveled, type of locomotion, location of mortality, number of cars that went by, and behavior in presence of vehicles. We collected crossing data on five species of amphibian: American Toads, Spring

Peepers, Gray Treefrogs, Red-spotted Newts, and Pickerel Frogs. Data was collected at night time (8:30pm-1am) and during the day (6:30am-11am) between February 24, 2016 and April 26, 2016. We also collected traffic data using pressure sensitive hoses that were put in place on SR 78 between May 27, 2015 at 4 pm and June 11, 2015 at 3 pm.

We calculated the probability of surviving a road crossing by species, as the proportion of the total number of individuals observed that successfully crossed, and we documented which lane mortality occurred in. We assessed locomotion, hopping or walking, by time of day and species. We analyzed the efficiency of road crossing by species and time of day. We also report on the behaviors exhibited in the presence of vehicles. All analyses were performed using t-tests among time of day within a species, and using an analysis of variance test with post-hoc Tukey test among species.

ROADWAY MORTALITY

The 1.2 mile stretch of State Route 78 from Burr Oak Blvd/Sylvania Ave. to the US 33 entrance ramp was surveyed on foot to count deceased animals (Dodd et al. 2004, Crawford et al. 2014). All deceased animals were identified to species, aged and sexed (if possible), georeferenced, then removed from the roadway (Teixeira et al. 2013, Beckmann and Shine 2015). Live animals seen during roadway mortality surveys were captured, measured, weighed, sexed, and marked (United States Geological Survey 2001, Ferner 2007).

Road mortality surveys took place daily March 13-June 23, 2015, August 24-November 23, 2015, February 22-June 24, 2016, and September 5-November 14, 2016, with additional surveys conducted earlier in the spring and fall. A total of 401 morning roadkill surveys were conducted in the fall and spring. During the summer of 2016 (June 25- September 4) roadway mortality surveys took place every 2-3 days, for a total of 27 summer roadkill surveys.

Carcass data was tabulated and summarized in graphical format. Number of carcasses is also compared to the population size to assess the approximate proportion of animals killed. Georeferenced mortality locations were mapped to produce maps of mortality patterns for several species.

BARRIERS, ECOPASSAGES, AND THE BARRIER-ECOPASSAGE SYSTEM

To monitor the effectiveness of barrier mitigation, pitfall traps were placed at the ends of the plastic fencing barrier (Figure 5-7). Traps were checked daily March 13-June 23, 2015, August 24-November 23, 2015, February 22-June 24, 2016, and September 5-November 14, 2016. Traps were checked a total of 390 times for a total of 1,560 trap nights (390 nights times four traps). Each animal captured was measured, weighed, sexed, and marked (United States Geological Survey 2001, Ferner 2007).

We assessed the ecopassages using camera traps to obtain images of animals using the ecopassages (Pagnucco et al. 2011, Leeb et al. 2013). Cameras equipped with break-beam sensors were placed at each entrance of the ecopassages to take photographs of amphibians in the tunnels (Figure 5-8). We used handmade wooden blocks that funneled animals within the view of the camera, which we measured at about 10 in. We recognize that adding the blocks made the tunnel opening smaller and may have effected amphibian use. As animals cross an infrared light beam at the entrance produced by a sensor the beam is no longer reflected to the sensor and triggers the camera to take a picture (Figure 5-8). Cameras with break-beam sensors were in place April 16-June 22, 2015, September 3-November 23, 2015, and February 22-November 14, 2016. By observing amphibian behavior from camera images and comparing animals found in pitfall traps to animals detected in camera images we could assess the effectiveness of the ecopassages and the barrier-ecopassage system.

RESULTS

POPULATION ESTIMATES

Throughout all our sampling methods we detected 17 amphibian species (Table 5-2), 14 of which were migratory species. Five species were detected using all the sampling methods. On average migratory species were detected by four sampling methods. Only two non-migratory species were detected with just one method.

Of the wetlands dip netted, wetland 3 (pictured in Figure 5-2) had the greatest number of adult amphibians captured with a total of five, whereas there were four wetlands in which no amphibians were captured (Table 5-3). As few adult amphibians were captured by dip net sampling, we did not continue this method in 2016.

As for minnow trapping, the most adult amphibians were captured in wetland 2 and wetland 3 (Figure 5-9, 5-10, 5-11), while we did not find any amphibians in wetland 6 (Figure 5-9, Figure 5-11, and Table 5-4) (wetland numbers pictured in Figure 5-2). Most of the catch was adult Red-spotted Newts, Northern Green Frogs, Spring Peepers, and American Bullfrogs. Note that the number of captures between 2015 and 2016 went down in all wetlands, despite similar amounts of sampling effort (Figure 5-9 and Figure 5-10). The Northern Green Frog was the most widely present, as it was found in 11 wetlands (Table 5-4). We detected all 13 wetland amphibian species in both wetland 5 and wetland 51 (Table 5-4 and Figure 5-12). Several species of reptile were also detected while dip netting and minnow trapping, however, this report focuses on the amphibians.

During our spring spot light surveys, we captured 1,356 amphibians, of which 360 were Spring Peepers (26.5% of the total) and 739 were Red-spotted Newt juveniles (54.5% of the total) (Figure 5-13). We captured more amphibians in 2016 than in 2015, but we also had 19 more nights of sampling effort. In the fall, we captured 51 amphibians in 2015 and 39 amphibians in 2016 (Figure 5-14). Of the amphibians captured between the fall of 2015 and 2016 67.8% were Red-spotted Newt juveniles.

Through our call surveys we detected nine amphibian species (Table 5-2). We focused our efforts on quantifying Spring Peepers, to get a population estimate for this species. The number of Spring Peepers detected per square foot varied between 2016 and 2015 in all four wetlands that were sampled both years (Figure 5-15). Spring Peeper call surveys were conducted in all wetlands with suitable breeding habitat (Figure 5-6).

We trapped 431 amphibians in pitfall traps during the spring of 2016 and 74 amphibians in the fall of 2016. Of these, 363 (71.9%), were Red-spotted Newt juveniles. The number of each species trapped is presented in Figure 5-16. Mammals and reptiles were also captured (data not shown).

We generated population estimates for eight species. Lincoln-Petersen and Chapman estimates were calculated for seven species (Table 5-5), while an area density estimate was calculated for Spring Peepers (Table 5-6). For the most abundant species, the Spring Peeper, we estimated a population size of 29,405 individuals (Table 5-6). The species with the lowest calculated population is the Marbled Salamander, with an approximate population size of 149-336 individuals (Table 5-5).

ROAD CROSSING BEHAVIOR

In our observations of 220 individual animals (Red-spotted Newts=98, American Toads=61, Pickerel Frogs=23, Spring Peepers=20, and Gray Treefrogs=18), we found that even the fastest species still only had a 69.8% chance of surviving a crossing attempt (Figure 5-17). For Red-spotted Newts, only 11.2% made it successfully across the road. We observed that some animals would turn around and return to the side they started on. Most animals died in the traffic lanes, although some were hit on the shoulder.

We observed three species crossing at night and during the day. Pickerel Frogs crossed the fastest, taking only 5-7 minutes to cross, while American Toads, Red-spotted Newts, and Gray Treefrogs took upwards of 15 minutes to cross (Figure 5-18). American Toads and Red-spotted Newts are significantly faster at crossing during the day than they are at night, but pickerel frogs did not significantly differ in their crossing speed. Even during the day, newts are slower than almost all other groups. In an analysis of variance comparison followed by a Tukey test, Red-spotted Newts at night were the slowest to cross, and Pickerel Frogs were the quickest to cross (but not significantly quicker than Spring Peepers and American Toads during the day).

We also found that for all species, except Pickerel Frogs, individuals that survived crossing were more efficient at crossing the roadway than those individuals who were hit by cars (Figure 5-19). Efficiency is how long it took for an animal to reach its end location within the 40-foot distance across the road divided by that distance, and does not include the actual distance hopped or walked. Interestingly, time of day did affect how toads chose to move across the roadway. During the day, most individual American Toads exhibited hopping and walking behaviors while at night most individuals walked only (Figure 5-20). In the fastest species, the Pickerel Frog, only one animal walked. Additionally, we found that many individuals would be physically flipped over by cars, but not killed. These flips would disorient the animal and interrupt movement for up to 6.5 minutes. The average Red-spotted Newt was flipped 2.3 times during the crossing (Figure 5-21). Even bigger amphibians still often had a 25-30% chance of being flipped during a road crossing attempt.

By analyzing the traffic data, we can see that traffic is greater than 100 cars per hour between 7am and 10pm (Figure 5-22). When we isolated the day (7am-11am) and night (8pm-1am), our averages for cars counted per minute during the behavior survey come out very close to the reported traffic data averages (Figure 5-22). An animal that is on the road for 10 minutes in the morning will experience 27 cars on the road on average, while at night it will experience about 17 cars.

ROADWAY MORTALITY

Through our roadkill surveys we detected a total of 13,766 carcasses, of which 13,251 were amphibian carcasses (96% of all carcasses) (Figure 5-23). In the spring of 2015 6,434 carcasses were detected 98% of which were amphibians (Figure 5-24). 1,156 carcasses were detected in the fall of 2015 of which 1,033 were amphibians (Figure 5-24). In spring 2016, 5,484 carcasses were detected, of which 5,298 were amphibians (Figure 5-24). In the summer of 2016, 177 carcasses were found, of which 148 were amphibian carcasses (Figure 5-24). In the fall of 2016, 515 carcasses were found, 90% of which were amphibians (Figure 5-24). In the spring of 2015 and 2016, amphibians made up 98-97% of all carcasses found, even in the summer and fall amphibians made up 90-83% of all carcasses found. Spring Peepers and Red-spotted Newts made up most of the amphibian mortality (43% and 37%, respectively).

We detected 14 amphibian species dead on the road. Patterns of mortality varied by species (Figure 5-25), though often there were fewer mortality events in 2016 than there were in 2015.

Based on population estimates, each amphibian population has a mortality rate of at least 3.0-14.6% (Table 5-7). Some species, such as the American Toad, may be experiencing as much as 33.7% population mortality each year.

Most amphibian species show similar spatial patterns of mortality along the roadway (Figure 5-26), with a mortality hotspot about 2,000 ft. southwest of the present barrier-ecopassage structure. Both the Northern Green Frog and American Toad experience very high mortality adjacent to the wetland, whereas the dots in the northern half of the map are just barely overlapping (Figure 5-26). The highest percentage of mortality per roadway stretch is in the area adjacent to the wetland complex (Figure 5-27).

BARRIERS, ECOPASSAGES, AND THE BARRIER-ECOPASSAGE SYSTEM

Frogs and salamanders were detected in the ecopassages (Figure 5-28). During the spring of 2015, 10 amphibians were detected in the ecopassage, however, only two Northern Green Frogs were seen traversing the whole length of the passage. In fall 2015, cameras detected three amphibians, with two Marbled Salamanders traversing the length of the ecopassage. In the spring of 2016, seven amphibians were detected in the tunnel, with two Northern Green Frogs crossing through the ecopassage. One amphibian was seen in the ecopassage in the summer of 2016 (between June 24-Sept. 5, 2017), and it did not go all the way through. In the fall of 2016, four amphibians were seen in the ecopassage with a Marbled Salamander and an American Bullfrog traversing the length of the tunnel. A total of 25 amphibians have been seen at the entrances, with eight animals passing all the way through (Figure 5-29). Many mammals and reptiles were documented by the camera traps using the ecopassage (data not shown).

In spring 2015, 101 amphibians were captured in pitfall traps: 32 in fall 2015, 84 in spring 2016, and 39 in fall 2016. Many small mammals and some reptiles were also trapped in the barrier pitfall traps (data not shown). We captured a total of 11 amphibian species in the barrier pitfall traps (Figure 5-30).

If we compare the number of amphibians captured in the pitfall traps at the ends of the barrier to the number documented in the ecopassage images, it does not appear that the passages are facilitating the movement of many animals (Figure 5-31). Additionally, we compared ecopassage use to the number of animals experiencing mortality (Table 5-8), to generate an ecopassage use rate for each amphibian population.

DISCUSSION

We investigated roadway mortality and use of a barrier-ecopassage system by amphibians along SR 78 throughout 2015 and 2016. Using five amphibian community sampling methods, we detected 17 amphibian species; of these, we generated population estimates for eight species (four salamanders and four frogs). Populations ranged from nearly 30,000 individuals down to few hundred. We classified road crossing behavior of five amphibian species and assessed roadway mortality and mitigation effectiveness in the context of estimated population sizes.

The three species with the lowest population estimates were all Mole Salamanders (Jefferson Salamander, Spotted Salamander, and Marbled Salamander). Mole Salamanders are long-lived amphibians that spend most of their time underground and emerge in the spring or fall to breed in wetlands (Petranka 1998, Pfingsten et al. 2013). Gibbs and Shriver (2005) suggest that to persist on a landscape, the mortality added by roadways must be less than 10% of the total population per year. Two of the Mole Salamander species we assessed, the Marbled Salamander and the Spotted Salamander, appear to be experiencing 10% roadway mortality per year or more (Table 5-7). In addition, we found that they already have small population sizes at this site (Table 5-5), thus, even low amounts of roadway mortality may impact the genetic diversity of their populations (Richardson 2012). We were unable to quantify Mole Salamander road crossing behavior due to low numbers of individuals crossing the roadway. The Marbled Salamander was the only Mole Salamander detected in the ecopassage camera images (Figure 5-28, 5-29, and 5-31), and the ecopassage facilitated the movement of 1.2-2.7% of the Marbled Salamander population (Table 5-8). In addition, all three Mole Salamander species were captured in pitfall traps at the ends of the barrier fencing (Figure 5-30 and Figure 5-31). Our study suggests that the Mole Salamanders may be facing more roadway mortality than their populations can withstand, and that the mitigation structure is only facilitating the movement of one Mole Salamander species (1.2-2.7% of the Marbled Salamander population).

It is difficult to generate a population estimate for Red-spotted Newts that incorporates roadway mortality, as this species has a complex life cycle with three stages, including an aquatic larva, a forest dwelling juvenile form called an eft, and an aquatic adult (Petranka 1998, Pfingsten et al. 2013). Red-spotted Newt roadway mortality is primarily juvenile newts, but when not migrating, the juveniles are hidden in the forest floor and are difficult to census. We generated a population estimate for the aquatic adults of 4,838-4,803 individuals (Table 5-5); this estimate is based on all adults captured during 2015 and 2016. However, the number of adults captured has declined; we captured 492 adults in spring 2015 and 61 in fall 2015, but 34 adults in spring 2016 and 12 in fall 2016. In our road crossing observations, only 11% of newts successfully crossed the road (Figure 5-17). In part, this may be because Red-spotted Newts at night are the slowest moving of the amphibians observed (Figure 5-18). In addition, the average newt was flipped over by 1.7-2.3 vehicles during its road crossing attempt (Figure 5-21). We documented one Red-spotted Newt in the ecopassage images, which did not traverse the tunnel, while we found 21 newts in the barrier pitfall traps. The decline of adults between 2015 and 2016 is concerning and could be related to a decrease in recruitment due to high added juvenile mortality, though other factors cannot be ruled out.

We calculated population estimates for two True Frogs, the American Bullfrog and the Northern Green Frog. Both species have robust population sizes (Table 5-5) and are experiencing less than 6.8% of population roadway mortality per year. We also observed at least one individual of each species fully traverse an ecopassage (Figure 5-29). However, 5-10 times more individuals were captured in the barrier pitfall traps (Figure 5-30 and Figure 5-31). We did not detect the other three species of True Frogs (Pickerel Frogs, Leopard Frogs, and Wood Frogs) in camera images, though we occasionally captured them in the barrier pitfall traps. We collected behavioral data on Pickerel Frogs crossing the road. They were the fastest species of any amphibian we observed to cross the road (Figure 5-18), and the had the highest probability of survival (69.8%) (Figure 5-17). If this successful crossing behavior can be extrapolated to the American Bullfrog and Northern Green Frog, it might explain why they were less affected by roadway mortality. Additionally, American Bullfrogs and Northern Green Frogs migrate less commonly, as they generally inhabit permanent ponds, wetlands, and creeks, which may buffer them from roadway effects (Carr and Fahrig 2001, Pfingsten et al. 2013). It appears that despite little use of the amphibian barrier-ecopassage system the American Bullfrog and Northern Green Frog are not immediately suffering from roadway mortality.

On the other hand, the American Toad is estimated to be experiencing 14.6-33.7% added mortality per year. This may be too much mortality to be sustainable, although Hels and Buchwald (2001) indicate that some species of frogs and toads may be able to withstand added mortality as high as 20% of the population per year. We assessed the road crossing behavior of American Toads and found them to be slow and inefficient, especially when crossing the road at night (Figure 5-18 and Figure 5-19), as most individuals walked (instead of hopping) at night (Figure 5-20). Only 41% of the 61 toads observed successfully made it across the road without being killed by a vehicle (Figure 5-17). This species was observed in the ecopassages, although no individual went all the way through a tunnel (Figure 5-29). Moreover, about eight times more individuals were found in the pitfall traps than in the ecopassage camera images (Figure 5-30 and Figure 5-31). The American Toad is likely experiencing unsustainable mortality and the mitigation structure appears to be ineffective for this species.

More Spring Peeper carcasses have been detected than any other species along SR 78 in 2015 and 2016 (n=5,746) (Figure 5-24 and Figure 5-25). This species has the largest population (Table 5-6) and is experiencing approximately 9.8% population mortality per year. We saw a drop in the number of carcasses found between 2015 and 2016 (Figure 5-25), which may indicate a decreasing population. Yet, we found that the number of individuals per square-foot of wetland remained similar (Figure 5-15). Also, we collected information on this species' road crossing behavior and found that they have the second highest survival probability, with 55% of individuals making it successfully across the roadway (Figure 5-17). However, Spring Peepers had a 74% chance of being flipped over by a passing vehicle (Figure 5-21). While this species has been witnessed at the ecopassage entrances and in pitfall traps, Spring Peepers are equipped with sticky toe pads and often climb out of traps and over fences (Enge 2001, Pfingsten et al. 2013). Thus, our assessment of the mitigation system in place along SR 78 is compromised for this species. It is not clear whether 9.8% mortality per year is expected to be sustainable for the Spring Peeper (Hels and Buchwald 2001, Gibbs and Shriver 2005).

Across all the species we have assessed, mortality rates are far greater than ecopassage use rates (Table 5-7 and Table 5-8). We do not believe this is a fault of our break-beam sensor camera, as it consistently collects images of small invertebrates and other animals when they pass through the sensor. The cameras also take 2.63-4.23 times more pictures when hooked up to the break-beam sensor than they do normally. It is possible that the blocks used to keep animals within the camera's field of view impacted ecopassage use. The barrier fencing appears to function well, as many amphibians follow the barrier to the pitfall traps (Figure 5-30). The barrier is an important part of the mitigation structure (Cunnington et al. 2014, Baxter-Gilbert et al. 2015). In sum, these findings suggest that the ecopassages themselves may be undesirable crossing structures for amphibians. Finally, when viewing the spatial patterns of mortality among species (Figure 5-26) and as a whole (Figure 5-27), it appears that the barrier-ecopassage system in place is northeast of the amphibian movement hotspot. 62% of the mortality occurs southwest of the present structure in one 700ft. section (Figure 5-27).

All of the wetlands constructed by ODOT to replace habitat lost during construction of the Nelsonville Bypass were colonized by amphibians (wetlands 2, 3, 5, and 7; pictured in Figure

5-2). On average there were 10.75 amphibian species found in each of the newly constructed wetlands (Figure 5-12).

RECOMMENDATIONS

The present barrier-ecopassage system does not appear to be providing adequate transport under the roadway for amphibian species. Below are recommendations concerning improvements to barrier-ecopassage system design and placement:

Design

- The present ecopassages have an aperture size of 20 in. x 16 in., which may be too small. Previous studies that have assessed aperture size recommend that a larger aperture is better, particularly for jumping frogs and toads (Woltz et al. 2008, Patrick et al. 2010). We conducted a preliminary choice study with Red-spotted Newts that suggests individuals will use the largest exit available to them (Hopkins, unpublished data).
- The present ecopassages have a concrete bottom, while previous studies indicate that natural substrates are preferred over concrete and plastic (Woltz et al. 2008, Patrick et al. 2010).
- The present ecopassages only have two rows of perforations along the top, which provide sky exposure. It has been shown that light and air flow encourage amphibian use of tunnels (Woltz et al. 2008). In addition, it is considered a “best practice” to provide as open a top as possible in ecopassages to encourage use (Clevenger and Huijser 2011, Gunson et al. 2016).
- The present ecopassages are crowned, which cuts with the roadway cutting off the line-of-sight to the other end of the tunnel, thus making the passage appear to have no end. The Wildlife Crossing Structure Handbook (Clevenger and Huijser 2011) recommends that structures follow the natural topography of the landscape. We recommend ecopassage choice testing before another structure is installed to assess the impact of line-of-sight on use.
- The barrier fencing has been successfully guiding amphibians to pitfall traps at the end of the barrier. However, three years after implementation the 2-ft. tall curved plastic fencing is beginning to show some signs of wear: there are places where the fencing has separated, and places where erosion has washed soil out from underneath the fence. We patched these gaps during our study, but if left unattended the gaps allow animals to trespass through the barrier structure. Barrier maintenance is important, as barriers guide amphibians toward ecopassages (Cunnington et al. 2014, Baxter-Gilbert et al. 2015, Gunson et al. 2016). In all future projects, we recommend that there be a maintenance plan in place for both barrier fencing and ecopassages.

Placement

- We found that the area where the barrier-ecopassage system is located does not experience as much roadway mortality because there are few amphibians crossing the road at this location. Where the current mitigation structure is located, wetlands are present on both sides of the road (Figure 5-2 and Figure 5-27). Thus, it may be that amphibians do not need to cross the road to breed. A confounding factor is that the amount of suitable wetland habitat near the ecopassages is small, thus supports fewer amphibians. In contrast with the wetlands near the current mitigation, the stretch of

SR 78 experiencing the most mortality (Figure 5-27) is where there is wetland habitat on one side of the road, with upland habitat on the other side of the road. We recommend that future migratory amphibian mitigation efforts be placed in areas where suitable breeding habitat cannot be found on both sides of the roadway (Patrick et al. 2012).

- We also recommend that in future new roadway projects a thorough quantitative examination of migratory routes be conducted to choose the mitigation site. In future roadway enhancement projects, a roadway mortality study should be done before construction begins to determine if a mitigation system is needed and where mitigation should be placed.
- Finally, we recommend that a study be undertaken to assess what spatial factors (land cover, slope, physiogeography, etc.) may influence where amphibians will cross road. This information should be used to inform future projects.

CONCLUSION

In our investigations of roadway mortality, we recovered a total of 13,766 carcasses, of which 13,251 were amphibian. This is a high mortality rate compared to many other studies (Aresco 2005, Sutherland et al. 2010, Andrews et al. 2015). Based on roadway mortality, we conclude that at least four amphibian species may be experiencing unsustainable mortality rates (Hels and Buchwald 2001, Gibbs and Shriver 2005). In our assessment of the amphibian mitigation that was installed, we find that the structure is not effective at transporting amphibians across the roadway. We found that the present mitigation structure, while a valuable first attempt, suffers from both design flaws and suboptimal placement along SR 78 (Woltz et al. 2008, Patrick et al. 2010, Patrick et al. 2012). We made several recommendations to improve future amphibian roadway mitigation projects.

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CHAPTER 6: BATS

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INTRODUCTION

The impacts of roads on bats are poorly understood in comparison to other groups of wildlife (Medinas et al. 2013; van der Ree et al. 2015; Altringham and Kerth 2016). Despite this knowledge gap, bats are clearly impacted by roads in many ways, including collisions with automobiles (Lesiński et al. 2010; Medinas et al. 2013; Russell et al. 2009), noise pollution (Schaub et al. 2008; Siemers and Schaub 2011; Kitzes and Merenlender 2014), and habitat loss and fragmentation (Altringham and Kerth 2016). Assessing each of these impacts is difficult but essential for any discussion of roadway impacts or the effectiveness of mitigation measures. While it is likely that the U.S. 33 Nelsonville Bypass (NVBP) impacts bats in each of these ways, the scope of this project does not include any impact assessment. Because the impact of the NVBP on bats has never been assessed, the data in this chapter cannot be used to determine the effectiveness of the measures put in place to mitigate those impacts. However, the data in this chapter provide a foundation for understanding the role that existing mitigation measures, especially high-mast lighting, play in attracting bats to roadways, both in and above the flow of traffic, where collision mortalities may happen.

Highway lighting along the NVBP was placed at heights (100 ft.) nearly twice that of typical highway lighting to entice bats, which may prey upon insects attracted to highway lights, above the flow of traffic while still providing light for motorist safety (Figure 6-1). When evaluating this mitigation strategy, it is important to note that foraging behavior varies widely among bat species (Norberg and Rayner 1987; Lacki et al. 2007), and it is therefore likely species are influenced by lighting and the presence of roadways in significantly differently ways. For example, species most vulnerable to collision are likely to be those that navigate along habitat edges such as roadways, and fly at the same height as passing traffic (Russell et al. 2009; Berthinussen and Altringham 2012; Altringham and Kerth 2016). Although limited, current research suggests that rate of road-crossings in these species is greatest when suitable habitat occurs on both sides of the road, as is the case with the NVBP (Lesiński 2007; Russell et al. 2009; Medinas et al. 2013). When suitable habitat is present, roadkill rates for species such as the Little Brown Myotis (*Myotis lucifugus*), a species of conservation concern in Ohio, have been found to be significant (Russell et al. 2009; Lesiński et al. 2010). However, the morphology, echolocation strategies, and behavior of these species all suggest it is unlikely that they would fly or forage at the height of the high-mast lighting (Norberg and Rayner 1987), despite potential for prey attraction to those lights. Species more likely to fly in the open, at the height of high-mast lighting, include species such as the Eastern Red (*Lasiurus borealis*), Big Brown (*Eptesicus fuscus*), and Hoary (*Lasiurus cinereus*) bats. There are no data on the impacts of highways on these species, but it would be reasonable to expect these species to be more effected by lighting mitigation measures than bats in the genus *Myotis*. Ohio University researchers working on other aspects of this report have found road-killed Eastern Red and Silver-haired (*Lasionycteris noctivagans*) bats along the NVBP, although it is unclear how many bats are killed each night, how many other species are impacted, and if high-mast lighting increases or decreases collision rates.

Although a complete assessment of the effectiveness of high-mast lighting is impossible without full knowledge of the various ways bats are impacted by the NVBP, the *potential* for these lights to reduce collision rates can be assessed on two levels. First, the attraction of bats to highway lighting can be measured as an indirect method of assessing whether lights draw bats to the NVBP. Second, the effectiveness of increasing the height of highway lighting to 100 ft. can be assessed to determine if bats are being lured to safe heights. The study reported in this chapter details the results of these assessments. Specifically, it was hypothesized that high-mast lighting would draw bats to the NVBP. Furthermore, it was hypothesized that large species such as the Big Brown, Eastern Red, and Hoary Bat would be more active at the level of mast lights than at the level of traffic.

In addition to the high-mast lighting features, bat roosting boxes were implemented in two of the large animal underpasses (Wildlife Underpass 2 and the Butterfly Bridge) to replace bat habitat lost during construction. The bat roosting structures are lattice style roosting boxes with the potential to provide habitat for thousands of bats (Figure 6-1).

METHODOLOGY

Acoustic bat detectors (SM4 Bat, Wildlife Acoustics, Inc.) were deployed at four locations along the NVBP. At each location, detectors were deployed at three heights above the flow of traffic. Bat detectors were deployed beginning April 28, 2016, and remained operational for the entire year. To test the hypothesis that highway lighting attracts bats to the NVBP, two of the four mast lights were either turned off or were selected because they were non-functional, while the remaining two mast lights were left functional. These lights turn on shortly before dusk and remain on until after dawn. To test the hypothesis that larger species of bats are attracted to the height of highway lights, bat detectors were placed at the level of traffic (3 ft. above ground, hereafter, the “low detector”), the height of typical highway lighting (50 ft. above ground, hereafter the “mid-detector”), and at the level of the high-mast highway lights (100 ft. above ground, hereafter the “high detector”). Bat detectors were programmed to turn on and record bat activity from a half-hour before sunset to a half-hour after sunrise. Detectors were checked every 3-5 weeks to download recorded data and change their batteries.

All recorded files were processed using the Kaleidoscope Pro 4 Analysis Software (Wildlife Acoustics, Inc.) to filter out recordings of noise from recordings of bat calls, and to identify recorded bat calls to species to the extent possible (poor quality recordings and short duration recordings are often not identifiable to the species level). Bat calls identified to species were placed into more general species groups to minimize errors in species identification. Some species, such as the Big Brown and the Silver-haired Bat, are often confused for one another, even by computer software. These species groups were defined as: 1) *Myotis* species, 2) Big Brown and Silver-haired Bats, 3) Eastern Red and Tri-colored Bats (*Perimyotis subflavus*), and 4) Hoary Bats (*Lasiurus cinereus*). Bat calls are summarized as both the total number of calls recorded per detector-night (1 detector-night = 1 bat detector functional for 1 night) and the total number of calls identified to each species group per detector-night.

Statistical analyses are not appropriate for these data because of the short duration of this study, which resulted in inadequate sample sizes. In the study design described above, each high-mast light represents the basic unit of experimental observation. Thus, only four independent locations have been sampled to date; too few for statistical analysis. As a result, the two hypotheses contained in this report are assessed qualitatively. To facilitate this qualitative assessment, the number of calls recorded per detector-night are reported for mast-lights that were turned on and off. These data are further summarized with respect to detector height and species groups. Data are reported for the entire study period, but emphasis is placed on calls recorded during the summer (May-August) to avoid using dates occurring during the migration and hibernation periods.

RESULTS

Bat detectors along the NVBP recorded 524,929 bat calls over 1,507 detector-nights between April 28 and December 9, 2016, averaging 348 bat calls/detector/night. Of these calls, 465,075 were recorded during 926 detector-nights (502 calls/detector/night) within the summer months. Of these 465,075 calls, the majority were identified to the Eastern Red and Tri-colored Bat species group (*n* = 195,300; 42%), followed by Hoary Bats (*n* = 166,797; 36%), the Silver-haired and Big Brown Bat species group (*n* = 94,507; 20%), and the *Myotis* species group (n = 608; <1%). Calls that were unable to be identified to species represented 2% of the dataset (*n* = 7,863).

During the summer months, a total of 384 detector-nights were sampled at mast lights that were turned on, compared to 542 detector-nights at mast lights that were turned off. Cumulatively, bat detectors at these mast lights recorded 327,740 (853 calls/detector/night) bat calls and 137,335 (253 calls/detector/night) bat calls, respectively, providing qualitative support of the hypothesis that highway lighting attracts bats. Despite higher sampling effort at mast lights that were turned off, 157,145 (80%) of Eastern Red and Tri-colored Bat calls were recorded at mast lights that were turned on. Similarly, 65% (*n* = 108,150) of Hoary Bat calls, 60% (*n* = 56,901) of Silver-haired and Big Brown Bat calls, 60% (*n* = 384) of *Myotis* species calls, and 66% (*n* = 5,182) of unidentified calls were recorded at functional mast lighting. A comparison of the number of calls recorded per detector-night at functional and non-functional mast-lights, separated by species groups, are contained in Figure 6-2.

Examination of the number of bat calls recorded at the three heights above ground suggest differences in activity patterns of bats underneath highway lighting compared to unlit areas (Figure 6-3). Although no statistical comparisons can be made due to small sample sizes, overall activity rates in lit and unlit areas show that the Eastern Red and Tri-colored Bat group, as well as Hoary Bats, had the greatest increase in activity at the level of the low detector. Meanwhile, bats in the Silver-haired and Big Brown Bat group had the greatest increases in activity at the high detector. Thus, our second hypothesis met with mixed support from a qualitative examination of these results.

DISCUSSION AND CONCLUSION

The data presented in this chapter provide an assessment of the *potential* for high-mast lighting to reduce collisions between bats and traffic along the NVBP. The hypotheses qualitatively assessed in this study suggest that bats in all species groups were more active underneath highway lighting, but only the Silver-haired and Big Brown Bat group demonstrated any evidence of activity increasing at levels high above the flow of traffic. Because Silver-haired Bats are mostly expected to occur in Ohio during spring and autumn migration (Johnson et al. 2011), most of calls identified to this group are likely to be Big Brown Bats. All other groups showed the greatest increase in bat activity at the level of traffic. Thus, although the impacts of the NVBP on local bat populations are yet to be assessed, the results of this short-term study do not suggest that increasing height of lighting along the highway is effective at mitigating highway mortality, with the possible exception of the Big Brown Bat.

Activity recorded at bat detectors cannot be interpreted to represent the number of bats active under highway lighting (Hayes 2000). Instead, the call rates presented in this study must be interpreted as activity rates. Thus, although only qualitative analyses are presented in this report, overall, bats are more active under functional highway lights. Bats are likely attracted to higher numbers of insect prey in these lit areas. This increase was more pronounced at the level of traffic for species groups that include large species such as the Eastern Red and Hoary Bats, contrary to expectations. However, the Silver-haired and Big Brown Bat group showed evidence of increasing activity at the level of high-mast lighting as expected.

Increased activity under highway lighting likely reflects increased foraging by local bats, which would result in more echolocation activity, and a greater number of call files. A bat foraging under a highway light can quickly produce dozens or hundreds of calls depending on the amount of time spent foraging in the area. The large volume of call files recorded under highway lights suggest this foraging activity. Additional research focusing on the behavior of bats foraging under lights is needed to ascertain the amount of time these foraging bats spend at the level of oncoming traffic.

Although Ohio University researchers have only reported a small number of road-killed bats (n=2; Table ES-2) during unrelated wildlife surveys, this should not be interpreted to suggest that few bats are killed along the NVBP. Bats killed on roads typically go unnoticed because they are small, are quickly scavenged, and because they can be propelled away from the road after being struck by a vehicle. Thus, the impact of the NVBP is uncertain, and must be assessed to place the results of this report in proper context.

It should be emphasized that highway impacts on bat communities extend beyond collision risk. For example, a recent study found evidence that some species avoid roadways (Altringham and Kerth 2016). In this way, roads present a barrier to some species, reducing their foraging opportunities and fragmenting populations. Bats are also known the affected by noise pollution stemming from roads (Schaub et al. 2008; Siemers and Schaub 2011; Kitzes and Merenlender 2014). Bats also suffer from the effects of habitat loss when new roads, such as the NVBP, are constructed. While bat roosting boxes were implemented to replace lost habitat, it is unclear at this time whether the boxes are inhabited. Visits to the bat roosting boxes have not resulted in encountering bat feces beneath the boxes, but bats have been detected in camera trap images at the Butterfly Bridge large wildlife underpass. The true impact of the NVBP must be considered in a larger context than simply the number of bats killed on the road, as habitat loss, habitat change, and habitat fragmentation all impact bat populations.

In conclusion, this preliminary study finds little evidence that high-mast lighting is effective at mitigating mortality of bats along the roads. Except for Big Brown Bats, activity of most bat species and species groups increased the most at the level of traffic under high-mast lights, suggesting these bats are foraging at heights where they are at risk of traffic collisions. However, without data on the number of bats killed in lit and unlit areas it remains unclear if these differences in activity translate to actual differences in the number of road-killed bats.

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CHAPTER 7: REPTILES

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INTRODUCTION

Habitat fragmentation and other forms of anthropogenic landscape modification are important drivers of biodiversity loss (e.g. Fischer & Lindenmayer 2007). Roads are a principal source of habitat fragmentation and impact wildlife through a wide range of ecological effects (reviewed in Forman & Alexander 1998, Trombulak & Frissell 2000, Fahrig & Rytwinski 2009, Holderegger & DiGuilio 2010, Andrews et al. 2015). At the core of this issue, roads impact wildlife populations in four ways: (1) habitat loss and modification; (2) mortality resulting from wildlife-vehicle collisions; (3) reduced access to resources; and (4) decreased connectivity and population subdivision across roads (Jaeger et al. 2005). These roadway impacts have demographic and genetic consequences that compromise the persistence of wildlife populations (e.g. Fahrig et al. 1995, Rudolph & Burgdorf 1997, Roe et al. 2004; Steen & Gibbs 2004, Row et al. 2007, Clarke et al. 2010).

Exclusion fencing and wildlife crossing structures are becoming more common mitigation tools used in the creation of new roads and to enhance existing transportation infrastructure (Beckmann et al. 2010). Studies have demonstrated that the use of exclusion fencing and crossing structures can reduce road mortality (e.g. Clevenger et al. 2001) and maintain connectivity (e.g. Mata 2008, Sawaya et al. 2013, Sawaya et al. 2014) in many wildlife populations, including reptiles and amphibians (Aresco 2005; Dodd et al. 2004). Globally, reptiles and amphibians (collectively = herpetofauna or herptiles) are widely threatened with extinction (IUCN 2016), and are the most negatively impacted by roads among vertebrate classes (Rytwinski & Fahrig 2012). Despite this vulnerability, studies evaluating road effects on herpetofauna have progressed at a slower pace compared with other vertebrates (Rytwinski & Fahrig 2012). Much is still to be learned about how roads affect herptile populations and their ecology. Studies that have evaluated the effectiveness of mitigation structures for herpetofauna have found that successful mitigation is contingent on sound design, construction, and maintenance of the structures (e.g. Dodd et al. 2004, Jochimsen et al. 2004, Baxter-Gilbert et al. 2015). Careful evaluation of wildlife mitigation treatments remains necessary to understand the causes for their success or failure, and guide the development of best management practices (BMPs).

The Nelsonville Bypass (NVBP) is a segment of U.S. Route 33 that was built through the Wayne National Forest, Ohio, in an area that harbors a remnant population of Ohio endangered Timber Rattlesnakes (*Crotalus horridus*). Snakes are often casualties of road mortality (reviewed in Andrews et al. 2008), and Timber Rattlesnakes are especially sensitive to road fragmentation due to a combination of life history traits, behaviors, and cultural prejudice towards snakes (reviewed below). Furthermore, road construction could subdivide an already small population, or isolate individuals from critical resources, exacerbating the risk of extirpation. To mitigate these impacts, rattlesnake exclusion fencing was installed to keep rattlesnakes off the NVBP, and small wildlife ecopassages (i.e. crossing structure) were installed under the roadway to allow snakes to safely cross to the other side. While Timber Rattlesnakes were the focal species, these mitigation structures could benefit a diversity of reptile species. The forestland in the Wayne National Forest (WNF) surrounding the NVBP is home to many other reptile species that also can be adversely affected by the road and benefit from the mitigation structures. These include the Box Turtle (*Terrapene carolina*) and several snake species, including the Copperhead (*Agkistrodon contortrix*), Black Racer (*Coluber constrictor*), Eastern Hog-nosed Snake (*Heterodon platirhinos*), Garter Snake (*Thamnophis sirtalis*), the Eastern Milk Snake (*Lampropeltis triangulum*), and others.

We conducted a two-year field study (2015 - 2016) that was designed to assess how Timber Rattlesnakes and other reptiles were impacted by the Nelsonville Bypass, and to evaluate the effectiveness of the rattlesnake mitigation structures. To evaluate the effectiveness of mitigation measures, road ecologist (Forman et al. 2003) have proposed the following criteria: (i) reduction in the abundance of wildlife on roads to reduce wildlife-vehicle collisions and road mortality, (ii) maintenance of dispersal routes, (iii) maintenance of habitat connectivity, (iv) preservation of gene flow within and among populations, (v) maintenance of metapopulation processes, and (vi) maintenance of ecosystem function. For practical purposes, these criteria can be distilled to criteria i and ii, as criteria iii, iv, and v are all functionally dependent upon criterion ii, and criterion vi is poorly defined and beyond the reach of most mitigation studies. Thus, our field study employed a combination of techniques to evaluate whether mitigation fencing is excluding rattlesnakes and other reptiles from the ROW (criterion i) and whether ecopassages are allowing dispersal across the highway (criterion ii). We also assessed habitat use to evaluate the impacts of mitigation structures on habitat connectivity (criterion iii) and discuss possible consequences of mitigation success for population connectivity (criteria iv & v). We quantified trespassing of the snake exclusion fence, use of the small wildlife ecopassages, reptile road mortality, as well as other metrics of habitat use and movement relevant to how rattlesnakes are interacting with the roadway. Collectively, those data were evaluated with the above criteria, and serve as the basis for our recommendations to ODOT.

The objectives of our study were:

1. To assess the impacts of the Nelsonville Bypass on Timber rattlesnakes.
2. To evaluate the effectiveness of the rattlesnake exclusion fencing.
3. To evaluate the effectiveness of the small wildlife ecopassages.

STUDY SITE

The Nelsonville Bypass ("NVBP" or "bypass") is an 8.5-mile segment of U.S. 33 that passes through Athens and Hocking Counties, Ohio (Figure 7-1). The bypass is a high speed (70 mph), high volume (~17,000 vehicles/day), four-lane divided highway. Construction of the NVBP began in 2007, and the entire length was opened to traffic in October 2013. The NVBP bisects the Athens Unit of the WNF, which includes more than 67,000 non-contiguous acres in five counties of southeastern Ohio. The WNF is an eastern deciduous forest (primarily Oak-Hickory-Maple forest at the NVBP) with outcroppings of Pennsylvanian sandstone.

Though the surrounding landscape is largely forested, it experiences regular disturbance. The NVBP sits less than one mile outside the city of Nelsonville and crosses six two-lane roads, all intersecting portions of the forest. While the patch of forest north of the bypass is mostly contiguous, the south side of the bypass bears a large gap in forest cover at the site of the Athens-Hocking Reclamation Center. Furthermore, the WNF near the NVBP contains approximately 75 miles of off-road vehicle (ORV) trails, a gas line right-of-way, and other infrastructure for oil, gas, and timber extraction including well pads and access roads.

The study site consists of habitats within the NVBP right-of-way (ROW) and the surrounding forest. We define **ROW habitats** as the area between the large wildlife fence (described below) and the roadway, and **forest habitats** as areas in the WNF beyond the fence. The wildlife fence generally tracks the ROW-forest boundary, with more open canopy habitats on the ROW side, and mostly closed canopy habitats on the forest side. ROW habitats include roadside fields (dominated by grasses and weedy vegetation, e.g. Asteraceae spp.), roadcuts, stone piles (drainage control structures), successional stands of sumac (*Rhus sp.*) and black locust (*Robinia pseudoacacia*), as well as some small patches of remnant forest.

In the decade prior to the completion of the bypass, Timber Rattlesnakes had been observed in the Dorr Run area, with confirmed sightings on the WNF ORV trails, crossing OH-278, and around the Athens-Hocking Reclamation Center. Pre-construction rattlesnake surveys were performed in WNF pursuant to the environmental impact assessment, but surveyors failed to detect rattlesnakes. During construction of the bypass, two rattlesnakes were encountered on separate occasions in the Dorr Run area where the rattlesnake mitigation structures were ultimately installed.

MITIGATION STRUCTURE: SNAKE FENCE

An 8-ft. tall right-of-way (ROW) exclusion fence ("tall wildlife fence") was constructed along the length of the bypass to prevent deer and other large wildlife from accessing the highway. However, the mesh of the wildlife fence is permeable to smaller wildlife including rattlesnakes, and thus an additional rattlesnake exclusion fence ("snake fence") was installed using a high-density material (1/4 in. mesh galvanized hardware cloth). The snake fence stands 3-4 ft. tall, with the base of the fence buried shallowly (< 8 in.) into the ground. This fence extends along both sides of the highway for ~1 mile west of the Dorr Run interchange (Figure 7-2), spanning the areas where rattlesnakes were observed during construction. The eastern half of the fence is attached to the base of the wildlife fence and tracks steep terrain across the ROW - forest boundary, while the western half is detached from the wildlife fence and travels closer to the roadway. The snake fence was not built at a consistent distance from the roadway and ranges from 25 ft. to 300 ft. from the pavement.

MITIGATION STRUCTURE: SMALL WILDLIFE ECOPASSAGES

Five wildlife crossing structures ("ecopassages") were installed along the U.S. 33 segment of the Nelsonville Bypass (Figure 7-3), and an additional two crossings were installed under the SR 78 access road (see Chapter 5 for more detail). Two of these structures along the U.S. 33 segment are 4 ft. diameter corrugated steel culverts designated as herpetofauna crossings. However, these structures could be used by any wildlife small enough to fit through the tunnels, and "small wildlife ecopassages" may be a more appropriate name for these crossings. The ecopassages are approximately 170 ft. long, and in the median, the circular culverts open into a 4-ft. wide rectangular box culvert that spans the width of the median. The ceiling of the box chamber is an elevated metal grate (tall enough for a person to stand comfortably), and allows natural lighting at the middle of the passage. One of these structures was installed in the Dorr Run area and is paired with the snake fence (SWE1; Figure 7-2 and 7-3), and the other ecopassage was installed 2.6 mi. west and beyond the extent of snake fencing (SWE2, Figure 7-3).

STUDY SPECIES

Timber Rattlesnakes (*Crotalus horridus*) are a large-bodied venomous snake (family: Viperidae) with a life history characterized by delayed maturity, infrequent reproduction, and high adult survival (Brown, 1993; Ernst and Ernst, 2003; Martin, 2001; Olson, 2015; Brown, 2017). They are a cryptic ambush predator that consumes a wide variety of endothermic prey, but eat primarily small mammals, including mice, voles, and chipmunks (Ernst & Ernst, 2003). Their spatial ecology is characterized by stark intraspecific variation in home range size (e.g. Reinert & Zappalorti 1998; Anderson 2010), movements (Waldron et al. 2006), and habitat use (Reinert 1984) owed to a snake's sex and reproductive status. Generally, males and non-gravid females prefer closed-canopy forests throughout the activity season, while gravid females prefer open-canopy habitats with rocky substrate or downed woody debris (Reinert 1984; Reinert & Zappalorti 1998). Males have larger home ranges and often travel long distances in search of females throughout the mating season (e.g. Waldron et al. 2006), which usually takes place in the late summer to early fall. Home ranges of all individuals are tethered to their winter hibernacula (i.e. den), for which they show strong site fidelity across years (Brown, 1993); rattlesnakes rarely abandon these sites even after significant disturbance to the forest ecosystem such as logging (e.g. Reinert et al. 2011; MacGowan et al. 2017). Rattlesnakes will use disturbed habitats, including road sides (Brown, 1993), primarily gravid females using them as gestation sites (Reinert & Zappalorti, 1998). However, vehicle strikes can be a common source of mortality for timber rattlesnakes (e.g. Adams, 2005). Timber Rattlesnakes cross roads slowly and often freeze in response to approaching vehicles (Andrews & Gibbons, 2005); this, combined with the persecution of snakes on roadways (e.g. Ashley et al. 2007) make it exceptionally difficult for Timber Rattlesnakes to safely cross unmitigated roadways. It is thus not surprising that roads also have been associated with reduced population densities of Timber Rattlesnakes (Rudolph et al. 1998), and reduce gene flow among populations (Bushar et al. 2015) and ultimately erode genetic diversity within populations (Clarke et al. 2010). This combination of life history and behavioral traits render Timber Rattlesnakes critically vulnerable to the impacts of roads.

METHODOLOGY

OBJECTIVE 1: ASSESS THE IMPACTS OF THE NELSONVILLE BYPASS ON TIMBER RATTLESNAKES

We began our assessment after the completion of the highway and pre-construction attempts to find rattlesnakes were unsuccessful, therefore we lack pre-construction data on Timber Rattlesnakes and other reptiles in WNF. Thus, there was no control treatment, and we could not evaluate changes in population size, survival or reproductive rates, body condition, home ranges, or other metrics relative to pre-construction conditions. However, we were able to assess the post-construction population with respect to mortality, habitat use relative to the ROW, and fence trespassing events using radio telemetry. We also performed road mortality surveys to document mortality events of rattlesnakes and other reptiles that were not radio tracked. Our protocol for these methods are described below.

OBJECTIVE 2: EVALUATE THE EFFECTIVENESS OF THE RATTLESNAKE EXCLUSION FENCE

Wildlife exclusion fencing should prevent animals from accessing the road and reduce or eliminate wildlife road mortality and wildlife-vehicle collisions (WVC). If fencing is paired with wildlife crossing structures, it should also be designed to direct animals to those crossing structures. Thus, fencing effectiveness can be evaluated based on three biologically relevant criteria: 1) evidence of fence trespassing; 2) reduction in road mortality compared to rates prior to the installation of mitigation structures, or compared to a suitable control area without fencing; and 3) evidence of wildlife being directed to crossing structures (i.e. higher crossing rates at ecopassage with fencing compared to ecopassages without fencing). Quantifying the trespass rate of barrier fencing is important because a permeable fence will be less effective for reducing road mortality and directing wildlife to crossing structures; this becomes increasingly important when populations are small or sparsely distributed, and the detection probability of road mortality is low. For slow growing populations such as box turtles and rattlesnake, even low road mortality rates may be unsustainable in small populations. A fourth, non-biological criterion is the physical integrity of fence; the fence should be durable in the local environment, and upkeep of the fence should occur at a frequency that maintains functionality of the barrier.

To measure fence trespass rates, we used a combination of radio telemetry (rattlesnakes) and capture-mark-recapture (other reptiles). Radio telemetry documented when rattlesnakes crossed the snake fence. For other reptiles, we used capture-mark-recapture to detect fence crossings. To capture animals, we deployed bidirectional box-funnel traps (Burgdorf et al. 2005) and tin cover boards (Grant et al. 1992) along both sides of the snake fence. Trapping and marking protocol are described below. We quantified reptile roadkill on the NVBP to evaluate the effectiveness of the snake fence in reducing road mortality. We compared the number of mortality events between the NVBP section with snake fencing to the rest of the bypass without snake fencing, controlling for distance. To evaluate the effectiveness of the snake fence for directing wildlife to the ecopassage, we compared the passage use rates as observed by game cameras (see below). Collaborators on this project surveyed the mitigation fencing for damage, which is reported in more detail in the structural evaluation of mitigation structures in other sections of this document. Throughout the field season we noted damage to the fencing as we discovered it, including small holes and defects visible only at ground level.

OBJECTIVE 3: EVALUATE THE EFFECTIVENESS OF THE SMALL WILDLIFE ECOPASSAGES

Ecopassages, or wildlife crossing structures, are tunnels, culverts, underpasses, or overpasses that allow animals to cross to the other side of the road without having to move directly across the road surface. When effective, these structures facilitate population connectivity and resource accessibility across the roadway. Thus, ecopassage effectiveness should be evaluated based on the evidence of complete crossings from one entrance to the entrance on the opposite side of the road. Another important criterion is the integrity of the design. Design integrity may be evaluated on the ecopassage suitability or willingness to use by target species, sound placement in the landscape, and integration with exclusion fencing. While radio telemetry provided a means of detecting use of the ecopassages by rattlesnakes, we also quantified use of the small animal ecopassages by using game cameras (described below).

RADIO TELEMETRY

We identified habitat use, documented fence crossings, and mortality events by radio tracking snakes throughout their active season. We surgically implanted radio transmitters into the body cavity of adult and large sub-adult rattlesnakes following Reinert and Cundall (1982). Surgeries were performed at Ohio University with IACUC approval (Protocol # 14-L-018). Snakes were anesthetized using isoflurane, which was administered at the far end of a sealed snake tube where the snake was restrained. Snakes were implanted with an ATS R1680 transmitter (0.13 oz.), which was always less than 2% of snake's body mass. After surgery, snakes were provided with water and a warm enclosure in the lab where they could recover for 2-7 days before being released at the location of capture. Rattlesnakes were tracked in the field using a Communication Specialists Inc. R-1000 Telemetry Receiver and a 3-Element Yagi Antenna. We tracked rattlesnakes a minimum of three times per week between Spring emergence (April – May) and when they returned to their overwintering dens in the Fall (September – October). When we tracked a snake in the field, we recorded its position using either a Garmin eTrex (2015 field season) or a Garmin Map 64 (2016 field season). We recorded which side of the fence the snake was on at each relocation to ensure that GPS locations matched field observations.

HOME RANGE ANALYSES

We used a combination of home range estimation techniques to quantify space and habitat use at the Nelsonville Bypass. The minimum convex polygon (MCP) is the minimum bounding geometry of all relocations belonging to an individual, providing a metric of the maximum spatial extent of an animal's movements. MCPs do not weight areas that receive more use across time, and often overestimate the amount of area used by an animal. Thus, MCPs are less informative from the perspective of habitat use, but are useful for understanding the spatial extent of an animal's activity. MCPs are also useful for comparative purposes because many studies have reported home range sizes of Timber rattlesnakes using the MCP method. The kernel method (i.e. kernel density estimator) estimates the probability of occurrence across space to generate a utilization distribution (i.e. identifies areas used more frequently than others; Worton 1989), but may extrapolate to areas that are not used by the animal, and thus fail to identify hard boundaries in an environment. LoCoH methods (local convex hull) can be thought of as a hybrid of these two approaches, where the relative distribution of points in space drives the formation of smaller polygon shapes (i.e. local convex hulls) using a nearest-neighbor algorithm (Getz et al. 2007). LoCoH can be used to generate utilization distributions that also identify hard boundaries. The disadvantage of LoCoH methods is that they require more time to construct, and subjective decisions need to be made by the researcher.

We generated 100% minimum convex polygons (MCP), 95% kernels, and 95% LoCoH, to quantify space use and home range boundaries. If the maximum length of MCPs exceed the length of snake fencing, or are positioned such that they do not overlap in spatial coverage, it would suggest that the snake fencing is not sufficient in scope. If 95% Kernels extrapolate home ranges across the highway or into the roadway when these areas are not actually used, it may suggest that the road bounded movements. 95% LoCoH provides a more conservative estimate of space use compared with MCP. We additionally generated 50% kernels and 50% LoCoH to quantify core activity areas. If core activity areas overlap with the ROW, it would suggest that habitats important to the rattlesnakes remain in these areas. Home range estimation using these three methods also allowed for direct comparison with a similar study (Andrews 2010).

Rattlesnake home ranges were generated in R (R Core Development Team, 2016) using the AdehabitatHR (Calenge 2006), ks (Duong 2007), and tlocoh (Lyons et al. 2013) packages. For kernels, we selected the PLUGIN bandwidth operator because it provided the most realistic and conservative estimates of activity areas. For LoCoH, we used the a-LoCoH function (adaptive LoCoH) because of its improved ability to model home ranges when the distribution of relocations contains both densely and sparsely populated activity areas (Getz et al. 2007).

ROAD AVOIDANCE

The Nelsonville Bypass is a large, high-traffic highway that poses an obvious disturbance to wildlife that encounter it. This disturbance may deter animals from attempting to cross the road, reducing population connectivity and access to resources, but also reducing road mortality. We modified the methods described in Shepard et al. (2008) to evaluate whether rattlesnakes were demonstrating statistical avoidance of the NVBP. We used correlated random walk (CRW) analysis (Kareiva & Shigesada 1983) to model rattlesnake movement paths. We quantified the frequency that simulated movements entered or crossed the highway, and made statistical comparisons between observed and expected crossings based on radio-telemetry observation and simulation results, respectively. We simulated 1,000 random walks (i.e. movement paths) for each individual using the step length and turn angle distributions derived from each individual's observed movement path (example provided in Figure 7-4). Each iteration was rooted to the individual's den site, and the number of steps (i.e. movements per random walk) was determined by counting the number of movements greater than 0 ft. observed throughout the individual's activity season. After movements paths were simulated, we calculated the number of times each simulated path crossed or entered the highway. Thus, for each individual we generated a distribution of road crossings that could be used to make statistical comparisons at the individual and population levels. At the individual level, we calculated avoidance by the determining the probability of sampling a value less than or equal to the observed number of crossings from the individual's crossing distribution. At the population level, we evaluated road avoidance using a one-tailed paired t-test. We used individual-years as replicates, and compared the observed number of crossings in that individual's activity season to the median value from that individual's random crossing distribution. We used the median value of crossings because it is less sensitive to extreme values. We used individual-years (as opposed to individuals) to compensate for the small sample size of telemetered individuals. Two individuals that were tracked in consecutive years were thus used twice, but we feel that minimal bias was introduced from pseudoreplication because of stark variation in movements and habitat use among years for these individuals. Movement path metrics and correlated random walks were generated in GME (Beyer 2015). Crossings were counted in ArcMap (ESRI 2014) and statistical tests were performed in R (R Core Development Team 2016).

CAPTURE-MARK-RECAPTURE SURVEYS

We deployed 12 bi-directional box-funnel traps (Burgdorf et al. 2005) to capture animals diverted along the snake fence. In 2015, we deployed six traps on each side of the highway; traps were spaced 325-975 ft. apart, and targeted areas that were of suitable habitat, and where the fence was most suitable for trapping (i.e. straight sections with minimal damage). On each side of the highway four traps were placed on the forest side of the fence and two traps were placed on the ROW side. In all locations, traps were positioned flush with the ground and against the fence. Because we did not catch rattlesnakes on the south side of the highway in 2015, we moved all 12 box-traps to the north side of the highway in 2016 to maximize rattlesnake captures, with six traps placed on each side of the fence in pairs. We deployed 32 tin cover board piles (Grant et al. 1992) along or adjacent to the snake fence; 16 tin piles were distributed on each side of the highway, with 8 piles on each side of the fence. Due to the sensitivity of this species to persecution and collection, we have intentionally omitted specific trapping locations.

For our capture-mark-recapture surveys, we included all captured species of snakes (excepting leaf-litter snakes e.g. *Carphophis amoenus*, *Diadophis punctatus*) and turtles. We excluded Eastern Fence Lizards (*Sceloporus undulatus*) and leaf-littler snakes from the mark-recapture surveys because the fence is permeable to these species. Snakes and turtles captured were transported to Ohio University where they were marked, measured, and sexed. All animals were released the following day at the location of capture, away from the trap, and on the same side of the fence where captured. Thus, when an individual was recaptured, we could determine whether that individual had been previously captured on the other side of the fence and crossed.

All snakes were marked with a PIT tag (Biomark MiniHPT8 134.2 kHz) that was injected using a MK165 injector with an 18-gauge needle; rattlesnakes also received a scale clip on the dorsal scales using surgical scissors (Brown & Parker, 1976). Scale clipping provided a secondary mark in the event a PIT tag was lost or failed. We collected standard morphometric data on snakes including snout-vent length (i.e. SVL; ± 0.04 in.), tail length (± 0.04 in.), and mass (± 0.04 oz.). Snakes were sexed by probing and rattlesnakes were further examined by counting the caudal scales (often correlated with sex). Turtles were marked with a shell notch on the marginal scutes using a rotary tool following Cagle (1939). All turtles were marked with a minimum of two notches, and no notches were placed on the marginal scutes of the bridge. For turtles, we collected plastron and carapace length (± 0.04 in.), shell height and width (± 0.04 in.), and mass (± 0.04 oz.). Turtles were sexed by examining sexually dimorphic features. In all cases, equipment was sterilized prior to marking each animal.

REPTILE ROAD MORTALITY SURVEYS

We drove the length of the NVBP in both directions 5-7 days/week throughout the rattlesnake activity season. While on the highway, we typically drove in the right lane at reduced speeds (55 mph), and scouted for road kills. We documented all dead reptiles we observed on the NVBP, and recorded species, sex (when possible), age, GPS location, and vehicle lane. Photographs were taken of all reptiles discovered dead on the road ("DOR").

ECOPASSSAGE MONITORING

Each small wildlife crossing was monitored with three Buckeye Game Cameras; a camera was deployed at both entrances, with an additional camera positioned in the middle of the tunnel. Cameras were triggered by movement (passive IR sensor), and photos were reviewed to quantify crossings or other activity within the ecopassages. Photo events were scored as crossings when the same animal was detected at both entrances of an ecopassage. Activity was scored as a potential crossing when an animal was detected at the middle of the tunnel and only one entrance, such that it was impossible to tell where the animal had entered or exited the ecopassage. Animals may have failed to trigger cameras due to their speed or position in the tunnel relative to the sensor. Potential crossings also included events when the duration between observations at both entrances of the tunnel made it unclear as to whether it was the same individual. When animals approached or entered the tunnel, but could not be further classified as a crossing or potential crossing, that event was scored as "entrance activity."

DEFINITIONS

For purposes of clarity within the results, we define the following terms as specified below:

Relocation: A researcher tracks to the location of a snake that had been implanted with a radio transmitter using radio telemetry. The location of the snake is recorded using a GPS and environmental data is recorded on habitat variables at that location.

Recapture: A snake that had been previously marked is captured in a trap or found incidentally without the use of radio telemetry to locate the individual. If a radio-tracked snake is captured in a trap it is considered a recapture. Additionally, if a radio-tracked snake was found without the use of radio telemetry, that was also a recapture. This distinction is important for the collection of demographic data and the estimation of population size.

Translocation: An animal is moved to a new location by the researcher, typically to remove the animal from a threatening environment, such as private property or the road surface.

RESULTS

RADIO TELEMETRY AND HOME RANGE ANALYSES

We captured 17 Timber Rattlesnakes, including adults of both sexes (2♂, 2♀), one juvenile (1♀), and 12 neonates (5♂, 7♀; Table 7-1). We telemetered five rattlesnakes, which included the four adults and one juvenile female large enough to bear a transmitter, generating 419 relocations over the course of the study (163 relocations of four individuals in 2015, and 256 relocations of four individuals in 2016). Of the snakes' radio-tracked, four occurred within the range of rattlesnake mitigation structures, and one was captured east of the Dorr Run interchange beyond the snake fencing. Three of the adult rattlesnakes were initially captured within the ROW, including two individuals that had bypassed the snake fence. All five telemetered rattlesnakes crossed between the forest and ROW habitats despite four of the snakes occurring where the snake fence was present (Figures 7-1 and 7-2). In total, we observed 20 fence crossings by telemetered rattlesnakes (Table 7-2). Despite the snake fence being a permeable barrier, no telemetered rattlesnakes were killed on the road, nor did we observe road related injuries. We did not observe rattlesnakes cross or attempt to cross the road directly or by way of the ecopassages, suggesting that rattlesnake movements were bounded by the roadway. On two occasions the same female moved to private land adjacent to the WNF. Because the landowner is a suspected rattlesnake poacher and is hostile to researchers, OH-DNR Wildlife Officers escorted researchers onto the property to translocate the snake back to public land. Although we recorded the locations of where we translocated the snake, the non-natural step lengths associated with translocations were omitted from the CRW analysis to ensure that simulations modeled only "natural" movements.

We generated 100% MCP home ranges for all individuals and for each year they were tracked (i.e. individual-years; Figures 7-5 and 7-6), and generated kernel and LoCoH home ranges (50% and 95%) for individual-years with complete or mostly complete activity seasons (6 of 8 rattlesnakes; due to the sensitivity of rattlesnakes to persecution and the accessibility of the study site, we have intentionally omitted figures specifying KDE and LoCoH home ranges). MCP area ranged from 8.9 to 63.5 acres and maximum length ranged from 1,000 to 3,075 ft. (Table 7-2). All MCP home ranges included both forest and ROW habitats, and were bounded by the highway (Figures 7-5 and 7-6). None of the rattlesnakes had individual home range lengths exceeding the length of the snake fence, but one individual dispersed beyond the extent of the snake fence, and another individual's home range was completely outside the extent of the snake fence. 95% Kernel home ranges over-predicted activity areas to include the roadway for 5 of 6 individual-years. While we did not observe rattlesnakes enter or cross the road, this statistic reflects that enough activity (i.e. relocations) occurred in close proximity to the NVBP such that even the most conservative kernel estimators predicted those areas to occur within the utilization distributions. 95% LoCoH home ranges identified the NVBP as a boundary and ranged in size from 4.4 to 39.3 acres. Five of six 50% kernels and four of six 50% LoCoH home ranges overlapped with ROW habitats, indicating that the ROW was a substantial components of core activity areas. Kernels produced more biologically realistic core (50%) home ranges compared with LoCoH. For example, a gravid female showed 90.7% overlap between her core home range and the ROW using kernels, but only 35.6% overlap using LoCoH despite 71.6% of her relocations occurring within the ROW (Table 2).

While male and non-gravid female rattlesnakes spent most of their time within the forest habitats (2.8 – 33.3% relocations within ROW), gravid females spent nearly all of their time within the ROW habitats until giving birth (85.4 – 95.2% relocations within the ROW when excluding post-parturition relocations; 65.1– 72.7% relocations within ROW when including relocations between parturition and hibernation). The road cut on the north side of the bypass created large south-facing rock escarpments exposed to full sunlight. Additionally, the ROW also contains large stone piles (i.e. riprap) that were installed as drainage control structures (Figure 7-7). The road-cuts and stone riprap created thermal and structural habitats preferred by gravid females, providing warm temperatures to facilitate embryonic development and refuge from predators. Habitat use was not restricted to rocky areas, as gravid and non-gravid snakes sometimes used grassy habitats and early successional scrub within the ROW (Figure 7-7). Non-gravid rattlesnakes traveled to ROW habitats intermittently to shed, thermoregulate after surgery, or to forage or search for mates. Most of the activity within the ROW occurred near the forest edge, especially for non-gravid rattlesnakes that rarely traveled more than 32.8-49.2 feet beyond the forest line. Gravid females were more willing to travel beyond the forest edge, far into the ROW, but they too were more active near the edge than away from it. These findings suggest that important habitats were generated within the ROW, often on the wrong side of the fence, and likely motivated fence crossings.

In 2015, we also tracked four (2♂, 2♀) Black Racers (*Coluber constrictor*) and one (♀) Copperhead (*Agkistrodon contortrix*). Surgical implantation and tracking followed the same procedures described for rattlesnakes, but these snakes were tracked less frequently than rattlesnakes. Three of the four racers were captured on the south side of the bypass, and two of those made long distance movements along the snake fence until eventually finding breaches, or reaching the end of the fence. These animals then spent extensive time foraging in road side fields and basked in open habitats when they needed to shed. One individual was relocated in a bush growing along the fence, and the snake could be observed resting in an arboreal position intertwined with the wildlife fence. On another occasion, when chasing an incidental Black Racer along the snake fence, the individual attempted to evade capture by climbing a bush of multiflora rose, and from there climbing to the top of the wildlife fence. The Copperhead we tracked was a gravid female that used the large stone pile in the ROW as a gestation site. In 2016, another Copperhead was discovered using a basking site on a road cut that was used by a gravid Timber Rattlesnake in the previous year.

ROAD AVIODANCE - CORRELATED RANDOM WALK

We performed CRW analyses for 6 individual-years (Table 7-3). We did not observe significant avoidance at the individual level, owing to the many potential movement paths that can avoid a single linear barrier (Figure 7-8). We did detect significant avoidance at the population level (*one-tailed paired t-test*, $t = 2.44$, $df = 5$, $P = 0.029$), which suggests that we should have observed a road crossing or road mortality event if rattlesnake were moving randomly with respect to the road.

CAPTURE-MARK-RECAPTURE

We monitored box traps for 3,696 traps nights, sampled 1,824 coverboard flips, and spent approximately 2,900 person hours in the field at the study site. We captured 223 reptiles (7 species of snakes, 1 species of turtle; Table 7-4) when excluding leaf litter snakes (42 *Diadophis punctatus* and 2 *Carphophis amoenus*) and Eastern Fence Lizards (55 *Sceloporus undulatus*), which were excluded from of our mark-recapture survey. Many of the reptiles detected were observed in ROW habitats; When including species that were only detected as road mortalities (Snapping Turtles and Painted Turtles) and species that were not marked (i.e. leaf litter snakes, fence lizards), we documented a total of 12 species of reptiles within the ROW. Eastern Fence Lizards were captured commonly on both sides of the fence, typically in canopy gaps. Leaf litter snakes also were captured on both sides of the fence, but usually only in areas with intact overstory and near the forest edge. We also captured 87 amphibians (9 species), 232 mammals (12+ species), and 26 birds (6+ species) as bycatch, and these species were released upon capture.

In total, we marked 174 individual reptiles across 8 species. We recaptured 18 snakes of 5 species, and identified snake fence crossings in Garter Snakes (*Thamnophis sirtalis*), Eastern Milk Snakes (*Lampropeltis triangulum*), and Black Racers (*Coluber constrictor*) (Table 7-5). We marked 45 individual Box Turtles (*Terrapene carolina*), 35 of which were in the rattlesnake mitigation treatment area. Within the treatment area we had 11 recaptures of 7 individual Box Turtles, and documented 1 fence crossing. Combined, this revealed 4 snake fence crossings to the forest side, and 3 crossings to the ROW side. In stark contrast to radio telemetry, which detected 20 fence crossings by Timber Rattlesnakes, we recaptured two rattlesnakes using traps over the course of the project and detected only one fence crossing.

REPTILE ROAD MORTALITY

We did not observe rattlesnake road mortality on the bypass, but 24 reptiles of 8 species were found “dead on the road” (DOR) (Table 7-6). We also captured and translocated two Box Turtles actively crossing the bypass. We moved the live turtles across the road, but we included them in our analyses because they identified crossing locations and we assumed a low probability of surviving without human intervention. Overall, five crossing locations were within 1 mi. of snake fencing, and 21 crossing locations were in the 7.6 mi. section of the NVBP without snake fencing (Tables 7-6 and 7-7, Figures 7-9 and 7-10). Two of the mortalities were within approximately 328 feet of the end of the fence, and it is possible that these individuals walked around the fence to enter the roadway. Of the 26 reptiles found on the road, 14 were Box Turtles (*Terrapene Carolina;* 54% of reptile road mortality), and 13 of these occurred in areas without snake fencing. While box turtles appeared to have lower road mortality rates within the mitigation zone (0.625 DOR/km in mitigated versus 1.083 DOR/km unmitigated areas), across all reptiles, DOR locations were found in higher density in the mitigation area (3.125 DOR/km in mitigated versus 1.75 DOR/km unmitigated areas). It should also be noted that overall reptile mortality rates on the bypass appeared low (1.91 DOR/km).

ECOPASSAGE MONITORING

We detected 38 species of vertebrates at the small wildlife ecopassages (Tables 7-8 and 7-9), but did not observe any reptiles (nor amphibians) complete crossings. Activity and crossings were dominated by mammals- especially Mice (*Peromyscus spp.*), Eastern Chipmunks (*Tamias striatus*), Raccoons (*Procyon lotor*), Virginia Opossums (*Didelphis virginiana*), and rabbits (*Sylvilagus floridanus*). We also detected activity of larger mesopredators including Bobcat (*Lynx rufus*), Coyote (*Canis latrans*), Red Fox (*Vulpes vulpes*), Gray Fox (*Urocyon cinereoargenteus*), and American Mink (*Neovison vison*). Across all forms of activity, we recorded 2,563 events in SWE1 (ecopassage with snake-fencing) and 2,647 events in SWE2 (ecopassage without snake-fencing). While this initially suggests that the exclusion fence failed to redirect wildlife to crossings, it should be noted that 57% of the activity at SWE2 was by *Peromyscus*, compared to only 27% at SWE1. When excluding *Peromyscus*, we observed 1,853 events at SWE1, and 1,229 events at SWE2. We observed 667 crossings (17 species) through SWE1 and 276 crossings (13 species) through SWE2, suggesting that the snake fence redirected animals to the ecopassage and facilitated crossing; this finding was consistent when including potential crossings (i.e. crossings + potential crossings; SWE1 = 1134, SWE2 = 813).

DISCUSSION

OBJECTIVE 1: IMPACTS OF THE NESLONVILLE BYPASS ON TIMBER RATTLESNAKES

Two field seasons have not provided us with enough data to statistically estimate the rattlesnake population size or make long term population projections. Given our sampling effort, capturing only five adult and sub-adult rattlesnakes (and recapturing two of them) indicates that the subpopulation adjacent to the Nelsonville Bypass is small. However, our observations of rattlesnakes at seemingly disjunct locations along the bypass suggests that rattlesnakes may be spread diffusely across the Athens Unit of WNF and within proximity to the NVBP. We observed reproduction in both years of the study, which suggests that this population may have the capacity to persist in the long-term if adult mortality remains low. A 12-year study of rattlesnakes in eastern West Virginia saw the number of gravid females vary between one and 13 among years (Martin, 2001), and our study may reflect years in which reproduction was relatively low. An alternative scenario is that the population could be in an extinction debt. We documented the death of one juvenile female that was killed by a predator in the second year of tracking, and we have yet to recapture a marked neonate (but this may be expected given the study duration). Unfortunately, gathering rigorous *C. horridus* population data in this region is challenged by their use of satellite dens with small population sizes. Ultimately, the fate of the population will likely depend upon metapopulation dynamics among satellite dens within WNF, maintaining low adult mortality, and habitat management that facilitates successful reproduction.

All rattlesnakes were found on the westbound (north) side of the bypass, but we cannot be sure if a subpopulation on the eastbound (south) side of the bypass was extirpated, or if their apparent absence was due to a lower encounter probability on that side of the highway. Rattlesnakes may have been more difficult to detect on the southern side of the NVBP because favorable habitats (south facing slopes and ridge tops) are found primarily on the south side of the patch, away from the bypass and closer to Old U.S. 33 (Haydenville Road). Although we visually surveyed much of this forest, our trapping efforts were concentrated along the snake exclusion fence, which is on the northern side of the forest patch and away from the preferred habitat. Historically, there were at least two rattlesnake observations from this forest patch. A rattlesnake was tracked on the Athens-Hocking Reclamation Center years before the construction of the bypass (Doug Wynn, pers. comm.), and another rattlesnake was observed south of the bypass during construction near the location where the rattlesnake ecopassage was installed (Mike Austin, pers. comm.). While it is possible that populations persist on the south side of the NVBP, it is unlikely that there will be gene flow among hibernacula separated by the NVBP if rattlesnakes are unwilling to use the ecopassages. Assuming there was dispersal across the landscape prior to construction, this isolation will disrupt metapopulation processes and gene flow, render subpopulations as functionally independent units, and exacerbate vulnerability of these populations to the demographic and genetic consequences of small population size.

The NVBP Timber Rattlesnakes exhibit smaller home ranges relative to other populations (Reinert & Zappalorti,1998; Reinert, 1999; Sealy, 2002; Adams, 2005; Waldron et al. 2006; Anderson, 2010; Andrews, 2010). Andrews (2010) found that Timber Rattlesnakes had larger foraging ranges in parts of a landscape undergoing residential and recreational development compared to less disturbed areas; she suggested that snakes may have been traveling greater distances in pursuit of food resources. Following that logic, small home ranges at the NVBP suggest that the bypass did not compromise prey availability. However, there are competing explanations for these small home ranges at the NVBP. Naturally occurring, large canopy gaps are uncommon in forest habitat at the study site, and the ROW may have created basking sites closer to dens than were previously available on the landscape, reducing the need to travel long distance for thermoregulation. The summer of 2015 was unusually cool and wet, and in that year, all four telemetered rattlesnakes moved to the forest edge and ROW habitats when shedding. The thermal opportunities provided by the ROW are most important for gravid females that maintain higher body temperatures (Gardner-Santana & Beaupre 2009) and are encumbered by reduced locomotor performance throughout pregnancy (Seigel et al. 1987). Gravid females used habitats within the ROW extensively for gestation during both years of the study, and ROW habitats made up the majority of their 50% kernel home ranges (64.9 – 90.7 % overlap with ROW for gravid snakes compared with 0 – 12.5 % overlap for non-gravid snakes). The NVBP appears to have increased the availability of high quality basking habitat. The proximity of these habitats to dens also reduces exposure to predators by providing both shorter commutes to these resources as well as structural refuge. Thus, the ROW may have modified habitat in some ways that benefit the local rattlesnake population. However, these benefits are contingent on ROW habitats not increasing mortality rates. If rattlesnakes are attracted to the ROW and are subsequently killed by vehicles, humans, or other predators, then these features would function as an ecological trap.

OBJECTIVE 2: EFFECTIVENESS OF THE RATTLESNAKE FENCE

All individual home ranges had shorter maximum lengths than the span of the snake fence indicating that the fence may be adequate in extent for a small, geographically isolated population. However, we discovered rattlesnakes distributed beyond the extent of the snake fencing, indicating that the fencing coverage was not sufficient for excluding rattlesnakes at the population level. Telemetry and mark recapture both revealed that rattlesnakes and other reptiles can cross the snake fence, but telemetry was far more effective for answering this question. The snake fencing suffered damage from washouts on steep slopes, corrosion in areas with acidic soils, overgrowth, and tree falls that knocked down fence (Figure 7-11). Rattlesnakes and other reptiles were able to exploit these gaps in the fence to access the ROW. Timber Rattlesnakes are also capable of climbing into trees (Coupe, 2001; Rudolph et al. 2004; this study), and rattlesnakes could have potentially climbed over the fence in areas where woody vegetation and tree falls occurred along the fence. Laidig & Golden (2004) studied a population of Timber Rattlesnakes adjacent to a residential development in New Jersey where a similar fence-ecopassage system was installed to keep rattlesnakes away from the development and allow dispersal across roadways. This fence was also built from 1/4 in. stainless steel hardware cloth, stood 3 ft. tall, was buried 6 in. beneath the surface, and extended 1.7 mi. As in our study, rattlesnakes traveled along the fence line until either finding a breach or reaching the end of the fence, and ultimately the fence did not prevent rattlesnakes from entering the development. The exclusion zone included core activity areas for several of the snakes, including gestation sites contributing to the snakes' motivation to trespass. This suggests that even if the NVBP snake fence was intact, it would need to be extended to exclude rattlesnakes from ROW habitats. However, if maintaining access to critical habitats is an important criterion for mitigating the impact of roadways, then the snake fence may have been placed in the wrong location. The snake fencing should prevent access to the road, but not deter access to ROW habitats that are providing high quality basking sites.

Reptile road mortality rates on the NVBP did not provide a large enough sample size to perform robust statistical comparisons among sections of the highway. The driving speed for the road surveys compromised our ability to detect small carcasses, but likely did not affect our ability to detect rattlesnakes or other large reptiles that died on the road. Turtle carcasses were often found in the right shoulder, and usually persisted on the road for days to weeks following mortality. A study of a highway in Florida (four-lane, 20,000+ vehicles/day) found that 95% of 343 DOR turtles were killed in the road shoulder and the remaining 5% were killed in the first two travels lanes (Aresco, 2005). While carcass detection in travel lanes may be lower, as those carcasses are likely destroyed more rapidly by vehicles, our findings are consistent with the distribution of carcasses in Aresco (2005), who surveyed roads 2-4 times daily. Carcass detection could have been reduced by animals that left the road after being struck (see Adams, 2005; Row et al. 2007). Independent components of our fieldwork required that we routinely walk sections of the NVBP berm, meaning that we inadvertently surveyed sections of the road on foot. This activity led to the detection of two carcasses (*L. triangulum* and *T. sirtalis*) during our study. While these findings support other studies that have demonstrated the superiority of pedestrian surveys for detecting small carcasses (e.g. Enge & Wood 2002), they do not suggest that substantial road mortality was missed.

While the number of DOR reptiles on the NVBP is low in context of other studies (see Andrews et al. 2008), these numbers cannot be immediately dismissed as unimportant. We found that Box Turtles (*T. carolina*) experienced the most road mortality (of reptiles) at the NVBP. Of the 10 turtles that could be sexed 3 were female, and at least one of these was gravid. While 7.5 Box Turtles per year may seem insignificant, this number must be considered in context of the population size and its demographic structure. Box Turtles have a bet hedging life history, making their populations sensitive to additive adult mortality (Congdon et al, 1994). Determining the proportion of the Box Turtle population being killed on the bypass annually will be necessary to understand these impacts and warrants further study.

The distribution of animal crossing locations is likely influenced by factors that influence animal movements across landscapes, including the relative locations of habitats (Langen et al. 2012), topography, site history, and position of the road (upslope/downslope) (Clevenger et al. 2003). Factors promoting road mortality may also be species-, sex-, and age class-specific (e.g. Jochimsen et al. 2014). Most studies reporting high reptile mortality are from sites adjacent to aquatic habitats (e.g. Bernardino & Dalrymple 1992; Dodd et al. 2004; Aresco, 2005), whereas the U.S. 33 portion of the NVBP is bordered by forested habitats and fields. Comparisons of road mortality between treatment areas with low sample sizes could lead to spurious conclusions about the effectiveness of these measures. Even within landscapes, any given location has a suite of landform and habitat covariates that influence habitat use and movement. For this reason, reliable control treatments are difficult to obtain outside of "Before-After-Control-Impact" study designs.

Road mortality prior to the start of the study could have depressed local populations and thus led to low rates of reptile road mortality observed on the bypass (Eberhardt et al. 2013). Individuals with home ranges bisected by roads are likely the first victims of road mortality. Even if NVBP reptile road mortality rates are naturally low, it is still important to ensure that mitigation structures are functional, as several of the species impacted by road mortality are demographically sensitive to additive mortality (e.g. Row et al. 2007), and because sites with good habitat and low road mortality may make suitable locations for population recovery (Eberhardt et al. 2013).

An alternative explanation for low observed road mortality is that many animals actively avoided the bypass. Rattlesnakes in our study did not cross the NVBP despite approaching within 16 ft. of the road, and analyses of road avoidance at the population level support that rattlesnakes were avoiding the roadway. Andrews and Gibbons (2005) found that Timber Rattlesnakes often balked during experimental trials of road crossing behavior. Brehme et al. (2013) examined the road avoidance of lizards and small mammals on three different road types: unpaved, secondary paved road, and two-lane highway. The authors found that the largest road examined, the two-lane highway, was the most avoided by all species, speculating that traffic volume, road vibrations, and noise could all be deterrents against crossing. By comparison, the NVBP is twice the size of the largest road examined in Brehme et al. (2013), and thus it seems reasonable that rattlesnakes and other animals could perceive the highway as a threatening environment that is to be avoided.

OBJECTIVE 3: EFFECTIVENESS OF THE SMALL WILDLIFE ECOPASSAGES

No rattlesnakes were observed using the ecopassages by either cameras or radio telemetry. Because rattlesnakes are ectotherms and their body temperatures are often similar to ambient conditions, it is possible that rattlesnakes failed to trigger the passive infrared sensors. However, we find this to be unlikely for multiple reasons. First, rattlesnakes' large body size confers thermal inertia, causing their body temperature to lag behind environmental temperatures. Second, the cameras detected many of the common reptiles at the study site, including Box Turtles, Black Racers, Garter Snakes, Northern Ring-necked Snakes, an Eastern Fence Lizard, and other small ectotherms, including a toad and multiple insects (data not shown for insects). Additionally, the cameras captured thousands of images of vegetation swaying at the entrance on windy days. While it is possible that rattlesnakes did not trigger the sensor because of the narrow field of detection (~10º), any undetected animal completing a crossing would have had to bypass three cameras.

Rattlesnakes may not have used the ecopassage for a combination of reasons. First, because the population is small, it is unlikely that many individuals encountered the ecopassage during our two-year study. Radio telemetry revealed that one rattlesnake passed near (< 10 ft.) the SWE1 entrance, but most individuals may remain unaware of the ecopassage. Alternatively, the habitat on the northern side of the highway may be meeting their ecological needs and crossing through the tunnel could pose an unnecessary risk. The ecopassages were used extensively by mammalian mesopredators, including Raccoons, Virginia Opossums, American Mink, Striped Skunk, Foxes, and occasionally Coyotes. Many mammalian mesopredators prey on young rattlesnakes, and adult rattlesnakes may still recognize these species as a threat. Rattlesnakes have acute olfactory perception, and may recognize that ecopassages are used by potential predators, discouraging use by rattlesnakes. Raccoons sometimes made repeated passes of the ecopassages, and perhaps incorporated ecopassages in foraging routes. However, there was only limited evidence of predation within the ecopassages. Some photos suggested that Weasels, Raccoons, American Mink, and potentially a Coyote, all caught prey within or near the ecopassages, but not with the regularity that would suggest the formation of an active prey trap. Despite the high volume of Mice and other small mammals using the ecopassages, there was no evidence of rattlesnakes foraging within or at the mouth of ecopassages.

Design of the ecopassages at the NVBP could have deterred their use by reptiles. The small wildlife ecopassages were not constructed to current design specifications recommended for reptiles and amphibians (Clevenger & Huijser 2011, Ontario Ministry of Natural Resources and Forestry 2016), which became available after the design and construction of the NVBP. Current best management practices (BMPs) state that herpetofauna passages require exclusion fencing to direct these species to the structures. At the NVBP, the southern entrance of SWE1 protrudes from a slope and sits away from the snake fence and some wildlife travelling along the fence can pass overtop the ecopassage rather than being led to it. The absence of snake fencing altogether at SWE2 fails to provide any mechanism to direct herpetofauna to the passage. Rectangular or square box culverts are recommended over circular culverts because vertical walls better facilitate the movement of amphibians and reptiles through a tunnel, and steel is not a desirable material for circular culverts because of its high thermal conductivity and coldness during the spring migratory periods. Most importantly, BMPs recommend that the tunnel width should scale with tunnel length. Clevenger and Huijser (2011) recommend that tunnels 165-200 ft. length should be no less than 8 ft. in diameter for circular culverts (or 7.5 ft. width x 6 ft. height for rectangular culverts). However, the most recent BMP publications recommend nothing smaller than an underpass for highways of similar width to the NVBP (Ontario Ministry of Natural Resources and Forestry 2016). Underpasses and wider tunnels would allow for more lighting and airflow compared to the 4 ft. diameter tunnels along the NVBP. Finally, Clevenger recommends that the maximum distance between herpetofauna crossing structures should be 150ft. (but 200 ft. could be used if guiding walls or fencing are funnel-shaped to guide movements). In comparison at the NVBP, the nearest crossing structure to the SW1 is 1.4 mi. west (gas line ROW underpass, i.e. "butterfly bridge"). Laidig & Golden (2004) observed two

Timber Rattlesnakes using crossing structures in New Jersey, but the culvert design and placement were different than the NVBP system. The New Jersey site featured 5 culverts spaced at 300 ft. intervals. These crossing structures were rectangular in dimensions and smaller than those used at the NVBP (3 ft. width x 1.5 ft. height), but bridged a much shorter distance (50 ft. length) compared with the round wildlife ecopassages of the NVBP (170 ft. length). Unfortunately, the recommendations of Clevenger and Huijser (2011) and the Ontario Ministry of Natural Resources and Forestry (2016) were unavailable at the time of planning and construction of the NVBP. While the failure of these structures for herpetofauna may seem regrettable, there are at least two silver linings: the first is that our findings reaffirm that crossing structures of this size are not adequate for herpetofauna passages mitigating large highways; the second is that these structures were successful for many mammals.

RECOMMENDATIONS

1. Snake and other wildlife exclusion fencing should be built near the roadway, avoid steep terrain, and maintain sufficient distance from the tree line. Fencing closer to the roadway would allow wildlife unrestricted access to valuable habitat within the ROW, and allow easier and likely less expensive maintenance of the fence. Placing the fence in areas with stable soils and avoiding steep slopes would reduce washouts created by erosion. Because trees and limbs inevitably fall, fencing should also be constructed away from the forest edge when possible.
2. Future snake fencing should be extended to span a distance sufficient to protect rattlesnakes and other reptiles along the bypass. Even in the absence of structural failures, the current extent of the snake fence does not cover the full extent of the local rattlesnake population. Furthermore, species such as Box Turtles which had reduced mortality in the snake fence mitigation zone would benefit from fencing the entire length of the NVBP.
3. Fencing should be built using materials with high longevity to improve function and reduce costs of maintenance (e.g. Stainless steel instead of galvanized wire).
4. Drainage culverts spanning the highway should be integrated into the exclusion fence system, provided they are safe for wildlife use and would not interfere with their function.
5. If new snake fencing is installed, the existing snake fencing should be removed from the base of the wildlife fence, as it is deterring movement between important habitats and is a source of mortality for Box Turtles where the two fences are conjoined.
6. Future design and implementation of herpetofauna crossing structures should reference the most up to date BMPs and guidelines available, which have become more readily available since the construction of the NVBP (e.g. *Best Management Practices for Mitigating the Effects of Roads on Amphibians and Reptile Species at Risk in Ontario*, Ontario Ministry of Natural Resources and Forestry, 2016; *Wildlife Crossing Structure Handbook*, Clevenger & Huijser, 2011).
7. Avoid mowing of the ROW during the reptile activity season, as Timber Rattlesnakes, Black Racers, and Box Turtles were all observed using grassy roadside habitats within the ROW. The rattlesnake activity period generally ranges from April-October, though other reptiles begin activity as early as February or March depending on the weather. Most rattlesnake activity within the ROW occurred in the summer months, from June through August, and mowing during this period would pose the greatest risk for conflict.

8. Avoid tree planting at the NVBP to revegetate the ROW. Succession of forest habitats via these activities would shift the forest line and edge habitats closer to the roadway, increasing the likelihood that a snake would venture onto the bypass. However, this recommendation comes with trade-offs. Seeding the ROW with native flora is likely important to curbing the spread of invasive species and controlling erosion. As a compromise, it may be optimal to maintain grassland and early successional habitats along the ROW.
9. Introduce habitat heterogeneity in the surrounding landscape within the WNF as a mitigation technique. Reptiles seek out canopy gaps to thermoregulate in forested landscapes and will often travel to habitat edges created by roads and other development. Providing patches of open canopy habitat within the WNF may shift habitat use away from the road. Sites with similar thermal properties but less human disturbance may be preferred. For example, access roads that will be decommissioned following construction could make suitable locations to leave open. Stone piles could also be installed at these sites to create high quality gestation sites outside of the ROW. However, this technique should not be implemented without careful consideration of the surrounding landscape and other species that may be harmed by such habitat modification.
10. Maintaining a speed of at least 55 mph for the road mortality surveys was requested by ODOT for liability and safety reasons. We recommend that future road surveys be allowed to drive at further reduced speeds, and allow travel along the road shoulder. Conducting road mortality surveys at slower speeds would have helped to identify road mortality.

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APPENDIX 1: FIGURES

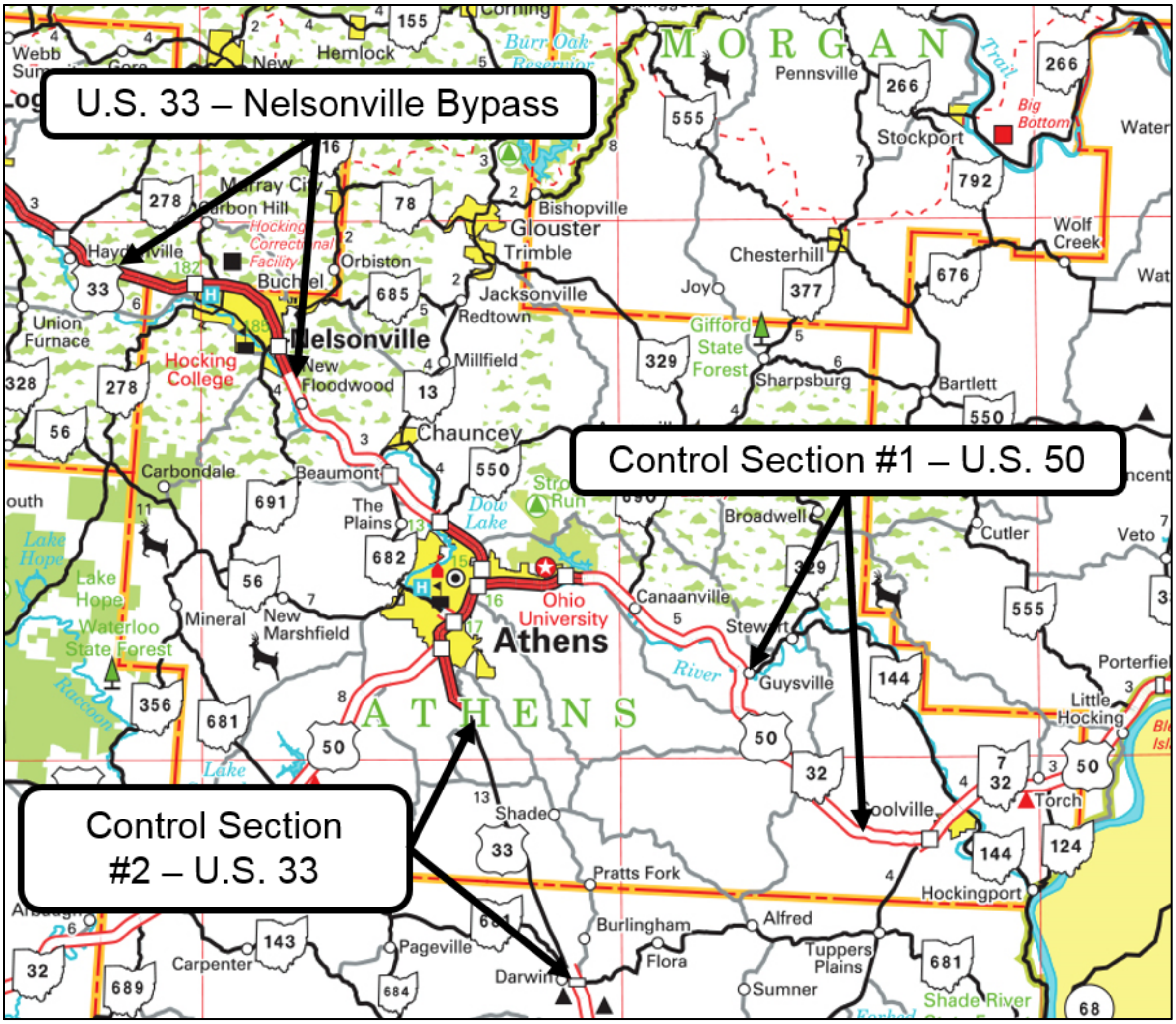


Figure ES-1. Map identifying the location of the U.S. 33 Nelsonville Bypass, Athens and Hocking Counties, Ohio and the two control sections: on U.S. 50 (Control Section #1) and on U.S. 33 (Control Section #2). These sections were surveyed on a regular basis from a vehicle for the presence of roadkill.

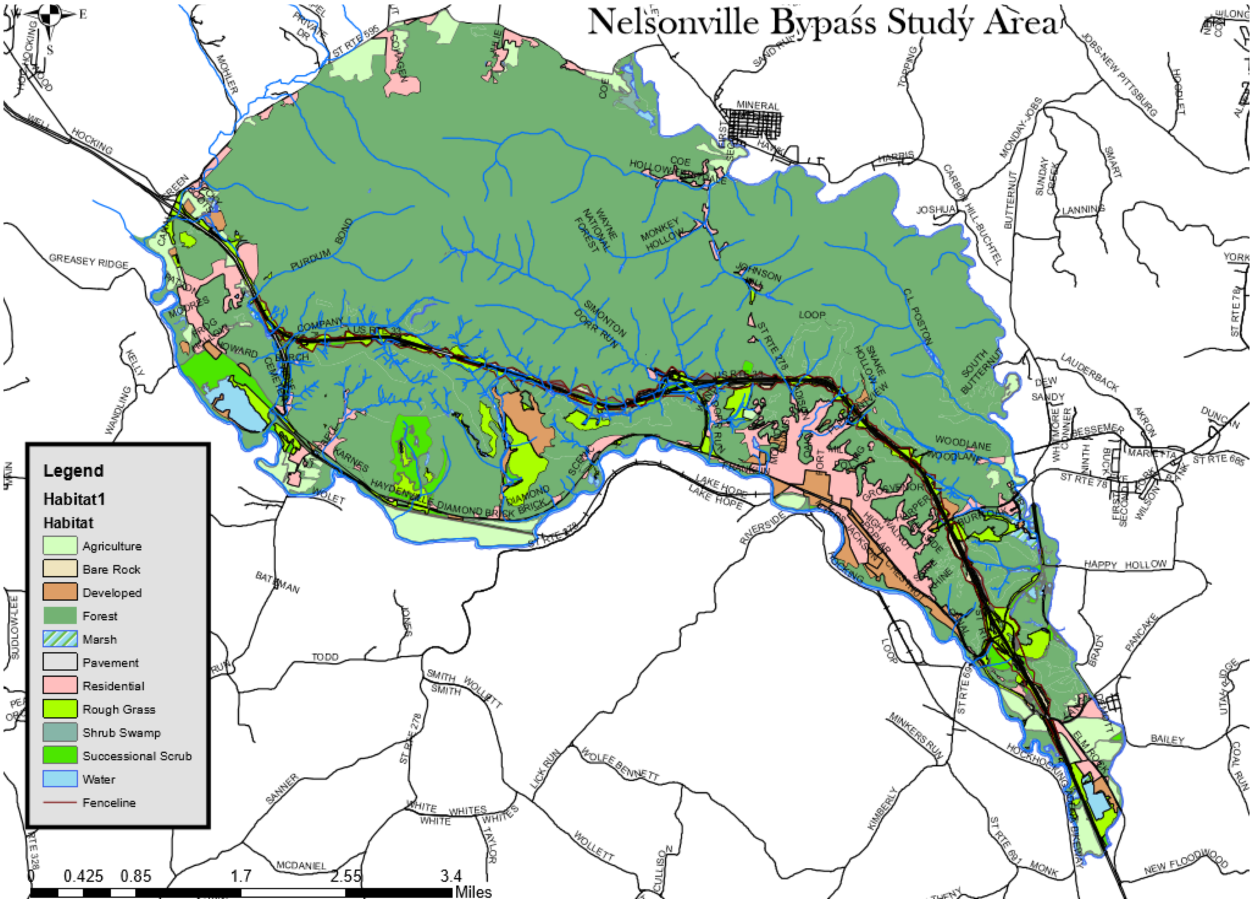


Figure 2-1. Habitat map encompassing the U.S. 33 Nelsonville Bypass, adjoining Wayne National Forest, and the Hocking River flood plain, including the town of Nelsonville, Ohio.

Figure 2-2. Map of the area within the U.S. 33 Nelsonville Bypass right-of-way (ROW). Road segments 1-11 are labeled and color coded. The map also depicts the locations of the one-way jump out mitigation structures (red dots) and fence gaps (blue plus signs).

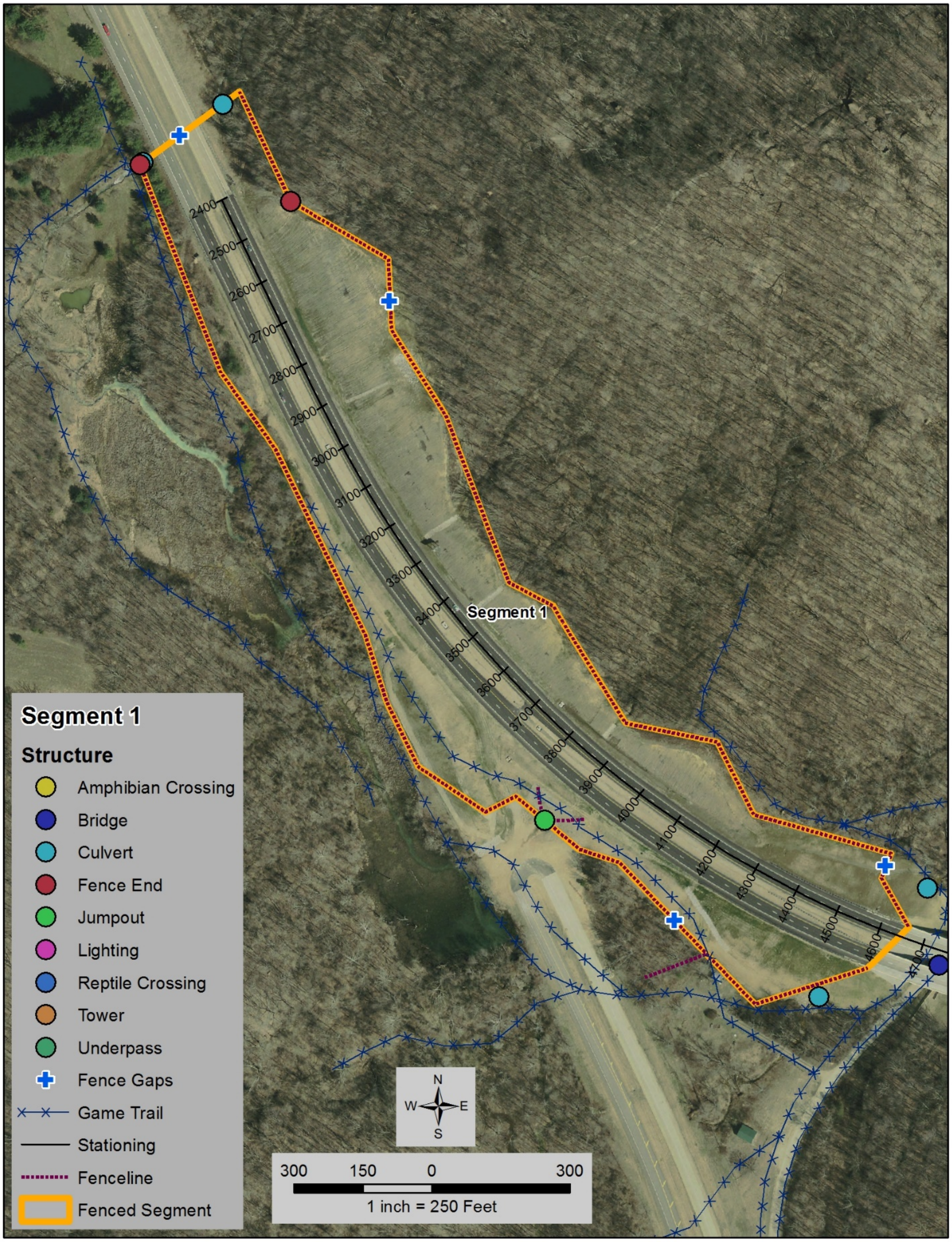


Figure 2-3. Section 1 of the U.S. 33 Nelsonville Bypass right-of-way, from the Company Road bridge to the western end of the bypass as identified by the end of the construction area.

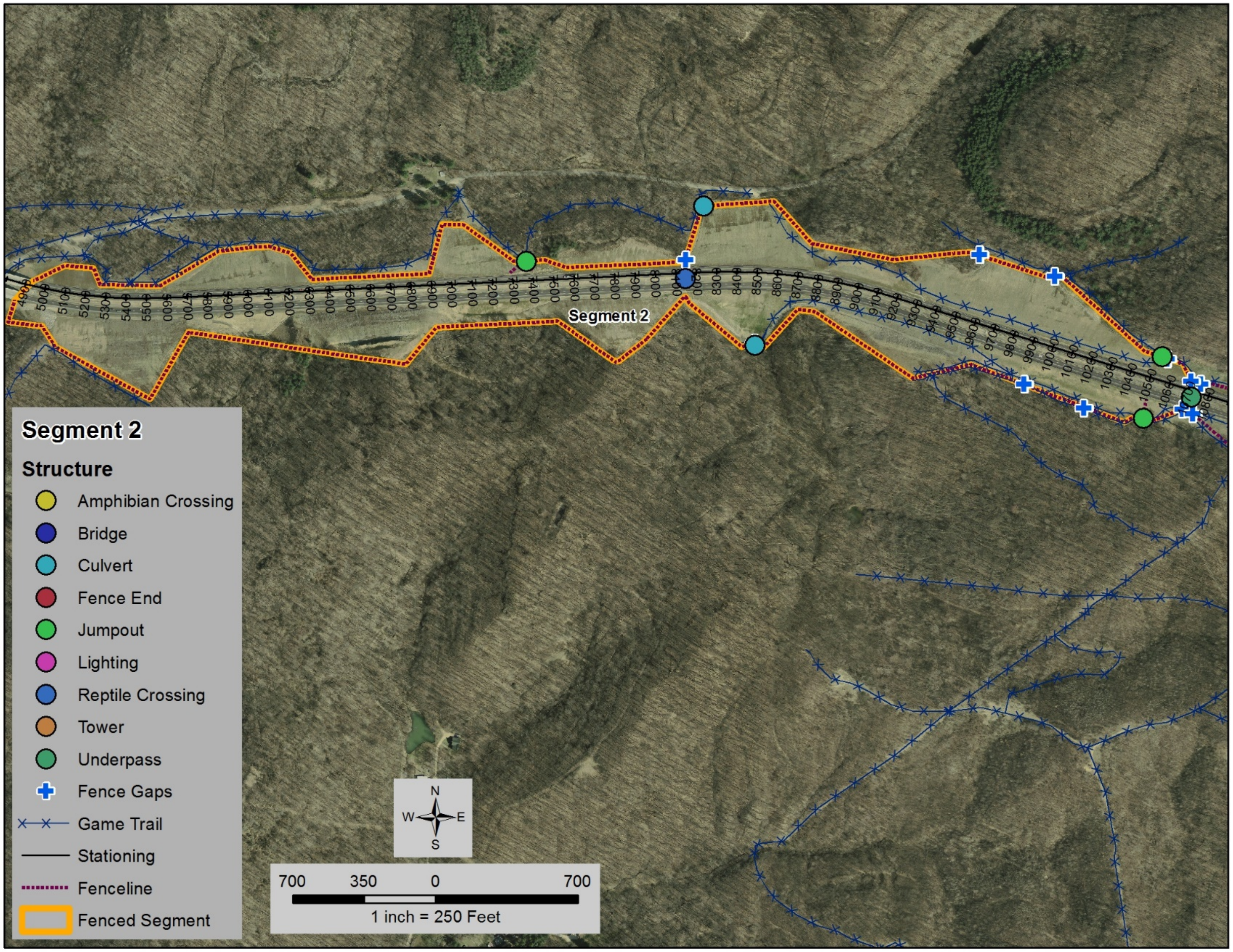


Figure 2-4. Section 2 of the U.S. 33 Nelsonville Bypass right-of-way, from the Company Road bridge to the Off-road Vehicle bridge (also known as the Wildlife Underpass 1 bridge).

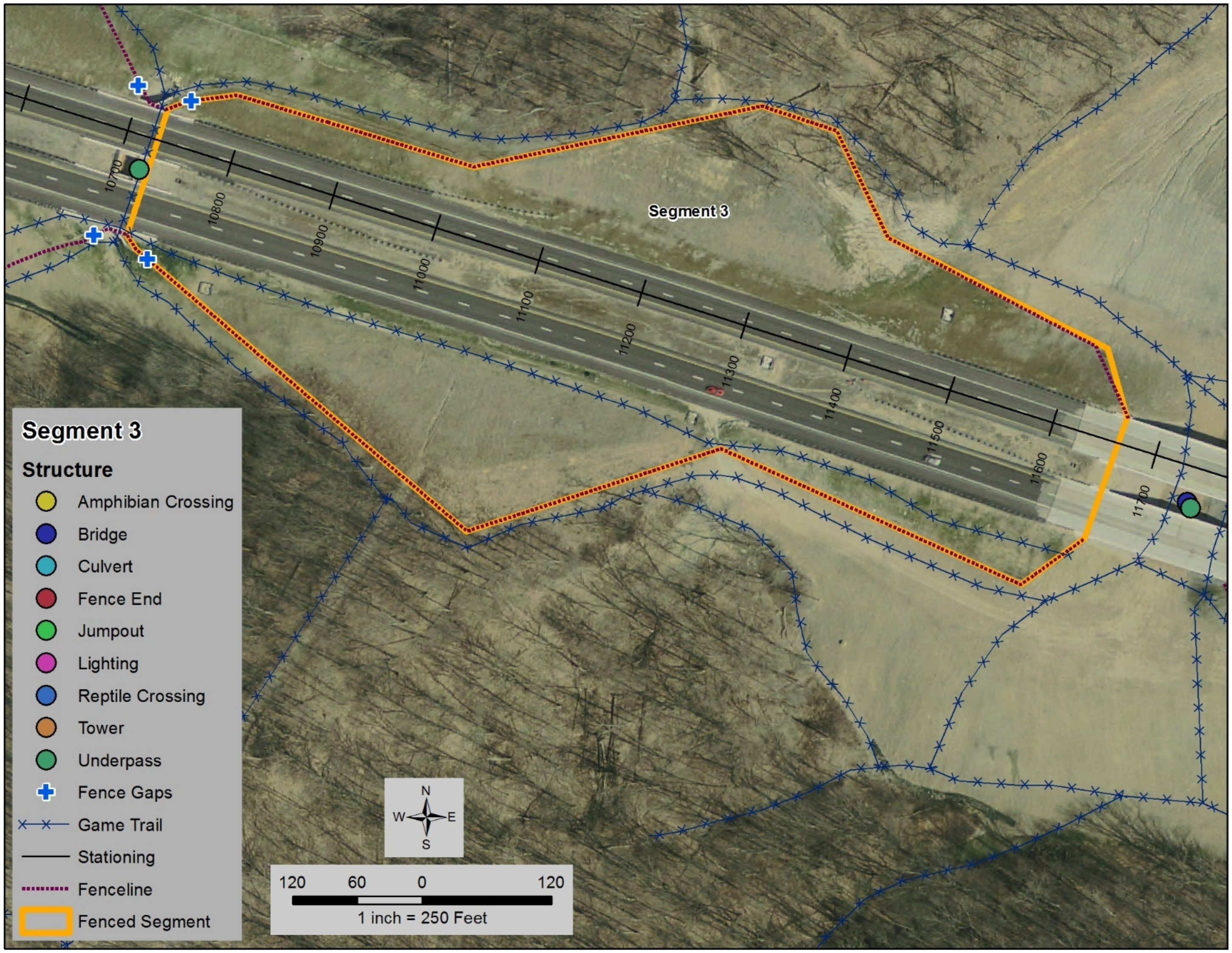


Figure 2-5. Section 3 of the U.S. 33 Nelsonville Bypass right-of-way, from the Butterfly Bridge to the Off-road Vehicle Bridge (also known as the Wildlife Underpass 1 bridge).

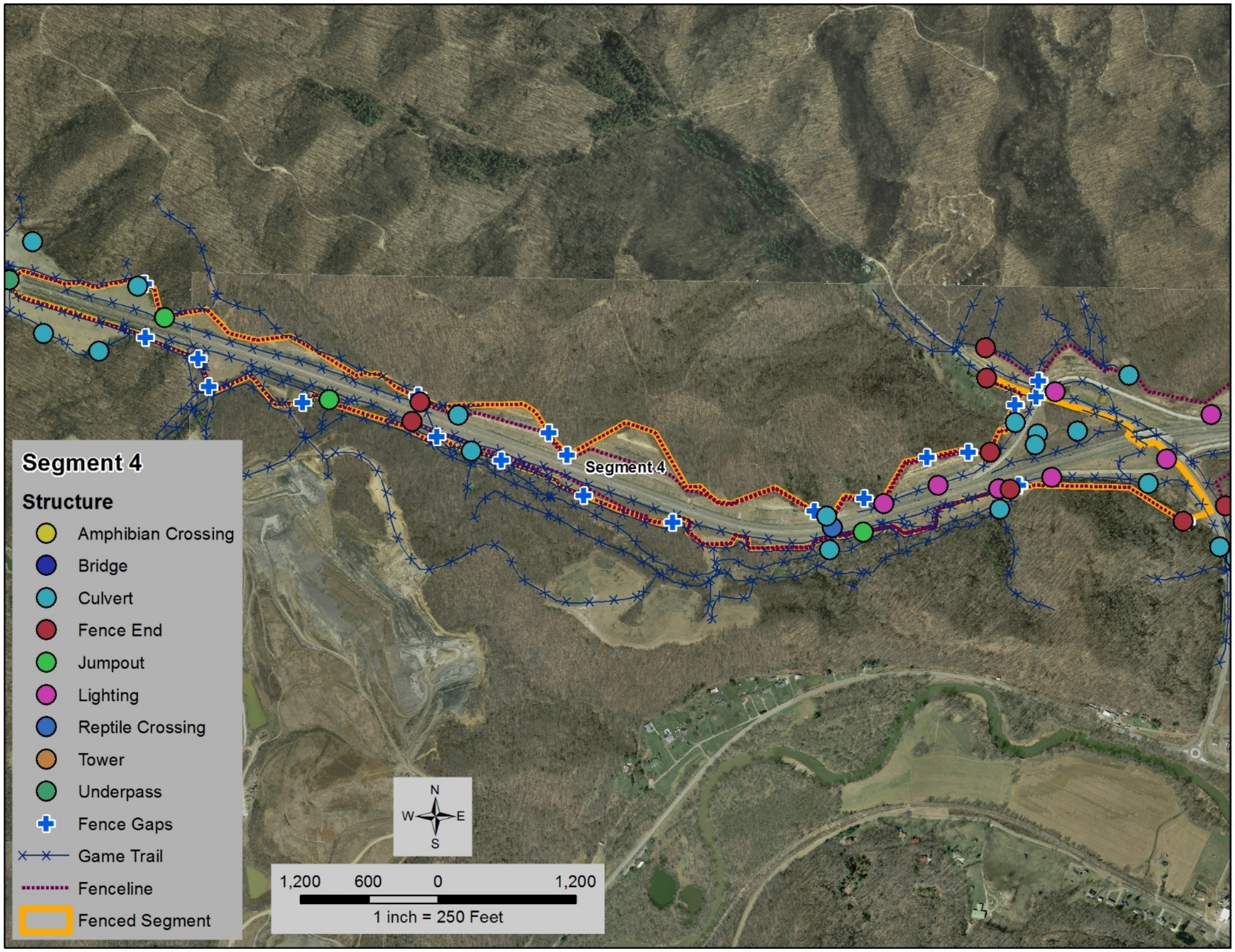


Figure 2-6. Section 4 of the U.S. 33 Nelsonville Bypass right-of-way, from the western end of the Dorr Run Road interchange in Nelsonville, Ohio to the eastern edge of the Butterfly Bridge.

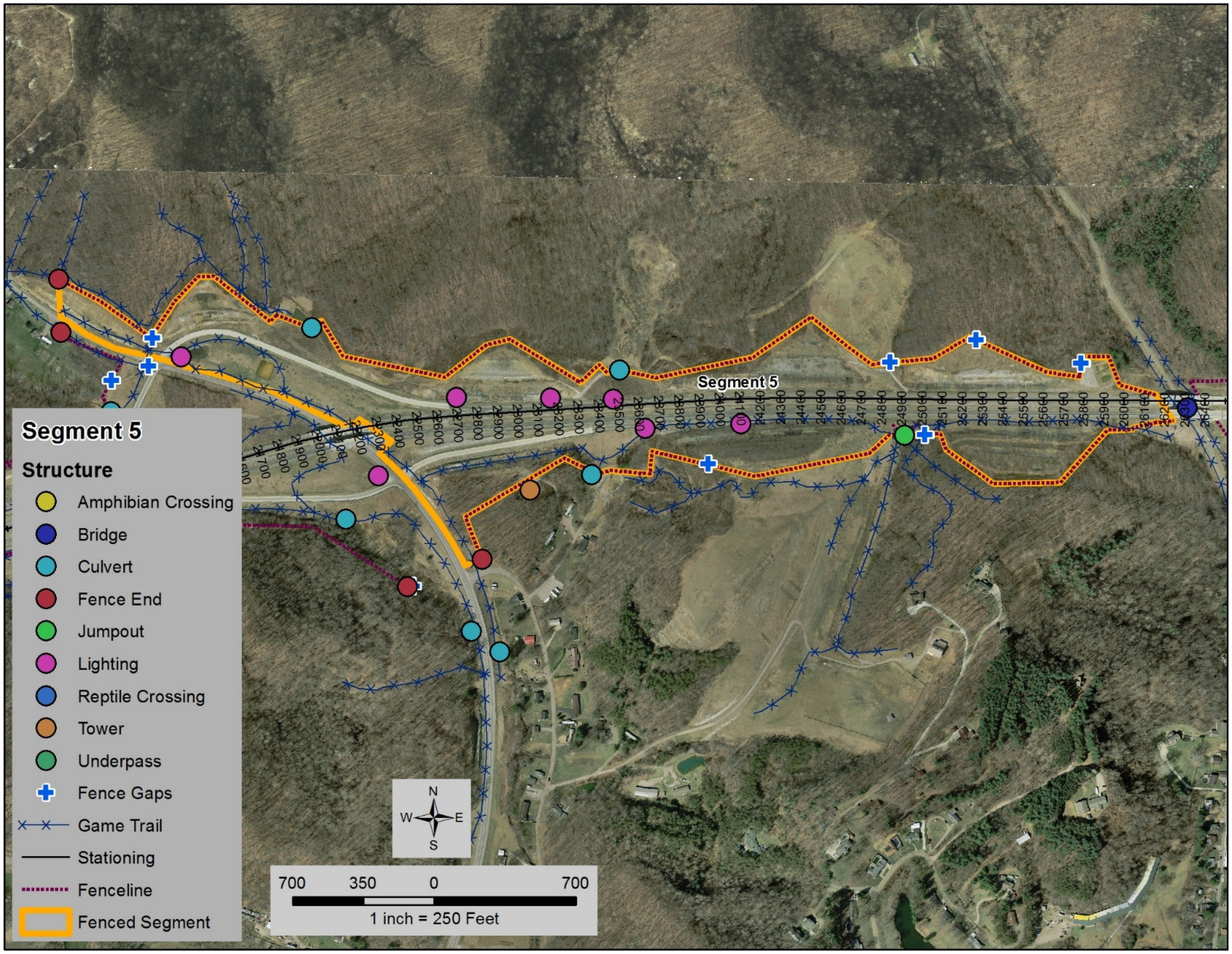


Figure 2-7. Section 5 of the U.S. 33 Nelsonville Bypass right-of-way, from the eastern edge of the bridge over Madison Road (Route 278) to the western end of the Dorr Run Road interchange in Nelsonville, Ohio.

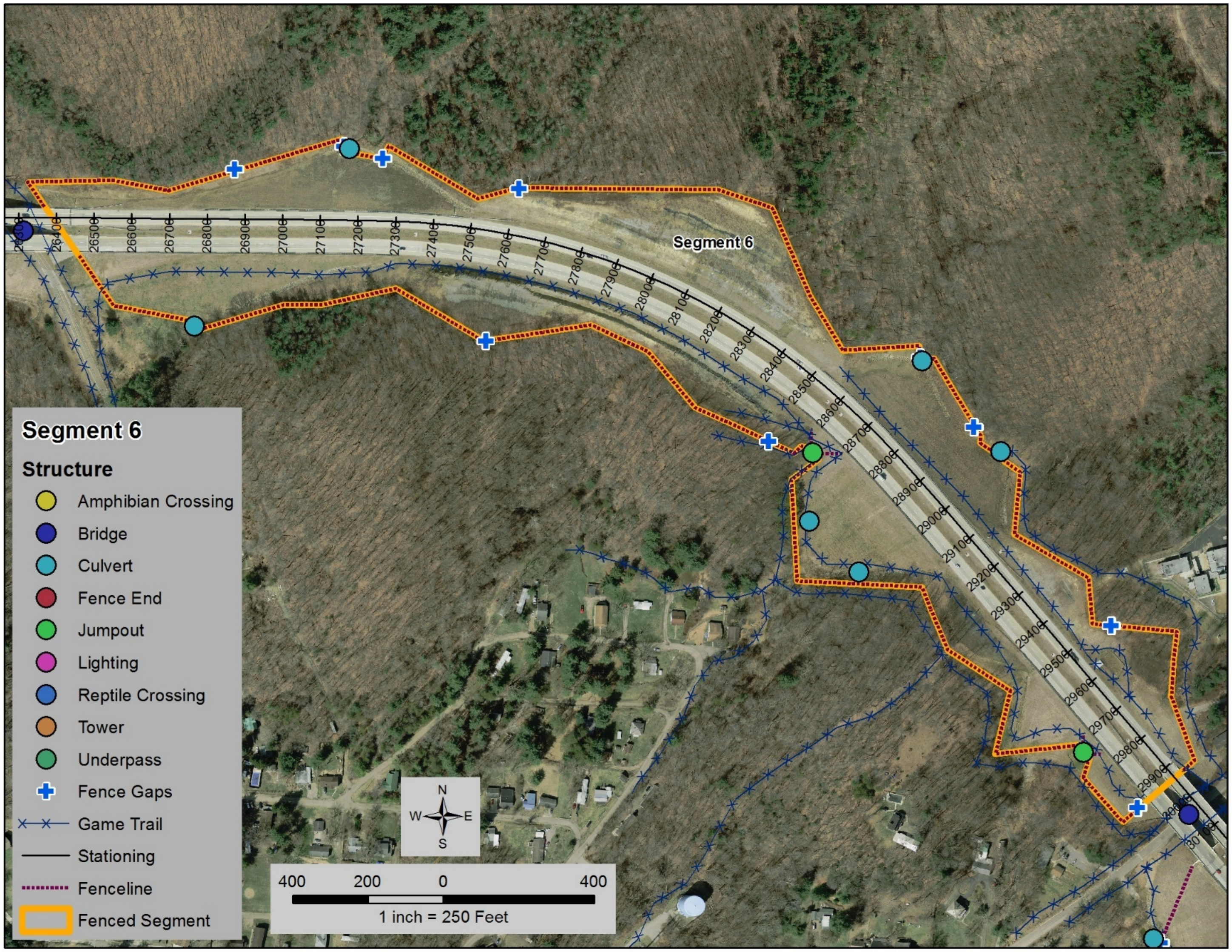


Figure 2-8. Section 6 of the U.S. 33 Nelsonville Bypass right-of-way, from the eastern edge of the bridge over Old Dump Road to the eastern edge of the bridge over Madison Road (Route 278) in Nelsonville, Ohio.

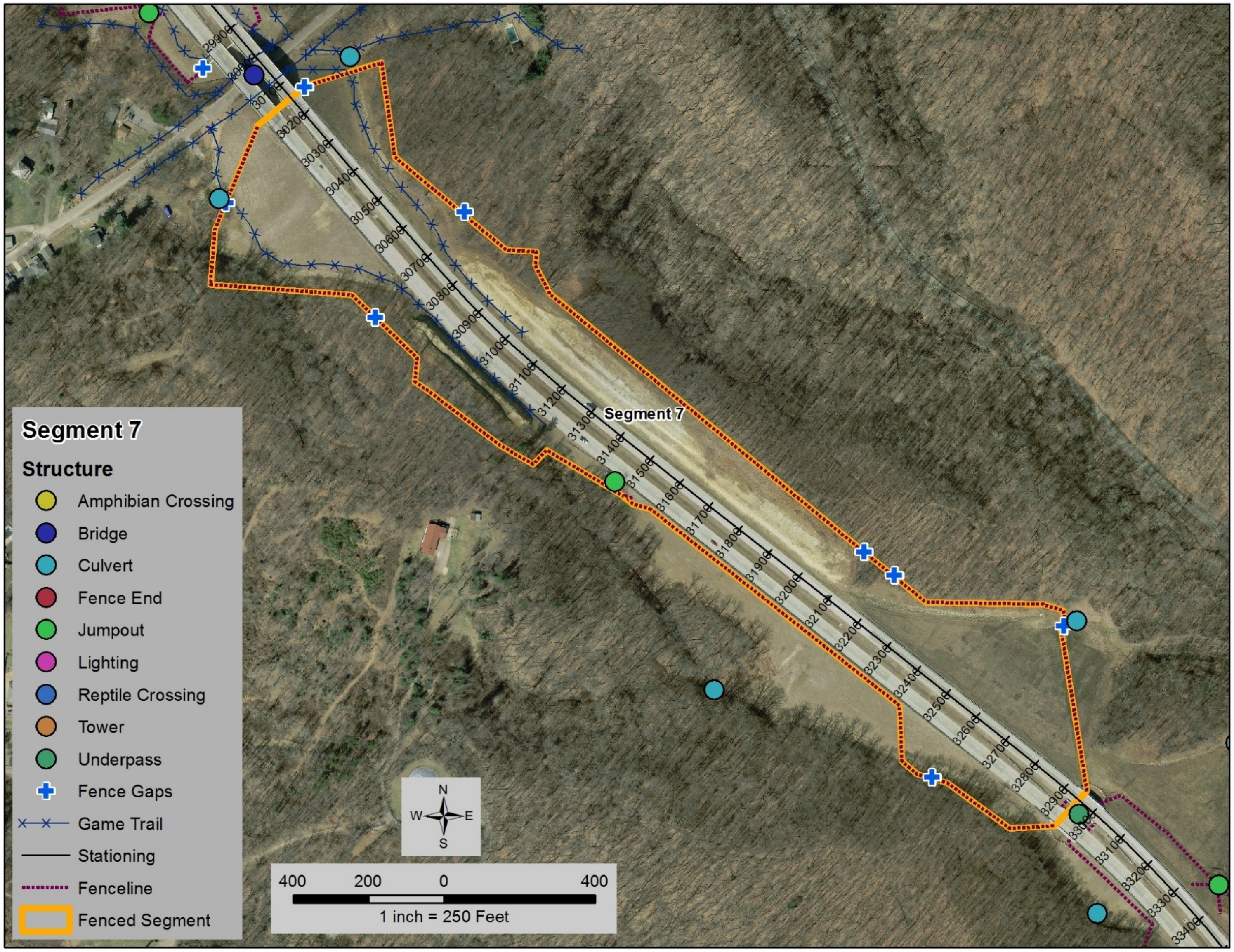


Figure 2-9. Section 7 of the U.S. 33 Nelsonville Bypass right-of-way, from the western edge of Wildlife Underpass 2 to the eastern edge of the bridge over Old Dump Road in Nelsonville, Ohio.

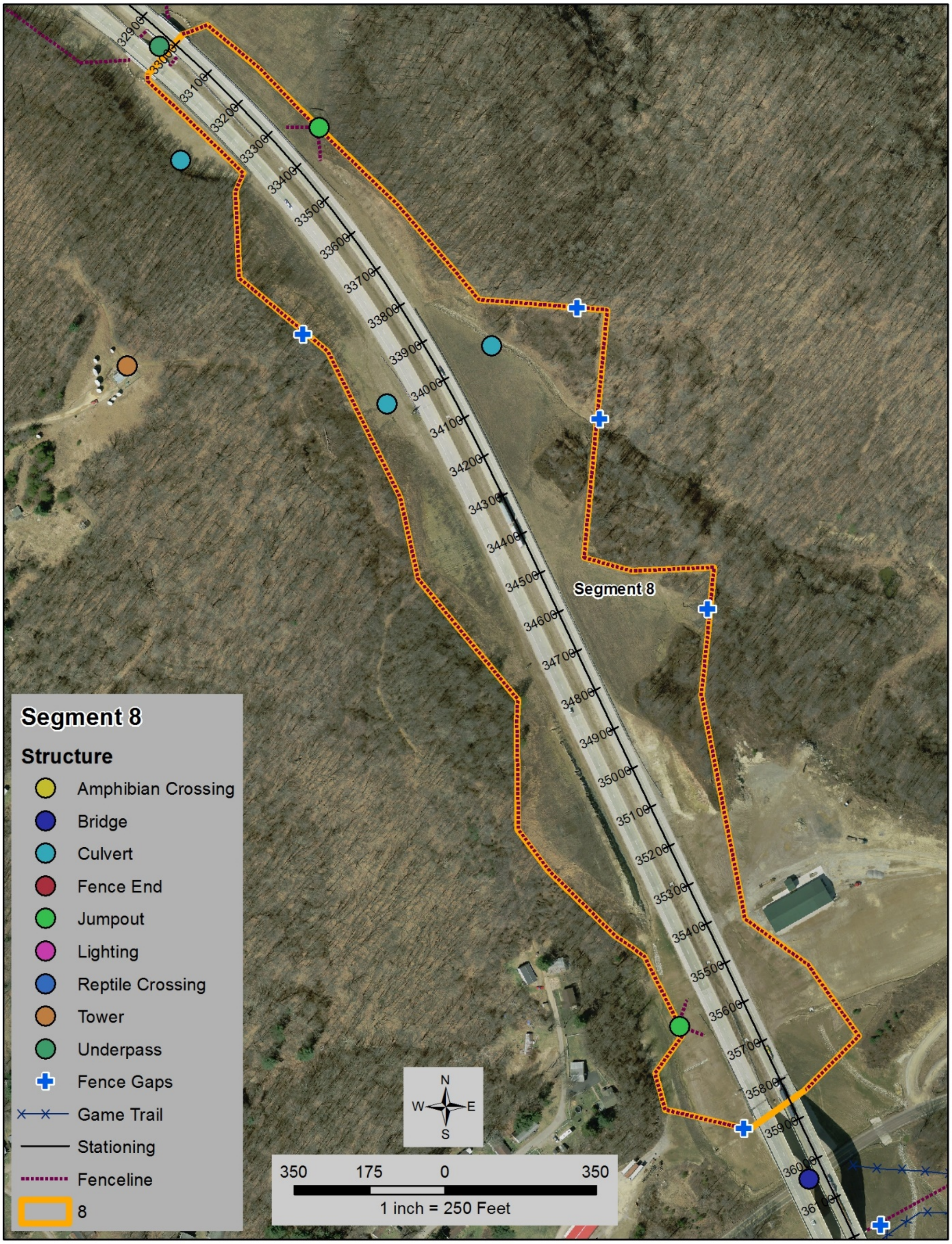


Figure 2-10. Section 8 of the U.S. 33 Nelsonville Bypass right-of-way, from the western edge of the bridge over old Ohio State Route 78 heading west to Wildlife Underpass 2.

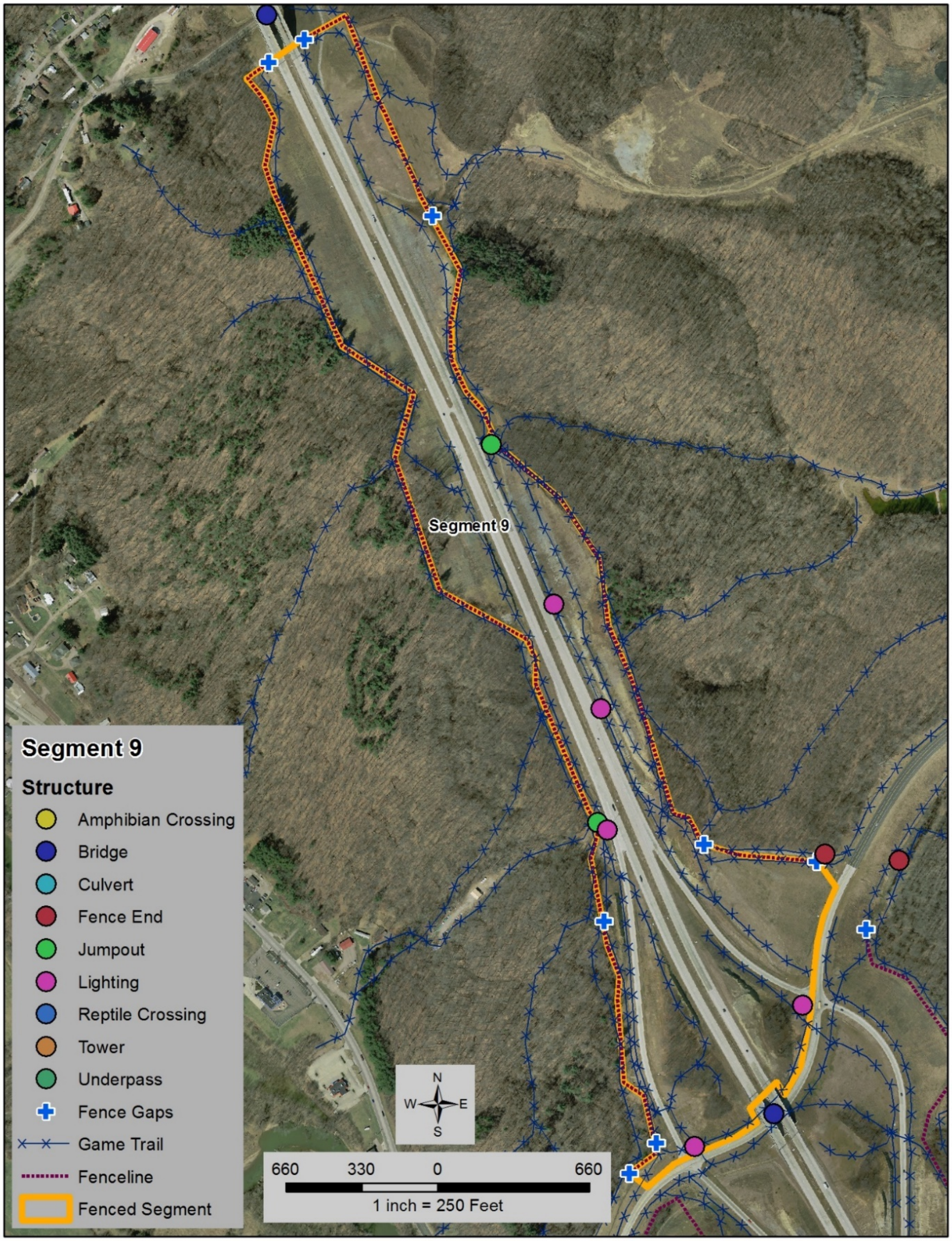


Figure 2-11. Section 9 of the U.S. 33 Nelsonville Bypass right-of-way, from the western end of the Ohio State Route 78 / old State Route 691 interchange west to the eastern edge of the bridge over old State Route 78.

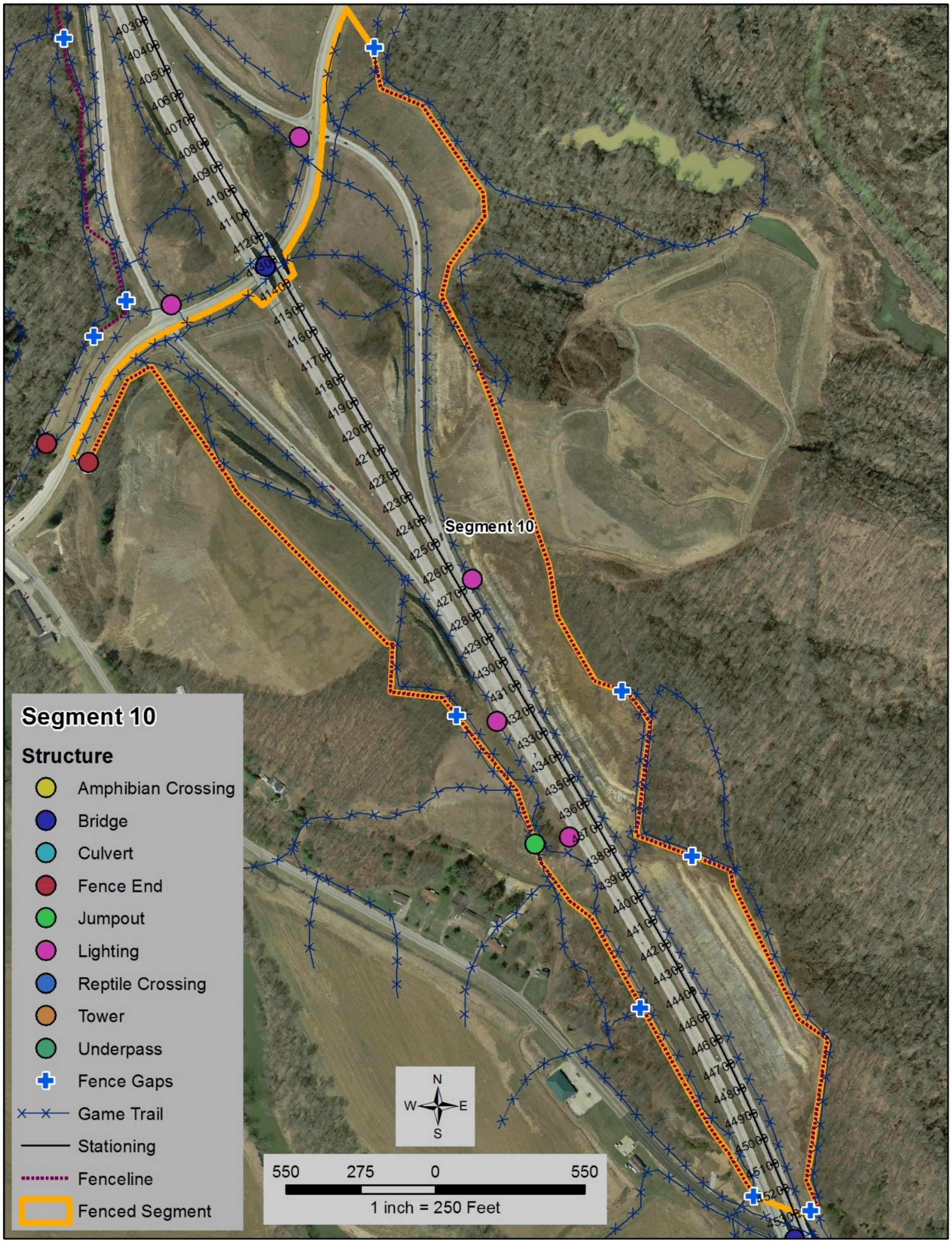


Figure 2-12. Section 10 of the U.S. 33 Nelsonville Bypass (NVBP) right-of-way, from the beginning of the eastern end of the Elm Rock Road overpass in Doanville, Ohio to the western end of the Ohio Stater Route 78 / old State Route 691 interchange. Fencing is the only mitigation feature in this section of the NVBP.

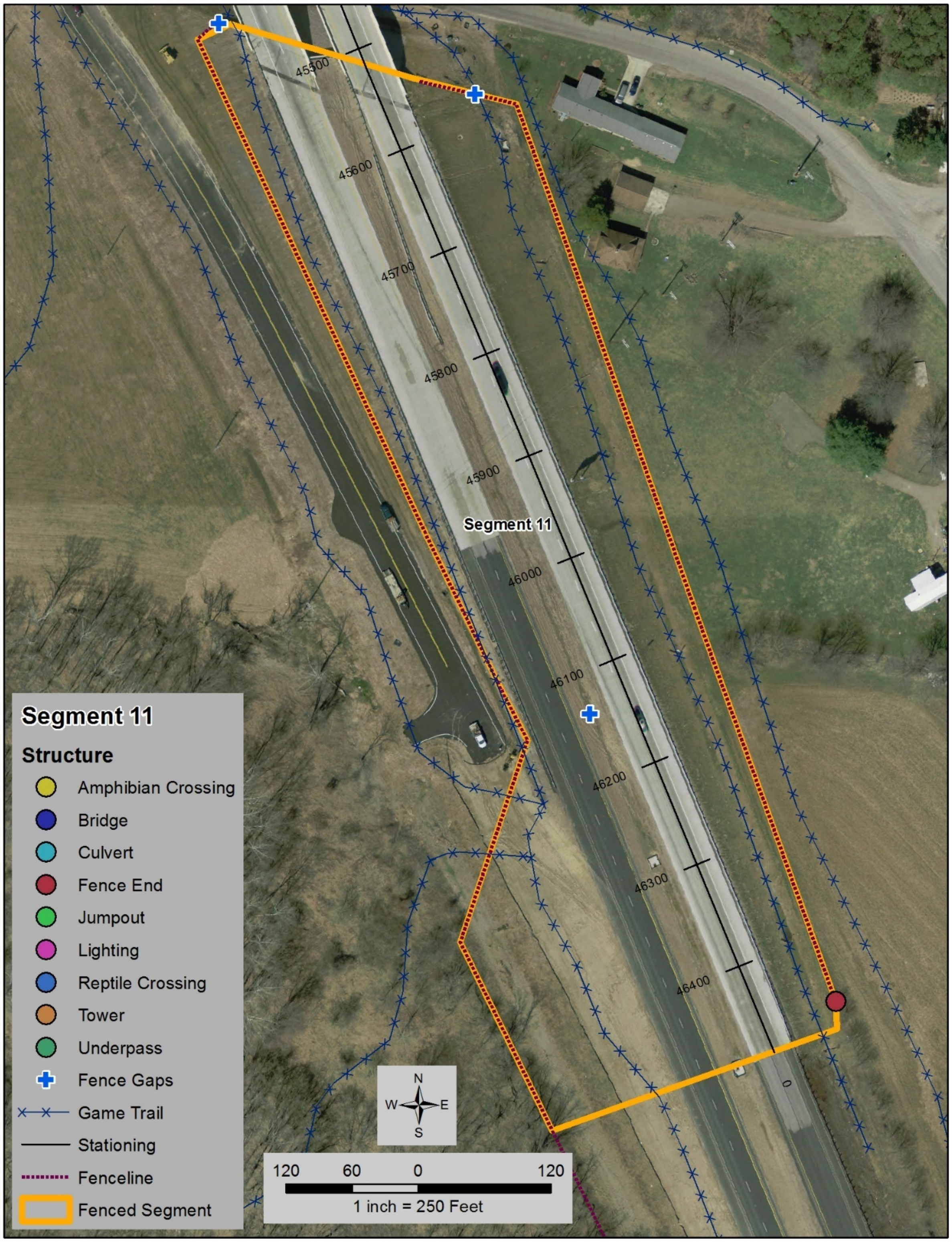


Figure 2-13. Section 11 of the U.S. 33 Nelsonville Bypass (NVBP) right-of-way, from the beginning of the eastern end of the construction area west to the Elm Rock Road overpass in Doanville, Ohio. Fencing is the only mitigation feature in this section of the NVBP.

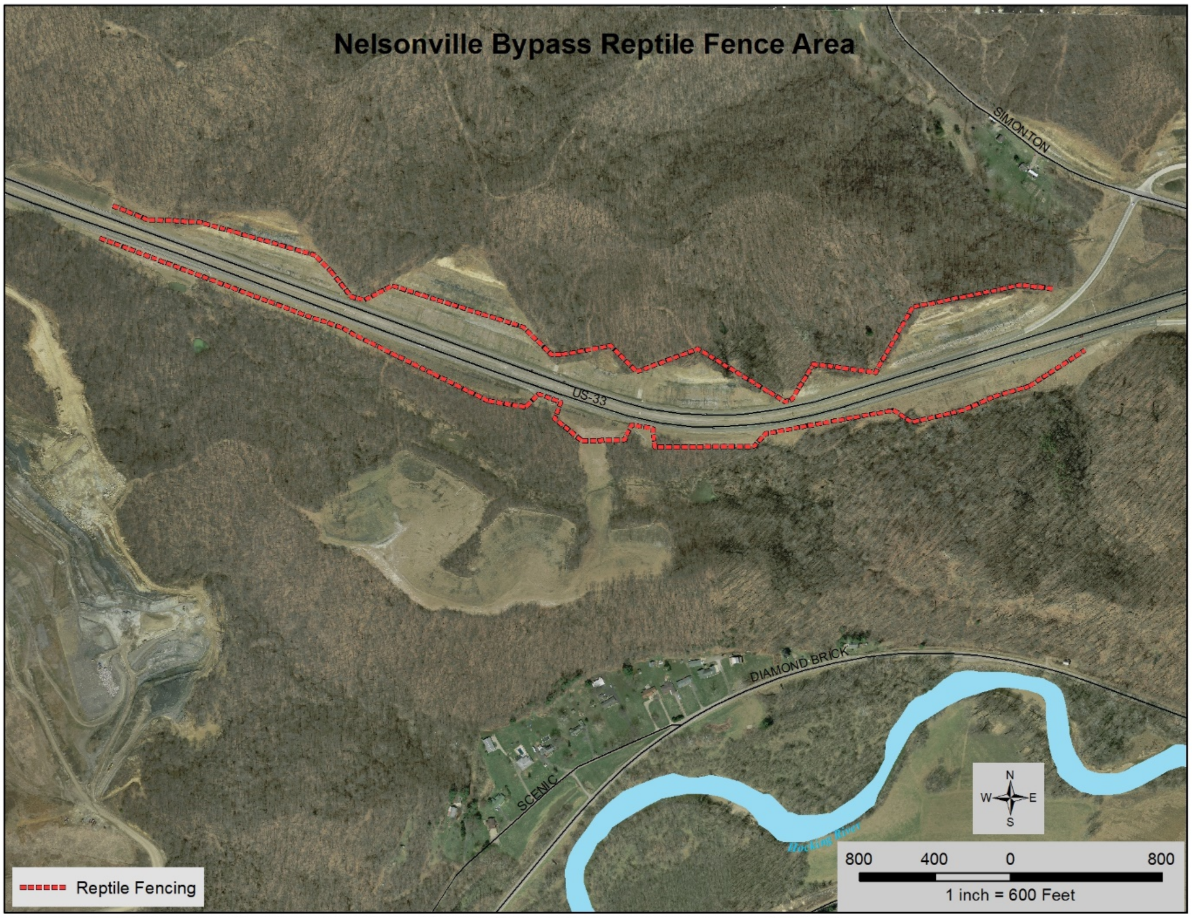


Figure 2-14. Map showing the extent of the small wildlife (reptile) fencing along the U.S. 33 Nelsonville Bypass right-of-way, Hocking County, Ohio. The fencing is just west of the Dorr Run interchange.

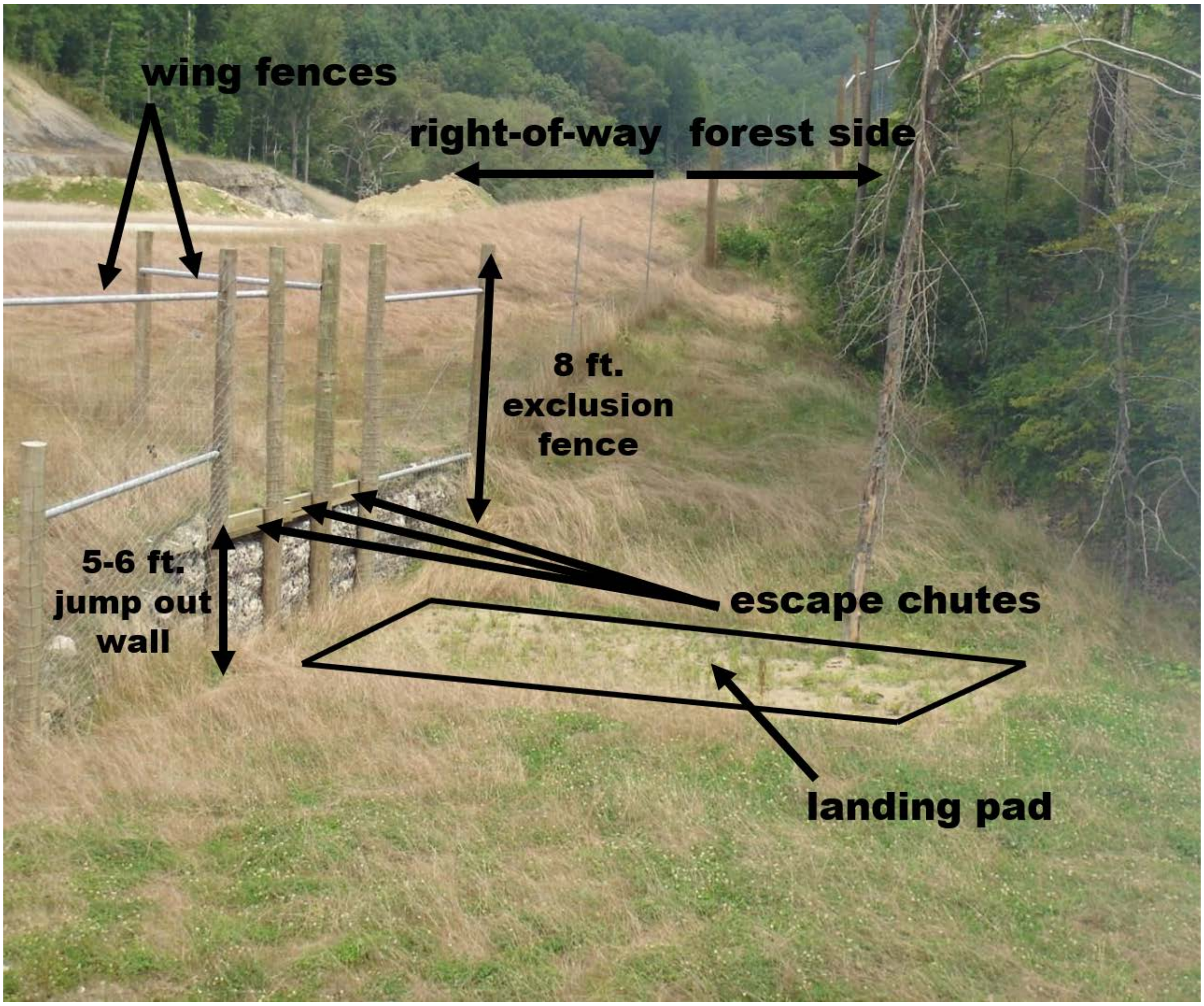


Figure 2-15. Image of a one-way jump out highlighting the jump out wall, wing fences, escape chutes, and landing pad. This jump out does not have knee bars.

Figure 2-16. White-tailed Deer exiting the U.S. 33 Nelsonville Bypass right-of-way through a one-way jump out. This jump out does have a knee bar. This jump out has no apparent landing pad.

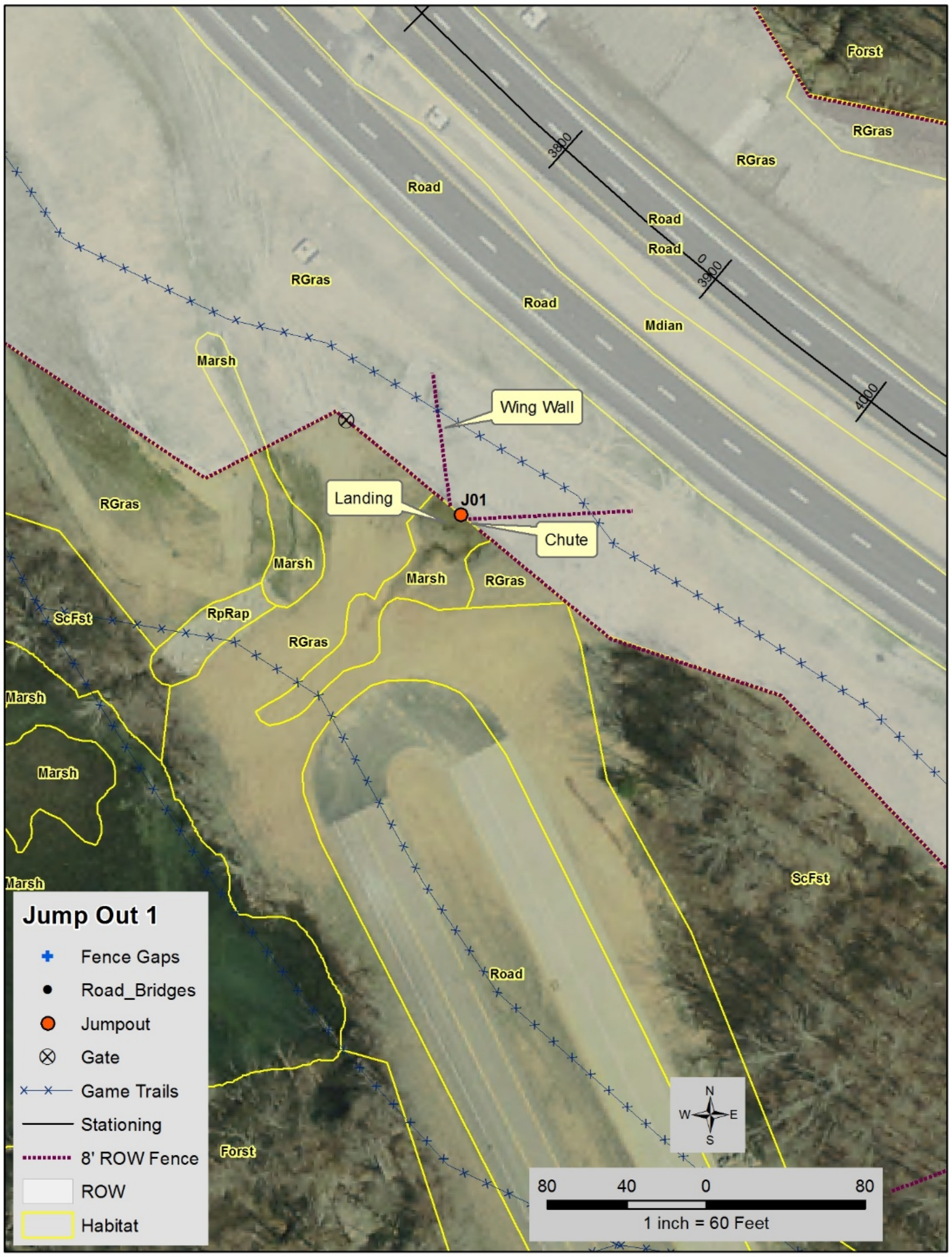


Figure 2-17. Schematic of Jump Out 1 (J1) showing wing walls, escape chute, and landing pad. J1 is the farthest west jump out along the U.S. 33 Nelsonville Bypass in Hocking County, Ohio. Habitat mapping codes are in Table 2-1.

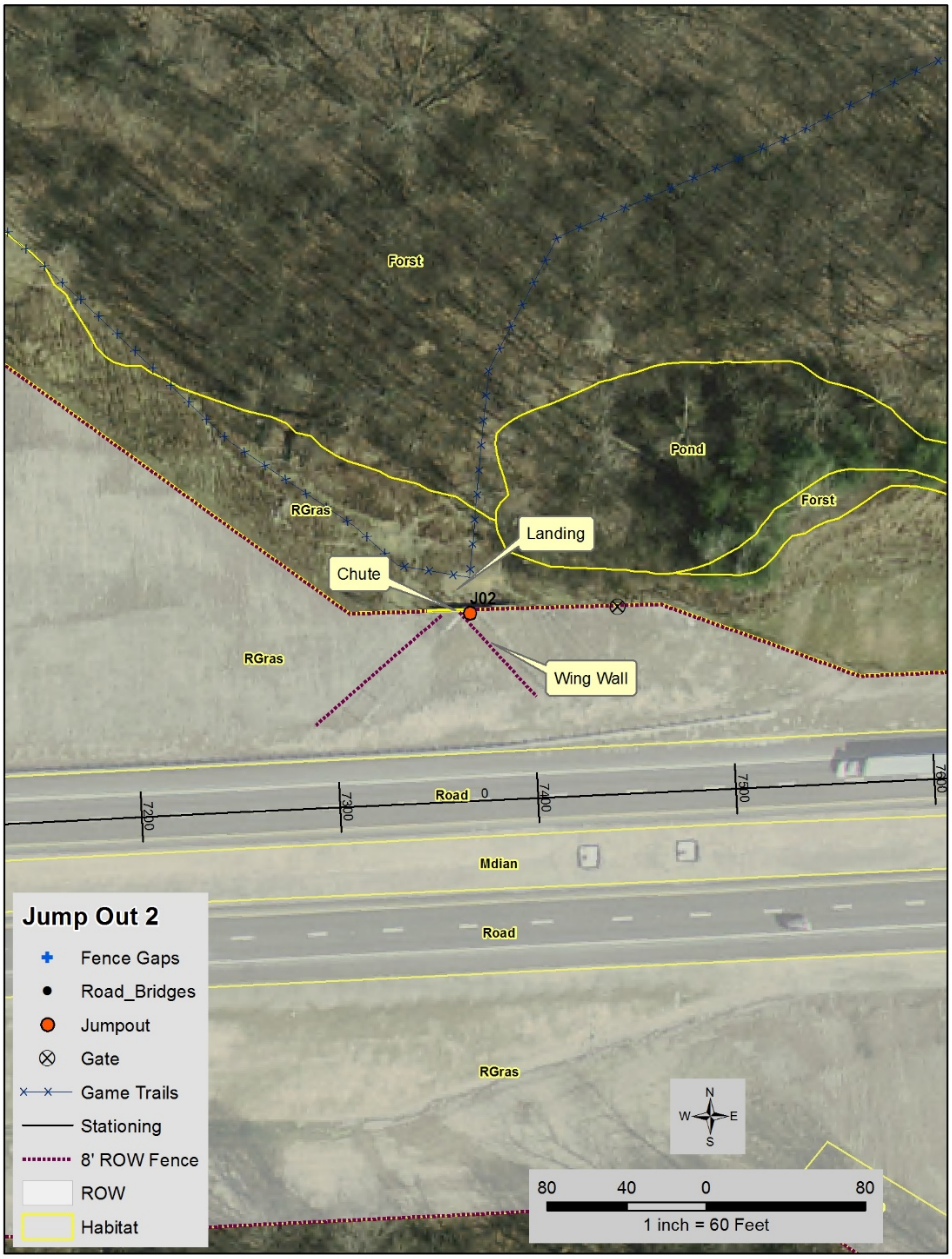


Figure 2-18. Schematic of Jump Out 2 showing wing walls, escape chute, and landing pad. Habitat mapping codes are in Table 2-1.

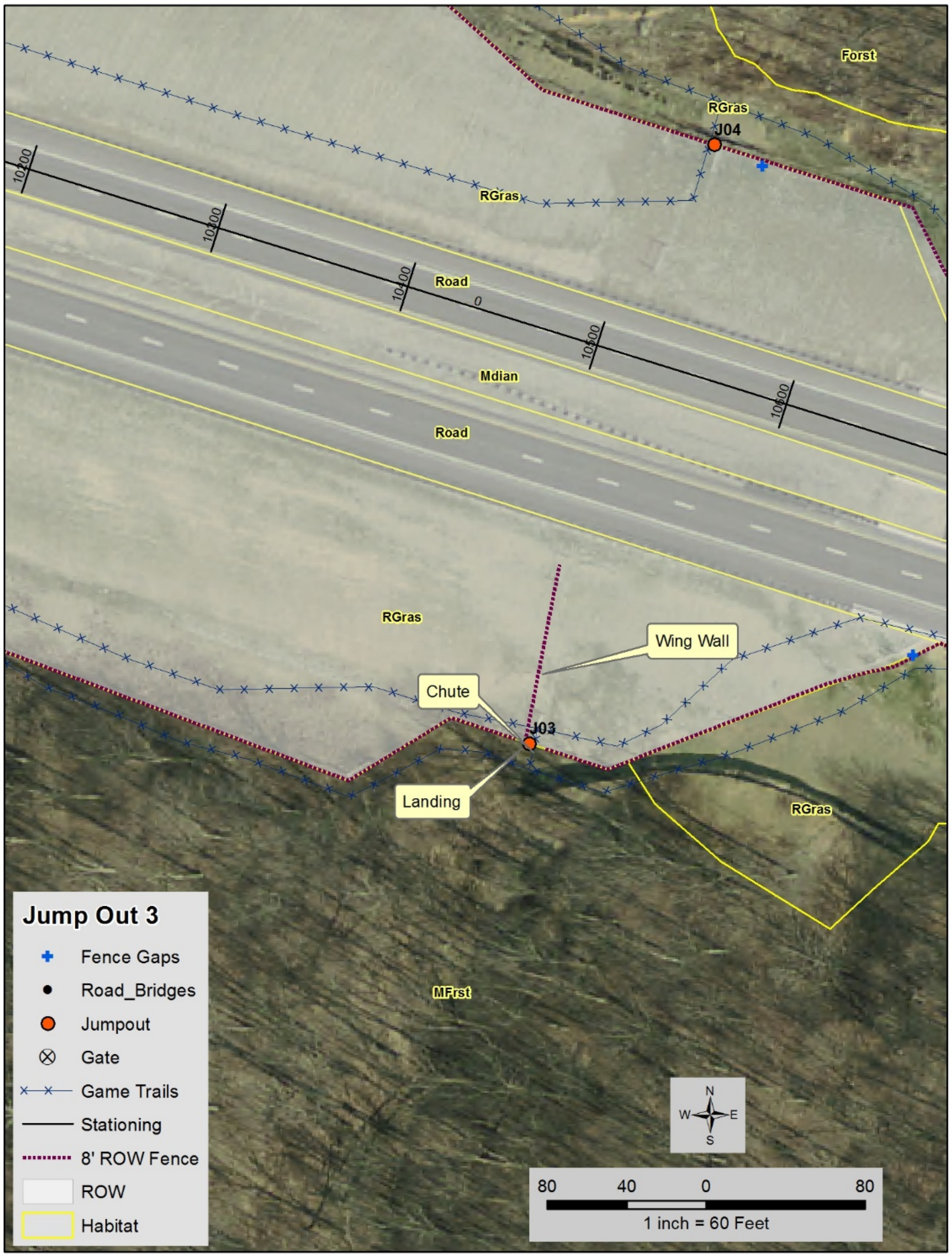


Figure 2-19. Schematic of Jump Out 3 showing wing walls, escape chute, and landing pad. Habitat mapping codes are in Table 2-1.

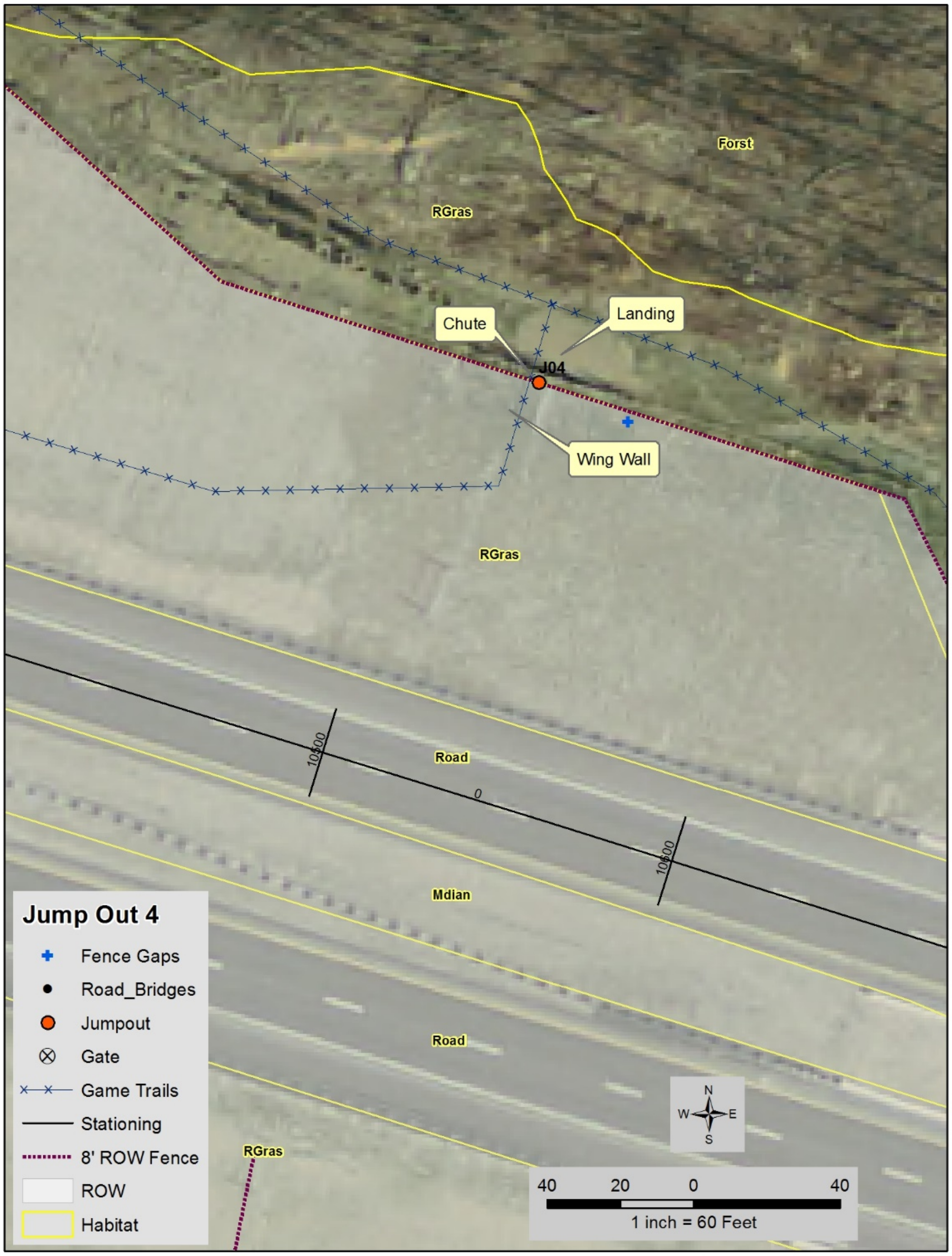


Figure 2-20. Schematic of Jump Out 4 showing wing walls, escape chute, and landing pad. Habitat mapping codes are in Table 2-1.

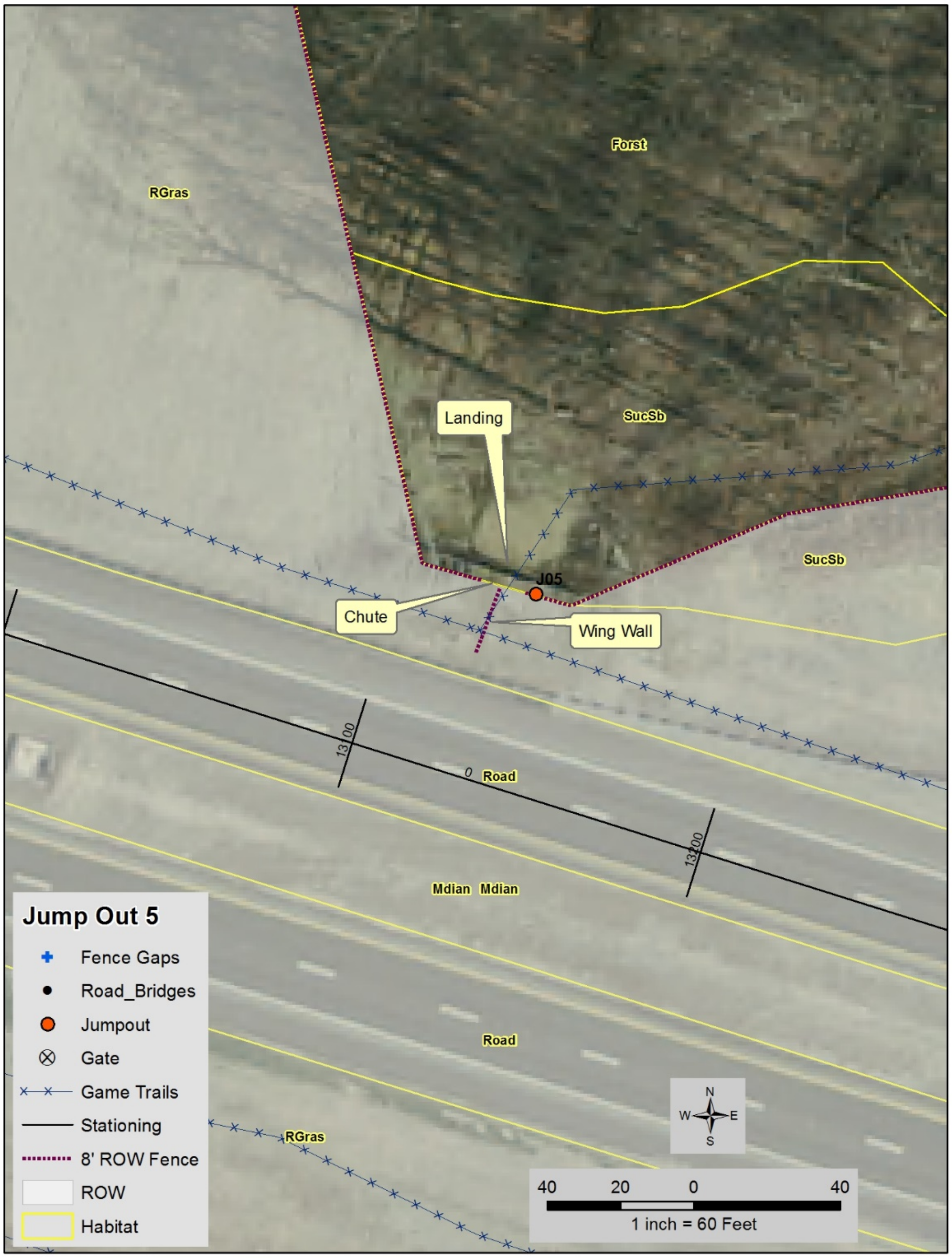


Figure 2-21. Schematic of Jump Out 5 showing wing walls, escape chute, and landing pad. Habitat mapping codes are in Table 2-1.

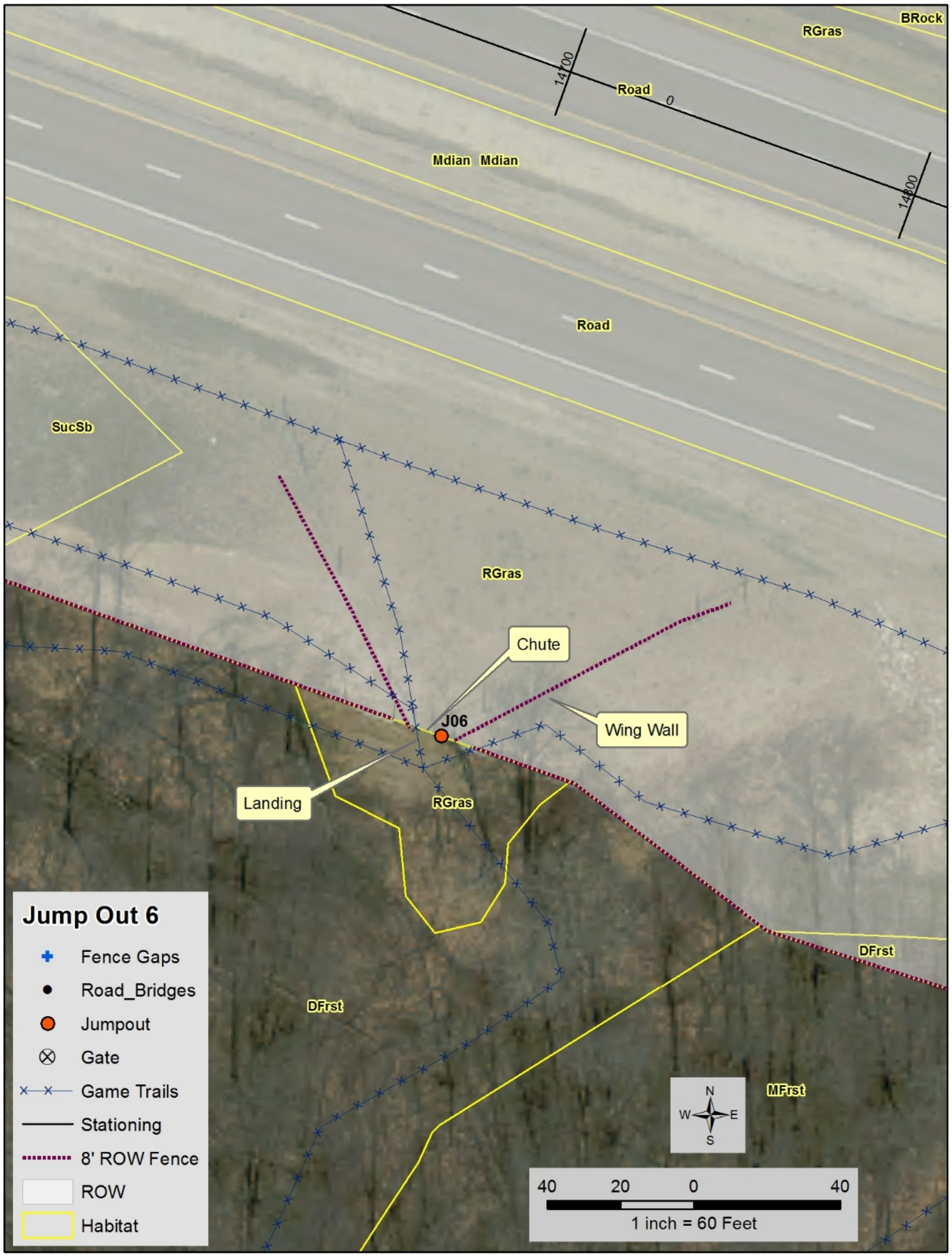


Figure 2-22. Schematic of Jump Out 6 showing wing walls, escape chute, and landing pad. Habitat mapping codes are in Table 2-1.

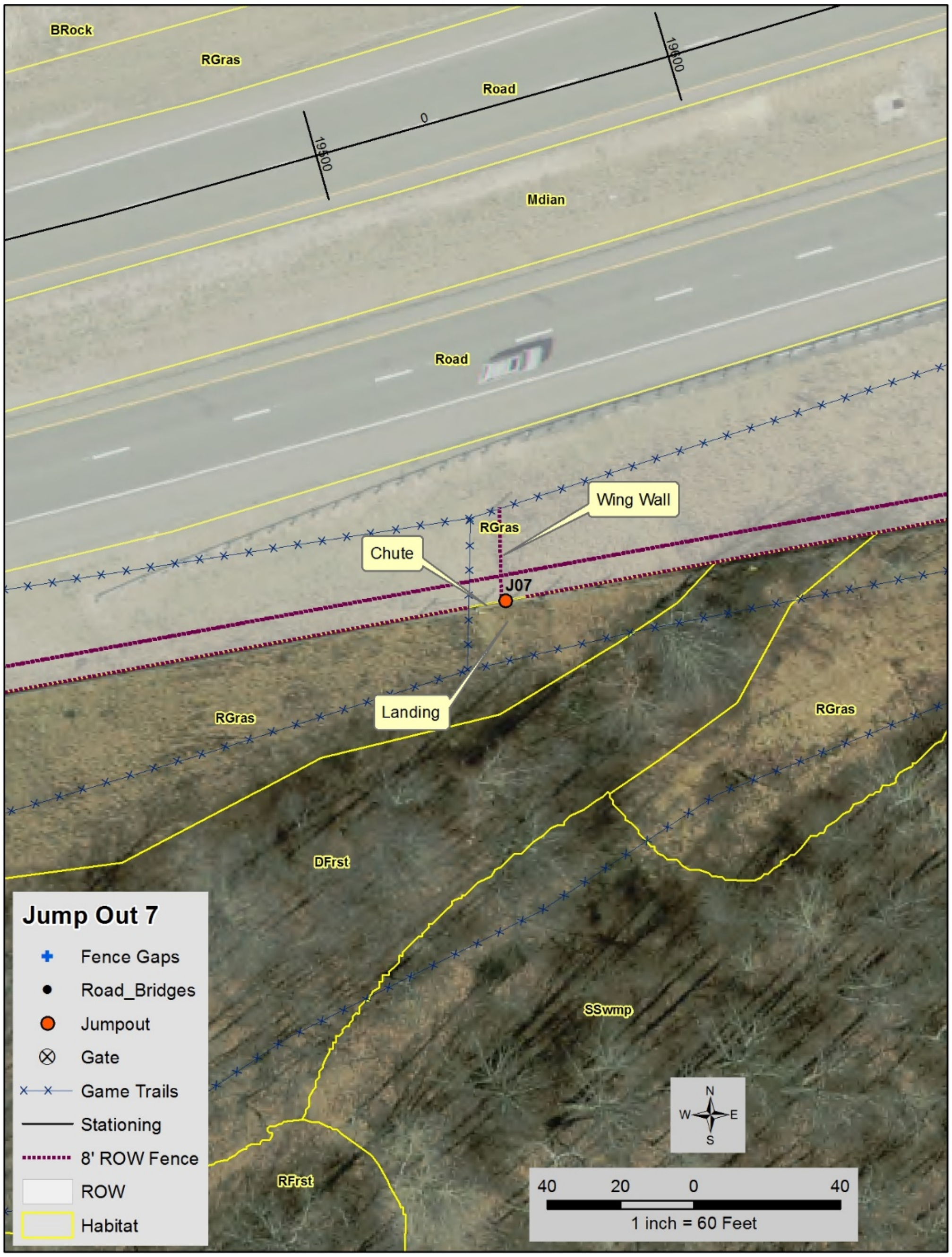


Figure 2-23. Schematic of Jump Out 7 showing wing walls, escape chute, and landing pad. Habitat mapping codes are in Table 2-1.

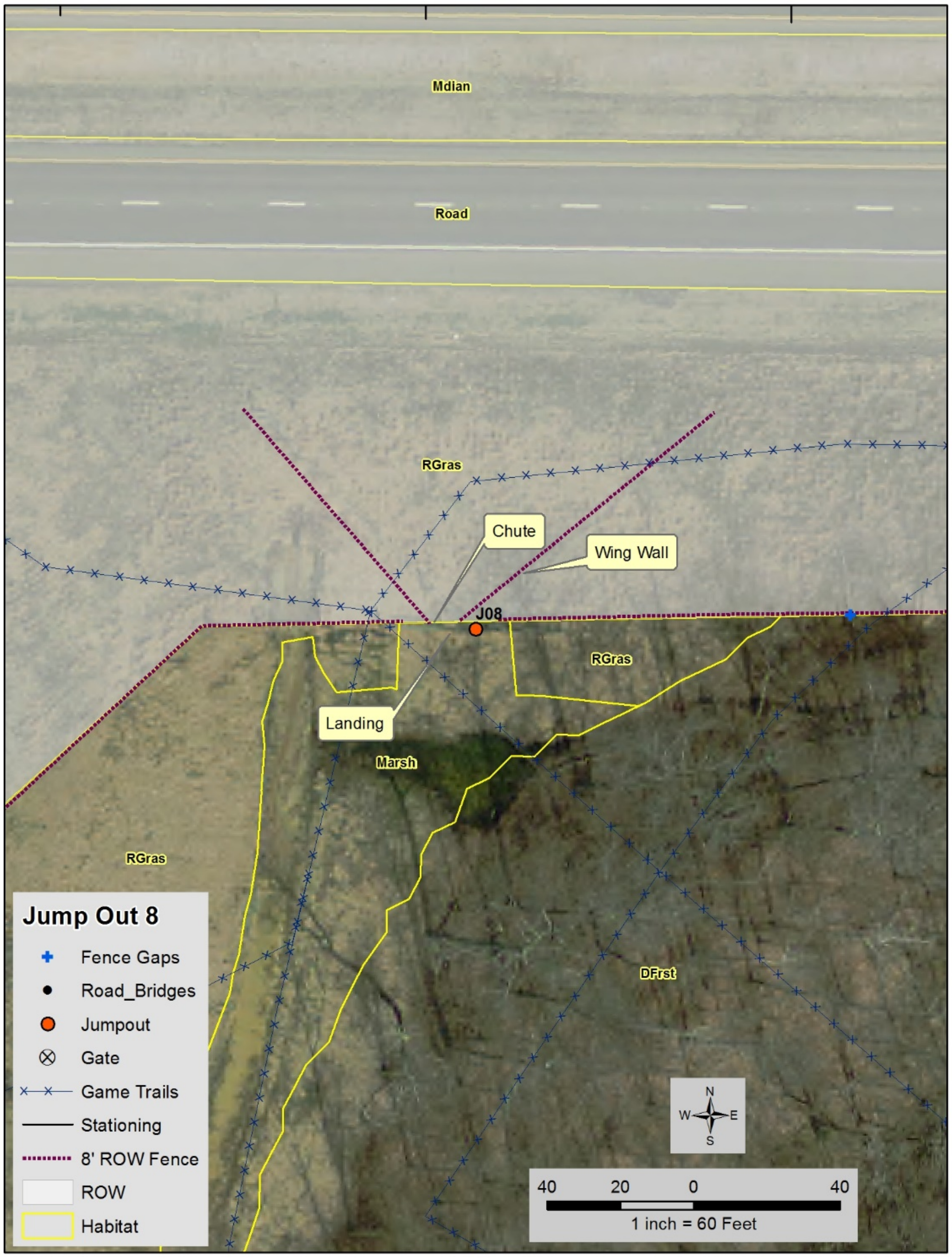


Figure 2-24. Schematic of Jump Out 8 showing wing walls, escape chute, and landing pad. Habitat mapping codes are in Table 2-1.

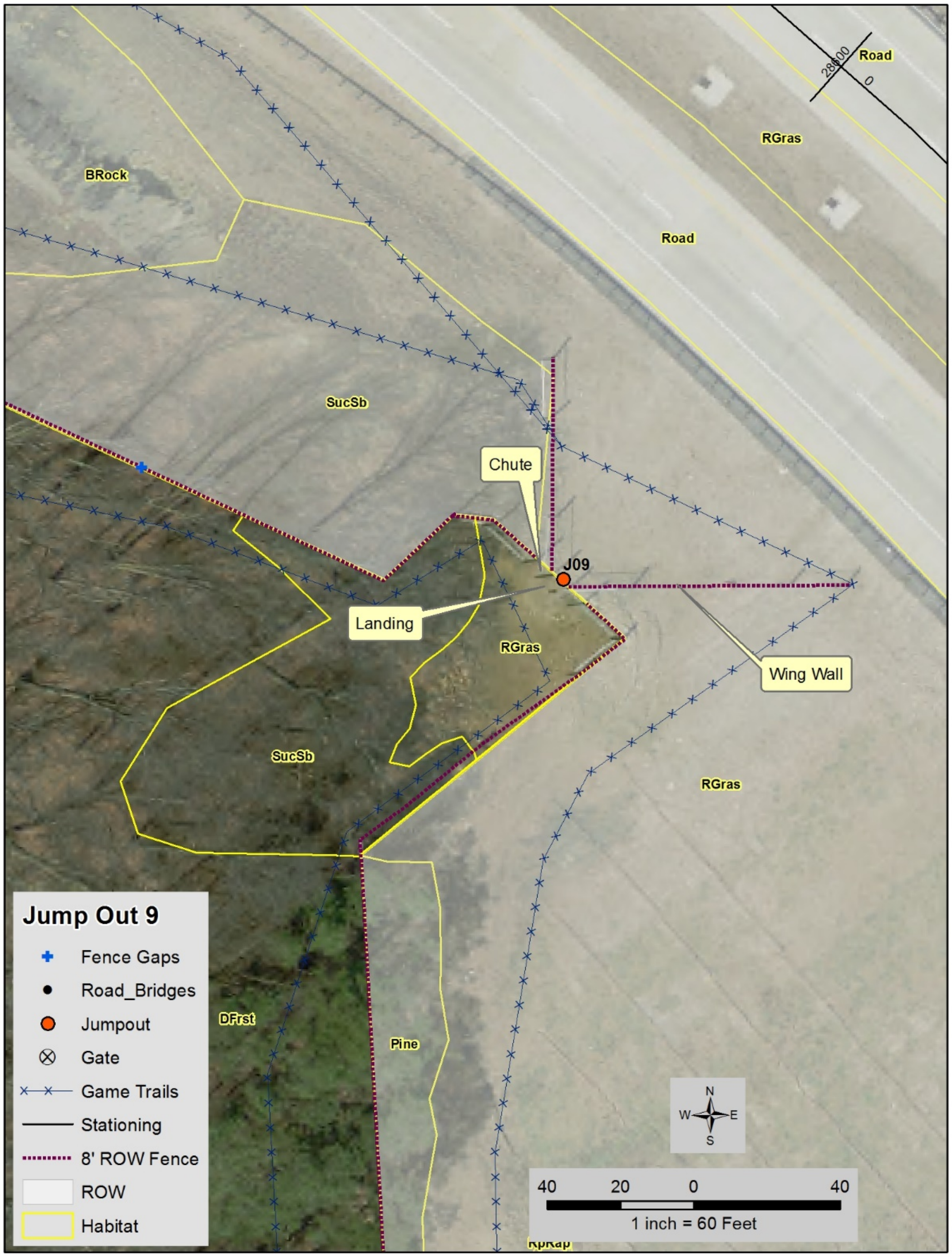


Figure 2-25. Schematic of Jump Out 9 showing wing walls, escape chute, and landing pad. Habitat mapping codes are in Table 2-1.

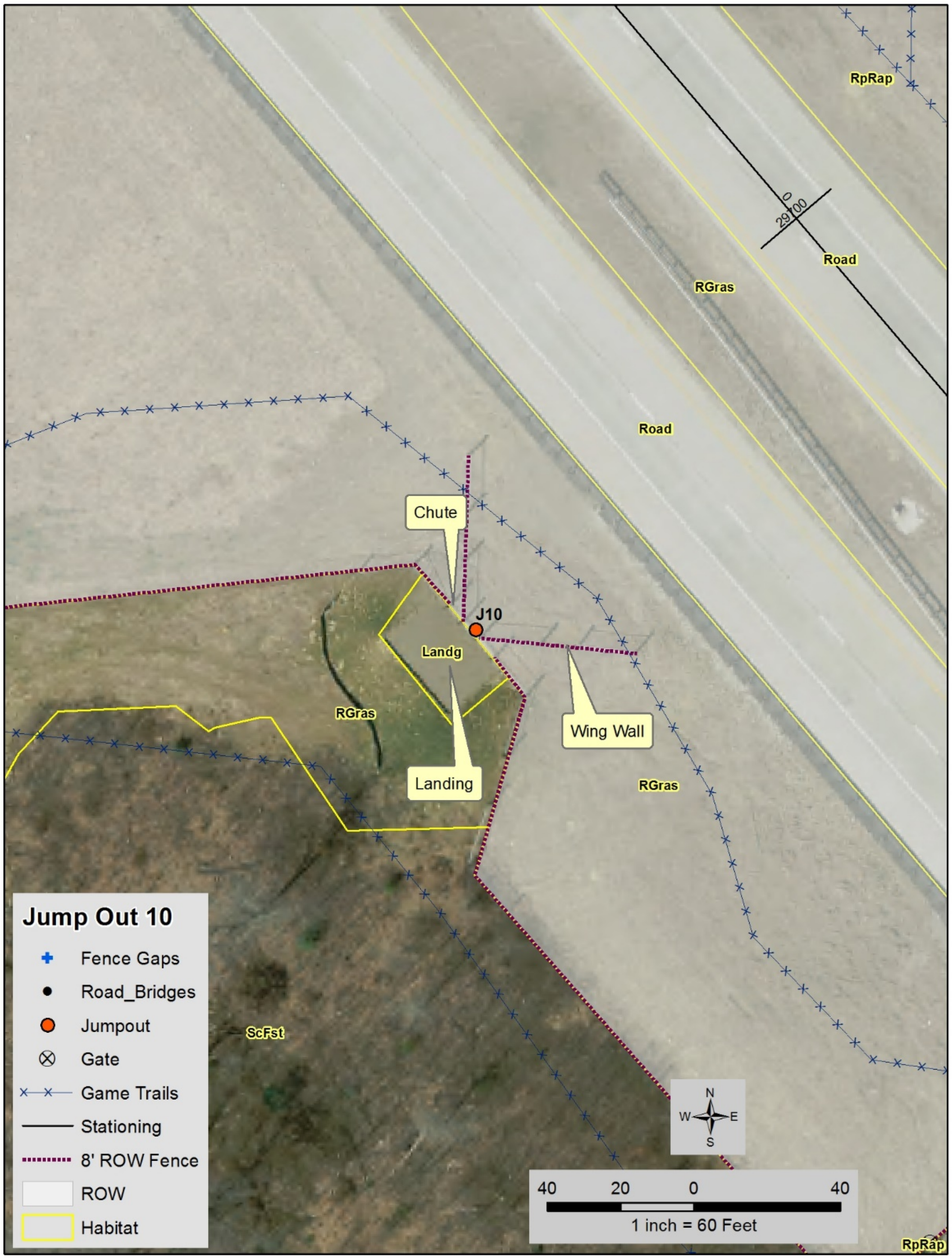


Figure 2-26. Schematic of Jump Out 10 showing wing walls, escape chute, and landing pad. Habitat mapping codes are in Table 2-1.

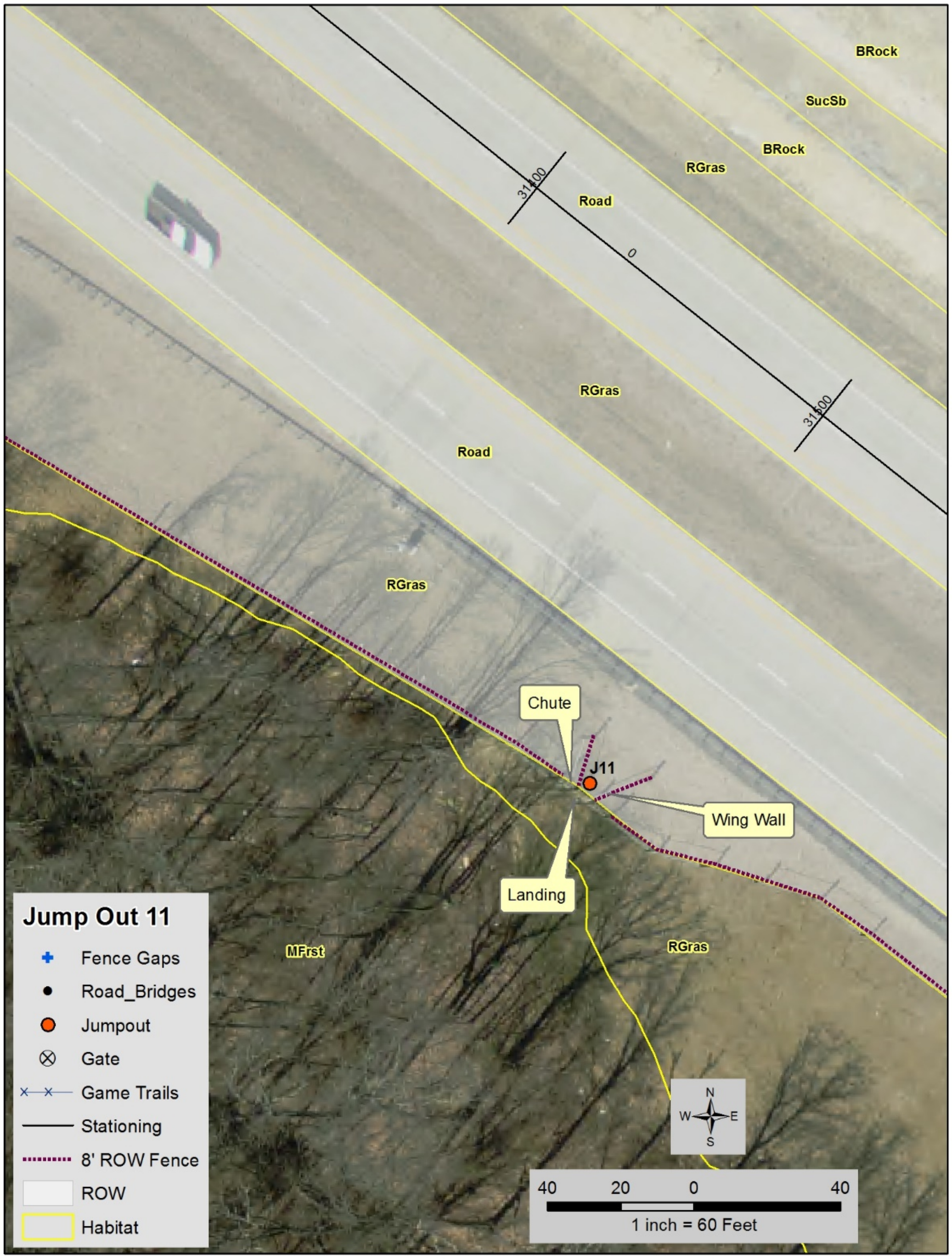


Figure 2-27. Schematic of Jump Out 11 showing wing walls, escape chute, and landing pad. Habitat mapping codes are in Table 2-1.

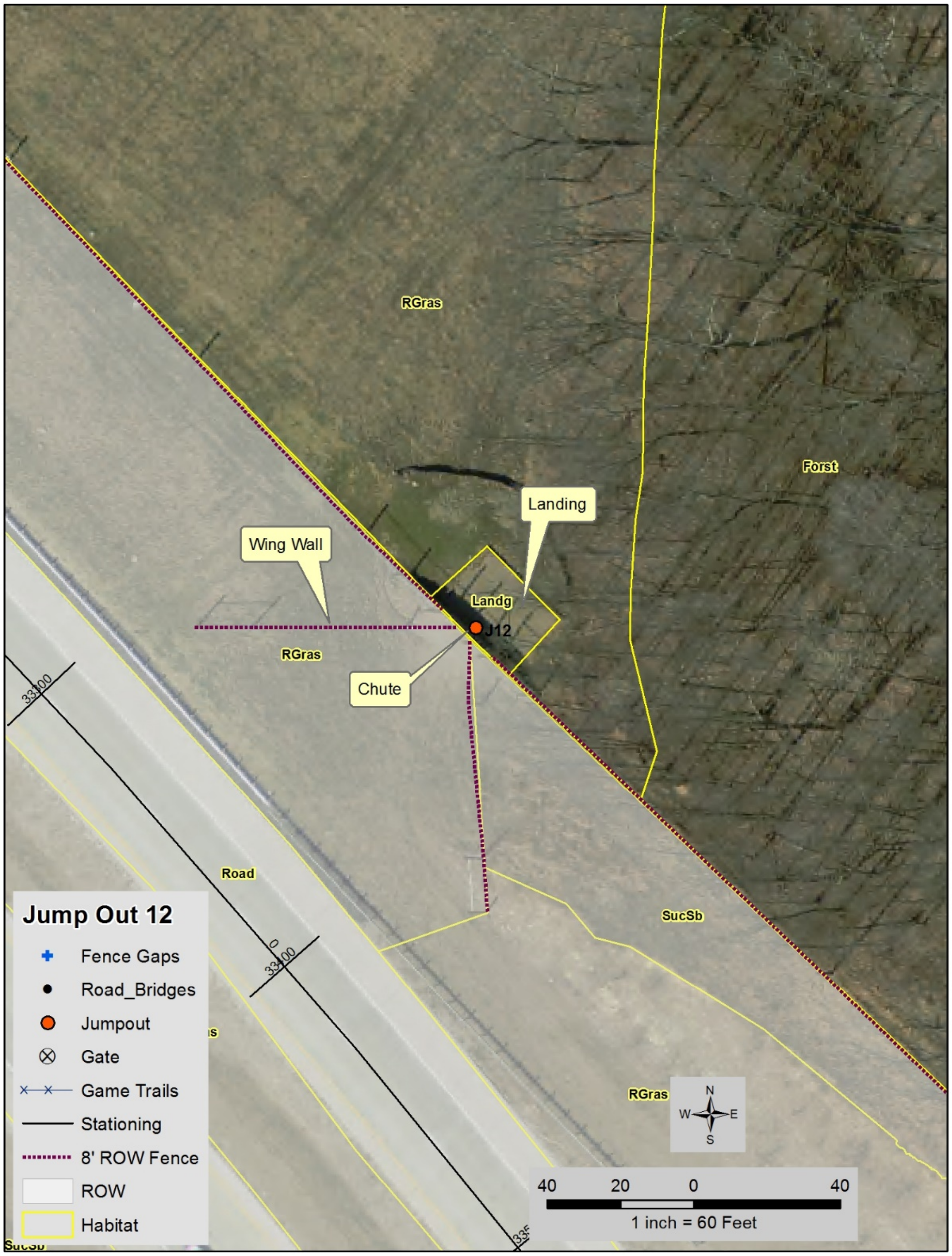


Figure 2-28. Schematic of Jump Out 12 showing wing walls, escape chute, and landing pad. Habitat mapping codes are in Table 2-1.

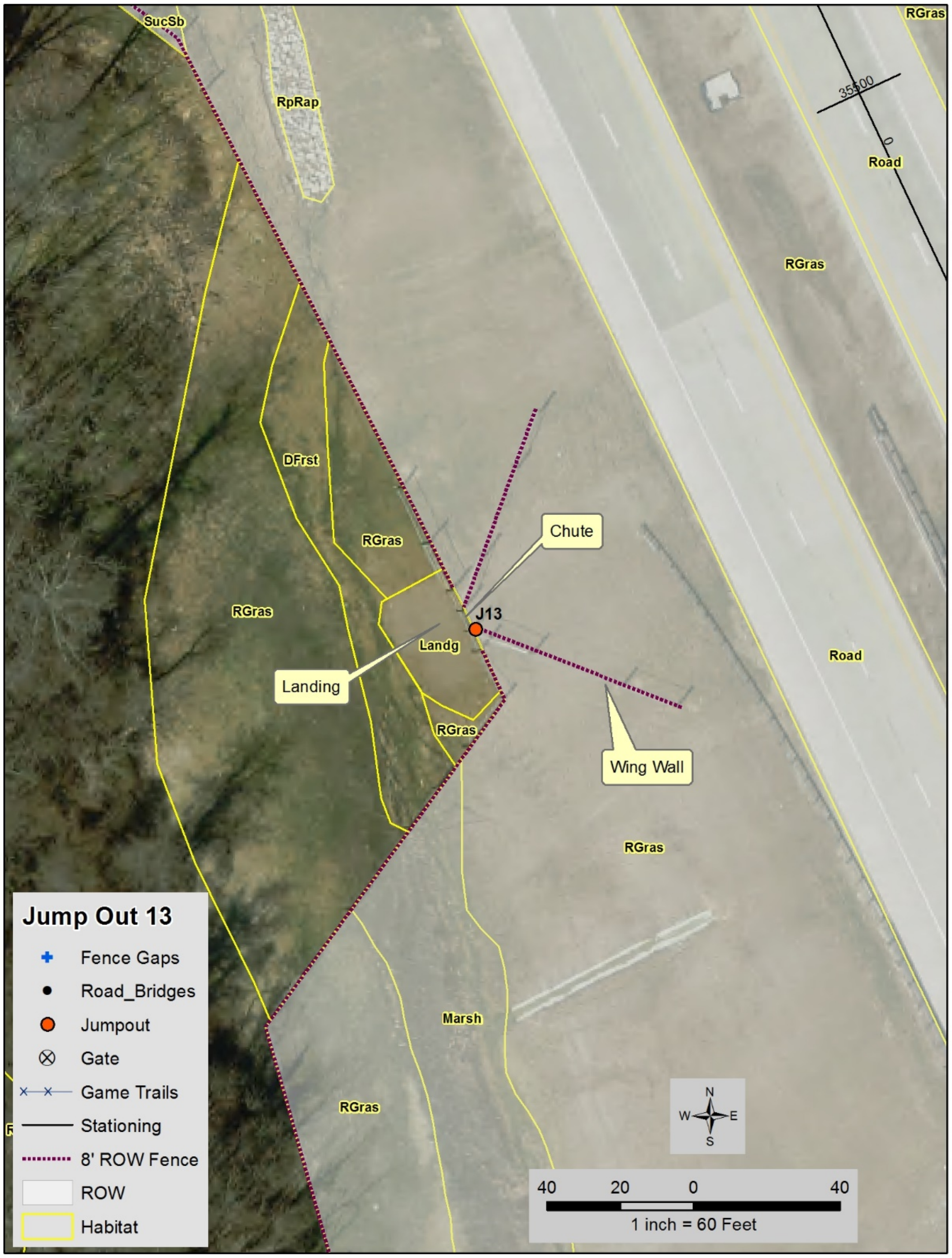


Figure 2-29. Schematic of Jump Out 13 showing wing walls, escape chute, and landing pad. Habitat mapping codes are in Table 2-1.

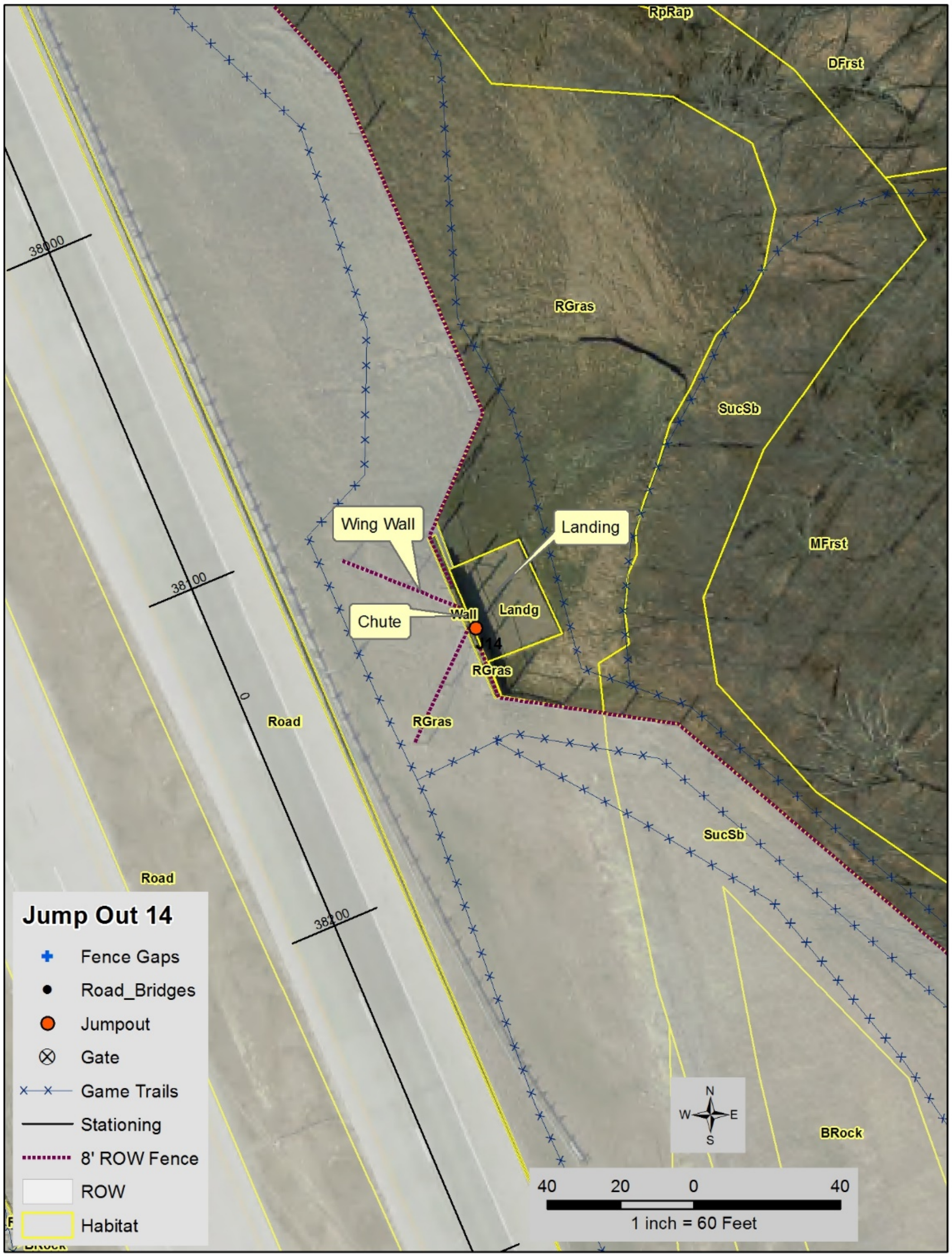


Figure 2-30. Schematic of Jump Out 14 showing wing walls, escape chute, and landing pad. Habitat mapping codes are in Table 2-1.

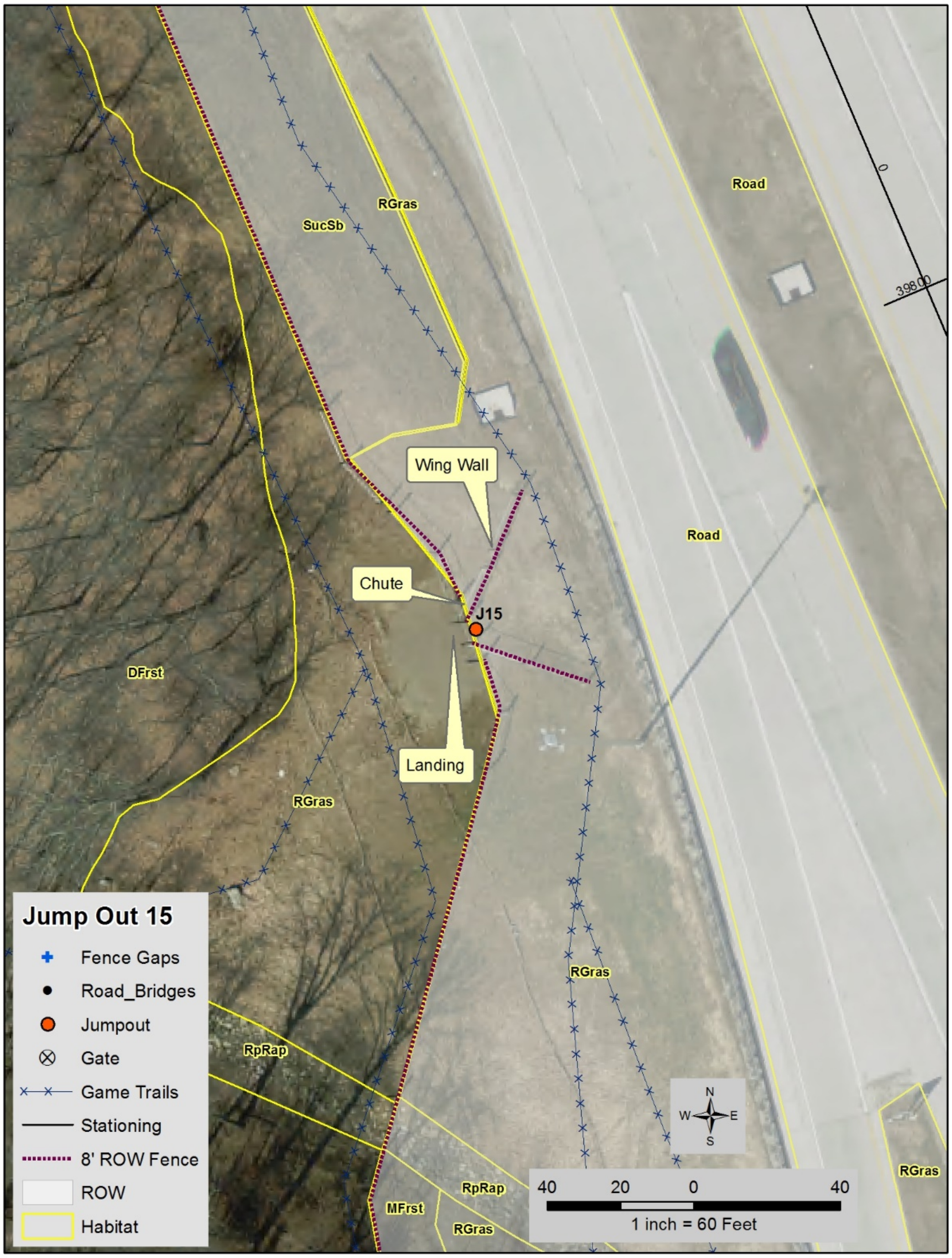


Figure 2-31. Schematic of Jump Out 15 showing wing walls, escape chute, and landing pad. Habitat mapping codes are in Table 2-1.

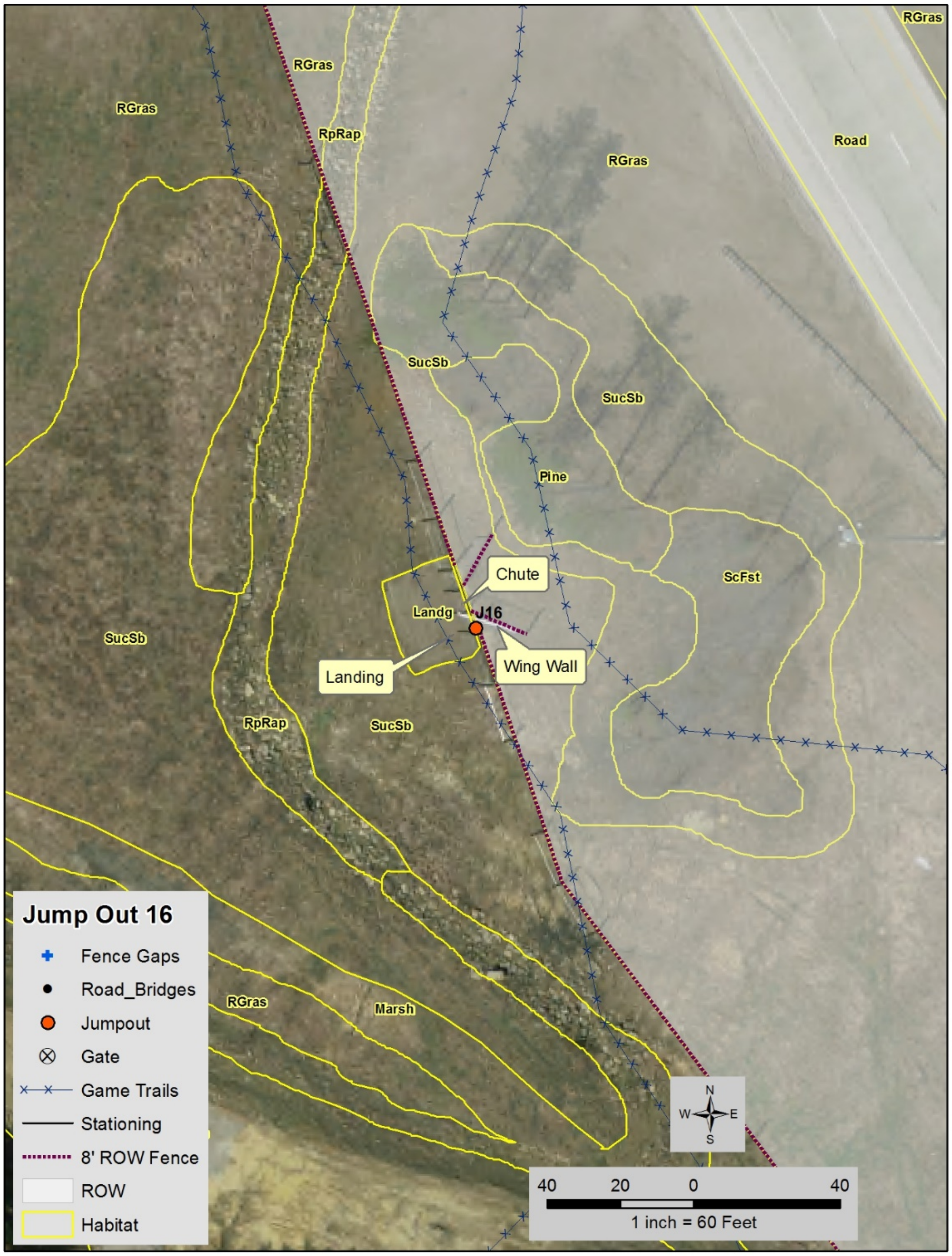


Figure 2-32. Schematic of Jump Out 16 (J16) showing wing walls, escape chute, and landing pad. J16 is the farthest east jump out along the U.S. 33 Nelsonville Bypass in Hocking County, Ohio. Habitat mapping codes are in Table 2-1.

Figure 2-33. Images of Wildlife Underpass 2 (UP2) for large wildlife use, along the U.S. 33 Nelsonville Bypass in Hocking County, Ohio. UP 2 is 125 ft. across with a bottom width of 35 ft. and a maximum height of 9 ft. Aerial photo of UP2 (top) and ground photo (bottom).

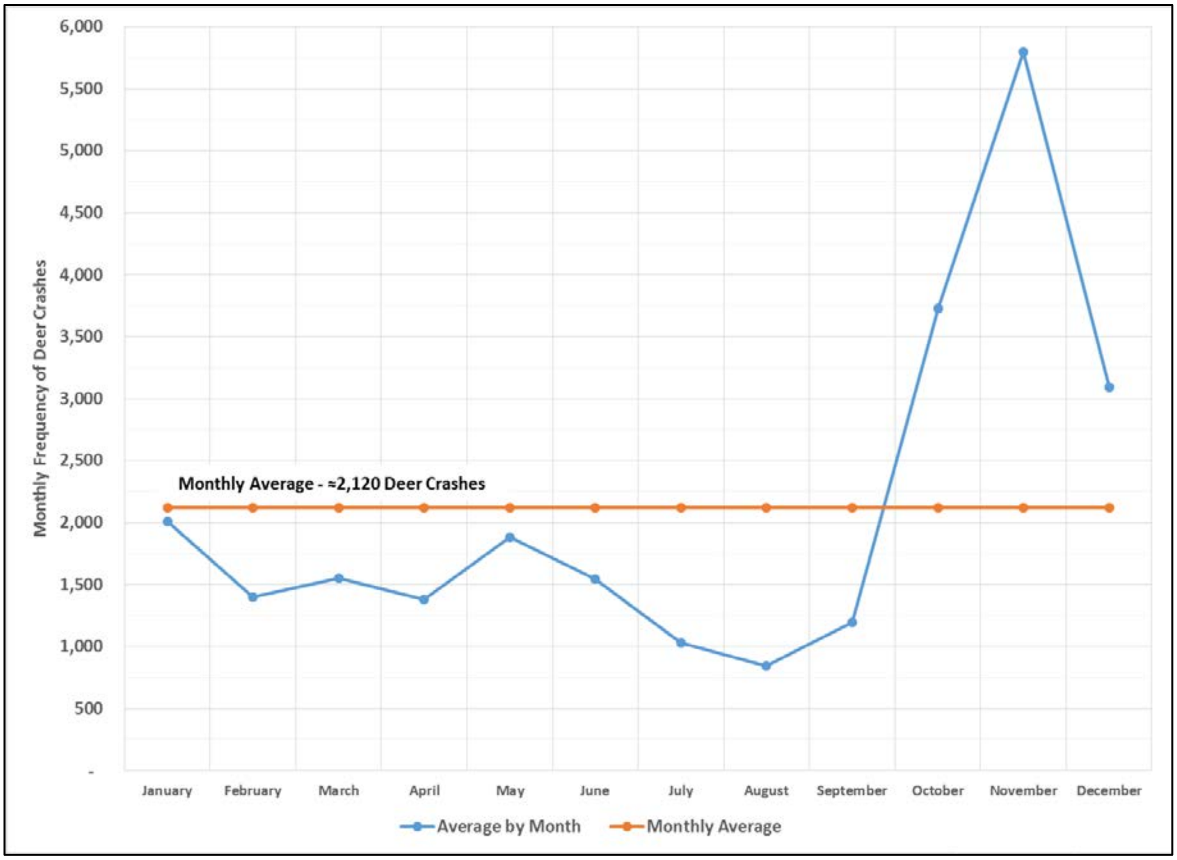


Figure 3-1. Average deer-vehicle crashes by month and annual monthly average for State of Ohio, 2001 – 2015 (Data Source: Ohio Department of Public Safety)

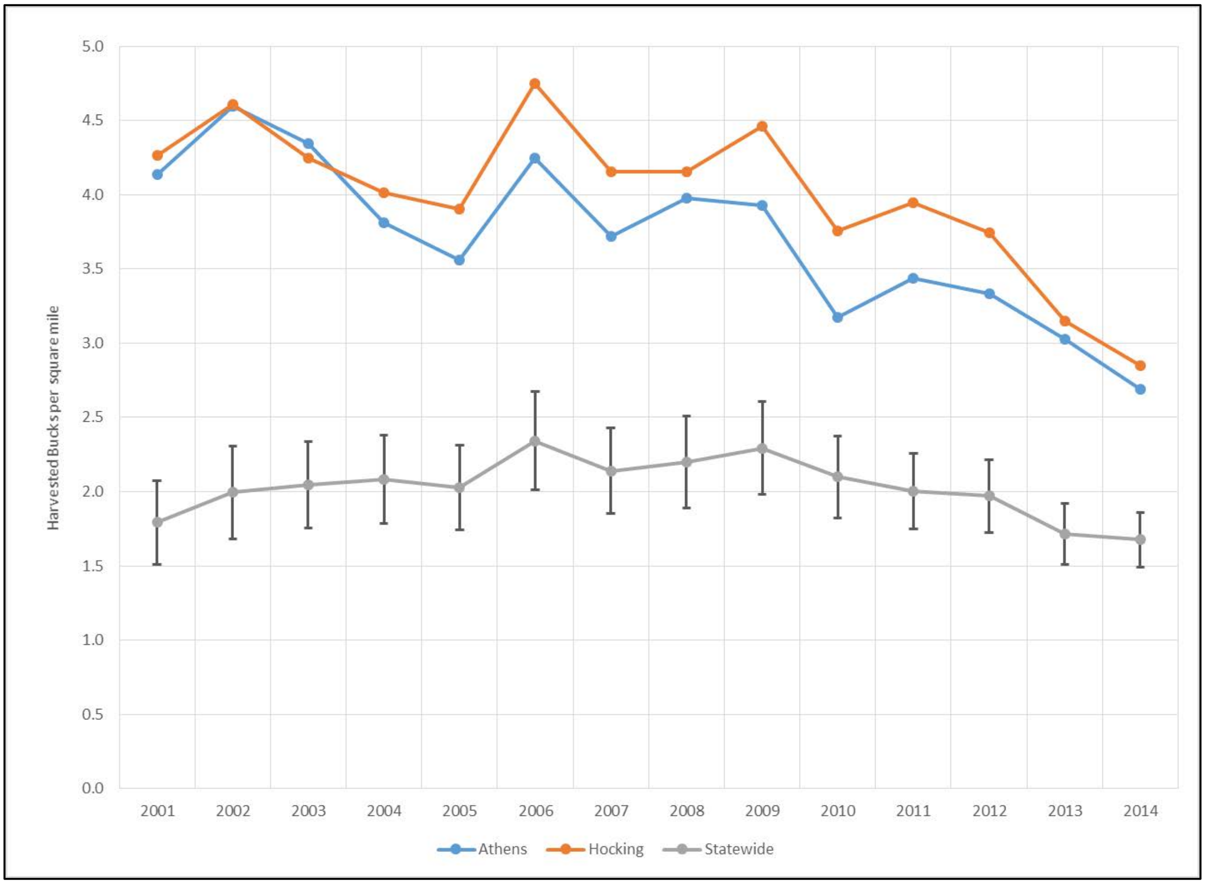


Figure 3-2. Buck harvest data for Ohio (grey), Athens County (blue) and Hocking County (red), 2001 – 2014 (Data Source: Ohio Department of Natural Resources).

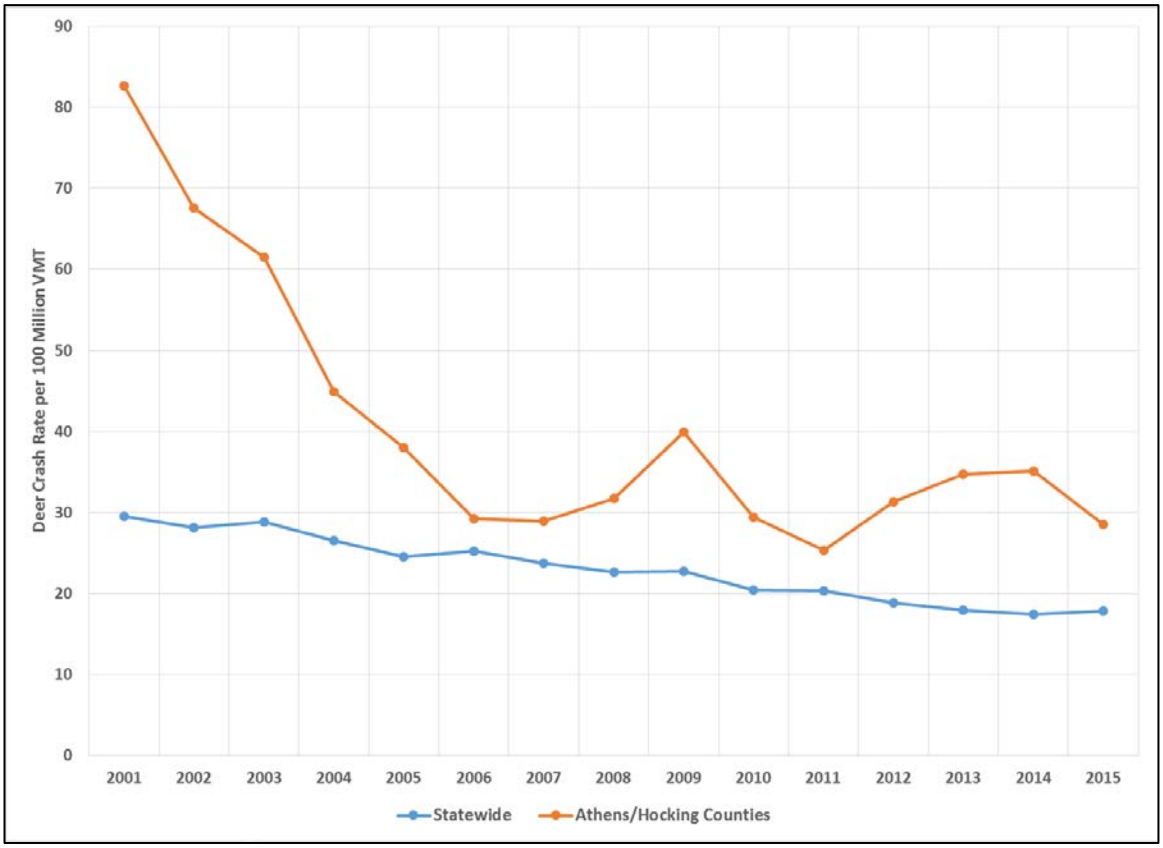


Figure 3-3. Deer-vehicle crashes per 100 million vehicle miles traveled (VMT) for Ohio (blue) and Athens/Hocking Counties combined (red), 2001 – 2015 (Data Source: Ohio Department of Public Safety and Ohio Department of Transportation).

Figure 4-1. White-tailed deer scat. Left - clumped group (diet rich in green forbs) versus Right - pellet group (diet rich in grasses).

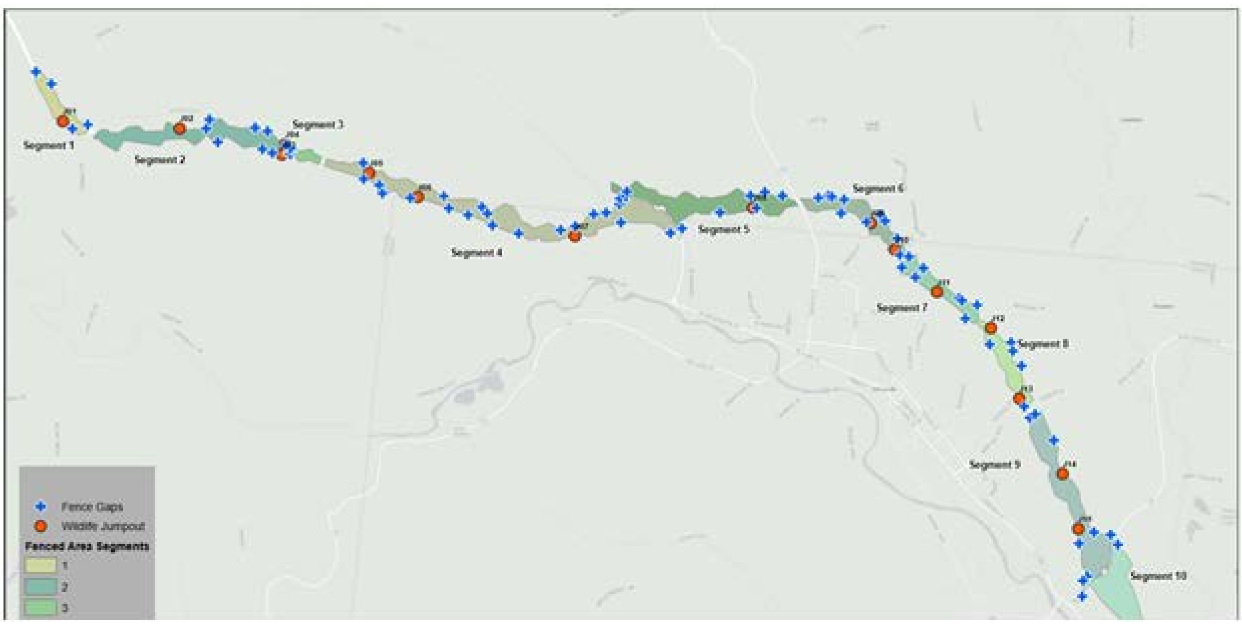


Figure 4-2. Map showing access gaps (blue plus signs) in the 8-ft. tall wildlife exclusion fencing along the U.S. 33 Nelsonville Bypass right-of-way, Athens and Hocking Counties, Ohio.

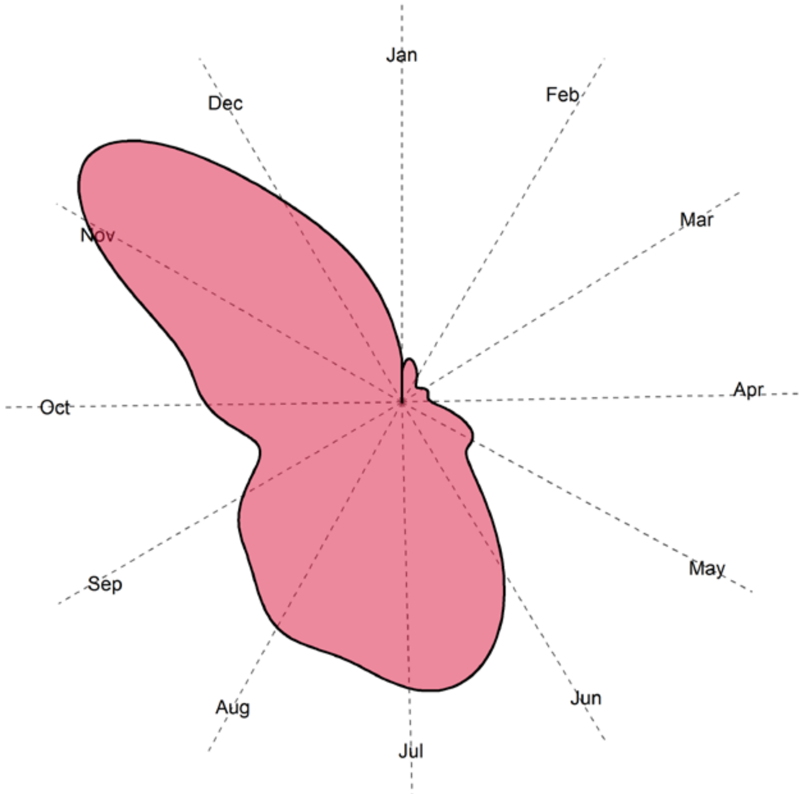


Figure 4-3. Circle plot of seasonal deer movement along the U.S. 33 Nelsonville Bypass. Deer movement is common throughout summer and fall and is highest in November during mating season.

Figure 4-4. Distribution of deer recorded at camera traps between October 1st and December 15th for 2015 (left) and 2016 (right). The peak of deer movement is during November in both years.

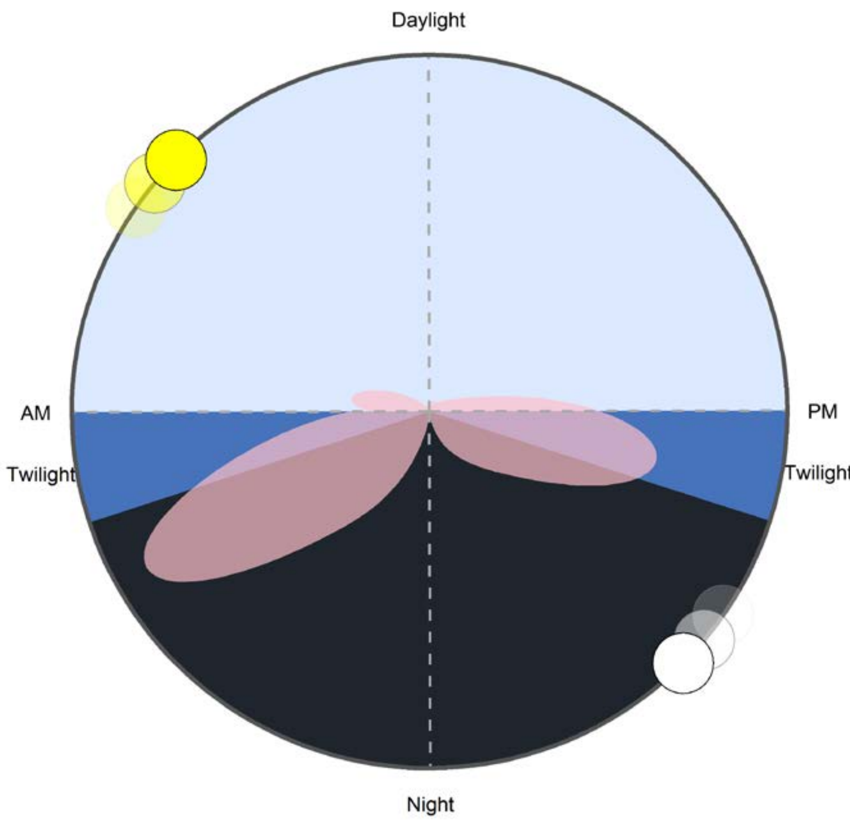


Figure 4-5. Circle plot showing the daily distribution of deer movements along the U.S. 33 Nelsonville Bypass, Athens and Hocking Counties, Ohio. The pink indicates when most deer are mobile; movement peaks are before and during the twilight hours of dawn and during and after the twilight hours of dusk.

Figure 4-6. Distribution of deer recorded at each camera trap along the U.S. 33 Nelsonville Bypass from July 2015 through December 2017. Features labeled ‘J’ denote jump outs; ‘UP’ = wildlife underpass; ‘BB’ = butterfly bridge; ‘F’ = cameras along wildlife fence; ‘Herp2’ = small wildlife ecopassage 1; ‘SU’ = special use (cameras located at fence gaps, culverts and other locations that allow deer access to the right-of-way).

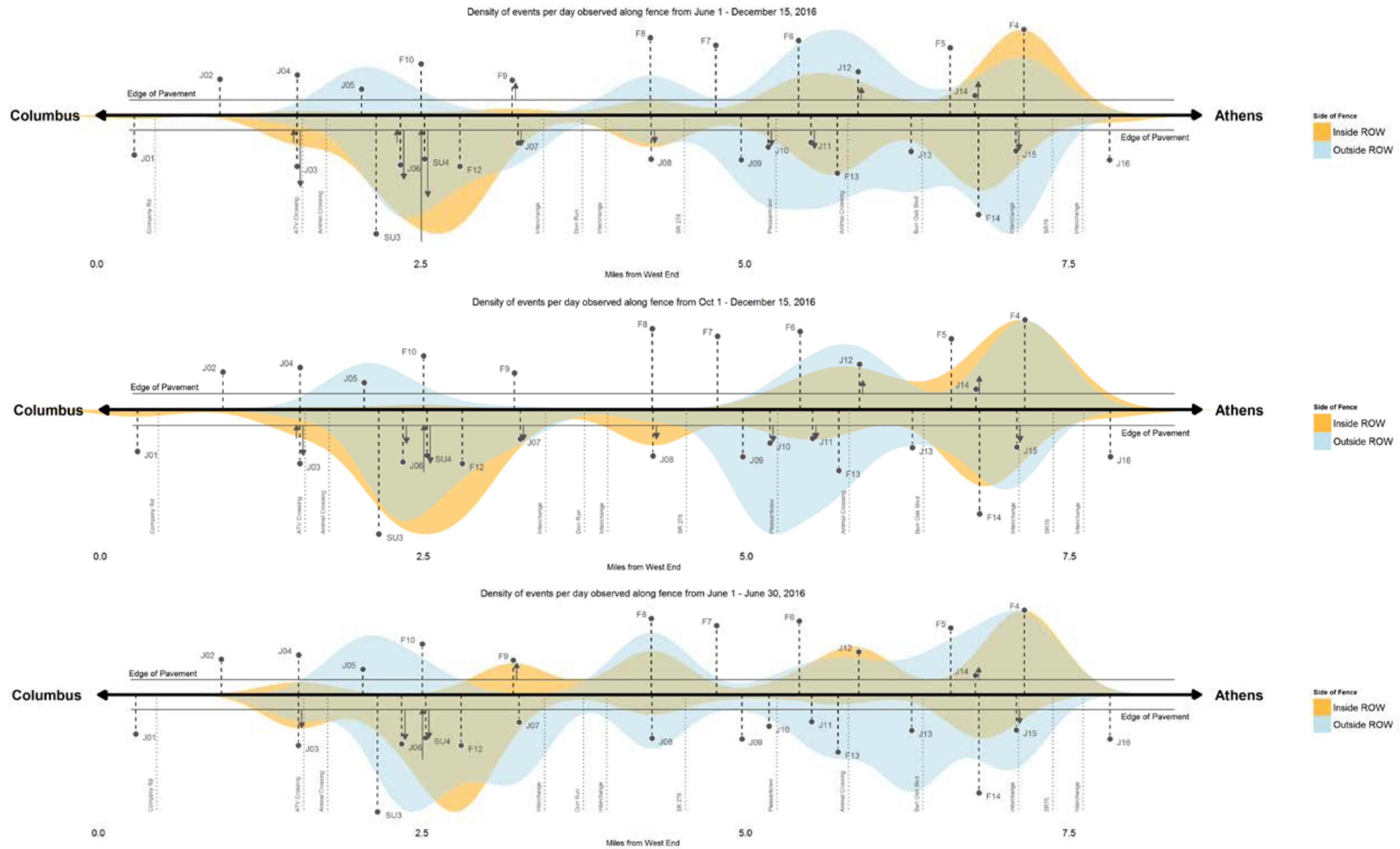


Figure 4-7. Distribution of deer movement events at features along the U.S. 33 Nelsonville Bypass 8-ft. tall wildlife exclusion fence in 2016. Camera traps depicted include: Jump outs (J), sites along the fence (F), and special use areas (SU: cameras located at fence gaps, culverts and other locations that allow deer access to the right-of-way). Data on underpasses and bridges are not added. (Top) Deer movements between June and end of rut period in 2016, thus capturing both movement peaks; (Middle) Deer movements during the 2016 rut season (second seasonal peak); (Bottom) Deer movement during June 2016 (first seasonal peak). Overall, movements outside the right-of-way (ROW) were greater than inside ROW, but there was high variation both spatially and temporally in the magnitude and direction of movement. Movements inside ROW were facilitated by the multitude of wildlife fence gaps.

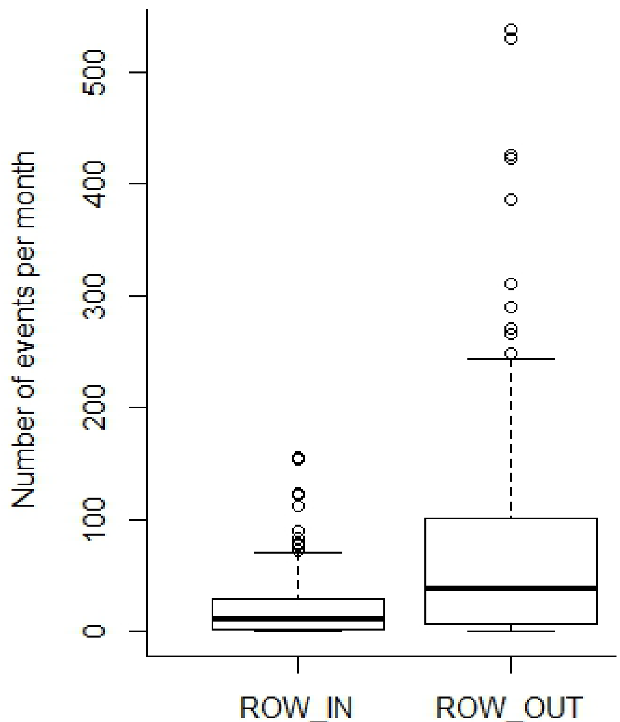


Figure 4-8. Number of deer events per month predicted to be inside the right-of-way (ROW_IN) or outside of the right-of-way (ROW_OUT). While most months and camera locations had <100 events, the peak months had noticeably higher use (500+ events at Jump out 12).

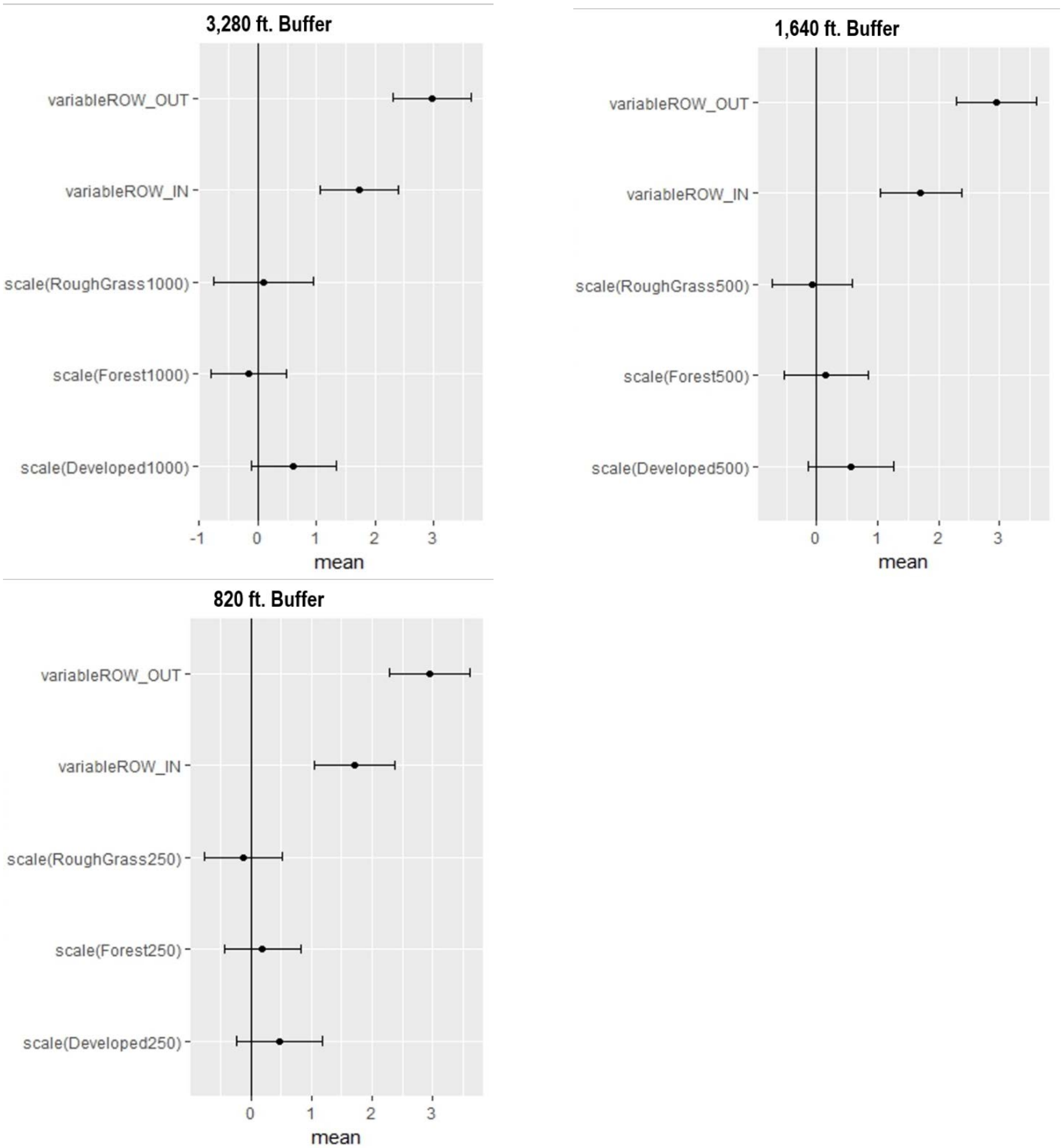


Figure 4-9. Model-averaged coefficients for variables used to predict movement and use of inside and outside right-of-way (ROW) habitats. Variables *RoughGrass*, *Forest* and *Developed* refer to % of those land cover types within 820, 1,640, or 3,280 ft. buffers centered on camera locations. Black dots to the right of the black vertical line denote positive association of habitat variables with deer use, and magnitude of difference (on a log scale) between inside right-of-way (ROW_IN) and outside right-of-way (ROW_OUT) deer events at camera traps. Variables with a *mean* close to 0 and confidence intervals extending well beyond the vertical line are poor predictors of deer movement; *%Developed* is the only variable showing a positive and consistent relation with deer movement along the wildlife fence, in particular within 3,280 ft. from cameras. Coefficients for ROW_IN and ROW_OUT show that there are a higher mean number of deer events per camera outside the ROW.

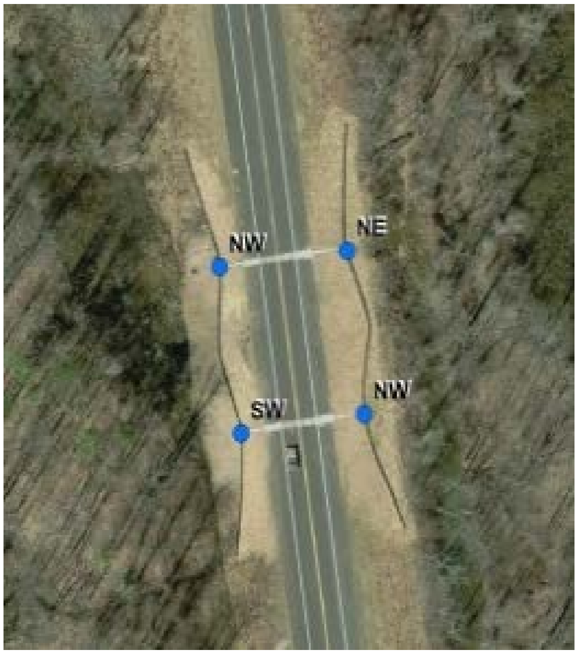


Figure 5-1. Aerial view of the barrier-ecopassage system in place along State Route 78, Athens County, Ohio.

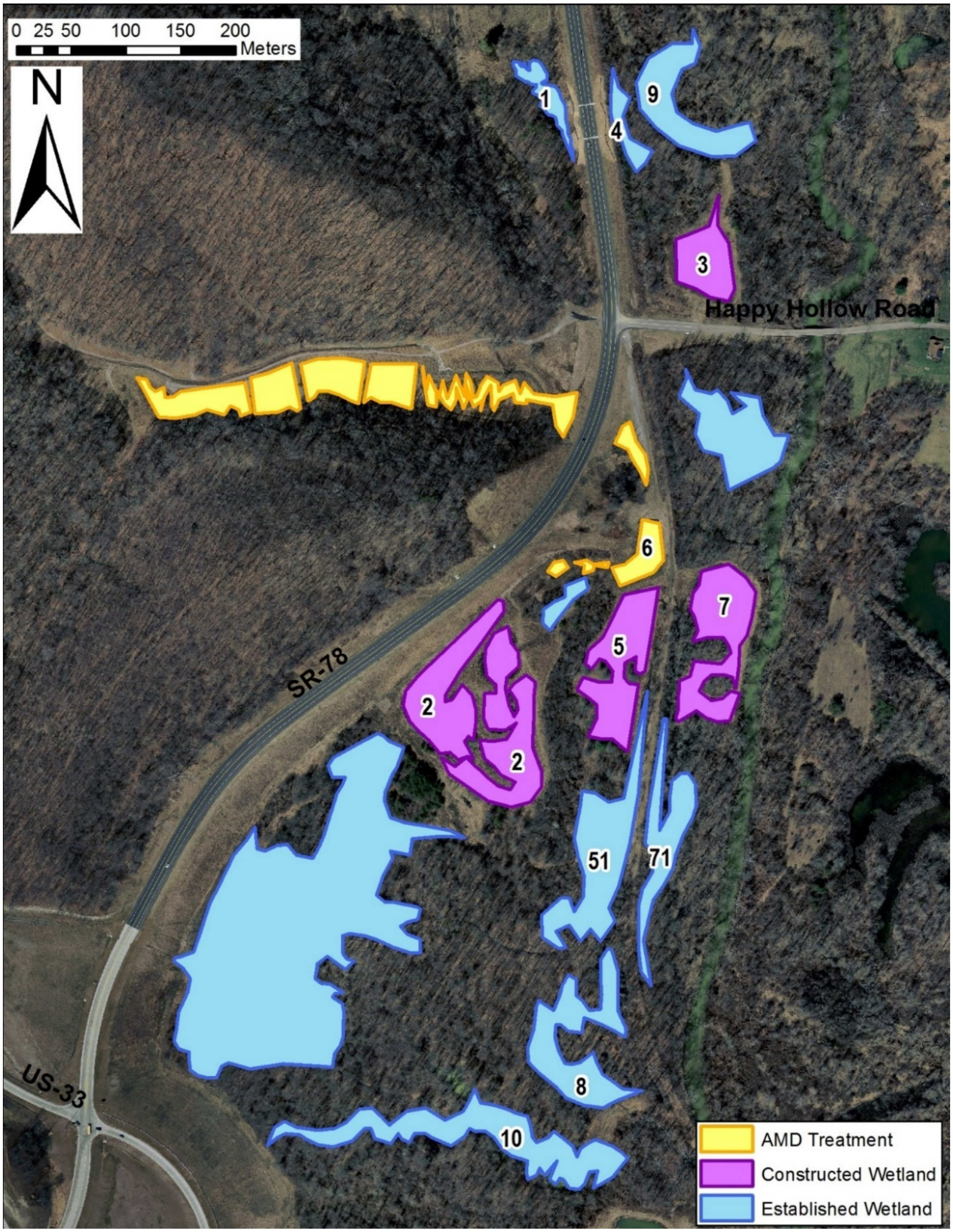


Figure 5-2. Map of wetlands along the State Route 78 section of the Nelsonville Bypass, Athens County, Ohio. Yellow wetlands are part of the Coe Hollow Acid Mine Drainage (AMD) Treatment Project, purple wetlands were constructed by the Ohio Department of Transportation in 2009 as mitigation, and blue wetlands are naturally occurring established wetlands. Wetland identification numbers, for wetlands that maintain productive standing water for amphibians, are labelled in this figure.

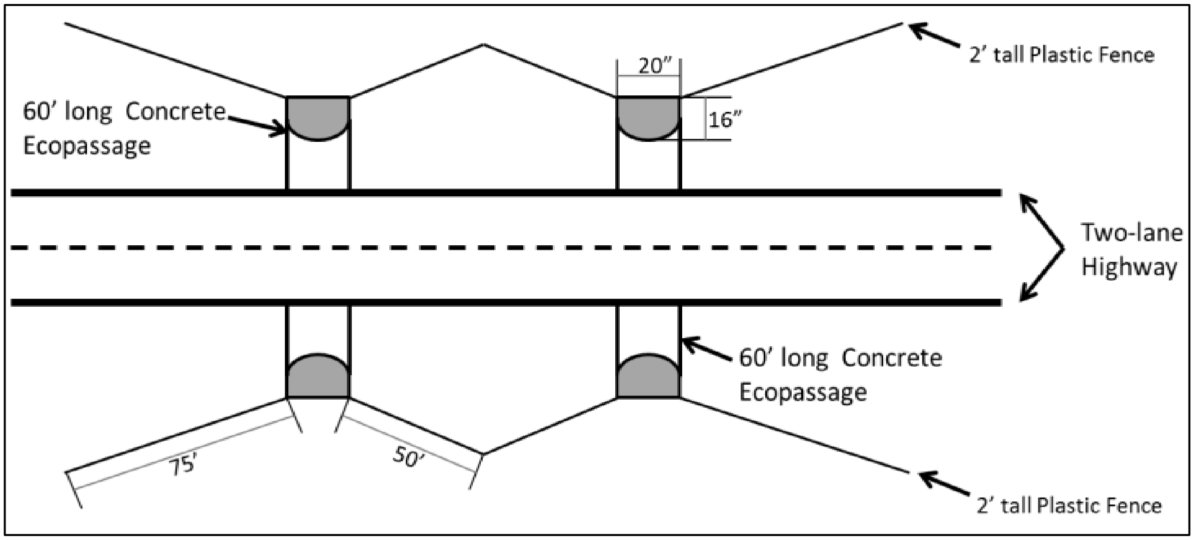


Figure 5-3. Diagram of barrier-ecopassage system along State Route 78, Athens County, Ohio.


Figure 5-4. Images of the ecopassage opening (left), ecopassage crossing under the road, perforations in the top can be seen (middle), and curved plastic fencing (right) in place along State Route 78, Athens County, Ohio.

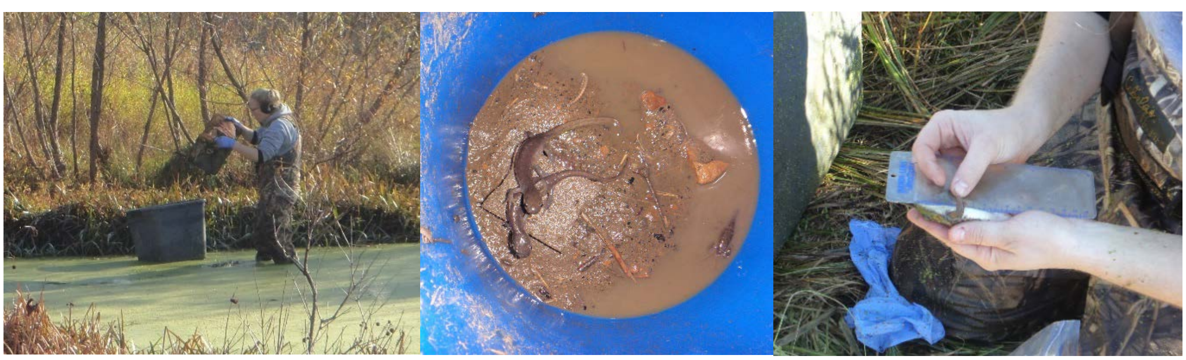


Figure 5-5. Images of C. B. Hopkins checking a minnow trap (left), two Jefferson Salamanders in a pitfall trap (middle), and a Green Frog being measured (right).

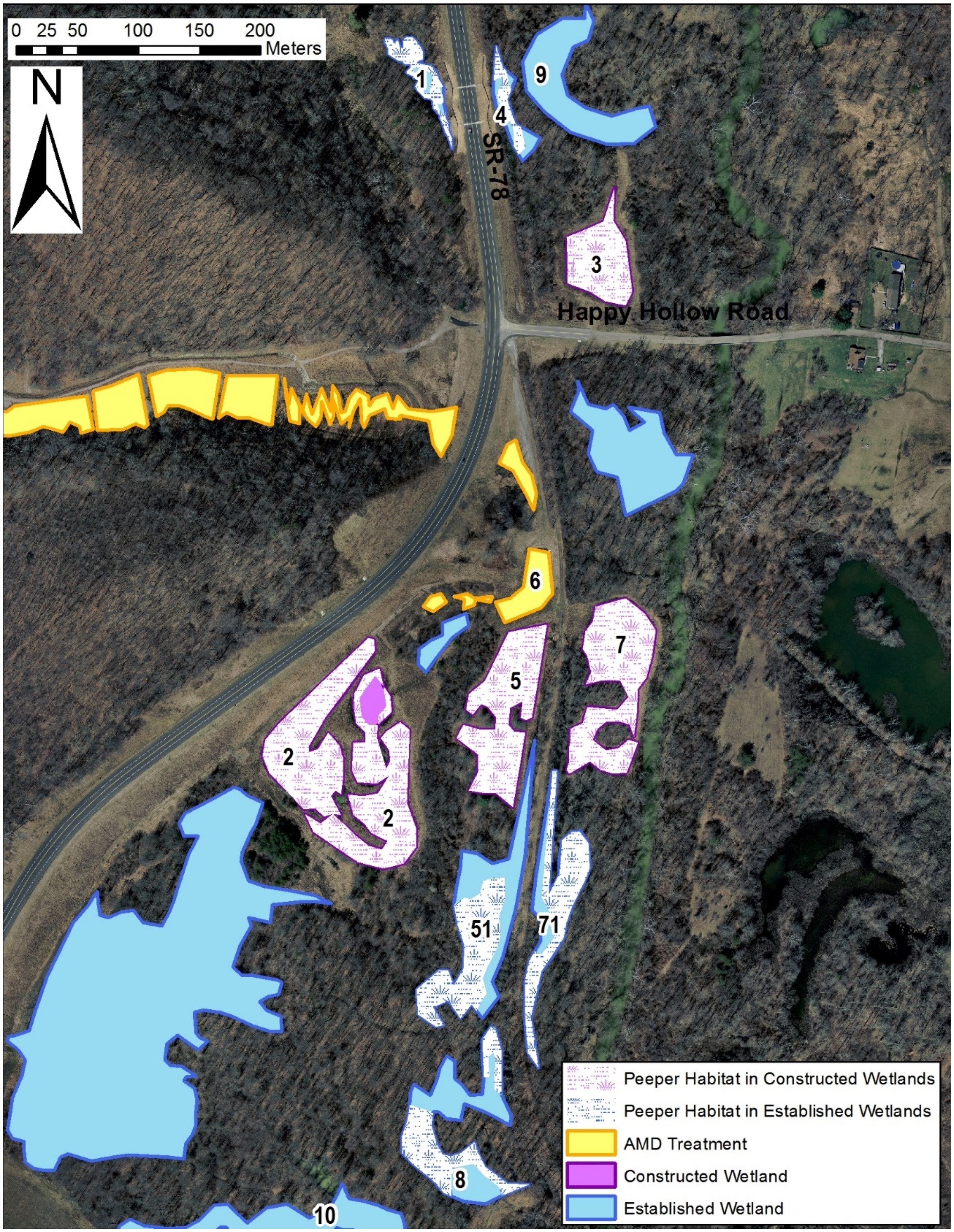
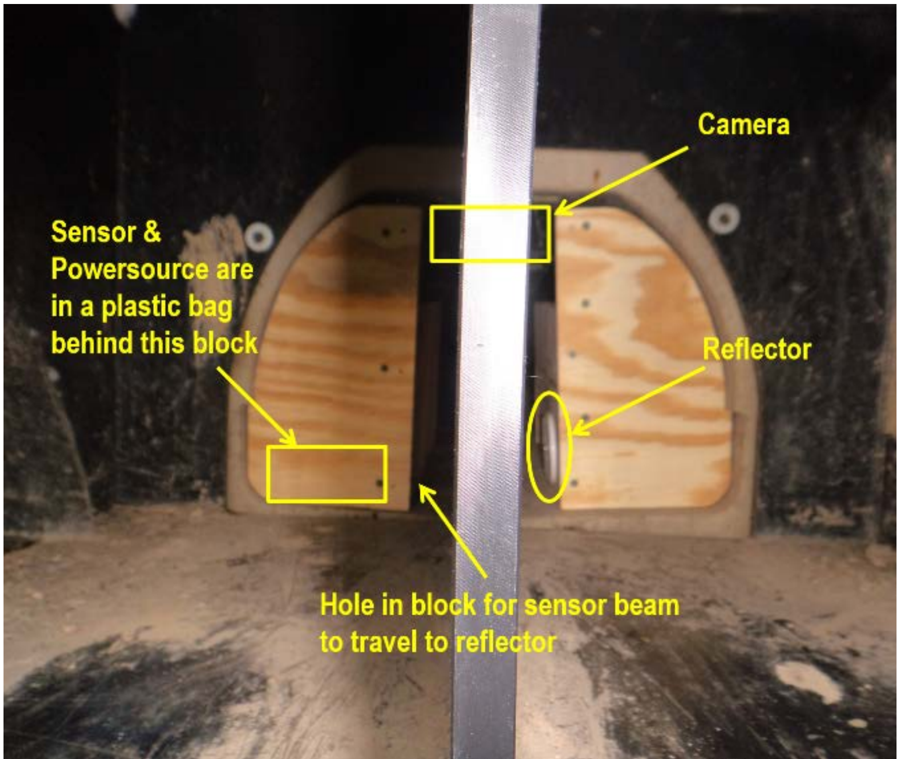


Figure 5-6. Map of wetlands along the State Route 78 section of the Nelsonville Bypass, Athens County, Ohio that have suitable Spring Peeper breeding habitat. Wetland identification numbers, for wetlands that maintain productive standing water for amphibians, are labelled in this figure. No suitable Spring Peeper breeding habitat was found in wetlands 6, 9, and 10.

Figure 5-7. Aerial image showing placement of the four barrier pitfall traps (left) and image of volunteer M. Ingle checking a pitfall trap (right).



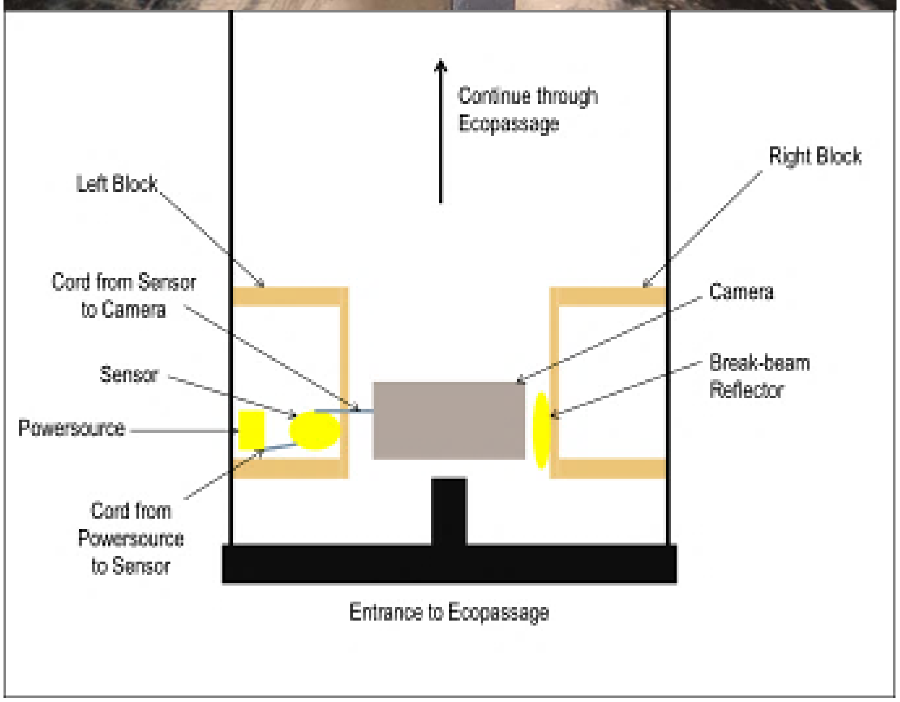


Figure 5-8. Image of the camera system in place in the ecopassages along State Route 78, Athens County, Ohio (top) and schematic of the camera system from a top-down view (bottom).

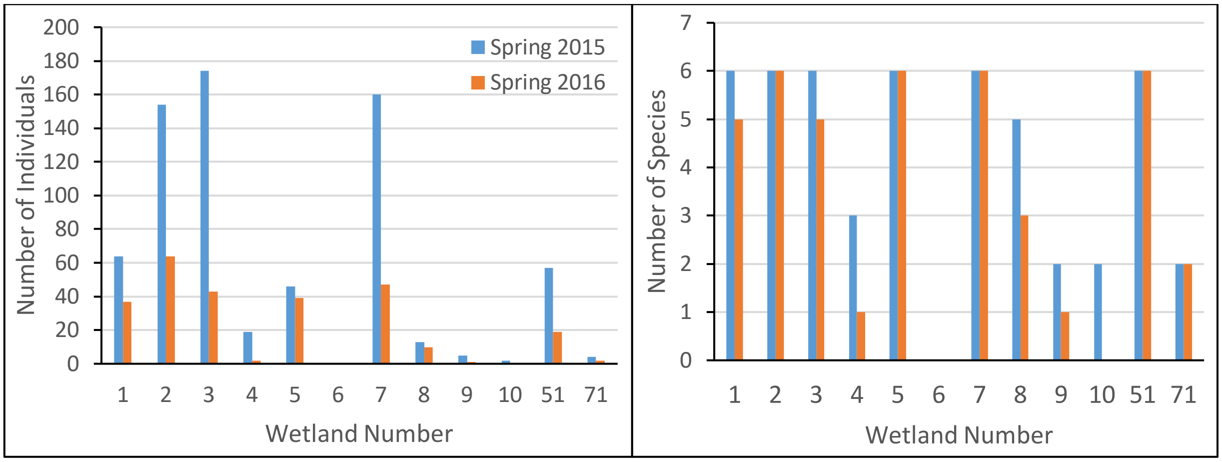


Figure 5-9. The number of individual adult amphibians (left) and the number of amphibian species (right) captured in minnow traps in each wetland during spring 2015 and spring 2016 (wetland 10 was not minnow trapped in 2016). Wetland numbers are provided in Figure 5-2.

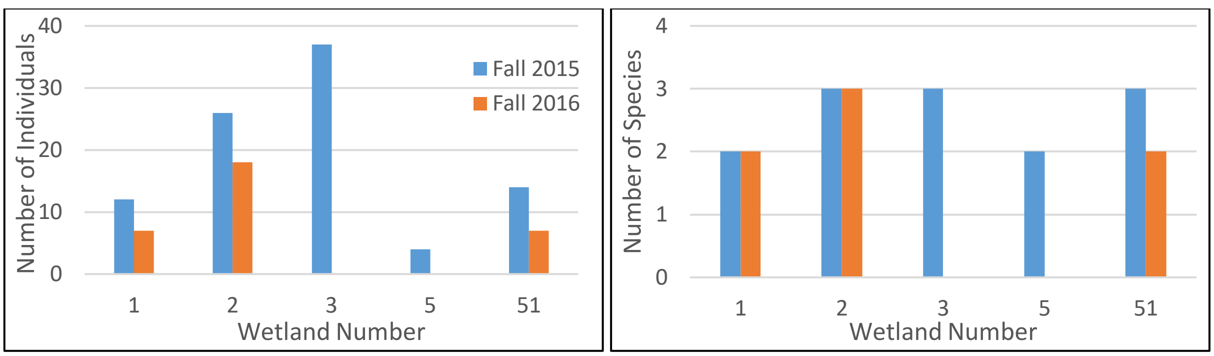


Figure 5-10. The number of individual adult amphibians (left) and the number of amphibian species (right) captured in minnow traps in each wetland during fall 2015 and fall 2016 (Wetlands 3 and 5 were dry in the fall of 2016). Wetland numbers are provided in Figure 5-2.

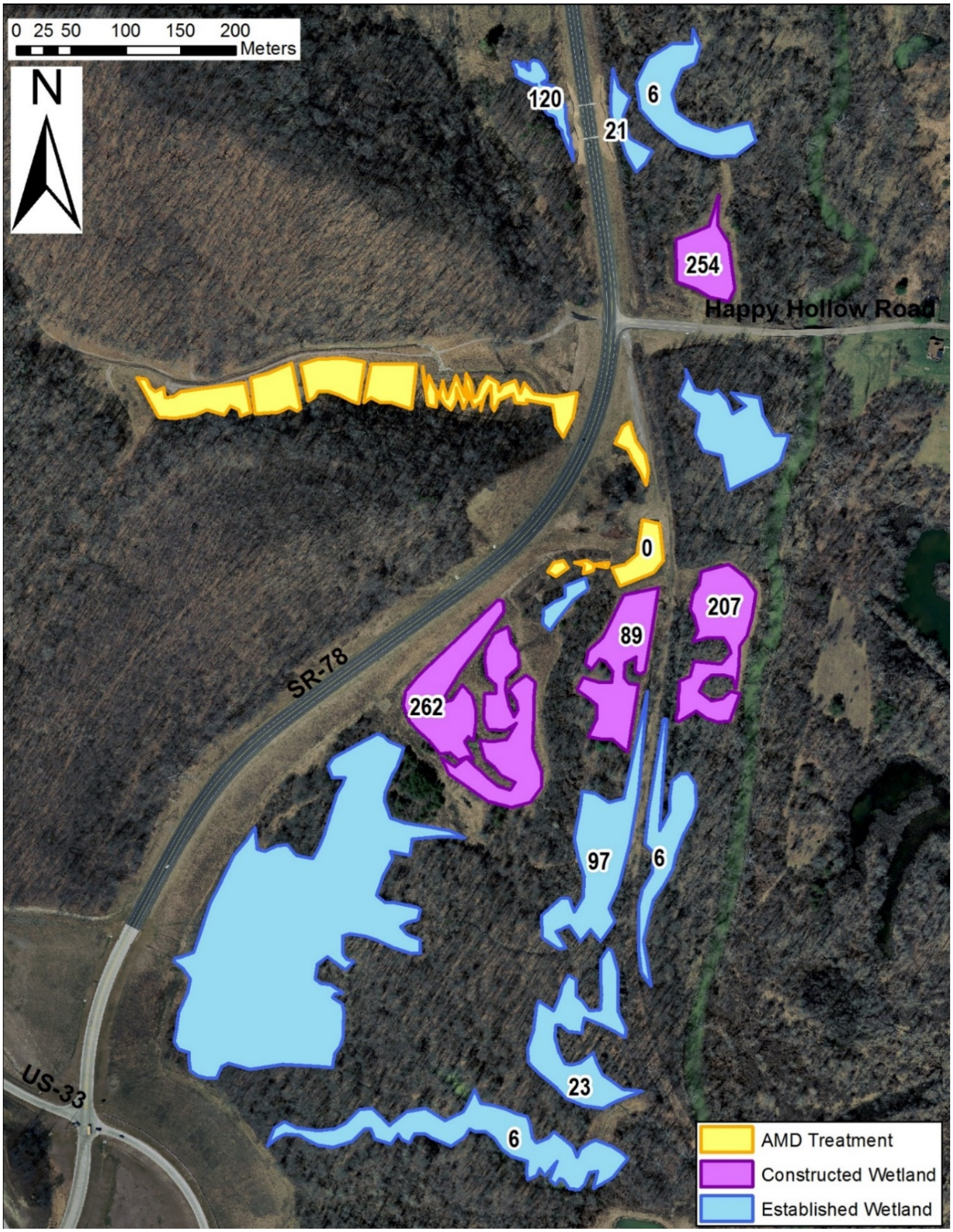


Figure 5-11. Map of wetlands along the State Route 78 section of the Nelsonville Bypass, Athens County, Ohio with the number of individual adult amphibians captured in 2015 and 2016 via minnow traps provided in the center of each wetland. Unnumbered wetlands were not minnow trapped due to lack of standing water for amphibians.

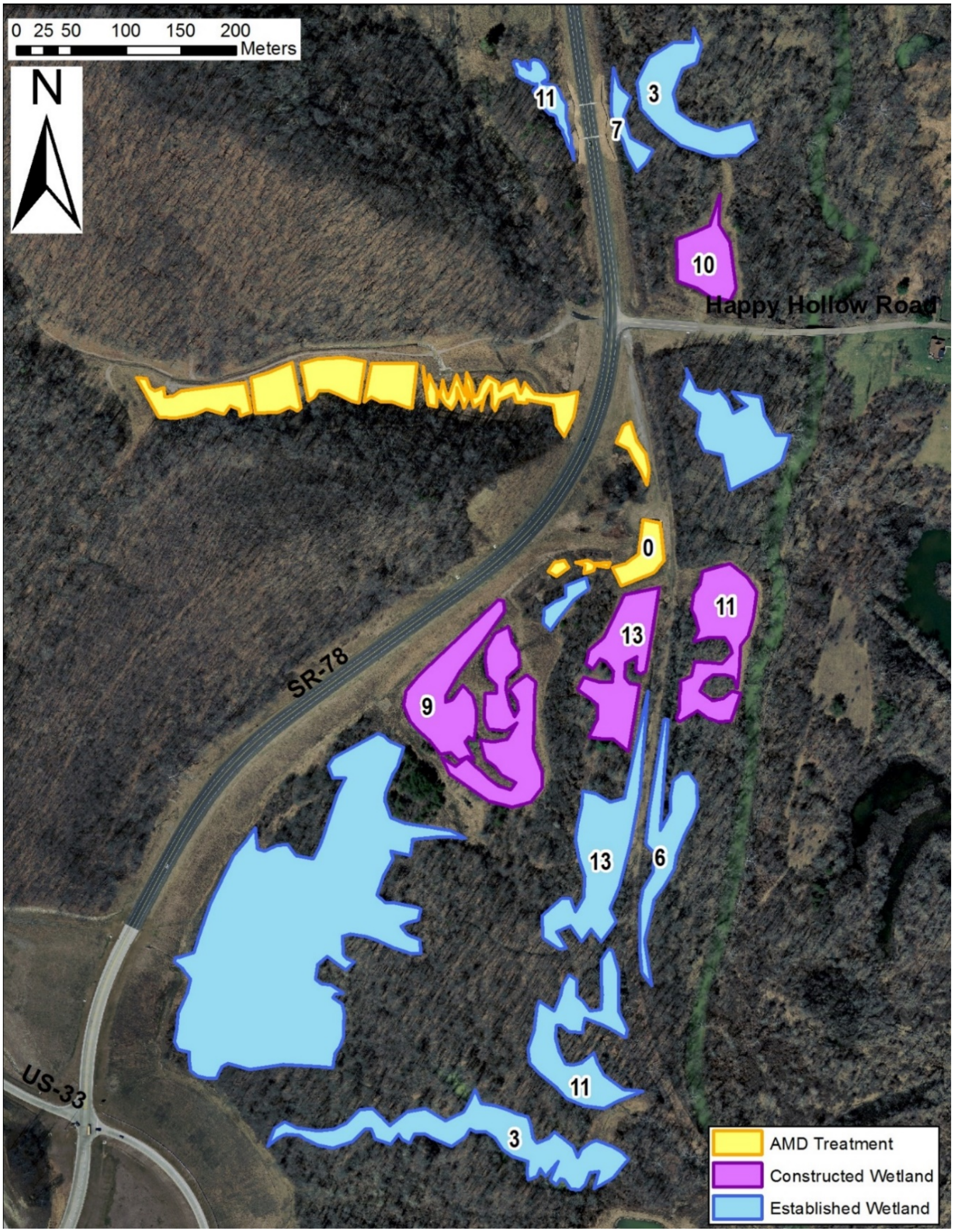


Figure 5-12. Map of wetlands along the State Route 78 section of the Nelsonville Bypass, Athens County, Ohio with the number of amphibian species, of all life stages, captured in 2015 and 2016 via minnow trapping and dip netting provided in the center of each wetland. Unnumbered wetlands were not surveyed due to lack of standing water for breeding amphibians.

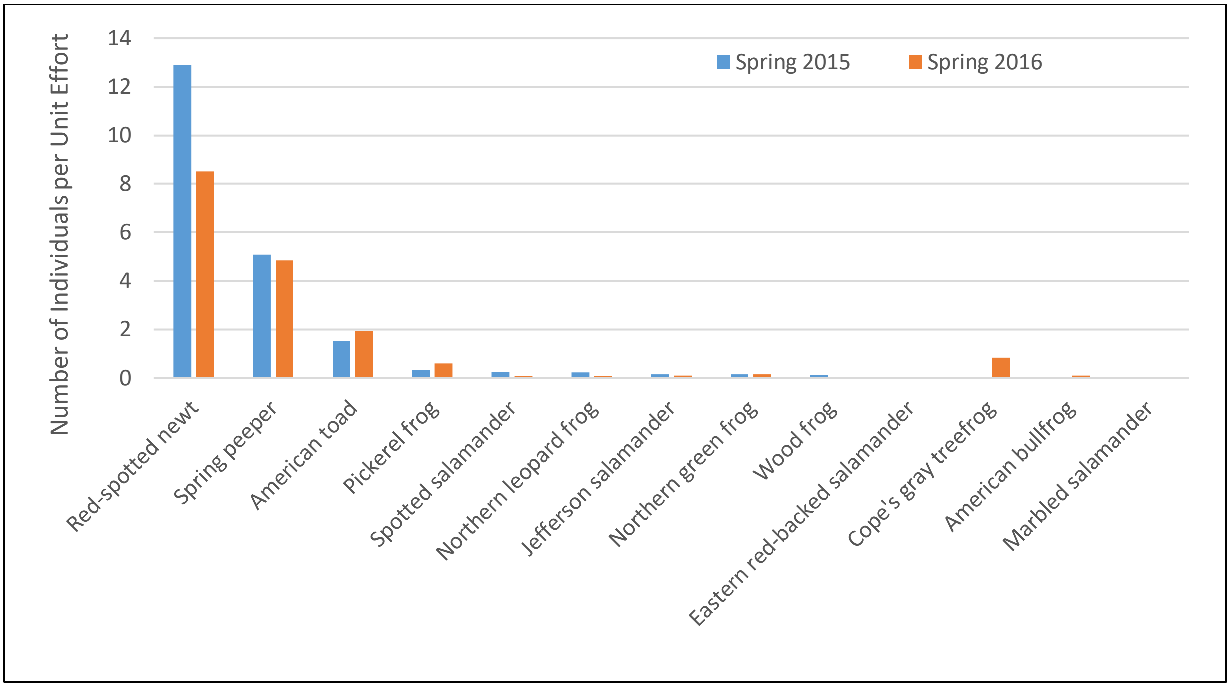


Figure 5-13. Number of individuals of each species captured per unit of effort during spot light surveys in spring 2015 and spring 2016.

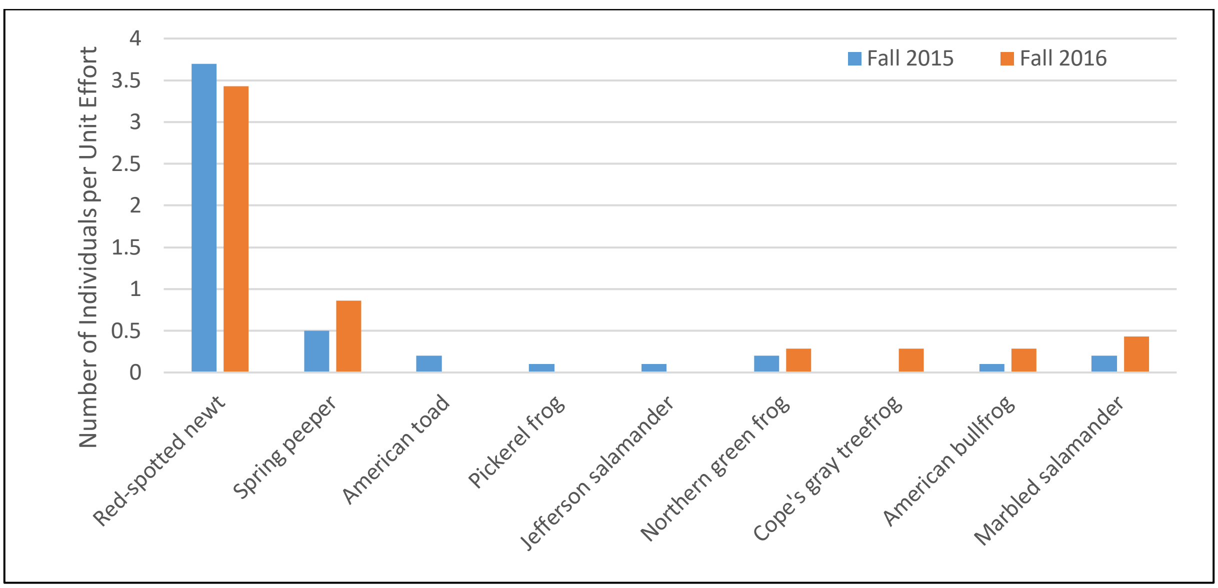


Figure 5-14. Number of individuals of each species captured per unit of effort during spot light surveys in fall 2015 and fall 2016.

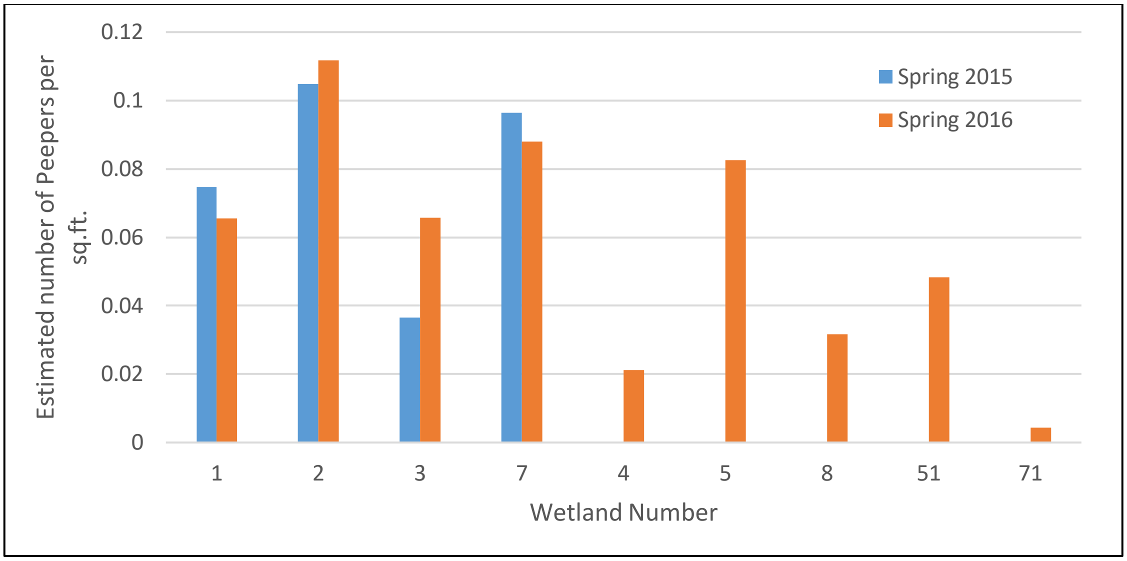


Figure 5-15. Estimated number of Spring Peepers per square foot for wetlands surveyed in spring 2015 and spring 2016. Wetlands 4, 5, 8, 51, and 71 were not sampled in 2015. Wetland numbers are provided in Figure 5-2 and Figure 5-6.

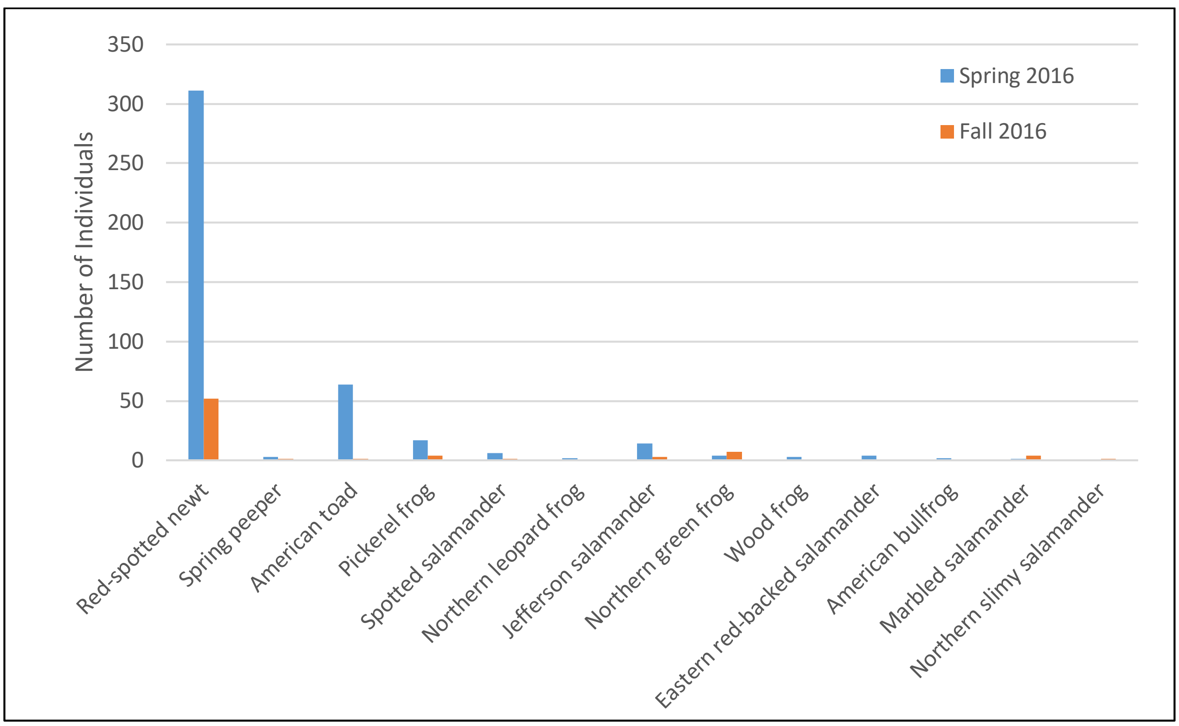


Figure 5-16. Number of individuals captured in pitfall traps by species for spring 2016 and fall 2016.

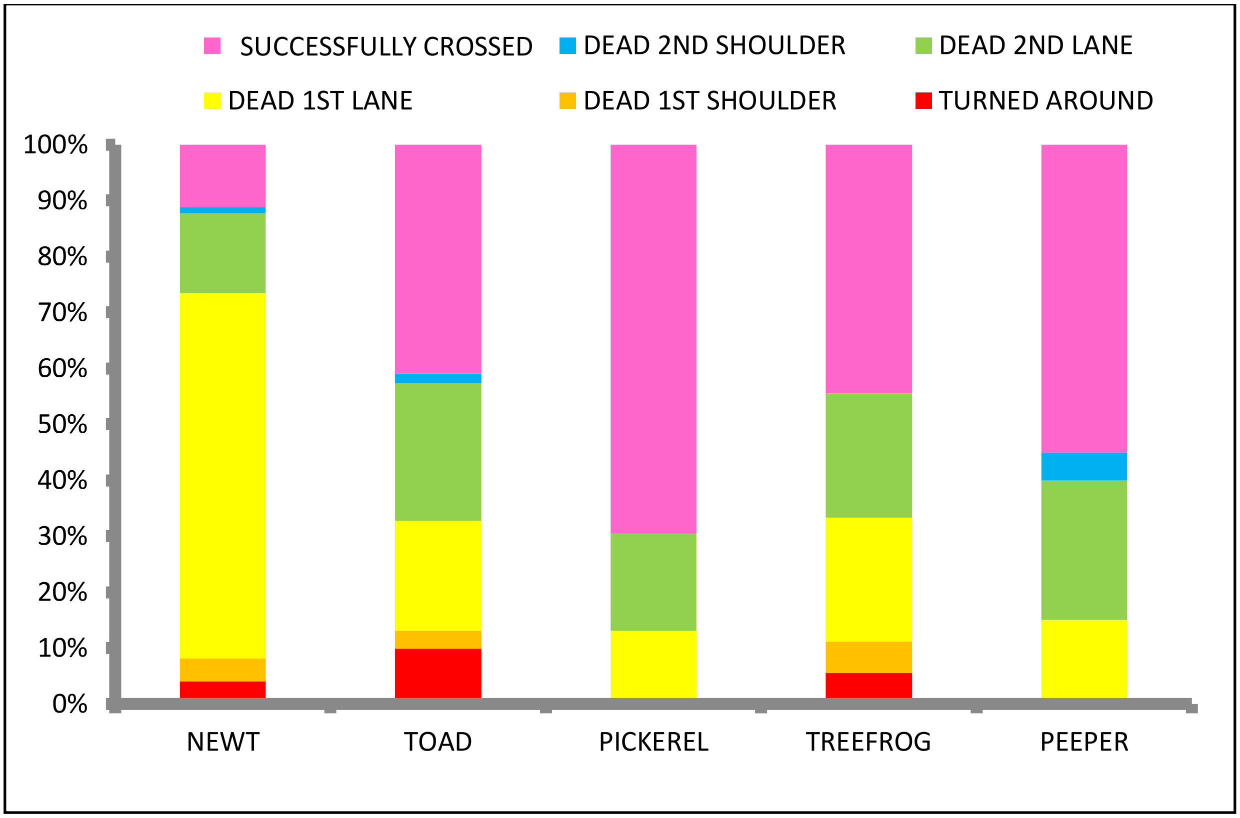


Figure 5-17. Percentage of individuals observed that successfully crossed the road, turned around and aborted the crossing attempt, or died for each of five species (Red-spotted Newt, American Toad, Pickerel Frog, Gray Treefrog, and Spring Peeper).

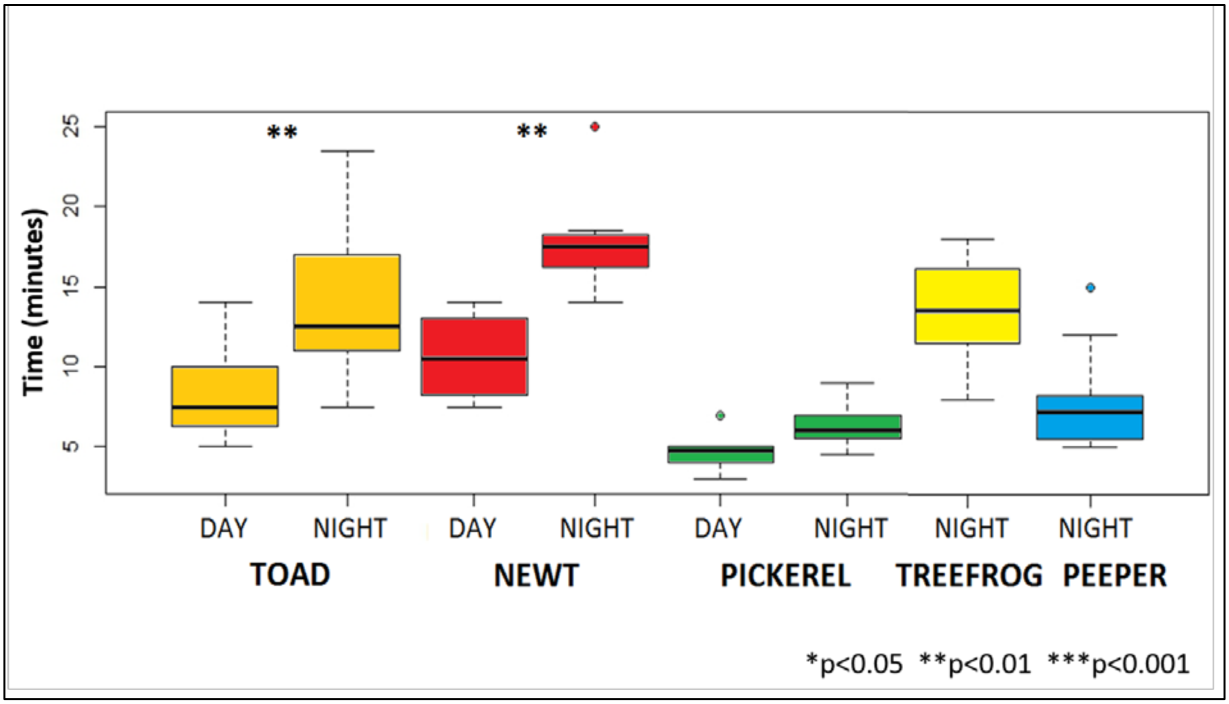


Figure 5-18. Box plot showing the time in minutes it took each species (American Toad, Red-spotted Newt, Pickerel Frog, Gray Treefrog, and Spring Peeper) to cross the road during the day or at night. Stars indicate significant differences between night and day crossing times.

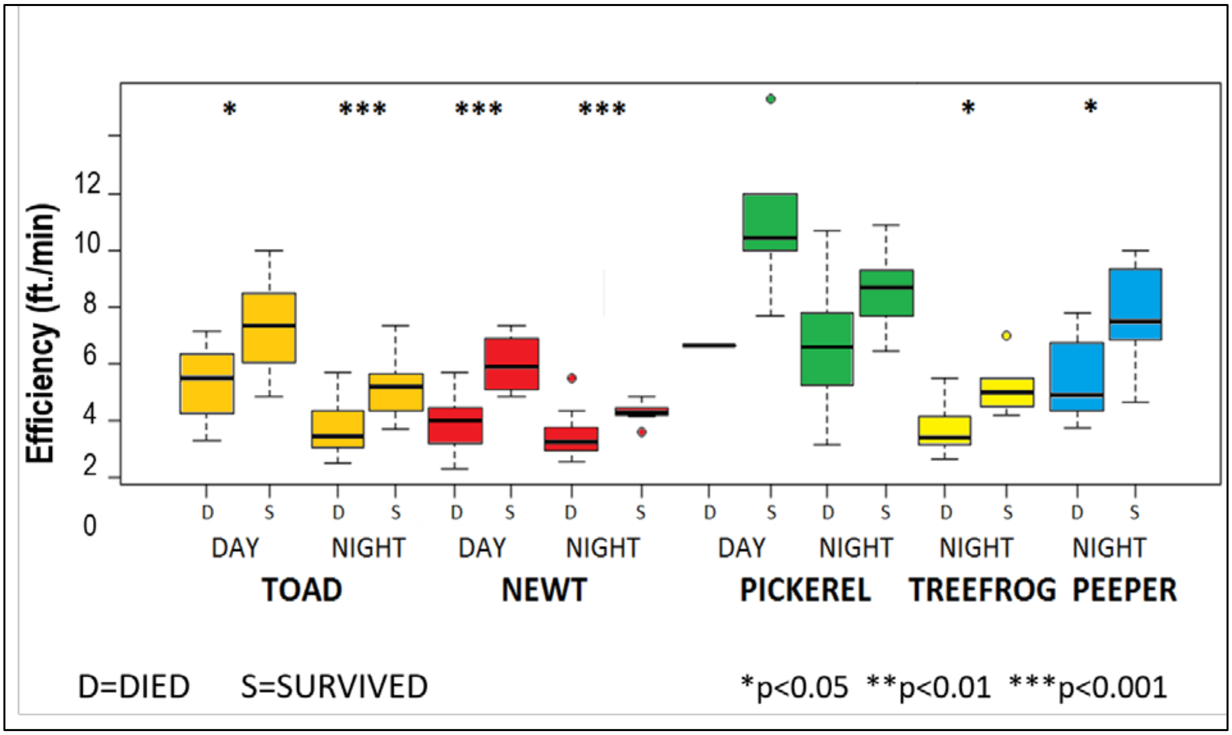


Figure 5-19. Box plot showing the efficiency of road crossing by individual amphibians of five species (American Toad, Red-spotted Newt, Pickerel Frog, Gray Treefrog, and Spring Peeper) in total roadway feet crossed per minute. Efficiency is shown for animals that died crossing (D) and those that survived crossing (S) during the day or night for each species. Stars indicate significant differences between individuals that died and those that survived.

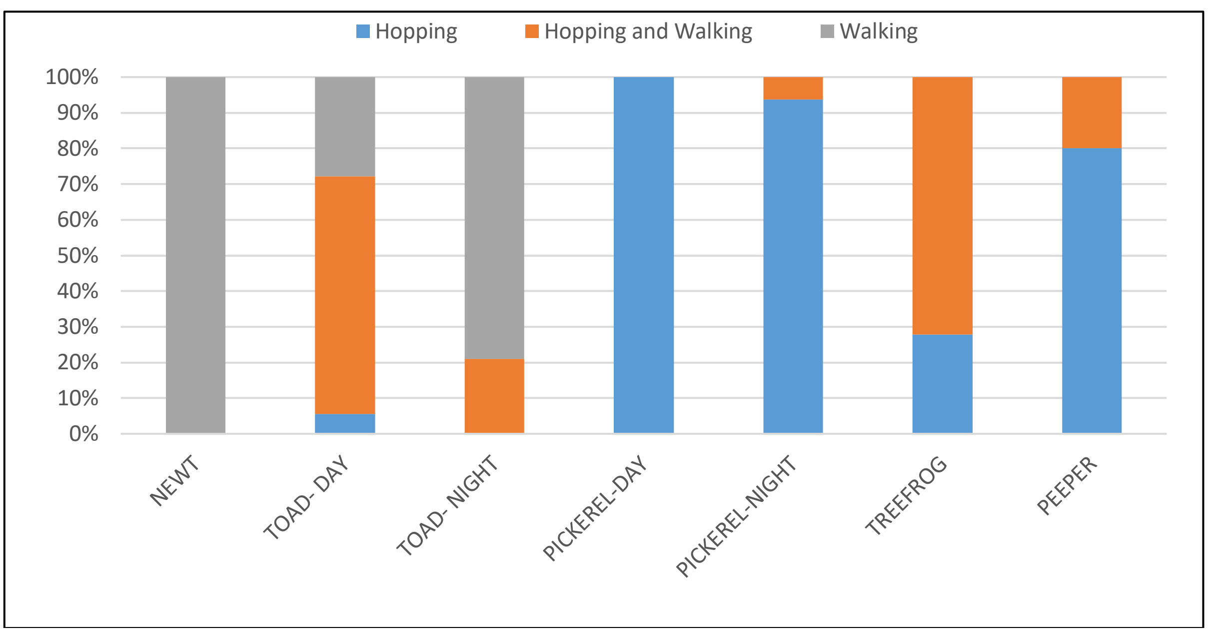


Figure 5-20. Percentage of individual amphibians observed that hopped only, hopped and walked, and walked only for five species (American Toad, Red-spotted Newt, Pickerel Frog, Gray Treefrog, and Spring Peeper).

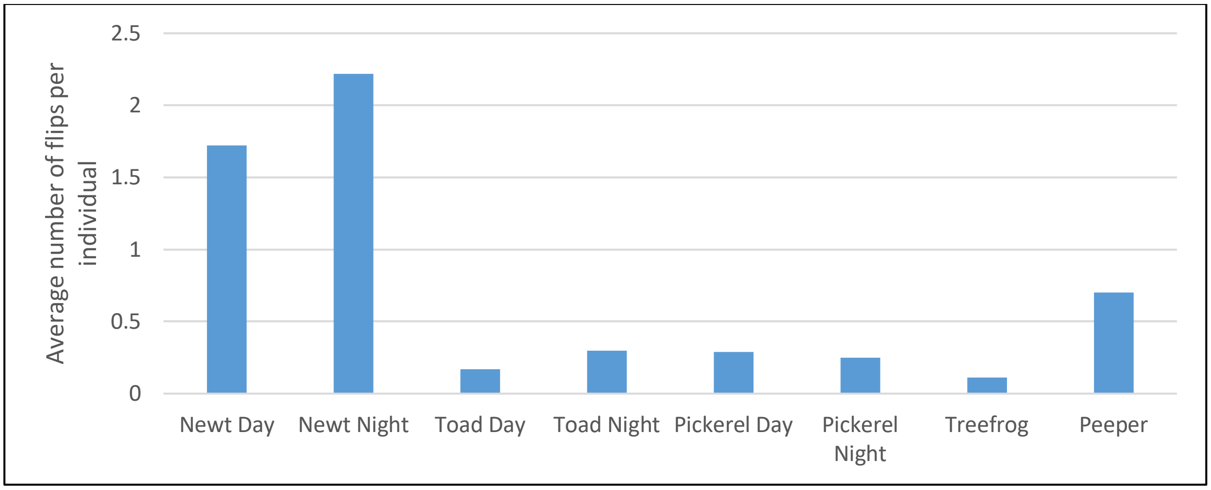


Figure 5-21. Average number of times an individual amphibian was flipped by a passing car by species and time of day for five species (American Toad, Red-spotted Newt, Pickerel Frog, Gray Treefrog, and Spring Peeper).

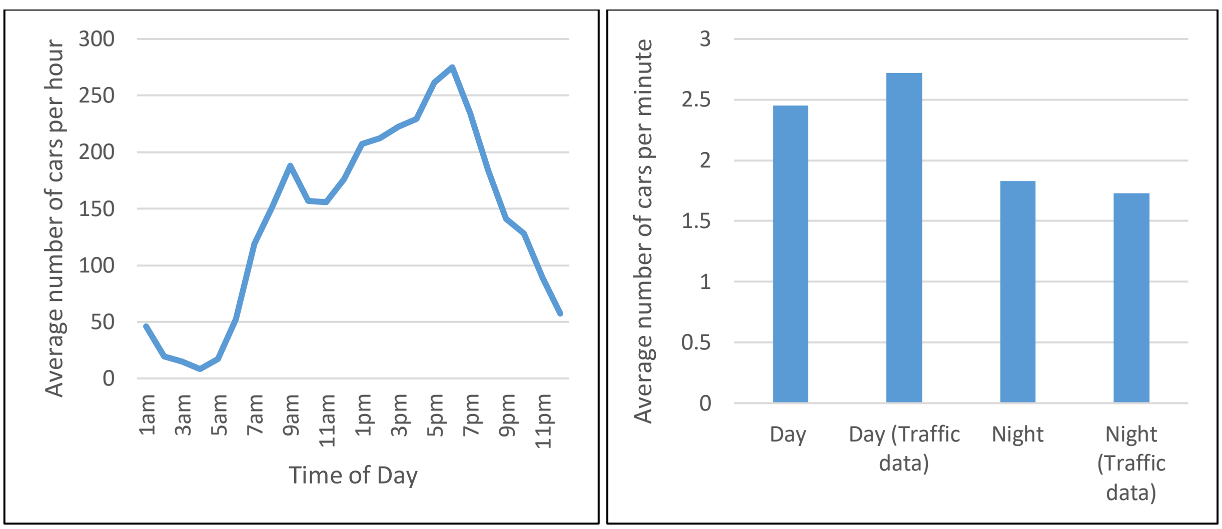


Figure 5-22. Average number of cars per hour along State Route 78, Athens County, Ohio by time of day (left) and average number of cars per minute calculated for day and night, using cars counted during behavioral observations and from traffic data (right).

Figure 5-23. Amphibian carcasses (Spring Peeper-far left, Spotted Salamander-middle left, Red-spotted Newt-middle right, and Pickerel Frog-far right) found along State Route 78, Athens County, Ohio.

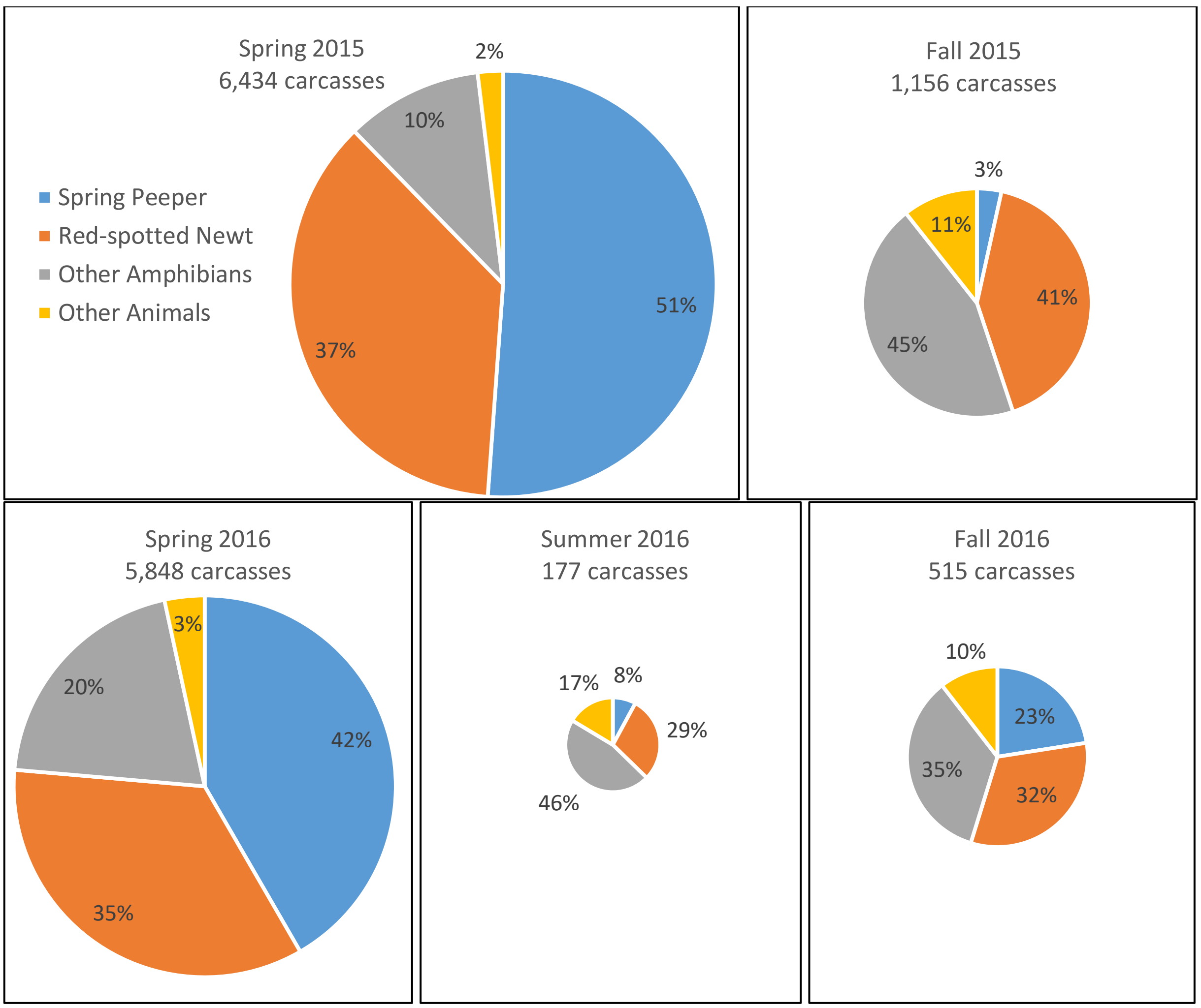
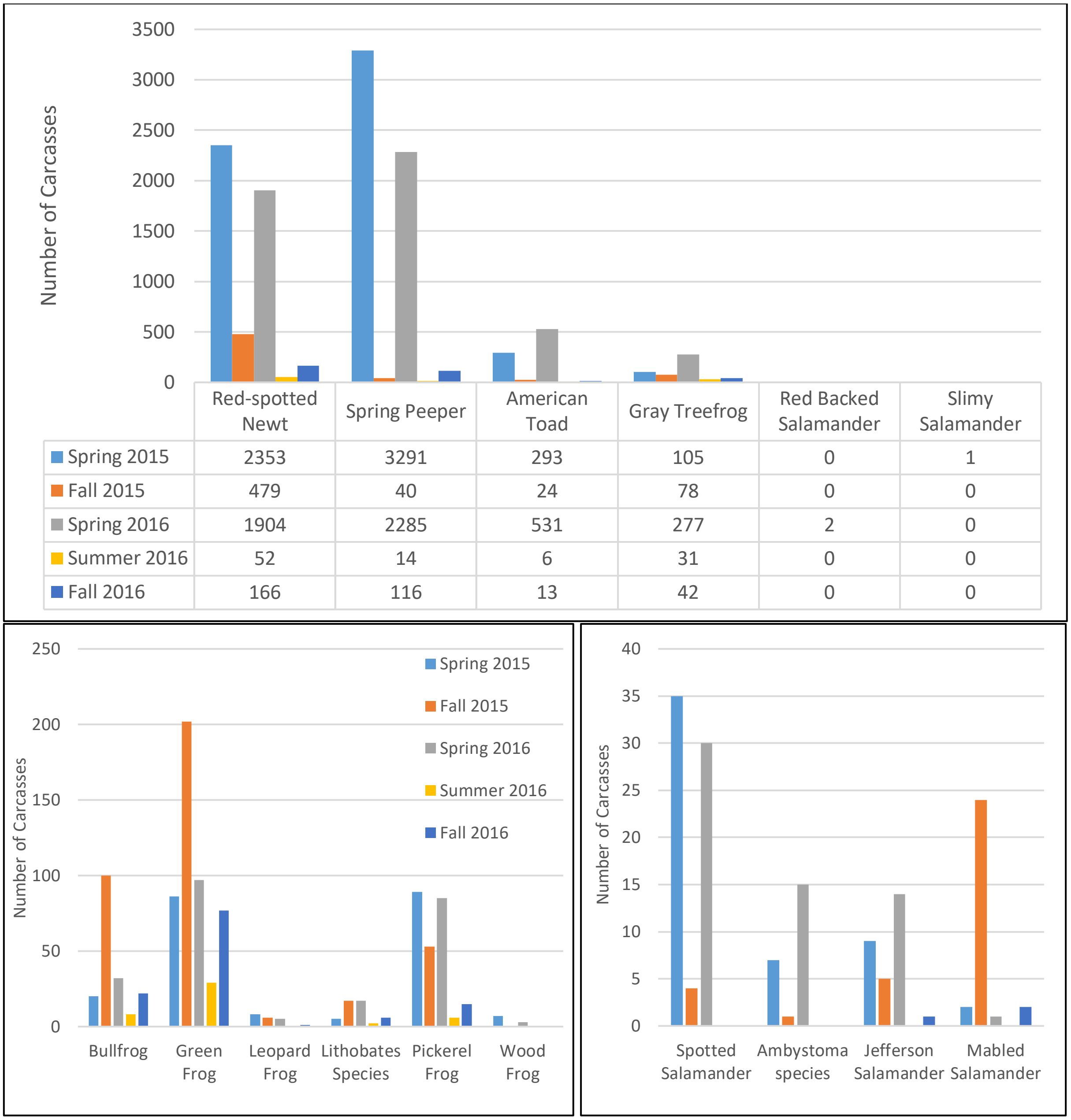


Figure 5-24. Percentage of carcasses found that were Spring Peepers, Red-spotted Newts, Other amphibians, and Other animals by season for 2015 and 2016. Chart size is scaled to the total number of carcasses recovered.



	Red-spotted Newt	Spring Peeper	American Toad	Gray Treefrog	Red Backed Salamander	Slimy Salamander
Spring 2015	2353	3291	293	105	0	1
Fall 2015	479	40	24	78	0	0
Spring 2016	1904	2285	531	277	2	0
Summer 2016	52	14	6	31	0	0
Fall 2016	166	116	13	42	0	0

Figure 5-25. Number of carcasses found per species in 2015 and 2016. The categories "*Lithobates* species" (also commonly referred to as *Rana* species) and "*Ambystoma* species" represent True Frogs and Mole Salamanders, respectively, that could not be identified to species.

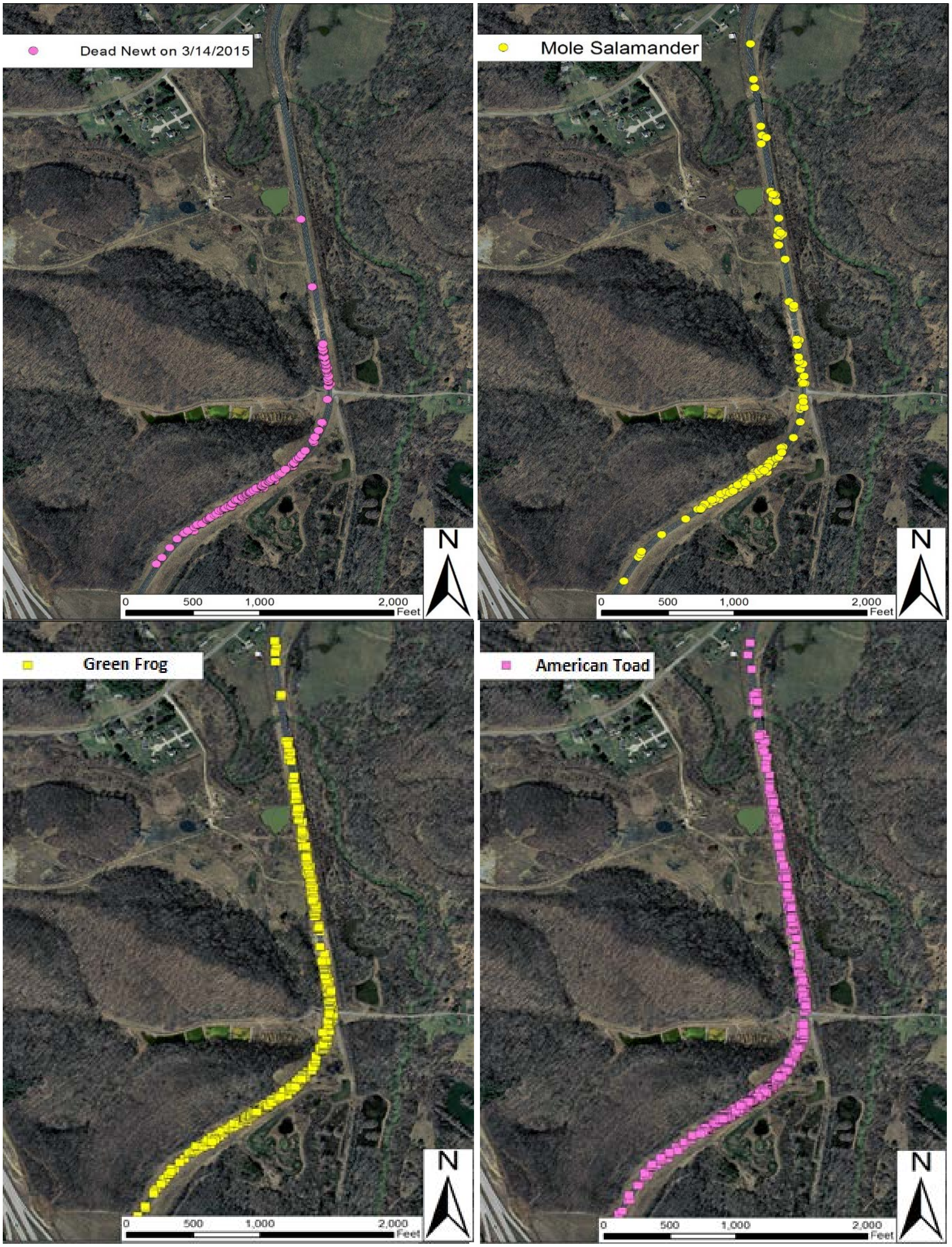


Figure 5-26. Mortality distribution maps for the Red-spotted Newt (on 3/14/2015, 321 individuals), Mole Salamanders (Jefferson, Spotted, and Marbled, 150 individuals), Northern Green Frog (491 individuals), and American Toad (867 individuals). Each dot represents an individual carcass along State Route 78, Athens County, Ohio.

Figure 5-27. Percentage of amphibian mortality from 2015-2016 occurring in each section of roadway along State Route 78, Athens County, Ohio. One section is based on where the mitigation structure is located and the other sections were defined based on habitat near the roadway.

Figure 5-28. Amphibians detected by the ecopassage camera traps (Green Frog-left, Marbled Salamander-middle, and American Toad-right).

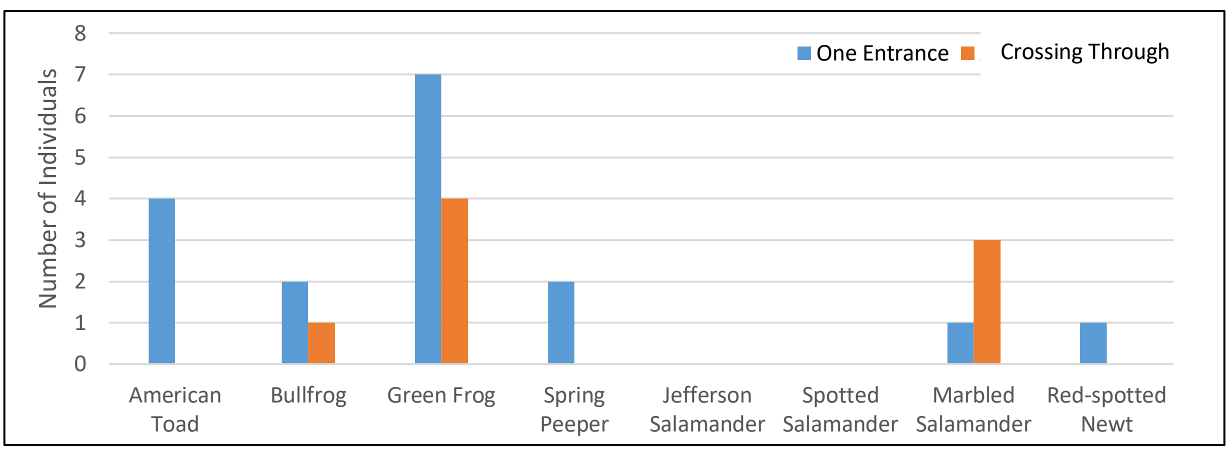


Figure 5-29. Total number of individual amphibians detected at one end of the ecopassage and those crossing through the passage by species.

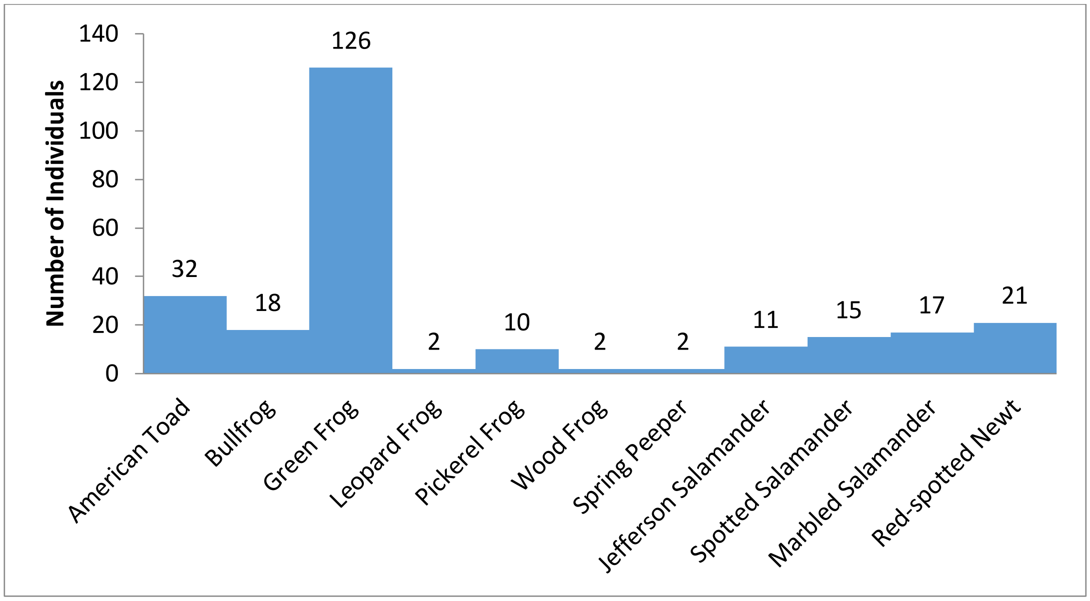


Figure 5-30. Total number of individual amphibians trapped in pitfall traps at the ends of the barrier fencing.

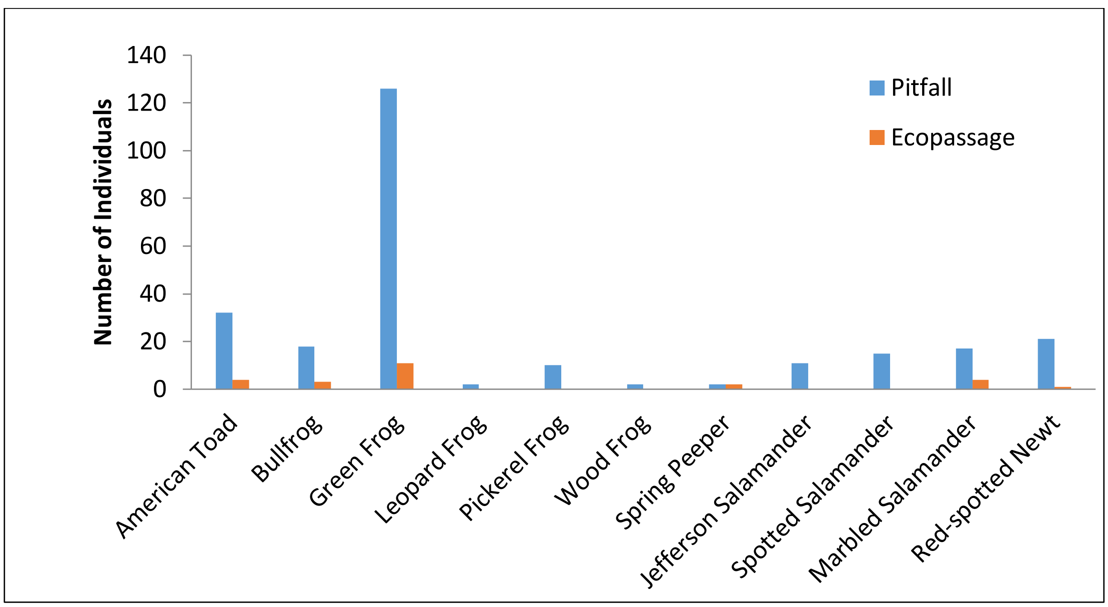


Figure 5-31. Total number of amphibians captured in pitfall traps along barrier and the total number of amphibians seen in each ecopassage by species.

Figure 6-1. Image of high-mast lighting (left) and lattice style bat roosting boxes (right) employed along the U.S. 33 Nelsonville Bypass, Athens and Hocking Counties, Ohio. High-mast lighting is designed to lure bats away from the flow of traffic and bat roosting boxes are intended to replace habitats removed during construction.

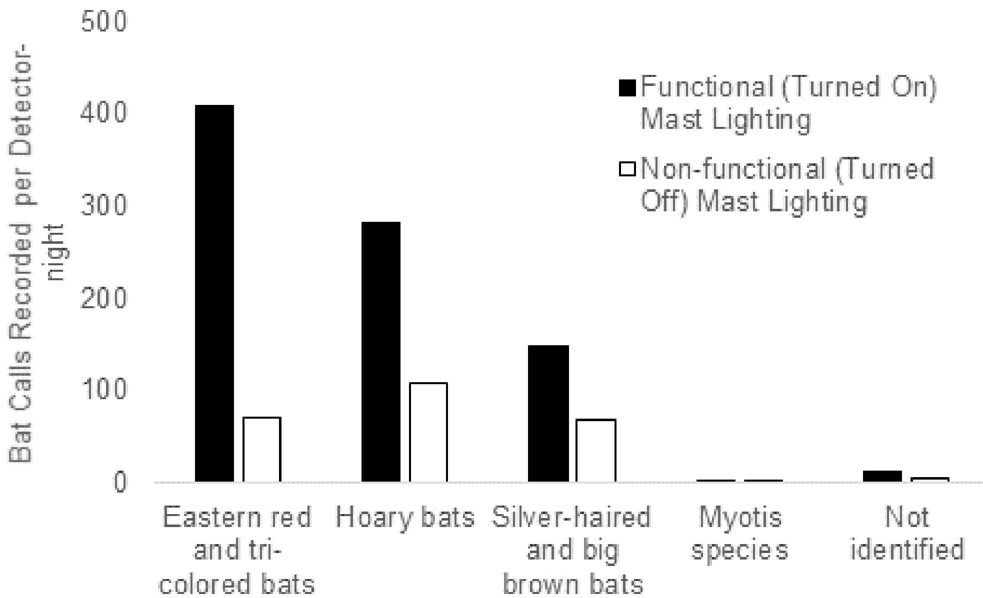


Figure 6-2. The number of bat calls recorded per detector-night between functional and non-functional high-mast lighting, summarized by species group, suggests that lighting increases bat activity along the U.S. 33 Nelsonville Bypass, Athens and Hocking Counties, Ohio.

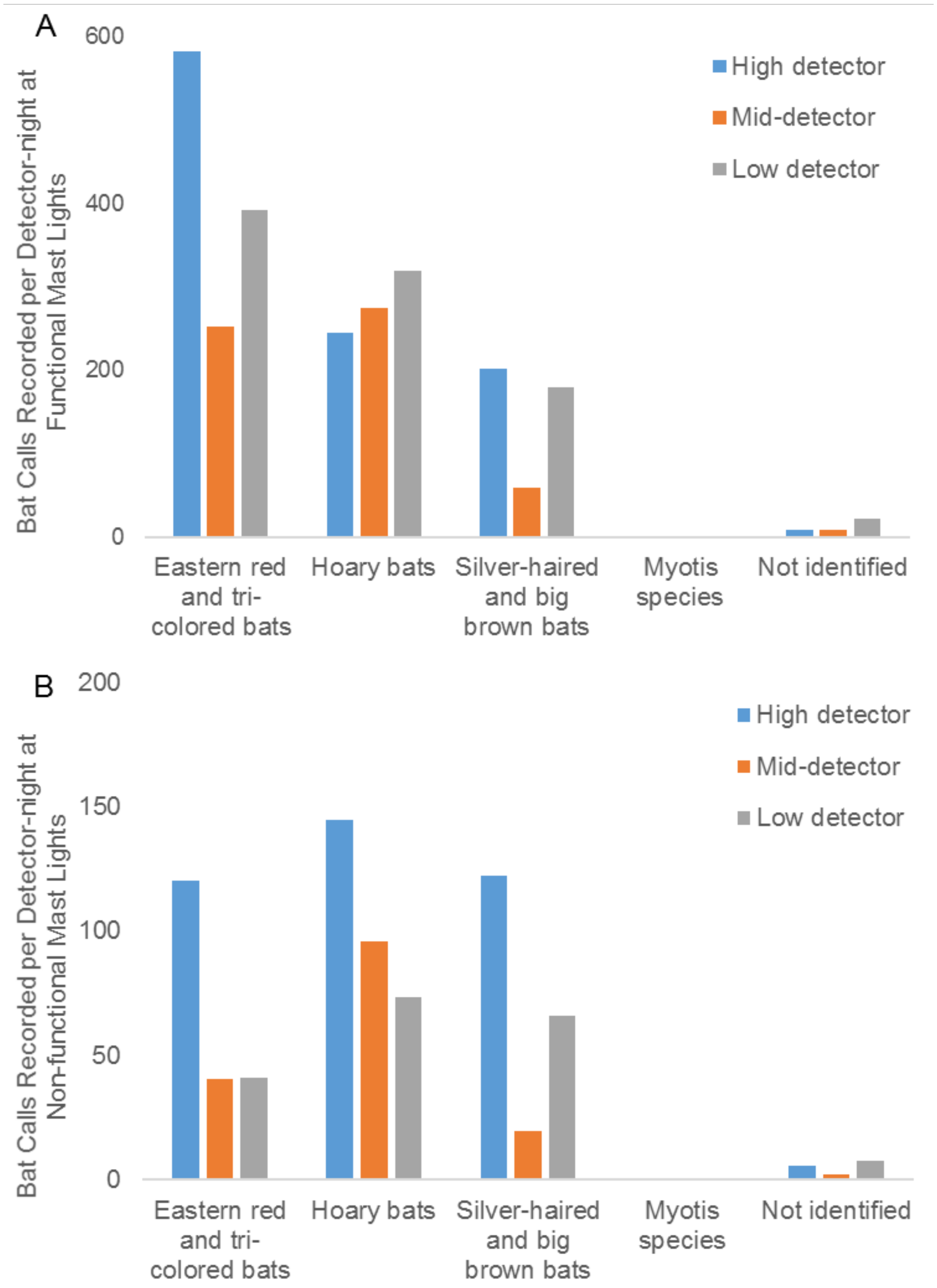


Figure 6-3. The number of bat calls recorded per detector-night at detectors located at traffic-level (low detector), the height of typical highway lighting (mid-detector), and at the level of high-mast lighting (high detector) at functional (A) and non-functional (B) mast lights suggests mixed responses to highway lighting. While the Eastern Red and Tri-colored Bat group and Hoary Bats showed the greatest increase in activity at low detectors under highway lighting, and the Silver-haired and Big Brown Bat group showed an increase at the high detectors.

Figure 7-1. The U.S. 33 Nelsonville Bypass Study Site, Athens and Hocking Counties, Ohio. Top: aerial imagery of the U.S. 33 Nelsonville Bypass study site, Bottom: photo taken at the study site showing the forest, right-of-way, and bypass itself.

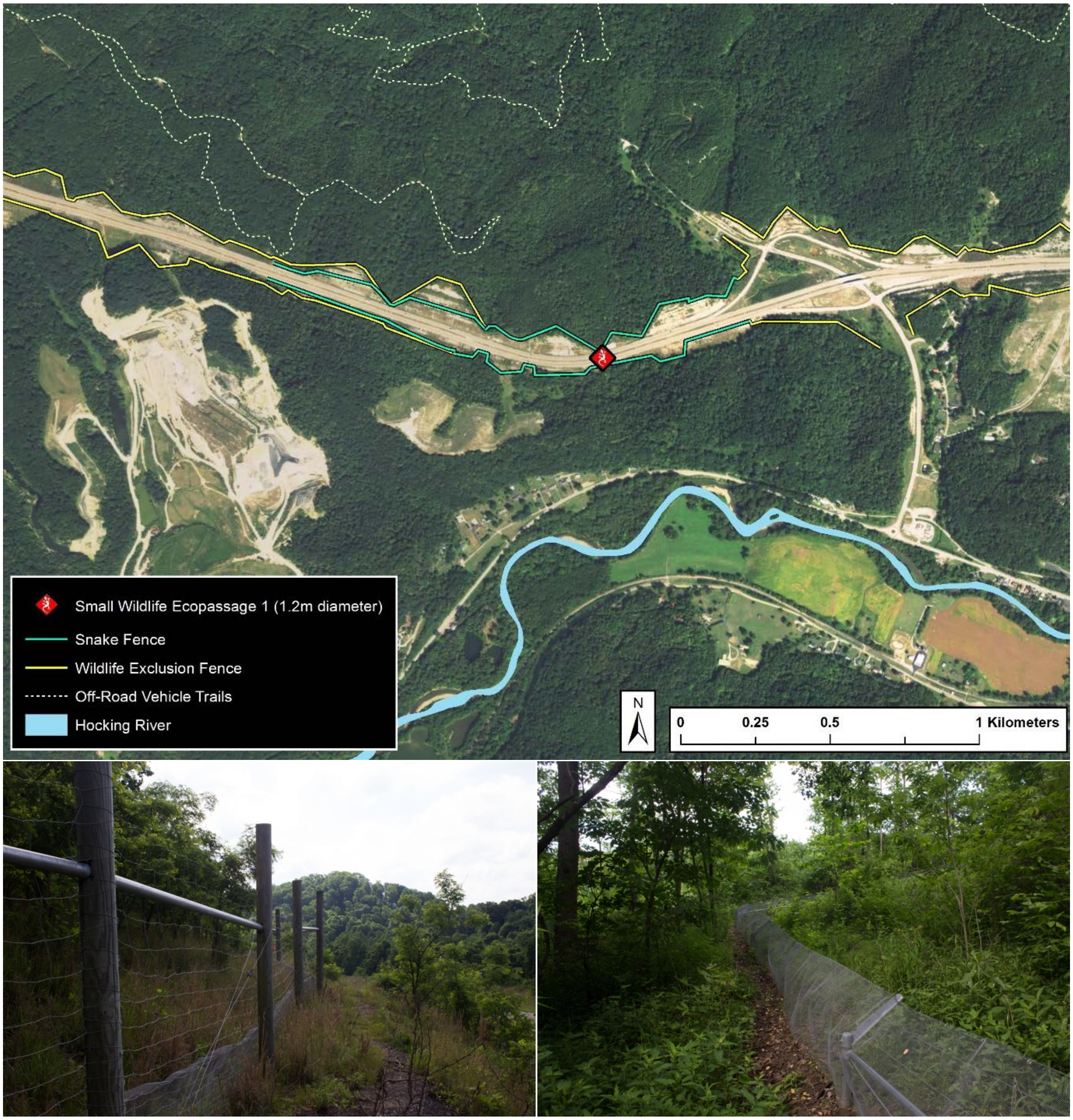


Figure 7-2. Snake exclusion fence along the U.S. 33 Nelsonville Bypass, Hocking County, Ohio. Top: map showing extent of snake exclusion fence, Bottom Left: snake fence attached to the 8-ft. tall wildlife exclusion fence, Bottom Right: snake fence installed independently from the 8-ft. tall wildlife exclusion fence.

Figure 7-3. Ecopassages (i.e. wildlife crossing structures) along the U.S. 33 segment of the Nelsonville Bypass. Top: ecopassages locations along the U.S. 33 Nelsonville Bypass, Bottom Left: Small Wildlife Ecopassage 1 entrance integrated into snake fence, Bottom Right: a look inside the ecopassages reveals a long, dark tunnel.

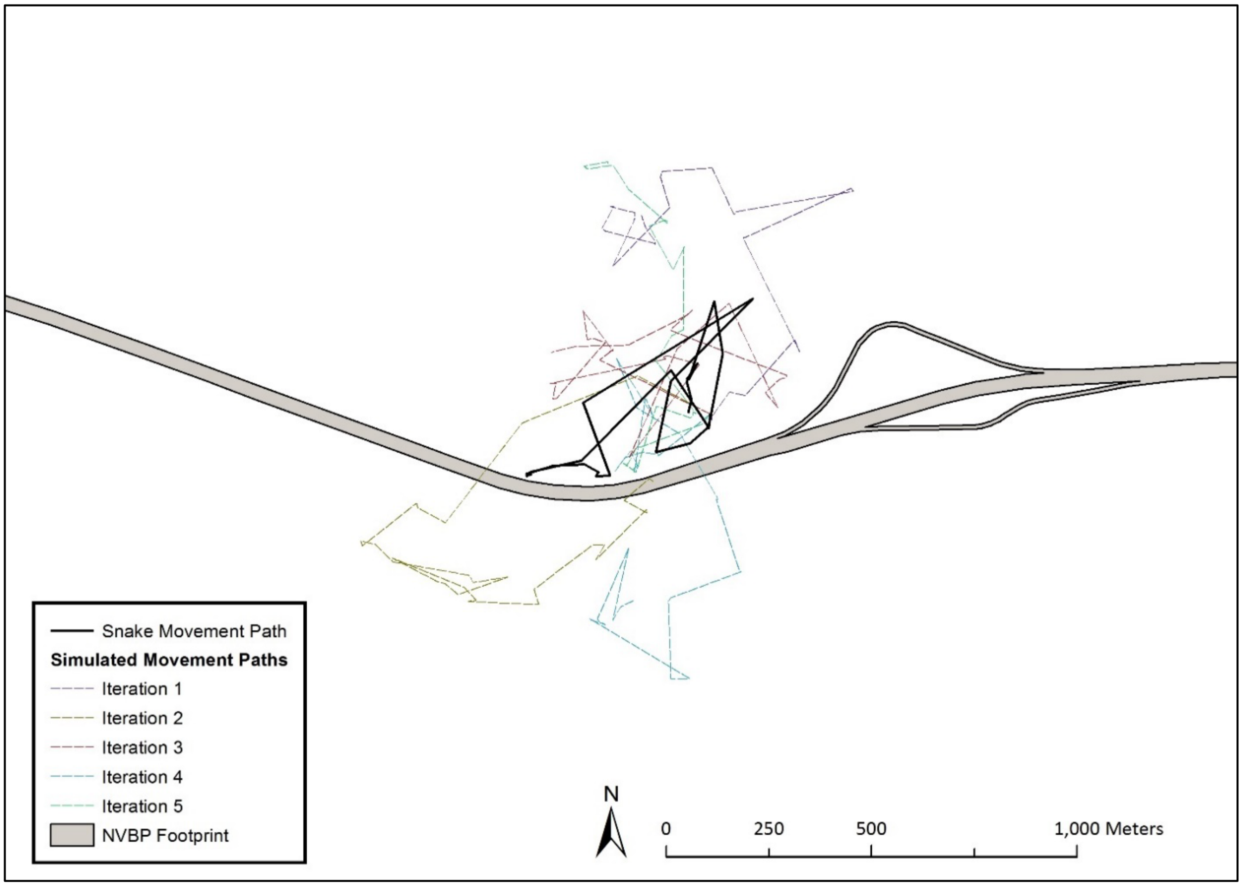


Figure 7-4. Example of correlated random walk analysis; solid line shows the - observed movement path; dashed lines - represent five simulated random walks.

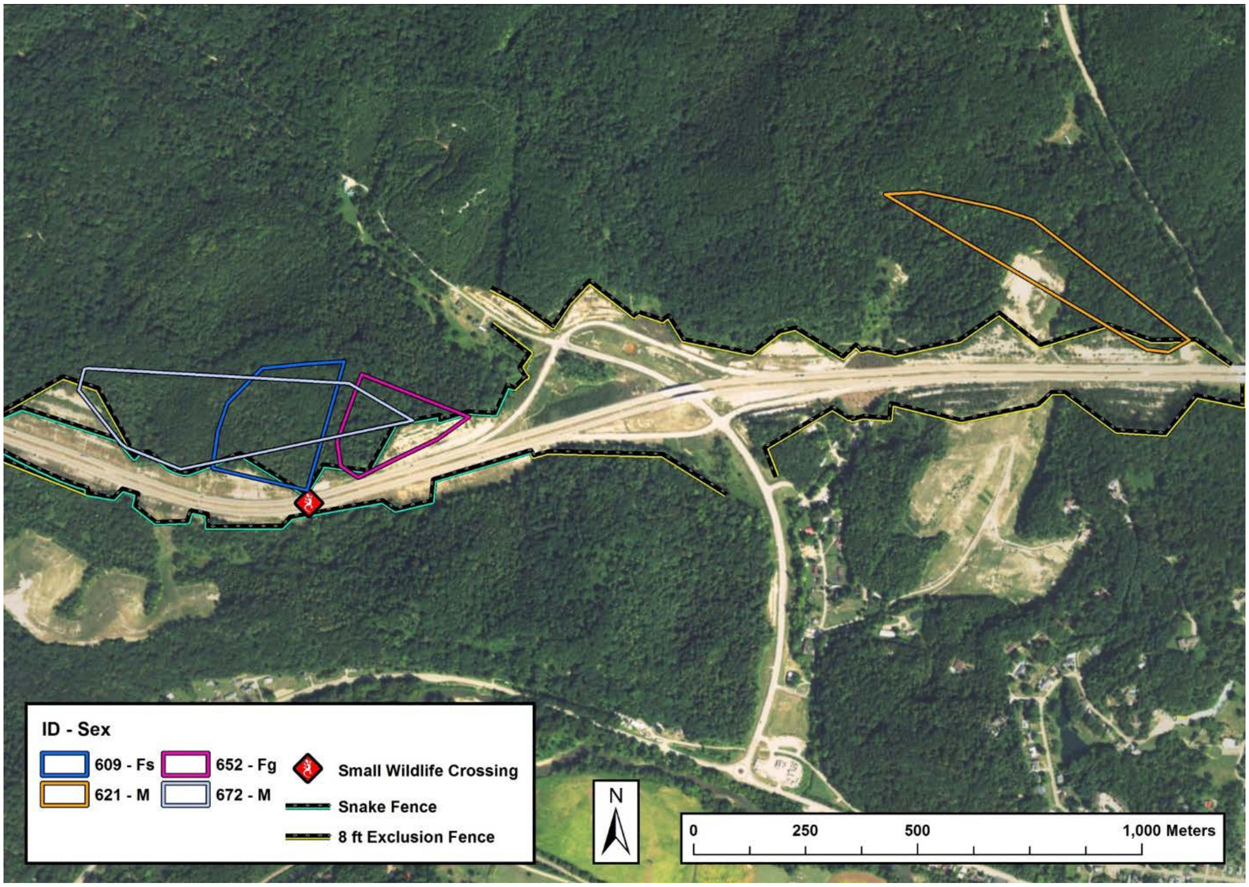


Figure 7-5. 100% minimum convex polygon home ranges for Timber Rattlesnakes in 2015.

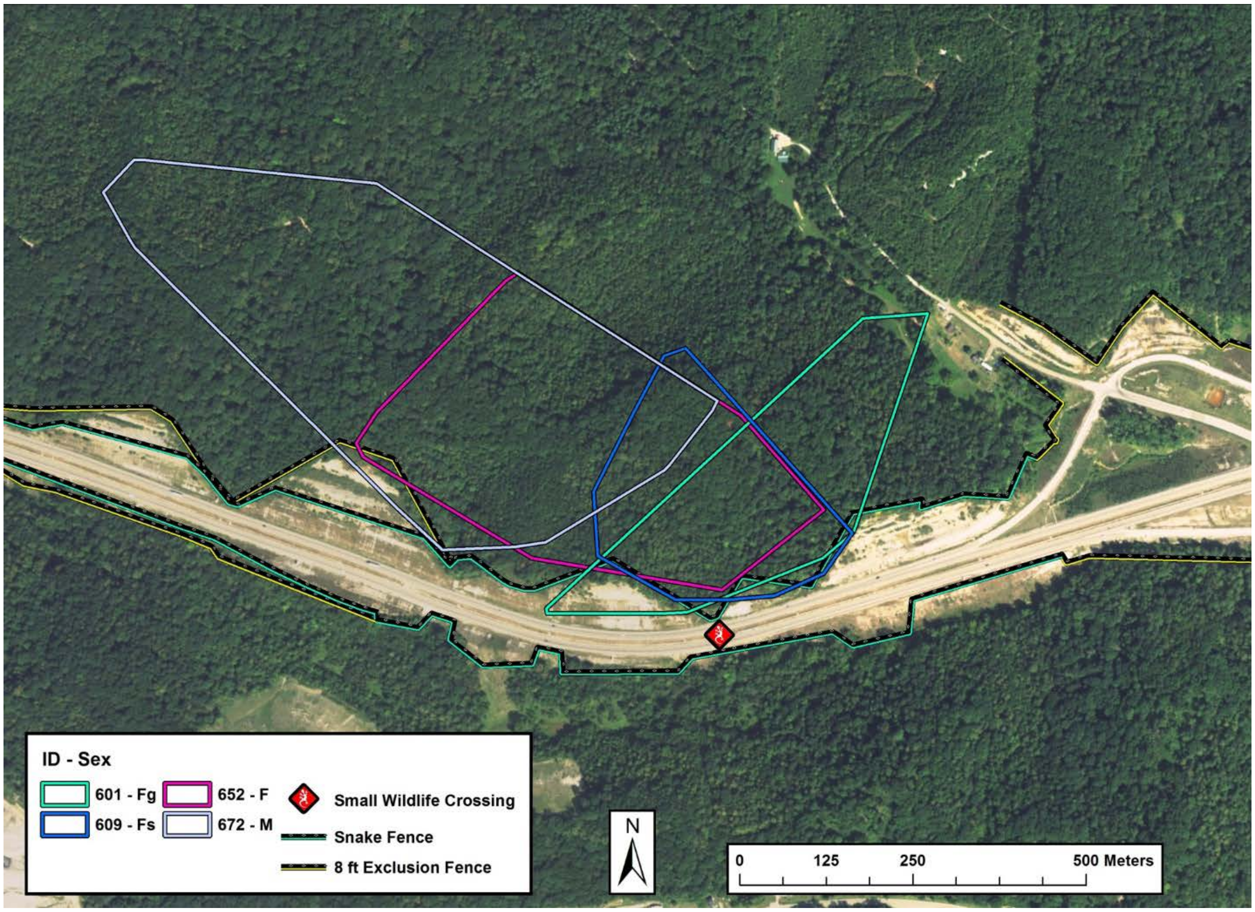


Figure 7-6. 100% minimum convex polygon home ranges for Timber Rattlesnakes in 2016.

Figure 7-7. Right-of-way (ROW) habitats used by rattlesnakes. Top: Gravid rattlesnake basking on an artificial stone pile in the ROW, Bottom: picture of other ROW habitats used by rattlesnakes, including grassy hillsides, scrub, and rocky roadcuts.

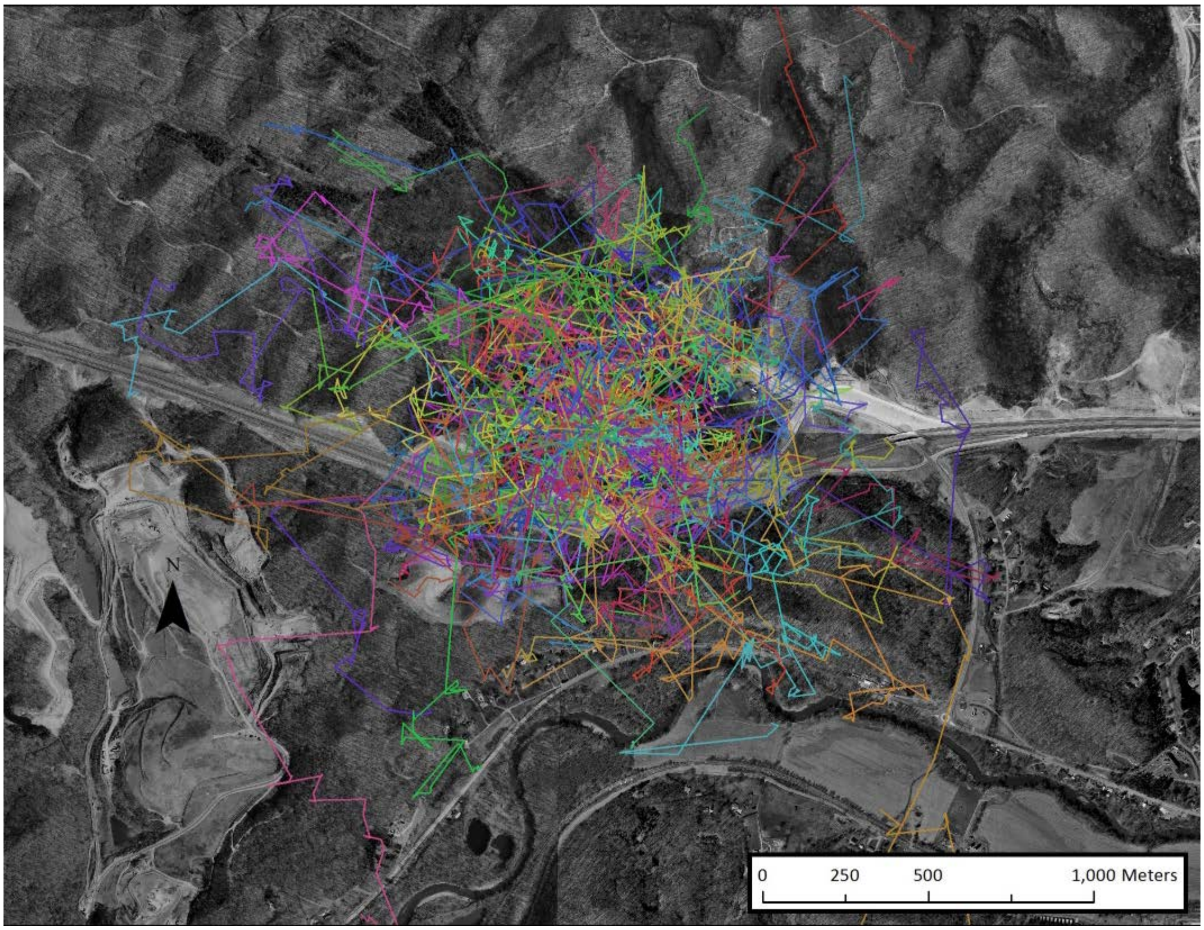


Figure 7-8. Example of 100 correlated random walks. Significant road avoidance is difficult to detect at the individual level when only a single linear barrier is present, as many simulated paths can avoid the road.

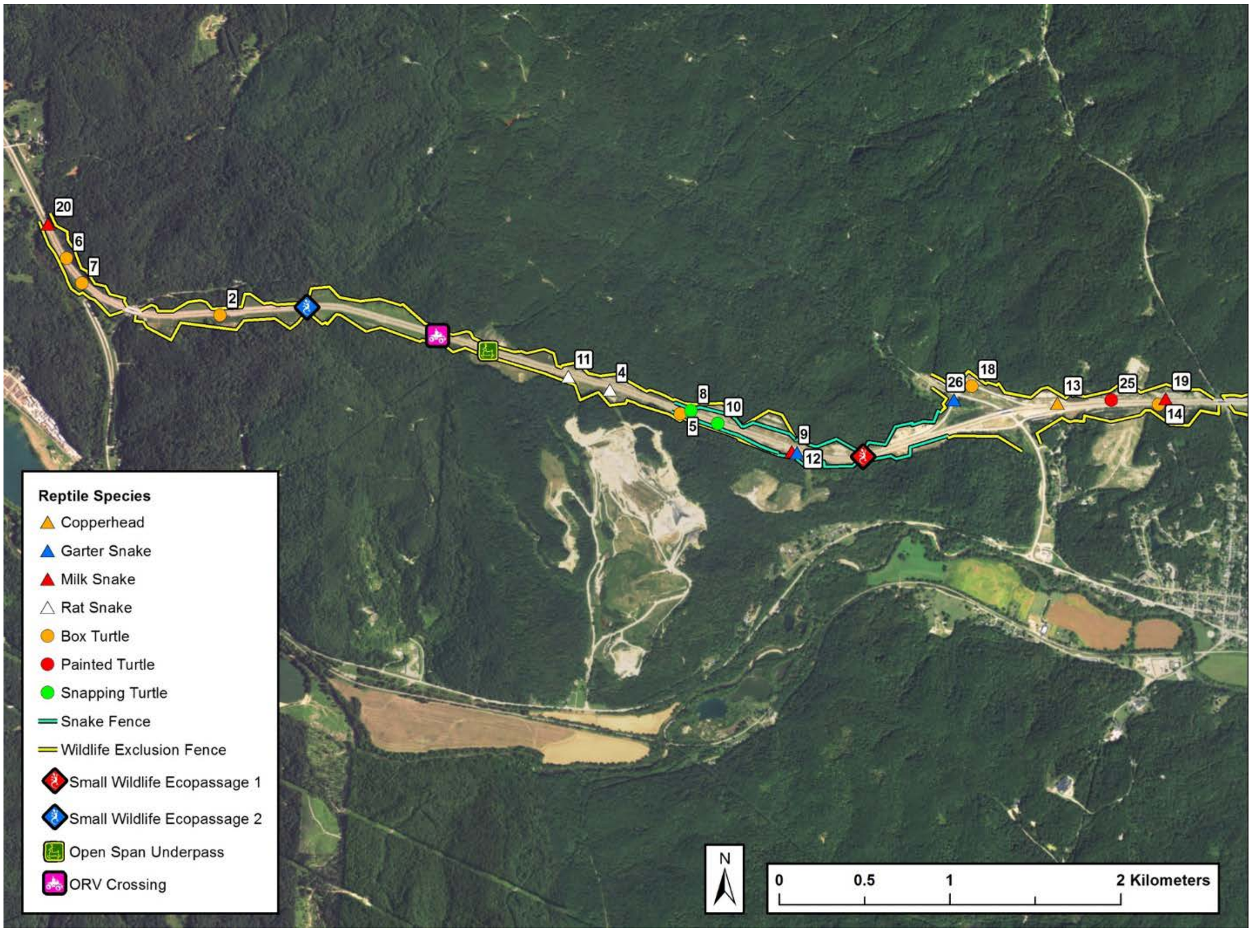


Figure 7-9. Reptile road crossing locations on the western section of the U.S. 33 Nelsonville Bypass, Athens and Hocking Counties, Ohio. Numbers correspond to key in Table 7-7.

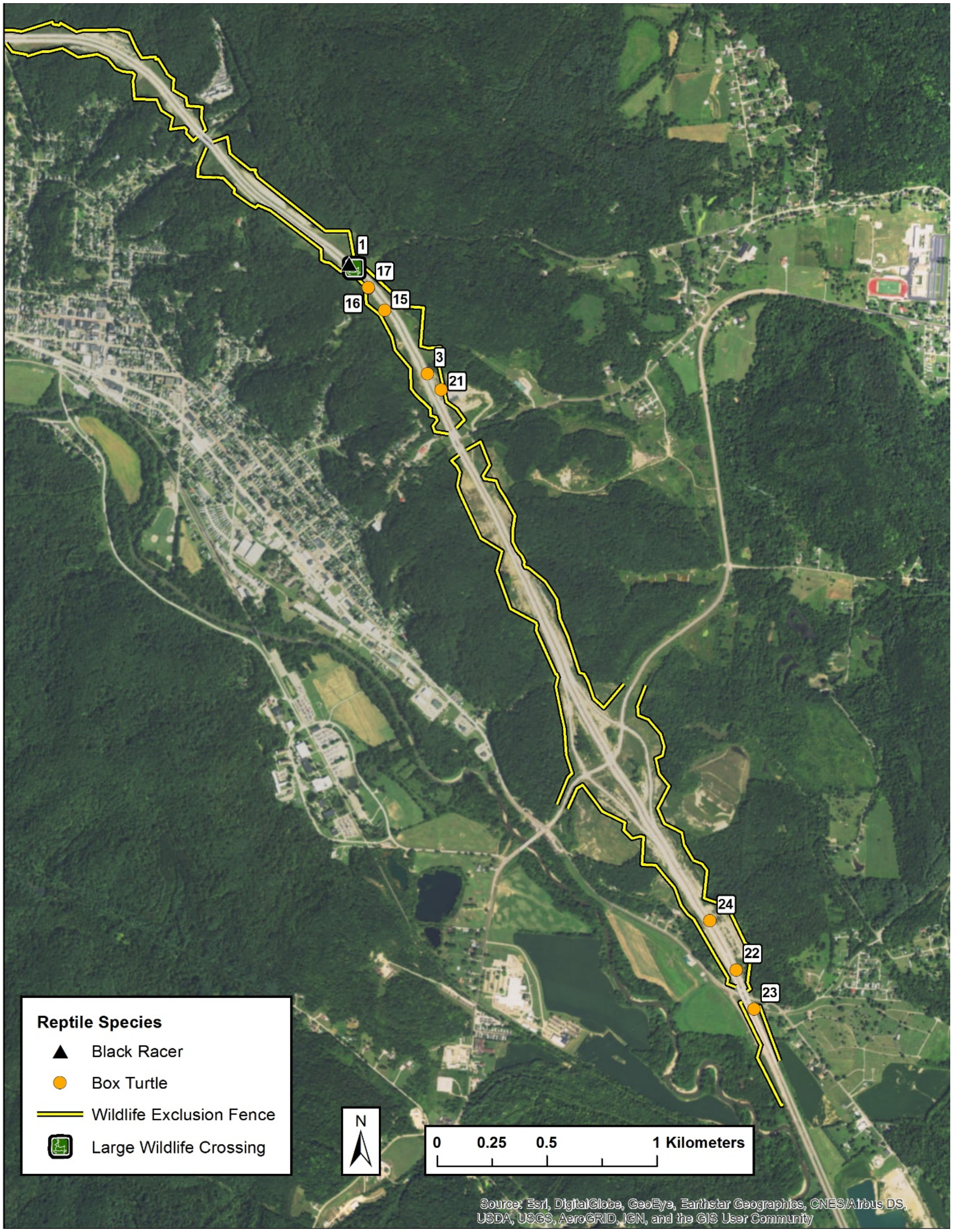


Figure 7-10. Reptile road crossing locations on the eastern section of the U.S. 33 Nelsonville Bypass, Athens and Hocking Counties, Ohio. Numbers correspond to key in Table 7-7; in absence of snake fence, mortality occurred even in close proximity to a crossing structure.

Figure 7-11. Damage to the snake fence. Top: corrosion damage, Middle: tree fall damage, Bottom: erosion damage.

APPENDIX 2: TABLES

Table ES-1. List of all vertebrates encountered during the Nelsonville Bypass Wildlife Mitigation Study. Columns "Along Fence" to "Underpass 1" are species detected by camera traps at the corresponding locations. "Snake Fencing" reports on animals captured along the snake fencing and in box traps deployed along the fence. "SR 78 Amphibian Study" are the animals detected in all aspects of the amphibian study focused on the wetlands on the Ohio State Route 78 tributary to the Nelsonville Bypass. "Acoustic bat detectors" were used to identify bats observed, and is reported in the final column. "X"s represent presence of that species among a wide range of detection methods or the inability of the sampling method to provide precise numbers of individuals.

	Camera Traps								
Species	**Along Fence**	**Bridge**	**Small Wildlife**	**Jump-outs**	**Special Use ATV**	**Under-pass 1**	**Snake Fencing**	**SR 78 Amphibian Study**	**Acoustic Bat Detectors**
Mammals									
Bobcat (*Lynx rufus*)	7	1	1	2	1	1			
Eastern Chipmunk (*Tamias striatus*)	4		816	2	3	1	88	X	
Coyote (*Canis latrans*)	44	141	4	85	77	22		X	
White-tailed Deer (*Odocoileus virginanus*)	842	2518	2	1255	1022	675		X	
Northern Flying Squirrel (*Glaucomys sabrinus*)	4								
Fox (*Vulpes* and *Urocyon cinereoargenteus*)	28	512	22	86	52	130		X	
Woodchuck (*Marmota monax*)	1		63	11				X	
Virginia Opossum (*Didelphis virginiana*)	4	19	353	7	38	56	8	X	
Eastern Cottontail (*Sylvilagus floridanus*)	36	21	741	71	10	48	11	X	
Raccoon (*Procyon lotor*)	55	41	775	41	71	353		X	
Squirrel, Grey and Fox combined (*Sciurus* spp.)	17		262	51	101	3	9	X	
American Mink (*Mustela vison*)		3	52	3	2			X	
Striped Skunk (*Mephitis mephitis*)		88	50	3	11	4		X	
North American Beaver (*Castor canadensis*)			1					X	
Weasel (*Mustela* spp.)			40		2	1	4	X	
Muskrat (*Ondatra zibethicus*)						1		X	
Mice (*Peromyscus* spp.)			2733	20	13		52	X	
Southern Bog Lemming (*Synaptomys cooperi*)			3						
Alleghany Wood Rat (*Neotoma magister*)			1						
Shrew (*Sorex* and *Blarina*)			34				43	X	

Vole (*Microtus* spp.)			101				29	X	
Bat (Order: Chiroptera)						23			
Domestic Cat (*Felis catus*)		9	41	226	22	201		X	
Domestic Dog (*Canis familiarus*)		6	2	11	20	28			
Hairy-tailed Mole (*Parascalops breweri*)							3	X	
Meadow Jumping Mouse (*Zapus hudsonius*)							25	X	
Hoary Bat (*Lasiurus cinereus*)									X
Silver-haired Bat (*Lasionycteris noctivagans*)									X
Eastern Red Bat (*Lasiurus borealis*)								X	X
Tri-colored Bat (*Perimyotis subflavus*)									X
Mouse-eared Bat (*Myotis* spp.)									X
Big Brown Bat (*Eptesicus fuscus*)									X
Unknown Mammal	3		19		1			X	
Reptiles									
Eastern Fence Lizard (*Sceloporus undulatus*)			1				X		
Black Racer (*Coluber constrictor*)			4				29	X	
Garter Snake (*Thamnophis sirtalis*)			2				65	X	
Copperhead (*Agkistrodon contortrix*)							9	X	
Timber Rattlesnake (*Crotalus horridus*)							19		
Eastern Milk Snake (*Lampropeltis triangulum*)							24	X	
Gray Ratsnake (*Pantherophis spiloides*)							12	X	
Smooth Earth Snake (*Virginia valeriae*)								X	
Northern Redbelly Snake (*Storeria occipitomaculata*)								X	
Northern Ring-necked Snake (*Diadophis punctatus*)							X	X	
Eastern Hog-nosed Snake (*Heterodon platirhinos*)							1	X	
Northern Watersnake (*Nerodia sipedon*)								X	
Unknown Snake			1						
Common Musk Turtle (*Sternotherus odoratus*)								X	
Box Turtle (*Terrepene carolina*)		3					60	X	
Painted Turtle (*Chrysemys picta*)							1	X	
Snapping Turtle (*Chelydra serpentina*)							X	X	

Amphibians								
Toad (*Anaxyrus* spp.)			2					
American Toad (*Anaxyrus americanus*)							17	X
Jefferson Salamander (*Ambystoma jeffersonianum*)							6	X
Spotted Salamander (*Ambystoma maculatum*)								X
Marbled Salamander (*Ambystoma opacum*)								X
Long-tailed Salamander (*Eurcyea longicauda*)								X
Gray and Cope's Gray Treefrog (*Hyla chrysocelis* and *Hyla versicolor)*							8	X
Red-spotted Newt (*Notophthalmus viridescens*)							9	X
Eastern Red-backed Salamander (*Plethodon cinereus*)								X
Northern Slimy Salamander (*Plethodon glutinosis*)							4	X
Spring Peeper (*Pseudacris crucifer*)							2	X
Western Chorus Frog (*Pseudacris triseriata*)								X
American Bullfrog (*Rana catesbeiana*)							3	X
Northern Green Frog (*Rana clamitans*)							38	X
Northern Leopard Frog (*Rana pipiens*)								X
Pickerel Frog (*Rana palustris*)								X
Wood Frog (*Rana sylvatica*)							1	X
Birds								
Turkey (*Meleagris gallopavo*)	29	33		19	3	18		X
Hawk (Order: Accipitriformes)				6	7			
Owl (Family: Strigidae)					1			
Vulture (*Cathartes aura*)				2		1		
Brown Thrasher (*Toxostoma rufum*)			2				1	X
Hooded Warbler (*Setophaga citrina*)			1					
Eastern Wood Peewee (*Contopus virens*)			75					
Chickadee (*Poecile* spp.)			1					
Gray Catbird (*Dumetella carolinensis*)			3				3	X

Common Grackle (*Quiscalus quiscula*)		1		
Barn Swallow (*Hirundo rustica*)				X
Brown-headed Cowbird (*Molothrus ater*)				X
American Crow (*Corvus brachyrhynchos*)				X
American Goldfinch (*Spinus tristis*)				X
Cuckoo (*Coccyzus* spp.)				X
Downy Woodpecker (*Picoides pubescens*)				X
Eastern Phoebe (*Sayornis phoebe*)				X
House Sparrow (*Passer domesticus*)				X
Northern Cardinal (*Cardinalis cardinalis*)				X
Red-bellied Woodpecker (*Melanerpes carolinus*)				X
Red-winged Blackbird (*Agelaius phoeniceus*)				X
Scarlet Tanager (*Piranga olivacea*)				X
Screech Owl (*Megascops asio*)				X
Warbler (Family: Parulidae)				X
Woodpecker (Family: Picadae)				X
Indigo Bunting (*Passerina cyanea*)				X
Killdeer (*Charadrius vociferus*)				X
Eastern Bluebird (*Sialia sialis*)				X
Sparrow (Family: Emberizidae)		4		X
Rock Dove (*Columba livia*)	22			
Wren (*Thryothorus* or *Troglodytes*)		30	13	X
American Robin (*Turdus migratorius*)		2	1	X
Wood Duck (*Aix sponsa*)		1		X
Eastern Towhee (*Pipilo erythrophthalmus*)			2	
Mourning Dove (*Zenaida macroura*)				X
European Starling (*Sternus vulgaris*)				X
American Woodcock (*Scolopax minor*)			1	
Domestic Chicken (*Gallus gallus didntmakeittus)*				X
Unknown Bird		5		X

Table ES-2. Summary of animals encountered during roadkill surveys in the Nelsonville Bypass Wildlife Mitigation Study. Column "Bypass" are the numbers of carcasses encountered during roadkill surveys along the U.S. 33 Nelsonville Bypass, which has wildlife mitigation. Columns "Control 1 (33E)" and "Control 2 (50E)" are the numbers of carcasses encountered during roadkill surveys along the two control sites that did not have mitigation structures. Column "SR 78 Amphibian Study" are the numbers of carcasses encountered during the roadkill surveys along Ohio State Route 78 a tributary of the Nelsonville Bypass. Species marked with † indicate a difference detected between the Bypass, Control 1, and Control 2 using a G-test (df = 2; †: P <0.05; ††: P < 0.01; NS: not significant).

Species	Bypass	Control 1 (33E)	Control 2 (50E)	SR 78 Amphibian Study
Mammals				
Eastern Chipmunk (*Tamias striatus*)				1
Coyote (*Canis latrans*)	3	2		
White-tailed Deer (*Odocoileus virginanus*) ††	15	22	37	4
Fox (*Vulpes vulpes* and *Urocyon cinereoargenteus*)	4		1	1
Woodchuck (*Marmota monax*)			2	3
Virginia Opossum (*Didelphis virginiana*) ††	14	6	27	12
Eastern Cottontail (*Sylvilagus floridanus*) ††	5	2	12	7
Raccoon *(Procyon lotor*) †	16	19	30	8
Squirrel, Grey and Fox combined (*Sciurus* spp.) ††	11	12	2	4
American Mink (*Mustela vison*)	3	1		1
Striped Skunk (*Mephitis mephitis*) NS	3	5	7	2
Weasel (*Mustela* spp.)		1		
Muskrat (*Ondatra zibethicus*)				1
Mice (*Peromyscus* spp.)			2	14
Shrew (*Sorex* and *Blarina*)				8
Vole (*Microtus* spp.)				4
Domestic Cat (*Felis catus*)	4	4	3	1
Domestic Dog (*Canis familiarus*)	3	2		
Hairy-tailed Mole (*Parascalops breweri*)				1
Meadow Jumping Mouse (*Zapus hudsonius*)				1
Silver-haired Bat (*Lasionycteris noctivagans*)	1			
Eastern Red Bat (*Lasiurus borealis*)				1
Unknown Mammal	4	1	9	19
Reptiles				
Black Racer (*Coluber constrictor*)				11
Garter Snake (*Thamnophis sirtalis*)				35
Copperhead (*Agkistrodon contortrix*)				3
Northern Redbelly Snake (*Storeria occipitomaculata*)				1
Northern Ring-necked Snake (*Diadophis punctatus*)				7
Eastern Milk Snake (*Lampropeltis triangulum*)				7
Gray Ratsnake (*Pantherophis spiloides*)	1	1		27
Eastern Hog-nosed Snake (*Heterodon platirhinos*)				1
Northern Watersnake (*Nerodia sipedon*)				75

Common Musk Turtle (*Sternotherus odoratus*)				1
Box Turtle (*Terrepene carolina*)	2	4	1	21
Painted Turtle (*Chrysemys picta*)				103
Snapping Turtle (*Chelydra serpentina*)	2		2	30
Amphibians				
American Toad (*Anaxyrus americanus*)				867
Jefferson Salamander (*Ambystoma jeffersonianum*)				29
Spotted Salamander (*Ambystoma maculatum*)				69
Marbled Salamander (*Ambystoma opacum*)				29
Unknown Mole Salamander (*Ambystoma* spp.)				23
Gray and Cope's Gray Treefrog (*Hyla chrysocelis* and *Hyla versicolor)*				533
Red-spotted Newt (*Notophthalmus viridescens*)				4,954
Eastern Red-backed Salamander (*Plethodon cinereus*)				2
Northern Slimy Salamander (*Plethodon glutinosis*)				1
Spring Peeper (*Pseudacris crucifer*)				5,746
American Bullfrog (*Rana catesbeiana*)			1	182
Northern Green Frog (*Rana clamitans*)			1	491
Northern Leopard Frog (*Ranas pipiens*)				20
Pickerel Frog (*Rana palustris*)				248
Wood Frog (*Rana sylvatica*)				10
Unknown True Frog (*Rana* spp.)				47
Birds				
Turkey (*Meleagris gallopavo*)				3
Hawk (Order: Accipitriformes)		1	4	
Owl (Family: Strigidae)		1	3	
Brown Thrasher (*Toxostoma rufum*)			3	3
Chickadee (*Poecile* spp.)				2
Wren (*Thryothorus* or *Troglodytes*)				4
American Robin (*Turdus migratorius*)				4
Wood Duck (*Aix sponsa*)				1
Red-Winged Blackbird (*Agelaius phoeniceus*)	2			5
American Crow (*Corvus brachyrhynchos*)	1	1		1
American Goldfinch (*Spinus tristis*)	1	1		2
Barn Swallow (*Hirundo rustica*)				1
Brown-headed Cowbird (*Molothrus ater*)				1
Cuckoo (*Coccyzus* spp.)				4
Downy Woodpecker (*Picoides pubescens*)				1
Eastern Phoebe (*Sayornis phoebe*)				1
House Sparrow (*Passer domesticus*)				2
Northern Cardinal (*Cardinalis cardinalis*)				13
Red-bellied Woodpecker (*Melanerpes carolinus*)				1
Scarlet Tanager (*Piranga olivacea*)				1

Screech Owl (*Megascops asio*)				1
Warbler (Family: Parulidae)				16
Woodpecker (Family: Picadae)				1
Indigo Bunting (*Passerina cyanea*)				6
Killdeer (*Charadrius vociferus*)				1
Eastern Bluebird (*Sialia sialis*)				2
Sparrow (Family: Emberizidae)				3
Mourning Dove (*Zenaida macroura*)				1
European Starling (*Sternus vulgaris*)				1
Domestic Chicken (*Gallus gallus didntmakeittus)*				3
Unknown Bird	1	1	2	15

Table 2-1. Fine detail habitats and land covers mapped in the broad study area around the U.S. 33 Nelsonville Bypass, Athens and Hocking Counties, Ohio during 2014-2016. Area (acres) of different habitat types are identified in Figure 2-1. Bolded habitats and land covers are mapped in Figure 2-1, and their area (acres) was calculated from totals of the non-bolded habitats and land covers beneath them.

Habitats and Land Covers	Area (acres)	Map Code	Habitats and Land Covers	Area (acres)	Map Code
Agriculture	**640.82**		**Marsh**	**72.01**	
Agriculture	591.28	Agric	Marsh	72.01	Marsh
Cemetery	49.54	Cemet	**Pavement**	**183.36**	Road
Bare Rock	**52.99**		**Residential**	**904.98**	
Road Cut	52.96	BRock	Residential	904.98	Resid
Rock Outcrop	0.03	BRock	**Rough Grass**	**717.17**	
Developed	**332.81**		Landing	0.07	RGras
Commercial	19.02	Comer	Median	23.11	RGras
Concrete Pad	0.01	Conct	Rip-rap	7.02	RpRap
Industrial	121.86	Indst	Rough Grass	686.97	RGras
Municipal	161.99	Munic	**Shrub Swamp**	**30.85**	
Park	2.36	Park	Shrub Swamp	30.85	SSwmp
Prison	5.85	Prison	**Successional Scrub**	**362.71**	
Railroad	17.53	RailR	Successional Scrub	362.71	SucSb
Tunnel	0.1	Tunel	**Water**	**437.43**	
Waste Treatment Plant	4.09	WWTP	AMD Treatment Wetland	2.58	AMD-TW
Forest	**10891.3**		Hocking River	193.86	HkgRv
Dry Forest	1340.99	DFrst	Mitigation Wetland	5.38	MonCk
Forest	8427.5	Forst	Monday Creek	86.66	MWetl
Mesic Forest	434.81	MFrst	Pond	148.95	Pond
Pine	176.53	Pine	**Grand Total**	**14626.9**	
Riparian Forest	376.17	RFrst			
Rock Outcrop	0.15	BRock			
Scrub Forest	42.24	ScFst			
Swamp	92.95	Swmp			

Table 2-2. Habitats and land covers (in acres) inside the fenced enclosure of the U.S. 33 Nelsonville Bypass, Athens and Hocking Counties, Ohio during 2014-2016. See Table 2-1 for definitions of habitat map codes and Figure 2-2 for a map of the highway segments. There are 17 specific habitats and land covers located within the fenced enclosure.

	HABITAT Map Code																
POSITION/ SEGMENT	Brdge	BRock	Conct	DFrst	Forst	Marsh	Mdian	MFrst	Pine	Pond	RFrst	RGras	Road	RpRap	ScFst	SSwmp	SucSb	**Total**
Middle							**16.55**					**9.71**	**11.94**	**0.09**				**38.29**
1							1.50											**1.50**
3							0.56											**0.56**
4							9.70											**9.70**
5							2.41							0.05				**2.46**
6												2.47						**2.47**
7												1.95		0.02				**1.97**
8												2.07		0.02				**2.09**
9												1.12	2.31					**3.43**
10							0.38					2.10	9.63					**12.11**
11							2.00											**2.00**
North	**0.06**	**33.31**	**0.01**	**0.36**	**0.40**	**0.77**			**0.02**	**0.54**	**0.28**	**109.95**	**37.93**	**2.23**	**9.36**	**0.27**	**41.48**	**236.97**
1					0.40							7.00	2.27	0.06			0.29	**10.02**
2												18.33			0.70		0.36	**19.39**
3												1.76	0.87					**2.63**
4	0.06	10.93		0.14		0.77				0.12		15.59	10.51	0.42	4.06		15.06	**57.66**
5		7.03								0.35		9.83	9.67	0.65	0.75		8.38	**36.66**
6		1.25	0.01							0.07		6.98	3.17	0.23	0.48		2.76	**14.95**
7		1.83		0.22								5.36	2.52	0.27	0.51		1.75	**12.46**
8											0.28	7.84	2.45	0.16	1.61	0.27	0.45	**13.06**
9		5.37							0.02			16.77	5.62	0.26	0.49		4.39	**32.92**
10		6.90										19.06		0.18	0.76		8.04	**34.94**
11												1.43	0.85					**2.28**

	HABITAT Map Code																	
POSITION/ SEGMENT	Brdge	BRock	Conct	DFrst	Forst	Marsh	Mdian	MFrst	Pine	Pond	RFrst	RGras	Road	RpRap	ScFst	SSwmp	SucSb	Total
South	**0.05**	**18.98**		**3.16**		**1.49**	**3.54**	**3.79**	**0.18**		**0.70**	**97.94**	**40.02**	**1.97**	**4.55**		**21.08**	**197.45**
1						0.02			0.07			4.44	2.26	0.04	0.57			**7.40**
2		1.81					3.54					15.51	11.14	0.57	0.33		5.55	**38.45**
3												1.52	0.97					**2.49**
4	0.05			0.69		1.24		1.50				24.12	10.80		0.68		3.01	**42.09**
5		5.49		1.39		0.12						7.24		0.05	1.72		3.54	**19.55**
6		1.69							0.05			7.28	3.30	0.37			3.13	**15.82**
7		0.40						1.41				3.99	2.53	0.26			0.54	**9.13**
8		0.99		0.07		0.11		0.08			0.70	3.19	2.56	0.02			2.55	**10.27**
9		7.57		1.01				0.80				12.81	5.58	0.31	1.18		1.01	**30.27**
10		1.03							0.06			16.71		0.35	0.07		1.75	**19.97**
11												1.13	0.88					**2.01**
Grand Total	**0.11**	**52.29**	**0.01**	**3.52**	**0.40**	**2.26**	**20.09**	**3.79**	**0.20**	**0.54**	**0.98**	**217.60**	**89.89**	**4.29**	**13.91**	**0.27**	**62.56**	**472.71**

Table 2-3. Locations (exit side and road segment) and structural characteristics (knee bar presence, number of escape chutes, and wall heights) of the 16 jump outs along the U.S. 33 Nelsonville Bypass, Athens and Hocking Counties, Ohio.

Jump Out ID #	Exit Side	Road Segment	Knee Bar	# of Chutes	Jump Out Wall Heights (ft.)			
					Left	Center	Right	Mean
J1	South	1	NO	3	5.5	5.5	5.5	5.5
J2	North	2	NO	3	5.5	5.5	5.5	5.5
J4	North	2	NO	2	5.5	5.5	5.5	5.5
J3	South	2	NO	2	5.5	5.5	5.5	5.5
J5	North	4	NO	2	5.5	5.5	5.5	5.5
J6	South	4	NO	3	4.0	5.0	5.5	4.83
J7	South	4	NO	2	8.5	8.5	8.5	8.5
J8	South	4	NO	3	5.5	5.5	5.5	5.5
J9	South	5	YES	3	5.0	5.0	5.5	5.17
J10	South	6	YES	3	5.5	5.5	5.0	5.33
J11	South	7	NO	3	5.5	5.0	5.0	5.33
J12	North	8	YES	3	5.5	5.5	5.0	5.33
J13	South	8	YES	3	5.0	5.5	5.5	5.33
J14	North	9	NO	3	5.0	5.0	5.0	5.0
J15	South	9	NO	3	4.5	5.5	5.5	5.17
J16	South	10	YES	3	5.0	5.5	5.5	5.33

Table 2-4. Physical properties (closest jump out, distance to closest jump out to the east, distance to closest jump out to the west, distance to nearest right-of-way (ROW) access point, distance to pavement edge, and distance to cover habitat) of the 16 jump outs (JO) along the U.S. 33 Nelsonville Bypass, Athens and Hocking Counties, Ohio. Access points include fence ends only; other gaps (see Chapter 4 concerning gaps) are not included.

Jump Out ID #	Nearest Jump Out	Distance to Nearest JO - East (ft.)	Distance to Nearest JO - West (ft.)	Distance to Nearest ROW Access (ft.)	Distance to Highway Edge (ft.)	Distance to Cover (ft.)
J1	J2	3462	NA	1692	87	120
J2	J4	2626	3462	5072	68	38
J3	J4	2620	3462	8316	118	20
J4	J3	1610	3135	8320	84	31
J5	J6	4806	2610	9141	27	61
J6	J5	5013	1610	7563	99	25
J7	J6	3470	4833	2770	41	28
J8	J9	1333	5313	2512	95	57
J9	J10	1751	3563	6131	70	45
J10	J9	1924	1133	7428	51	50
J11	J10	2243	1751	9100	34	10
J12	J11	2519	1876	8011	73	60
J13	J14	1725	2243	5767	66	105
J14	J13	3833	2563	3210	46	95
J15	J14	3833	1725	1530	43	61
J16	J15	NA	3819	2315	139	230

Table 3-1. Annual average daily traffic volumes, U.S. 33 Nelsonville Bypass Section, 2014-2016 (Data Source: Author Analysis of Ohio Department of Transportation Office of Technical Services Traffic Data). TR=Township Road and SR=State Route.

Segment	Segment Endpoints	2014	2015	2016
1	West End of Bypass Project Dorr Run Road (TR 346) Interchange	15,840	16,400	17,020
2	Dorr Run Road (TR 346) Interchange Happy Hollow Road (SR 78) Interchange	13,940	14,440	14,990
3	Happy Hollow Road (SR 78) Interchange Elm Rock Road (TR 36) Underpass	18,130	18,770	19,480

Table 3-2. Annual average daily traffic volumes, Control Section #1 - U.S. 50, 2011-2016 (Data Source: Author Analysis of Ohio Department of Transportation Office of Technical Services Traffic Data). CR=County Road.

Segment	Segment Endpoints	2011	2012	2013	2014	2015	2016
1	SR 329 Intersection Vanderhoof Road (CR 65) Intersection	7,010	7,130	7,190	7,280	7,530	7,650

Table 3-3. Annual average daily traffic volumes, Control Section #2 - U.S. 33, 2011-2016 (Data Source: Author Analysis of Ohio Department of Transportation Office of Technical Services Traffic Data). CR=County Road, SR=State Route, and ATH-MEG=Athens-Meigs.

Segment	Segment Endpoints	2011	2012	2013	2014	2015	2016
1	Start of Control Section 2 Pleasant Hill Road (CR 21) Intersection	6,850	6,970	7,030	7,110	7,360	7,480
2	Pleasant Hill Road (CR 21) Intersection Pleasanton Road (CR 16) Intersection	5,430	5,530	5,570	6,360	6,560	6,670
3	Pleasanton Road (CR 16) Intersection Rainbow Lake Road (CR 89) Intersection	5,370	5,470	5,510	5,580	6,190	6,290
4	Rainbow Lake Road (CR 89) Intersection ATH-MEG County Line	5,410	5,510	5,550	5,620	5,610	5,700
5	ATH-MEG County Line SR 681 Interchange	5,180	5,280	5,320	5,660	5,690	5,780

Table 3-4. Ohio deer-vehicle crash frequency and severity, 2001-2015 (Data Source: Ohio Department of Public Safety Annual Crash Facts Report).

Year	Total Crashes (All Types)	Total Crashes (Deer Only)	Percentage Deer Crashes	Fatal Deer Crashes	Injury Deer Crashes
2001	387,075	31,586	8.16%	7	1,084
2002	386,076	30,306	7.85%	5	1,040
2003	392,683	31,729	8.08%	7	989
2004	381,639	29,874	7.83%	5	980
2005	358,590	27,366	7.63%	9	941
2006	334,206	28,240	8.45%	12	1,024
2007	328,742	26,304	8.00%	10	991
2008	320,876	24,590	7.66%	6	979
2009	298,646	25,146	8.42%	3	983
2010	300,164	23,203	7.73%	4	920
2011	297,831	22,733	7.63%	7	903
2012	287,050	20,996	7.31%	5	874
2013	269,079	20,201	7.51%	7	844
2014	282,368	19,705	6.98%	4	798
2015	302,307	21,061	6.97%	4	891
15-Year Average		**25,536**	**7.77%**	**6.33**	**949.40**

Table 3-5. Combined Athens/Hocking County deer-vehicle crash frequency, 2001-2015 (Data Source: Ohio Department of Public Safety Annual Crash Facts Report).

Year	Total Crashes ATH/HOC (All Types)	Total Crashes ATH/HOC (Deer Only)	Percentage Deer Crashes (ATH/HOC)	Percentage Deer Crashes (Statewide)
2001	3,069	680	22.16%	8.16%
2002	2,914	559	19.18%	7.85%
2003	2,916	515	17.66%	8.08%
2004	2,642	392	14.84%	7.83%
2005	2,363	324	13.71%	7.63%
2006	2,160	251	11.62%	8.45%
2007	2,154	249	11.56%	8.00%
2008	2,157	267	12.38%	7.66%
2009	2,149	337	15.68%	8.42%
2010	2,132	260	12.20%	7.73%
2011	1,939	222	11.45%	7.63%
2012	1,965	273	13.89%	7.31%
2013	1,828	276	15.10%	7.51%
2014	1,823	285	15.63%	6.98%
2015	1,813	245	13.51%	6.97%
15-Year Average		**342**	**15.09%**	**7.77%**

Table 3-6. Highway segment definitions, U.S. 33 Nelsonville Bypass and Control Sections, Athens, Hocking, and Meigs Counties, Ohio.

Highway Segment	**Endpoints (Statewide Milepost)**	**Length (Miles)**
U.S. 33 – Nelsonville Bypass	Start: West End of Bypass Project (178.41) End: Elm Rock Road (TR 36) Underpass (186.55)	8.14
Control Section #1 – U.S. 50	Start: SR 329 Intersection (183.27) End: Vanderhoof Road (CR 65) Intersection (189.65)	6.38
Control Section #2 – U.S. 33	Start: West End of Control Section 2 (199.77) End: SR 681 Interchange (211.30)	11.53

Table 3-7. Deer-vehicle crash analysis, U.S. 33 Nelsonville Bypass Section, 2014-2016.

	2014	**2015**	**2016**
Total Crashes	30	52	44
Deer-Related Crashes	7	11	4
VMT (100 Million)	0.451	0.467	0.486
Total Crash Rate	66.49	111.30	90.48
Deer Crash Rate	15.51	23.54	8.23
Percent Deer-Related Crashes	23.3%	21.2%	9.1%
Total Crash Rate (Three-Year Average)	89.70		
Deer Crash Rate (Three-Year Average)	15.66		
Percent Deer-Related Crashes (Three-Year Average)	17.5%		
Note: Crash rates expressed as crash per 100 million VMT			

Table 3-8. Deer-vehicle crash analysis, Control Section #1 - U.S. 50, 2011-2016.

	2011	**2012**	**2013**	**2014**	**2015**	**2016**
Total Crashes	15	28	19	19	24	14
Deer-Related Crashes	8	13	13	9	15	8
VMT (100 Million)	0.163	0.166	0.167	0.170	0.175	0.179
Total Crash Rate	91.89	168.18	113.48	112.07	136.87	78.37
Deer Crash Rate	49.01	78.08	77.64	53.09	85.54	44.78
Percent Deer-Related Crashes	53.3%	46.4%	68.4%	47.4%	62.5%	57.1%
Total Crash Rate (Three-Year Average)	124.71			108.88		
Deer Crash Rate (Three-Year Average)	68.39			61.12		
Percent Deer-Related Crashes (Three-Year Average)	54.8%			56.1%		
Note: Crash rates expressed as crash per 100 million VMT						

Table 3-9. Deer-vehicle crash analysis, Control Section #2 - U.S. 33, 2011-2016.

	2011	**2012**	**2013**	**2014**	**2015**	**2016**
Total Crashes	19	15	18	34	23	22
Deer-Related Crashes	10	10	8	19	12	8
VMT (100 Million)	0.234	0.239	0.240	0.254	0.264	0.270
Total Crash Rate	81.13	62.72	74.89	133.98	86.96	81.63
Deer Crash Rate	42.70	41.81	33.29	74.87	45.37	29.68
Percent Deer-Related Crashes	52.6%	66.7%	44.4%	55.9%	52.2%	36.4%
Total Crash Rate (Three-Year Average)	72.86			100.28		
Deer Crash Rate (Three-Year Average)	39.23			49.51		
Percent Deer-Related Crashes (Three-Year Average)	53.8%			49.4%		
Note: Crash rates expressed as crash per 100 million VMT						

Table 3-10. Summary of roadkill survey data for U.S. 33 Nelsonville Bypass and Control Sections.

Location	**Crashes (Total)**	**Crashes (Deer-Related)**	**Roadkill Observed (Deer Only)**	**Percent Deer Crashes**	**Roadkill/ Deer Crash Ratio**
U.S. 33 – Nelsonville Bypass	52	5	15	9.6%	3.00
Control Section 1 – U.S. 50	22	13	42	59.1%	3.23
Control Section 2 – U.S. 33	24	11	23	45.8%	2.09
Note: All data for period 3/30/2015 through 3/24/2016 excluding 4/29/2015 through 5/28/2015					

Table 3-11. Summary of deer-vehicle crash analysis showing deer-vehicle crash rate and percent deer-vehicle crashes for Ohio (Statewide), Athens/Hocking County, U.S. 33 Nelsonville Bypass, and Control Sections, 2011 – 2016.

Location	**Deer Crash Rate (per 100 Million VMT)**		**Percent Deer Crashes**	
	2011 – 2013	**2014 – 2016**	**2011 – 2013**	**2014 – 2016**
Statewide	19.01	17.68	7.5%	7.0%
Athens/Hocking County	30.32	31.72	13.5%	14.6%
U.S. 33 – Nelsonville Bypass	**N/A**	**15.66**	**N/A**	**17.5%**
Control Section 1 – U.S. 50	68.39	61.12	54.8%	56.1%
Control Section 2 – U.S. 33	39.23	49.51	53.8%	49.4%

Table 4-1. Distribution of pellet count transects among the main habitat types in the U.S. 33 Nelsonville Bypass right-of-way (ROW), Athens and Hocking Counties, Ohio.

Herbaceous vegetation = 70% of ROW habitat	35 transects
Regenerating woody vegetation = 20% of ROW habitat	10 transects
Forest = 10% of ROW habitat	5 transects
TOTAL	**50 transects**

Table 4-2. Deer usable gaps along the U.S. 33 Nelsonville Bypass right-of-way, Athens and Hocking Counties, Ohio. Gap segment location, description of gap cause, side of right-of-way gap is on, highway station and location (latitude and longitude) are reported for each gap.

SEGMENT	DESCRIP	COMMENT	SIDE	STATION	LAT	LON
1	Road	Connection to old 33 270 feet	Center	2280	39° 28.942' N	-82° 19.0-82' W
1	Post	Eroded out of soil	North	2750	39° 28.883' N	-82° 18.983' W
1	Tree fall	Fence crushed fallen tree	South	4200	39° 28.663' N	-82° 18.848' W
1	Tree fall	Fence crushed fallen tree	North	4580	39° 28.684' N	-82° 18.750' W
2	Tree fall	Fence crushed fallen tree	North	8160	39° 28.674' N	-82° 18.004' W
2	Culvert Top	Wide wires over large culvert	North	8240	39° 28.718' N	-82° 17.987' W
2	Gap	30-40" gap at fence-stream crossing	South	8460	39° 28.608' N	-82° 17.932' W
2	Tree fall	Fence crushed fallen tree	North	9540	39° 28.682' N	-82° 17.698' W
2	Tree fall		South	9910	39° 28.578' N	-82° 17.650' W
2	Erosion	24' Gap under from deep erosion	North	9920	39° 28.665' N	-82° 17.619' W
2	Tree fall		South	10220	39° 28.559' N	-82° 17.587' W
2	Tree fall		North	10560	39° 28.600' N	-82° 17.501' W
2	Gap	Gap over low wingwall	North	10700	39° 28.582' N	-82° 17.476' W
2	Gap	Gap over low wingwall	South	10710	39° 28.559' N	-82° 17.484' W
3	Gap	Gap over low wingwall	South	10740	39° 28.556' N	-82° 17.474' W
3	Gap	Gap over low wingwall	North	10760	39° 28.580' N	-82° 17.465' W
4	Tree fall		North	12900	39° 28.517' N	-82° 17.017' W
4	Tree fall		South	13030	39° 28.440' N	-82° 17.012' W
4	Tree fall		South	13510	39° 28.411' N	-82° 16.915' W
4	Gap	Fence over stream channel 36"	South	13680	39° 28.370' N	-82° 16.893' W
4	Tree fall		South	14490	39° 28.350' N	-82° 16.720' W
4	Culvert Top		North	15440	39° 28.362' N	-82° 16.506' W
4	Culvert Top		South	15710	39° 28.303' N	-82° 16.470' W
4	Tree fall		South	16320	39° 28.271' N	-82° 16.350' W
4	Tree fall		North	16830	39° 28.311' N	-82° 16.263' W
4	Culvert Top	Wide wires over culvert	North	16840	39° 28.279' N	-82° 16.228' W
4	Erosion	Erosion under fence 24"	South	17110	39° 28.222' N	-82° 16.196' W
4	Tree fall		South	17900	39° 28.185' N	-82° 16.031' W
4	Tree fall		North	19140	39° 28.204' N	-82° 15.769' W
4	Tree fall		North	19590	39° 28.223' N	-82° 15.677' W

Figure 4-2. Deer usable gaps along the U.S. 33 Nelsonville Bypass right-of-way (continued).

4	Tree fall		North	20230	39° 28.284' N	-82° 15.562' W
4	Tree fall		North	20590	39° 28.292' N	-82° 15.485' W
4	Erosion	40" erosion under gate	South	20920	39° 28.245' N	-82° 15.392' W
4	Culvert Top		South	20990	39° 28.334' N	-82° 15.402' W
4	Tree fall		North	21090	39° 28.361' N	-82° 15.400' W
4	Road	Dorr Run North 50 feet	North	21320	39° 28.373' N	-82° 15.361' W
5	Road	Dorr Run North 110 feet	North	21350	39° 28.396' N	-82° 15.357' W
4	Road	Door Run South 240 feet	South	22200	39° 28.197' N	-82° 15.080' W
5	Road	Dorr Run South 115 feet	South	22710	39° 28.219' N	-82° 15.008' W
5	Tree fall		South	23910	39° 28.300' N	-82° 14.771' W
5	Erosion	Erosion channel under fence	North	24870	39° 28.384' N	-82° 14.581' W
5	Tree fall		South	25020	39° 28.326' N	-82° 14.544' W
5	Tree fall		North	25260	39° 28.403' N	-82° 14.492' W
5	Tree fall		North	25780	39° 28.386' N	-82° 14.381' W
6	Gap	Fence open at slope concavity 20"	North	26890	39° 28.378' N	-82° 14.150' W
6	Gap	Fence over drainage 38 "	North	27180	39° 28.389' N	-82° 14.088' W
6	Gap	Fence over channel 28"	North	27270	39° 28.384' N	-82° 14.066' W
6	Gap	Fence detached 20" Wide	South	27540	39° 28.305' N	-82° 14.007' W
6	Gap	Fence open along ridge transition 34"	North	27610	39° 28.372' N	-82° 13.990' W
6	Tree fall		South	28530	39° 28.263' N	-82° 13.847' W
6	Gap	2 fence gaps over channel, 24", 18"	North	28680	39° 28.300' N	-82° 13.762' W
6	Tree fall		North	28870	39° 28.270' N	-82° 13.731' W
6	Tree fall		North	29510	39° 28.184' N	-82° 13.652' W
6	Gap	Fence-abutment gap 20"	South	29930	39° 28.105' N	-82° 13.636' W
7	Gap	Fence-abutment gap 20"	South	30140	39° 28.098' N	-82° 13.578' W
7	Gap	Erosion under fence 20"	South	30280	39° 28.046' N	-82° 13.622' W
7	Tree fall		North	30680	39° 28.044' N	-82° 13.488' W
7	Tree fall		South	30720	39° 27.997' N	-82° 13.537' W
7	Tree fall		North	32080	39° 27.898' N	-82° 13.260' W
7	Tree fall		North	32170	39° 27.888' N	-82° 13.243' W
7	Tree fall		North	32590	39° 27.867' N	-82° 13.147' W

Figure 4-2. Deer usable gaps along the U.S. 33 Nelsonville Bypass right-of-way (continued).

7	Tree fall		South	32630	39° 27.800' N	-82° 13.220' W
8	Tree fall		South	33750	39° 27.676' N	-82° 13.065' W
8	Tree fall		North	33940	39° 27.687' N	-82° 12.929' W
8	Gap	Erosion under fence 30"	North	34210	39° 27.645' N	-82° 12.918' W
8	Tree fall		North	34710	39° 27.573' N	-82° 12.863' W
8	Gap	Fence-abutment gap 18"	South	35870	39° 27.375' N	-82° 12.842' W
9	Gap	Fence-abutment gap 16"	North	36210	39° 27.339' N	-82° 12.774' W
9	Gap	Fence-abutment gap 18"	South	36220	39° 27.322' N	-82° 12.806' W
9	Tree fall		North	37120	39° 27.213' N	-82° 12.653' W
9	Tree fall		North	40080	39° 26.765' N	-82° 12.394' W
9	Tree fall		South	40280	39° 26.709' N	-82° 12.486' W
9	Road	Gap SR 78 140 feet	North	40350	39° 26.754' N	-82° 12.290' W
10	Road	SR 78 North 135 feet	North	40720	39° 26.706' N	-82° 12.243' W
9	Tree fall		South	41190	39° 26.551' N	-82° 12.434' W
9	Road	SR 78 south road gap 100 feet	South	41270	39° 26.529' N	-82° 12.459' W
10	Road	SR 78 road gap 60 feet	South	41630	39° 26.452' N	-82° 12.463' W
10	Tree fall		South	43120	39° 26.302' N	-82° 12.172' W
10	Tree fall		North	43270	39° 26.319' N	-82° 12.043' W
10	Tree fall		North	43940	39° 26.219' N	-82° 11.986' W
10	Gap	Erosion under 20"	South	44380	39° 26.127' N	-82° 12.025' W
10	Gap	Fence-abutment gap 30"	South	45040	39° 26.014' N	-82° 11.935' W
10	Gap	Fence over rocky stream 20"	North	45310	39° 26.006' N	-82° 11.890' W
11	Gap	Fence-abutment gap 20"	South	45450	39° 25.977' N	-82° 11.913' W
11	Jump over	4-foot fence	North	45570	39° 25.967' N	-82° 11.864' W
11	Road	Old 33 connection to ROW 185 feet	Center	46140	39° 25.874' N	-82° 11.840' W

Table 4-3. Number of pellet groups found for each strip transect for the initial visit to each transect (May 30-June 3, 2016) and the revisit to each transect (June 25-29, 2016). Transects were located along the eastbound or westbound side of the U.S. 33 Nelsonville Bypass, Athens and Hocking Counties, Ohio in forest, regenerating woody vegetation, or herbaceous vegetation habitats.

No.	Direction	Transect	Habitat	Number of Pellet Groups	
				Initial visit 30 May - 3 June	Revisit 25 - 29 June
1	Eastbound	Transect 00	Herbaceous	0	0
2	Eastbound	Transect 01	Herbaceous	0	0
3	Eastbound	Transect 02	Regen woody vegetation	0	0
4	Eastbound	Transect 03	Regen woody vegetation	0	0
5	Eastbound	Transect 04	Herbaceous	0	0
6	Eastbound	Transect 05	Herbaceous	0	0
7	Eastbound	Transect 06	Herbaceous	4	4
8	Eastbound	Transect 07	Herbaceous	0	0
9	Eastbound	Transect 08	Herbaceous	0	0
10	Eastbound	Transect 09	Herbaceous	0	0
11	Eastbound	Transect 10	Forest	2	2
12	Eastbound	Transect 11	Regen woody vegetation	1	2
13	Eastbound	Transect 12	Regen woody vegetation	1	1
14	Eastbound	Transect 13	Herbaceous	0	0
15	Eastbound	Transect 14	Herbaceous	0	0
16	Eastbound	Transect 15	Herbaceous	0	0
17	Eastbound	Transect 16	Regen woody vegetation	0	0
18	Eastbound	Transect 17	Herbaceous	0	0
19	Eastbound	Transect 18	Regen woody vegetation	0	0
20	Eastbound	Transect 19	Regen woody vegetation	0	0
21	Eastbound	Transect 20	Herbaceous	0	1
22	Eastbound	Transect 21	Herbaceous	0	0
23	Eastbound	Transect 22	Herbaceous	0	0
24	Eastbound	Transect 23	Forest	0	3
25	Eastbound	Transect 24	Herbaceous	0	0
26	Westbound	Transect 25	Regen woody vegetation	8	8
27	Westbound	Transect 26	Herbaceous	1	1

28	Westbound	Transect 27	Regen woody vegetation	1	1
29	Westbound	Transect 28	Regen woody vegetation	0	0
30	Westbound	Transect 29	Regen woody vegetation	2	6
31	Westbound	Transect 30	Herbaceous	1	1
32	Westbound	Transect 31	Forest	2	3
33	Westbound	Transect 32	Herbaceous	1	1
34	Westbound	Transect 33	Regen woody vegetation	0	1
35	Westbound	Transect 34	Forest	2	2
36	Westbound	Transect 35	Herbaceous	0	0
37	Westbound	Transect 36	Regen woody vegetation	0	0
38	Westbound	Transect 37	Regen woody vegetation	0	0
39	Westbound	Transect 39	Herbaceous	0	0
40	Westbound	Transect 40	Herbaceous	0	0
41	Westbound	Transect 41	Herbaceous	0	0
42	Westbound	Transect 42	Regen woody vegetation	0	0
43	Westbound	Transect 43	Herbaceous	0	0
44	Westbound	Transect 44	Herbaceous	0	0
45	Westbound	Transect 45	Forest	0	0
46	Westbound	Transect 46	Herbaceous	0	0
47	Westbound	Transect 47	Herbaceous	0	0
48	Westbound	Transect 48	Herbaceous	0	0
49	Westbound	Transect 49	Herbaceous	0	0
50	Westbound	Transect 50	Herbaceous	3	3
		TOTAL		29	40

Table 4-4. Number of deer events recorded at camera traps along the U.S. 33 Nelsonville Bypass right-of-way in 2015 and 2016. 'Non-rut events' are much lower in 2015 because cameras were installed after the first annual peak (end-May - early-July).

Year	Non-Rut Events	Rut Events
2015	727	933
2016	3748	1575

Table 5-1. List of amphibian species that could be found at the site along State Route 78, Athens County, Ohio. Migratory species have stars (*) next to the common name.

Common Name	Scientific Name
Blanchard's Cricket Frog*	*Acris blanchardi*
Jefferson Salamander*	*Ambystoma jeffersonianum*
Spotted Salamander*	*Ambystoma maculatum*
Marbled Salamander*	*Ambystoma opacum*
Small-mouthed Salamander*	*Ambystoma texanum*
American Toad*	*Anaxyrus americanus*
Fowler's Toad*	*Anaxyrus fowleri*
Northern Dusky Salamander	*Desmognathus fuscus*
Southern Two-lined Salamander	*Eurycea cirrigera*
Long-tailed Salamander	*Eurycea longicauda*
Spring Salamander	*Gyrinophilus porphyriticus*
Cope's Gray Treefrog*	*Hyla chrysoscelis*
Gray Treefrog*	*Hyla versicolor*
Common Mudpuppy	*Necturus maculosus*
Red-spotted Newt*	*Notophthalmus viridescens*
Eastern Red-backed Salamander	*Plethodon cinereus*
Northern Ravine Salamander	*Plethodon electromorphus*
Northern Slimy Salamander	*Plethodon glutinosus*
Mountain Chorus Frog*	*Pseudacris brachyphona*
Spring Peeper*	*Pseudacris crucifer*
Western Chorus Frog*	*Pseudacris triseriata*
Midland Mud Salamander	*Pseudotriton montanus diastictus*
Northern Red Salamander	*Pseudotriton ruber*
American Bullfrog*	*Rana catesbeiana*
Northern Green Frog*	*Rana clamitans melanota*
Pickerel Frog*	*Rana palustris*
Northern Leopard Frog*	*Rana pipiens*
Wood Frog*	*Rana sylvatica*
Eastern Spadefoot	*Scaphiopus holbrookii*

Table 5-2. List of amphibian species found at the site along State Route 78, Athens County, Ohio using pitfall traps, dip nets, minnow traps, spot light surveys, and/or call surveys (adult amphibians only). Migratory species have stars next to the common name. Gray Treefrog species are lumped together because they cannot be separately identified in the field without listening to their call.

Common Name	Scientific Name	Pitfall trap	Dip net	Minnow trap	Spot light	Call Survey
Jefferson Salamander*	*Ambystoma jeffersonianum*	X	X	X	X	
Spotted Salamander*	*Ambystoma maculatum*	X	X	X	X	
Marbled Salamander*	*Ambystoma opacum*	X			X	
American Toad*	*Bufo americanus*	X	X	X	X	X
Long-tailed Salamander	*Eurycea longicauda*		X			
Gray Treefrogs*	*Hyla chrysoscelis* & *Hyla versicolor*			X	X	X
Red-spotted Newt*	*Notophthalmus viridescens*	X	X	X	X	
Eastern Red-backed Salamander	*Plethodon cinereus*	X			X	
Northern Slimy Salamander	*Plethodon glutinosus*	X				
Spring Peeper*	*Pseudacris crucifer*	X	X	X	X	X
Western Chorus Frog*	*Pseudacris triseriata*			X		X
American Bullfrog*	*Rana catesbeiana*	X	X	X	X	X
Northern Green Frog*	*Rana clamitans melanota*	X	X	X	X	X
Pickerel Frog*	*Rana palustris*	X	X	X	X	X
Northern Leopard Frog*	*Rana pipiens*	X		X	X	X
Wood Frog*	*Rana sylvatica*	X		X	X	X

Table 5-3. Number of times each wetland was dip netted in spring 2015, how many individual amphibians were caught, and the number of species captured. Wetland numbers are provided in Figure 5-2.

Wetland #	# of times dip netted	# of individuals caught	# of species caught
1	3	2	2
2	3	4	3
3	3	5	2
4	3	2	2
5	3	2	2
6	2	0	0
7	3	1	1
8	3	0	0
9	3	0	0
10	1	0	0
51	3	2	2
71	2	2	2

Table 5-4. Amphibian species found using dip nets and minnow traps, including all life stages, marked with an ‘X’ indicating presence in each wetland. Bottom row shows the total number of amphibian species detected per wetland and the last column shows the total number of wetlands each species was found in. Wetland identification numbers are provided in Figure 5-2.

Species	Wetland #	1	2	3	4	5	6	7	8	9	10	51	71	Total # of Wetlands
Northern Green Frog		X	X	X	X	X		X	X	X	X	X	X	**11**
Gray Treefrogs		X	X	X	X	X		X	X	X	X	X		**10**
Red-spotted Newt		X	X	X	X	X		X	X	X		X	X	**10**
American Bullfrog		X	X	X	X	X		X	X		X	X		**9**
Spring Peeper		X	X	X	X	X		X	X			X	X	**9**
Spotted Salamander		X		X	X	X		X	X			X	X	**8**
American Toad			X	X		X		X	X			X	X	**7**
Pickerel Frog		X	X	X		X		X				X	X	**7**
Western Chorus Frog		X	X	X		X		X	X			X		**7**
Northern Leopard Frog		X	X	X		X		X				X		**6**
Wood Frog		X			X	X			X			X		**5**
Marbled Salamander						X		X	X			X		**4**
Jefferson Salamander		X				X			X			X		**4**
Total # of Species		**11**	**9**	**10**	**7**	**13**	**0**	**11**	**11**	**3**	**3**	**13**	**6**	

Table 5-5. High and low Lincoln-Petersen and Chapman's population estimates for seven species of amphibian. High estimates use roadway mortality information to help inform the estimate (High estimates are unavailable for Red-spotted Newts because the juvenile eft stage experiences the mortality rather than adults).

Species	Lincoln-Petersen High Estimate	Chapman High Estimate	Lincoln-Petersen Low Estimate	Chapman Low Estimate
American Bullfrog	2,181	1,938	1,605	1,430
American Toad	2,961	2,914	1,305	1,287
Jefferson Salamander	478	399	420	352
Marbled Salamander	336	294	168	149
Northern Green Frog	5,353	5,117	3,780	3,617
Red-spotted Newt	NA	NA	4,838	4,803
Spotted Salamander	484	430	267	239

Table 5-6. Area density population estimate for Spring Peepers in the nine wetlands that have suitable Spring Peeper habitat (Figure 5-6). Wetland numbers can be seen in Figure 5-2 and Figure 5-6.

Wetland	Suitable Habitat (sq. ft.)	Peepers in 2016 (per sq. ft.)	Estimated Number of Peepers
1	13,322	0.066	874
2	122,468	0.112	13,676
3	31,169	0.066	2,051
4	9,101	0.021	192
5	55,109	0.083	4,549
7	58,205	0.088	5,125
8	27,834	0.032	881
51	39,677	0.048	1,920
71	31,543	0.004	137
	Estimated Total Number of Spring Peepers		**29,405**

Table 5-7. Percentage of population experiencing mortality annually based on population estimates and average number of carcasses detected per year for eight species. 10% mortality annually is a rough estimate of a mortality rate that is not sustainable for amphibian populations.

Species	High Population Estimate	Low Population Estimate	Average Number of Carcasses per Year	Percentage of Population Experiencing Mortality Annually
American Bullfrog	2,181	1,430	91	4.2-6.4%
American Toad	2,961	1,287	434	14.6-33.7%
Jefferson Salamander	478	352	15	3.0-4.1%
Marbled Salamander	336	149	15	4.3-9.7%
Northern Green Frog	5,353	3,617	246	4.6-6.8%
Red-spotted Newt	4,838	4,803	2,477	NA
Spotted Salamander	484	239	35	7.1-14.4%
Spring Peeper	29,405		2,873	9.8%

Table 5-8. Percentage of populations detected in the ecopassage structures based on population estimates and the number of individuals detected by camera traps by species.

Species	High Population Estimate	Low Population Estimate	Number of Individuals Detected by Camera Traps	Percentage of Population Seen in Ecopassages
American Bullfrog	2,181	1,430	3	0.14-0.21%
American Toad	2,961	1,287	4	0.14-0.31%
Jefferson Salamander	478	352	0	0%
Marbled Salamander	336	149	4	1.19-2.68%
Northern Green Frog	5,353	3,617	11	0.21-0.30%
Red-spotted Newt	4,838	4,803	1	0.02%
Spotted Salamander	484	239	0	0%
Spring Peeper	29,405		2	0.01%

Table 7-1. List of Timber Rattlesnake (*Crotalus horridus*) captures along the U.S. 33 Nelsonville Bypass, Hocking County, Ohio.

PIT ID	Sex	Captured	SVL (cm)	Mass (g)	Snake Mitigation Area	Capt. Location	Capture Method
982000365990609	F_S	5/27/2015	72	275	Y	Forest	Cover Board
982000365990652	F_G	6/26/2015	103	964	Y	ROW	Incidental
982000365990672	M	8/5/2015	93	723	Y	ROW	Box Trap
982000365990621	M	8/23/2015	102	980	N	ROW	Incidental
982000365990587	M_N	9/6/2015	33	27	Y	ROW	Box Trap
982000365990588	M_N	9/19/2015	31	25	Y	Forest	Box Trap
982000365990601	F_G	5/21/2016	105	1135	Y	Forest	Box Trap
982000365990524	F_N	9/5/2016	32	25	Y	ROW	Incidental
982000365990554	M_N	9/5/2016	30	22	Y	ROW	Incidental
982000365990541	F_N	9/5/2016	31	26	Y	ROW	Fence Line
982000365990518	F_N	9/5/2016	30	23	Y	ROW	Fence Line
982000365990561	M_N	9/5/2016	31	23	Y	ROW	Cover Board
982000365990558	F_N	9/6/2016	30	24	Y	ROW	Box Trap
982000365990542	F_N	9/6/2016	31	24	Y	ROW	Cover Board
982000365990486	F_N	9/6/2016	32	25	Y	ROW	Cover Board
982000365990526	M_N	9/8/2016	32	27	Y	ROW	Box Trap
982000365990564	F_N	9/8/2016	31	23	Y	ROW	Box Trap

Sex: M, male; F, female; S, sub-adult; G = Gravid, N = Neonate. Capture location refers to the side of the wildlife exclusion fence where an individual was captured; Forest = outside the right-of-way (ROW), ROW = within the ROW.

Table 7-2. Home ranges and fence crossings for radio-telemetered rattlesnakes. Relocs. = the number of activity season relocations, and in parentheses, the proportion of relocations within the right-of-way (ROW); Home ranges are reported in hectares with percent ROW-overlap in parentheses; minimum convex polygon (MCP) maximum length is reported in meters.

ID	Field Season	Sex	SVL (cm)	Relocs.	100% MCP	95% KDE	95% LoCoH	50% KDE	50% LoCoH	Snake Fence Crossings	MCP Max Length
652	2015	F_G	103	55 (72.7)	3.6 (30.4)	1.2 (46.9)	1.9 (24.6)	0.2 (90.7)	0.6 (35.6)	5	306
652	2016	F	103	71 (2.8)	17.1 (1.0)	12.9 (6.9)	8.5 (0.3)	3.5 (0.0)	1.9 (0.0)	0	682
601	2016	F_G	105	63 (65.1)	9.7 (11.1)	5.3 (47.4)	1.8 (25.8)	0.6 (64.9)	1.0 (5.8)	6	700
609	2015	F_S	72	71 (21.1)	5.7 (7.9)	3.2 (17.3)	1.9 (16.3)	0.8 (12.5)	0.7 (13.7)	4	378
609	2016	F_S	77	48 (33.3)	8.4 (4.0)	6.4 (26.3)	3.2 (8.3)	0.5 (5.4)	2.0 (11.1)	4	380
672	2016	M	97	74 (17.6)	25.7 (2.3)	22.6 (13.8)	15.9 (2.3)	2.6 (12.4)	2.0 (0.0)	0	937
672[I]	2015	M	93	20 (20.0)	10.4 (4.4)	NA	NA	NA	NA	1	749
621[I]	2015	M	102	17 (17.6)	6.2 (4.6)	NA	NA	NA	NA	NA	752

[I] = Individual-year reflects incomplete activity season, and we did not generate KDE or LoCoH home ranges for these individual-years due to insufficient data. For purposes of comparison with home range diameters, the snake fence spans 1 mi.

Table 7-3. Summary data for the road avoidance simulations; results of correlated random walk analysis modelling rattlesnake movement paths.

						Predicted Crossings		
ID	Field Season	Sex	SVL (cm)	Steps	Observed Crossings	Median	Range	P≤ observed
652	2015	F_G	103	34	0	1	0 - 11	0.370
652	2016	F	103	54	0	3	0 - 18	0.200
601	2016	F_G	105	31	0	2	0 - 14	0.240
609	2015	F_S	72	33	0	0	0 - 12	0.576
609	2016	F_S	77	35	0	0	0 - 9	0.539
672	2016	M	97	61	0	1	0 - 20	0.319

F_G, gravid female; F, non-gravid female; F_S, sub-adult female; M, male; SVL, snout-vent length; Steps, number of steps in random walk was determined by the number of movements > 0 m across the activity season; P ≤ observed, the probability of sampling a value from the crossing distribution ≤ the number of observed crossings.

Table 7-4. Reptile captures from the forest and right-of-way (ROW) sides of the wildlife exclusion fence.

Snakes	Species	Forest	ROW	Total
Copperhead	*Agkistrodon contortrix*	6	3	9
Black Racer	*Coluber constrictor*	16	13	29
Timber Rattlesnake	*Crotalus horridus*	6	13	19
Eastern Hognose	*Heterodon platirhinos*	1	0	1
Eastern Milk Snake	*Lampropeltis triangulum*	13	11	24
Gray Ratsnake	*Pantherophis spiloides*	8	4	12
Garter Snake	*Thamnophis sirtalis*	57	8	65
Snakes Total		107	55	162
Turtles				
Box Turtle	*Terrapene carolina*	49	12	61
	Reptiles Total	156	67	223

Data includes box trap, cover board, fence line, incidental captures, and recaptures. Occasionally, animals were unfit for marking (i.e. too small, injured, or dead).

Table 7-5. Fence crossings and total recaptures as measured by capture-mark-recapture methods.

Snakes	Species	Cross to Forest	Cross to ROW	Total Recaptures (no. individuals)	Total Marked
Copperhead	*Agkistrodon contortrix*	0	0	0	8
Black Racer	*Coluber constrictor*	1	1	3 (3)	25
Timber Rattlesnake	*Crotalus horridus*	1	0	2 (2)	17
Eastern Hognose	*Heterodon platirhinos*	0	0	0	1
Eastern Milk Snake	*Lampropeltis triangulum*	1	1	6 (5)	15
Gray Rat Snake	*Pantherophis spiloides*	0	0	1	12
Garter Snake	*Thamnophis sirtalis*	1	0	6 (5)	51
Snakes Total		4	2	18 (15)	129
Turtles					
Box Turtle	*Terrapene carolina*	0	1	12 (8)	45
	Reptiles Total	4	3	30 (23)	174

Data includes box trap, cover board, fence line, incidental captures. Discrepancies between total animals captured and marked are a result of some individuals being unfit for marking, and the list of captures includes recaptured animals. ROW = right-of-way.

Table 7-6. Summary of reptiles observed crossing or dead on the road.

Common Name	Species	Within Snake Mitig. Area	Outside Snake Mitig. Area	Total
Box Turtle	*Terrapene carolina*	1 (0.625)	13 (1.083)	14
Painted Turtle	*Chrysemys picta*	0	1 (0.083)	1
Snapping Turtle	*Chelydra serpentina*	2 (1.25)	0	2
	Turtles	3 (1.875)	14 (1.167)	17
Copperhead	*Agkistrodon contortrix*	0	1 (0.083)	1
Black Racer	*Coluber constrictor*	0	1 (0.083)	1
Milk Snake	*Lampropeltis triangulum*	1 (0.625)	2 (0.167)	3
Rat Snake	*Pantherophis spiloides*	0	2 (0.167)	2
Garter Snake	*Thamnophis sirtalis*	1 (0.625)	1 (0.083)	2
	Snakes	2 (1.25)	7 (0.583)	9
	Reptiles	5 (3.125)	21 (1.75)	26

Data displayed as raw count and distance corrected (reptiles/km) in parentheses. Distance corrected was calculated as the raw count of reptiles divided by the length (km) of the treatment area (mitigated or unmitigated).

Table 7-7. Road survey observations of reptiles found crossing or dead on the road.

Map Marker	Date	Common Name	Species	Sex	Age Class	Highway Direction	Vehicle Lane	Dead /Alive	Snake Mitigation Area
1	4/27/2015	Black Racer	*Coluber constrictor*	-	Adult	West	Left Shoulder	Dead	No
2	5/11/2015	Box Turtle	*Terrapene carolina*	M	Adult	East	Right Lane	Alive	No
3	5/25/2015	Box Turtle	*Terrapene carolina*	F	Adult	West	Right Shoulder	Dead	No
4	6/4/2015	Rat Snake	*Pantherophis spiloides*	-	Juvenile	East	Right Shoulder	Dead	No
5	6/6/2015	Box Turtle	*Terrapene carolina*	-	Adult	East	Right Shoulder	Dead	Yes
6	6/11/2015	Box Turtle	*Terrapene carolina*	M	Adult	West	Right Shoulder	Dead	No
7	6/24/2015	Box Turtle	*Terrapene carolina*	-	Adult	East	U-Turn	Dead	No
8	6/27/2015	Snapping Turtle	*Chelydra serpentina*	-	Juvenile	West	Right Shoulder	Dead	Yes
9	7/9/2015	Milk Snake	*Lampropeltis triangulum*	-	Juvenile	East	Berm	Dead	Yes
10	7/22/2015	Snapping Turtle	*Chelydra serpentina*	-	Adult	East	Right Shoulder	Dead	Yes
11	7/26/2015	Rat Snake	*Pantherophis spiloides*	-	Juvenile	East	Right Shoulder	Dead	No
12	8/9/2015	Garter Snake	*Thamnophis sirtalis*	-	Adult	East	Right Shoulder	Dead	Yes
13	8/16/2015	Copperhead	*Agkistrodon contortrix*	-	Adult	West	Exit Lane	Dead	No
14	9/5/2015	Box Turtle	*Terrapene carolina*	M	Adult	East	Right Shoulder	Dead	No
15	5/13/2016	Box Turtle	*Terrapene carolina*	F	Adult	East	Right Shoulder	Dead	No
16	5/27/2016	Box Turtle	*Terrapene carolina*	M	Adult	East	Right Shoulder	Dead	No
17	5/27/2016	Box Turtle	*Terrapene carolina*	M	Adult	East	Right Shoulder	Alive	No
18	6/4/2016	Box Turtle	*Terrapene carolina*	F_G	Adult	West	Exit Ramp Lane	Dead	No
19	6/17/2016	Milk Snake	*Lampropeltis triangulum*	-	Juvenile	West	Right Shoulder	Dead	No
20	6/23/2016	Milk Snake	*Lampropeltis triangulum*	-	Adult	West	Right Shoulder	Dead	No
21	6/24/2016	Box Turtle	*Terrapene carolina*	-	Adult	West	Right Shoulder	Dead	No
22	7/29/2016	Box Turtle	*Terrapene carolina*	M	Adult	West	Right Shoulder	Dead	No
23	8/1/2016	Box Turtle	*Terrapene carolina*	M	Adult	West	Right Shoulder	Dead	No
24	8/1/2016	Box Turtle	*Terrapene carolina*	-	Adult	West	Right Shoulder	Dead	No
25	9/7/2016	Painted Turtle	*Chrysemys picta*	F	Adult	West	Right Shoulder	Dead	No
26	9/9/2016	Garter Snake	*Thamnophis sirtalis*	-	Adult	West	Exit Ramp Right Shld.	Dead	No

Table 7-8. Photo observations in Small Wildlife Ecopassage 1 (with snake fencing).

Common Name	Species	Crossings	Potential Crossings	Entrance Activity	Total Activity
REPTILES	**TOTAL**	**0**	**0**	**7**	**7**
Black Racer	*Coluber Constrictor*	0	0	1	**1**
Fence Lizard	*Sceloporus undulatus*	0	0	1	**1**
Box Turtle	*Terrapene carolina*	0	0	3	**3**
Garter Snake	*Thamnophis sirtalis*	0	0	2	**2**
AMPHIBIANS	**TOTAL**	**0**	**0**	**2**	**2**
American Toad	*Anaxyrus americanus*				**0**
MAMMALS	**TOTAL**	**659**	**466**	**1408**	**2533**
Coyote	*Canis latrans*	1	0	3	**4**
Opossum	*Didelphis virginiana*	180	28	79	**287**
Domestic Cat	*Felis catus*	10	6	6	**22**
Groundhog	*Marmota monax*	3	2	0	**5**
Striped Skunk	*Mephitis mephitis*	2	0	12	**14**
Vole	*Microtus pennsylvanicus*	5	0	71	**76**
Short-tailed Weasel	*Mustela erminea*	8	4	9	**21**
Mink	*Neovison vison*	10	5	14	**29**
Mole	*Parascalops breweri*	0	0	2	**2**
Mouse	*Peromyscus spp.*	29	16	665	**710**
Raccoon	*Procyon lotor*	297	114	133	**544**
Fox Squirrel	*Scurius niger*	5	7	139	**151**
Shrew	*Sorex / Blarina sp.*	0	0	9	**9**
Eastern Cottontail	*Sylvilagus floridanus*	42	207	100	**349**
Lemming	*Synaptomys cooperi*	1	0	1	**2**
Chipmunk	*Tamias striatus*	59	68	158	**285**
Gray Fox	*Urocyon cinereoargenteus*	1	1	1	**3**
Red Fox	*Vulpes vulpes*	6	8	6	**20**
BIRDS	**TOTAL**	**8**	**1**	**12**	**21**
Wood Duck	*Aix sponsa*	8	0	0	**8**
House Sparrow	*Passer domesticus*	0	0	4	**4**
Grackle	*Quiscalus quiscula*	0	0	1	**1**
Carolina Wren	*Thryothorus ludovicianus*	0	0	6	**6**
American Robin	*Turdus migratorius*	0	1	1	**2**
ANIMALS	**TOTAL**	**667**	**467**	**1429**	**2563**

Table 7-9. Photo observations in Small Wildlife Ecopassage 2 (without snake fencing).

Common Name	Species	Crossings	Potential Crossings	Entrance Activity	Total Activity
REPTILES	**TOTAL**	**0**	**0**	**4**	**4**
Black Racer	*Coluber constrictor*	0	0	3	**3**
Ring-necked Snake	*Diadophis punctatus*	0	0	1	**1**
MAMMALS	**TOTAL**	**276**	**537**	**1788**	**2601**
Coyote	*Canis latrans*	0	1	0	**1**
Domestic Dog	*Canis lupus familiaris*	0	0	2	**2**
Beaver	*Castor canadensis*	1	0	0	**1**
Opossum	*Didelphis virginiana*	14	12	24	**50**
Domestic Cat	*Felis catus*	2	0	4	**6**
Bobcat	*Lynx rufus*	0	0	1	**1**
Groundhog	*Marmota monax*	9	32	14	**55**
Striped Skunk	*Mephitis mephitis*	1	4	26	**31**
Vole	*Microtus pennsylvanicus*	0	0	15	**15**
Short Tailed Weasel	*Mustela erminea*	1	3	13	**17**
Mink	*Neovison vison*	2	13	10	**25**
Mole	*Parascalops breweri*	0	0	3	**3**
Mouse	*Peromyscus sp.*	112	166	1240	**1518**
Raccoon	*Procyon lotor*	91	122	55	**268**
Fox Squirrel	*Sciurus niger*	7	21	65	**93**
Shrew	*Sorex / Blarina sp.*	0	0	25	**25**
Eastern Cottontail	*Sylvilagus floridanus*	15	141	191	**347**
Lemming	*Synaptomys cooperi*	0	0	1	**1**
Chipmunk	*Tamias striatus*	20	22	96	**138**
Red Fox	*Vulpes vulpes*	1	0	3	**4**
BIRDS	**TOTAL**	**0**	**0**	**42**	**42**
Peewee	*Contopus virens*	0	0	12	**12**
Gray Catbird	*Dumetella carolinensis*	0	0	3	**3**
Chickadee	*Poecile sp.*	0	0	1	**1**
Hooded Warbler	*Setophaga citrina*	0	0	1	**1**
Carolina Wren	*Thryothorus ludovicianus*	0	0	24	**24**
Brown Thrasher	*Toxostoma rufum*	0	0	1	**1**
ANIMALS	**TOTAL**	**276**	**537**	**1834**	**2647**