Exploration of opportunities to address the impacts of roads and traffic on wildlife in and around Harpers Ferry National Historical Park, and New River Gorge National Park and Preserve, West Virginia

Final Report

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16. Abstract

This report explores the opportunities for wildlife mitigation in and around two national park units in West Virginia; Harpers Ferry National Historical Park, and New River Gorge National Park and Preserve. The wildlife mitigation measures that will be explored are aimed at: 1. Reducing wildlife-vehicle collisions with large mammals (i.e. coyote and larger), and thereby also improving human safety; 2. Reducing direct road mortality for Species of Greatest Conservation Need (SGCN); and 3. Reducing the barrier effect of roads and traffic and increasing habitat connectivity across major highways for large mammals (i.e. coyote and larger) and for SGCN species. In addition, this report specifically explores - based on a literature review - the potential to combine wildlife crossing structures with non-motorized human co-use (i.e. multi-functional crossing structures). This effort focuses on select trails for non-motorized use (hiking, bicycling, and equestrian trails).

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1 Introduction

1.1 Background

This report explores the opportunities for wildlife mitigation in and around two national park Units in West Virginia:

- Harpers Ferry National Historical Park.
- New River Gorge National Park and Preserve.

The wildlife mitigation measures that will be explored are aimed at:

- Reducing wildlife-vehicle collisions with large mammals (i.e. coyote and larger), and thereby also improving human safety.
- Reducing direct road mortality for Species of Greatest Conservation Need (SGCN) in the 2 areas Species groups included in the SGCN category are amphibians, reptiles, and mammals (but excluding bats).
- Reducing the barrier effect of roads and traffic and increasing habitat connectivity across major highways for large mammals (i.e. coyote and larger) and for SGCN species.

In addition, this report specifically explores - based on a literature review - the potential to combine wildlife crossing structures with non-motorized human co-use (i.e. multi-functional crossing structures). This effort would focus on selected trails for non-motorized use (hiking, bicycling, and equestrian trails).

1.2 Tasks

Task 1: Select the road sections included in the study (Chapter 2).

Task 2: Compile a list of the species of interest in the 2 areas (Chapter 3). The species include:

- Large wild mammal species (coyote and larger) that may be a concern to human safety in case of a collision.
- Species of Greatest Conservation Need (SGCN) that may be present in the 2 areas. The selected species are limited to amphibians, reptiles, and mammals (excluding bats).

Task 3: Select trails for non-motorized use (hiking, bicycling, and equestrian trails) in or around the 2 park areas, including the Appalachian Trail which runs through Harpers Ferry National Historical Park (see Appendix C). Identify where these hiking trails cross the selected road sections.

Task 4: Compile a generic synthesis based on a literature review on the pros and cons of combining wildlife and non-motorized human use at the same crossing structures, and associated design recommendations.

Task 5: Conduct a site visit of the two areas and visit the selected road sections in the 2 areas (see task 1) and conduct a coarse scale assessment for potential future mitigation measures aimed at reducing direct road mortality and reducing the barrier effect for the selected species. In addition, explore the potential for underpasses or overpasses where hiking, bicycling or equestrian trails cross the selected road sections. These potential future crossing structures would be multi-functional, they would be designed for shared use by both humans and wildlife.

Task 6: Given the target species (large mammals (i.e. coyote and larger) and Species of Greatest Conservation Need (SGCN), and the results of the site visit, formulate generic, not necessarily location-specific, measures aimed at reducing direct road mortality and improving habitat connectivity. This will likely relate to design recommendations for barriers (e.g. wildlife fences), designated wildlife crossing structures, and multifunctional crossing structures.

2 Effects of roads and traffic on wildlife

Roads and vehicles can affect wildlife in several ways. In general, not specific for large wild mammals, there are five different categories of the effects of roads and traffic on wildlife (Figure 1) (e.g. van der Ree et al., 2015):

- Habitat loss: e.g., the paved road surface, heavily altered environment through the road-bed with non-native substrate, altered hydrology, vegetation removal, seeded species and mowing in the clear zone.
- Direct wildlife road mortality because of collisions with vehicles.
- Barrier to wildlife movements: e.g., animals do not cross the road as often as they cross natural terrain and only a portion of the crossing attempts is successful.
- Decrease in habitat quality in a zone adjacent to the road: e.g., noise and light disturbance, air and water pollution, increased access to the areas adjacent to the highways for humans and associated disturbance.
- Right-of-way habitat and corridor: Depending on the surrounding landscape, the right-of-way can promote the spread of non-native or invasive species (surrounding landscape largely natural or semi-natural) or it can be a refugium for native species (surrounding landscape heavily impacted by humans).

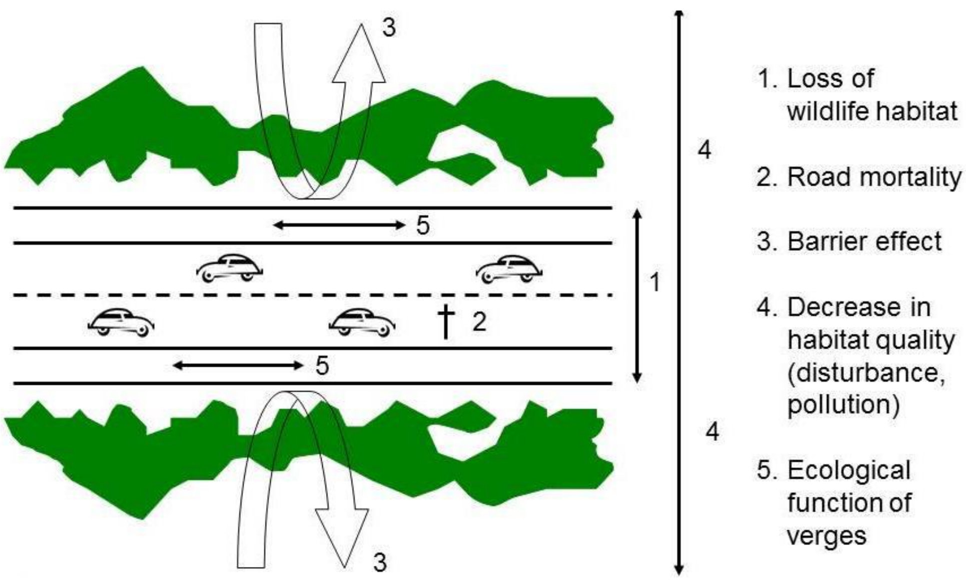

Figure 1: The effects of roads and traffic on wildlife.

While the effects of roads and traffic are varied, direct road mortality, either for the purpose of human safety or biological conservation, and the barrier effect are the most often addressed types of effects. Habitat loss, a decrease in habitat quality in a zone adjacent to a road, and the spread of non-native invasive species are acknowledged and dealt with less often.

3 Avoidance, mitigation, and compensation strategies

While mitigation (reducing the severity of an impact) is common, avoidance is better and should generally be considered first (Cuperus et al., 1999). For example, the negative effects of roads and traffic may be avoided if a road is not constructed, or the most severe negative effects may be avoided by re-routing away from the most sensitive areas (Figure 2). If the effects cannot be avoided, mitigation is a logical second step. Mitigation is typically done in the road-effect zone (Figure 2) and may include measures aimed at reducing wildlife-vehicle collisions and reducing the barrier effect (e.g., through providing for safe wildlife crossing opportunities) (Clevenger & Huijser, 2011; Huijser et al., 2021). However, mitigation may not always be possible, or the mitigation may not be sufficient. In such situations, a third approach may be considered: compensation or off-site mitigation. Compensation may include increasing the size of existing habitat patches, creating new habitat patches, or improving the connectivity between the habitat patches that would allow for larger, more connected, and more viable network of populations. Finally, in some situations, a combination of avoidance, mitigation, and compensation may be implemented.

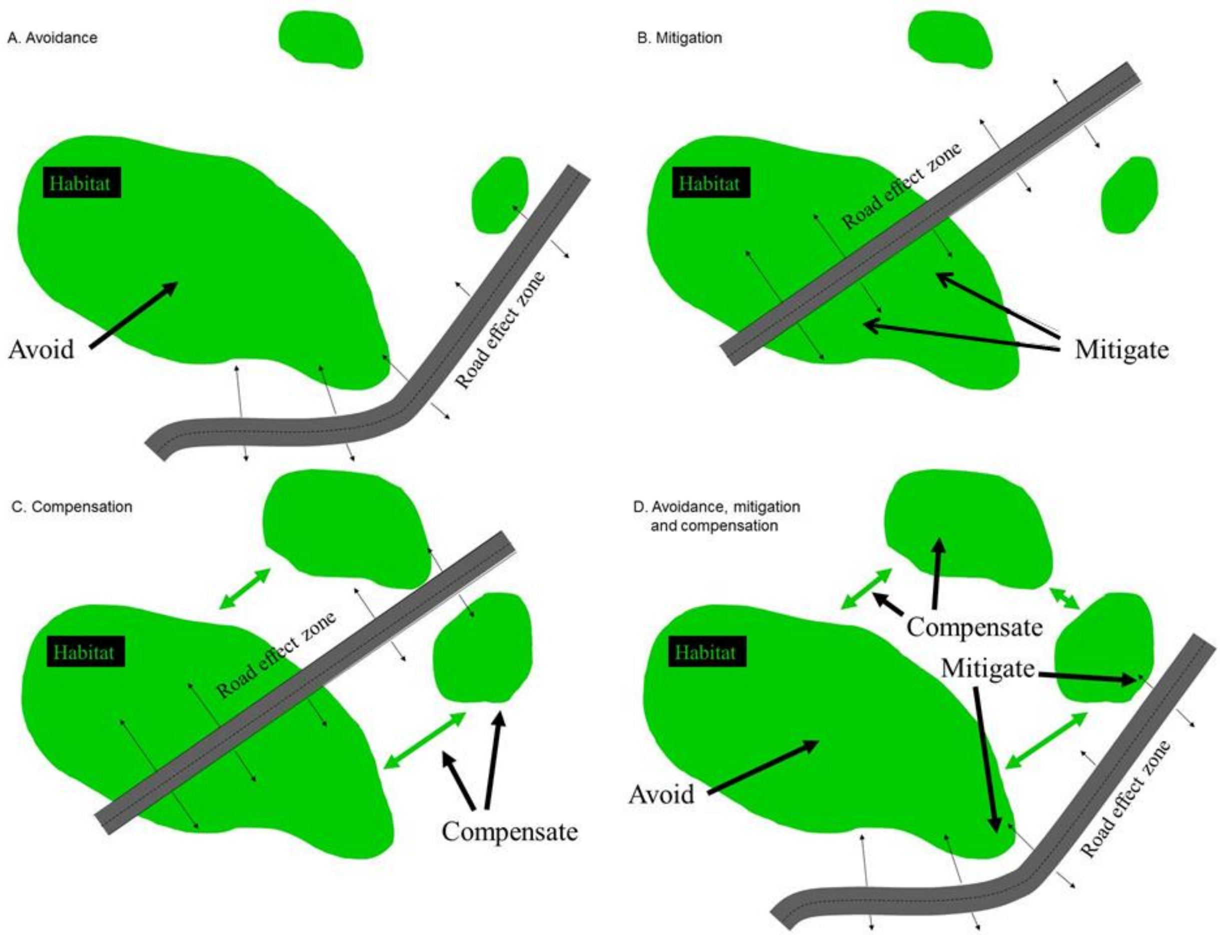

Figure 2: A three step approach: A. Avoidance, B. Mitigation, C. Compensation, D. Combination of avoidance, mitigation and compensation.

4 The functions of fences and crossing structures

Other than permanent, seasonal, or night-time road closures, fences in combination with wildlife crossing structures are the most robust and effective mitigation measure to both reduce collisions with large and small animal species and maintain or improve connectivity for wildlife (Huijser et al., 2021; 2022). However, it is important to be aware of the distinct functions of fences vs. the function of crossing structures and how that relates to the "departure point" of a mitigation project.

If human safety and direct road mortality of a species are the primary concern, then:

- Road sections with a high concentration of collisions and dead animals are identified and prioritized (e.g., Spanowicz et al., 2020). The target species may be large common mammals if human safety is the primary concern (e.g. Huijser et al., 2008). If reducing unnatural mortality for rare species is the concern, the target species can be of any body size (e.g. Kramer-Schadt et al., 2004; Huijser et al., 2008; Boyle et al., 2021).
- From a human safety perspective, it is logical to identify and prioritize road sections that currently have a concentration of collisions. However, from a biological conservation perspective, direct road mortality may have already caused population depletion. This means that the greatest threat to population persistence due to direct road mortality may not always be along the road sections that currently have the highest concentration of dead individuals of the target species (Teixeira et al., 2017).
- Fences or other barrier types are the primary measure, as the primary purpose of fences along roads is to keep animals off the highway and reduce animal-vehicle collisions (Huijser et al. 2016).
- Since fences alone would result in an absolute or near-absolute barrier for the target species, fences are typically combined with safe crossing opportunities for wildlife, especially wildlife crossing structures (underpasses and overpasses).
- The secondary function of the wildlife fences is to guide or funnel wildlife species to these crossing structures (Dodd et al., 2007; Gagnon et al., 2010).

If habitat connectivity for wildlife is the primary concern, then:

- Road sections where habitat connectivity needs to be maintained or restored are identified and prioritized. This may be based on the connectivity needs (genetic, demographic) for individual species (the "target species"), a wide suite of species or species groups, seasonal migration of certain species (e.g. for ungulates), dispersal to allow for colonization or recolonization of areas nearby or further away, or ecosystem processes in general (biotic and abiotic parameters), including those associated with climate change (e.g. Kramer-Schadt et al., 2004; Clevenger & Huijser, 2011; Sawaya et al., 2013; 2014; Lister et al., 2015; Sawyer et al., 2016; Jarvis et al., 2018).
- While it seems logical to identify and prioritize road sections that currently have observations of animals living or moving close to the road and observations of animals crossing the road (both unsuccessfully and successfully), the greatest population level conservation benefit of reducing the barrier effect of a road may not be where most animals are currently. From the perspective

of biological conservation at the population level, areas where most animals are now may have high population viability, potentially despite being isolated because of the barrier effect of transportation infrastructure. In such cases, reducing the barrier effect does not necessarily lead to an increase in population viability. Instead, the greatest population level benefits of reducing the barrier effect can be where small and isolated populations can be made more viable by providing safe crossing opportunities. This may even include road sections that currently isolate unoccupied habitat patches, and that bisect planned habitat corridors rather than existing ones. In other words, crossing structures may also be required or can also be beneficial for population persistence in areas where the target species has low abundance or where it is currently entirely absent.

- Wildlife crossing opportunities, especially wildlife crossing structures, are the primary measure, as the purpose of wildlife crossing structures is to provide safe crossing opportunities.
- Crossing structures alone do not necessarily reduce collisions (Rytwinski et al., 2016). Therefore, wildlife crossing structures are typically combined with wildlife fences.
- An added benefit of connecting crossing structures to wildlife fences is that it guides or funnels wildlife to the crossing structures and that this increases the use of the structures (Dodd et al., 2007; Gagnon et al., 2010).

In this context, it is also important to be aware of the limitations of existing crossing structures that were not built for wildlife versus designated wildlife crossing structures. While designated wildlife crossing structures should be located where connectivity for wildlife is needed most, existing structures that were not built for wildlife are not necessarily located where connectivity for wildlife is needed most. Nor are existing crossing structures necessarily of the right type (e.g. overpass vs. underpass) or dimensions given the target species, and there are typically limits to potential modifications to existing structures to improve the suitability for the target species.

In conclusion, fences and wildlife crossing structures are almost always implemented together, regardless of whether the primary objective is to reduce animal-vehicle collisions or to reduce the barrier effect of roads and traffic for wildlife. However, the road sections where the measures are implemented are very much dependent on the primary objectives or departure points, and they may include road sections where the target species is not hit or no longer hit, and where the target species may have low population density or where it is currently not present at all.

5 Spacing of wildlife crossing structures

The appropriate spacing of wildlife crossing structures can be determined in more than one way and is dependent on the goals one may have. Examples of possible goals are:

- Provide permeability under or over the road for ecosystem processes, including but not restricted to animal movements. Ecosystem processes include not only biological processes, but also physical processes (e.g. water flow). It is good practice to design structures that are primarily needed for hydrology in such a way that they can also function for wildlife. However, only providing wildlife crossing opportunities in low and wet areas means that no connectivity is provided for species that depend on high and dry habitat. Thus, a possible strategy is to identify the different ecosystems and habitat types (not just streams, rivers or wetlands) and ecosystem processes that permeability needs to be provided for and then provide appropriate mitigation measures in each of those ecosystems or habitat types.
- Allowing a wide variety of species, or selected targets species, to change their spatial distribution drastically, for example in response to climate change.
- Maintaining or improving the population viability of selected species based on their current spatial distribution. This includes striving for larger populations with a certain degree of connectivity between populations (including allowing for successful dispersal movements).
- Providing the opportunity for individuals (and populations) to continue seasonal migration movements (e.g. mule deer, pronghorn or elk) as this can be seen as a component of the biological integrity of an ecosystem.
- Allowing individuals of selected target species that have their home ranges on both sides of the highway to continue to use these areas. This may result in a road corridor that is substantially permeable to those species, at least for the individuals that live close to the road.

A further complication is that individuals that disperse, that display seasonal migration, or that live in the immediate vicinity of a road may display differences in behavior with regard to where and how they move through the landscape, how they respond to roads, traffic, and associated barriers (e.g. wildlife fencing), and their willingness to use safe crossing opportunities. For example, dispersing individuals may grow up far away from the areas adjacent to roads and may shy away from human disturbances and human made features, they may not move through habitat the way we might expect them to, and they typically travel long distances, much further and quicker compared to resident individuals. Safe crossing opportunities may not be encountered by dispersing individuals as they are new in the area and are not familiar with their location, and when confronted with a road or associated wildlife fence, they may return or change the direction of their movement before they encounter and use a safe crossing opportunity. Furthermore, if dispersing individuals do encounter a safe crossing opportunity, they may be more hesitant to use it compared to resident individuals that not only know about their location, but that also have had time to learn that it is safe to use them. Since dispersal can be a relatively rare phenomenon, one may not be able to afford to have a dispersing individual fail to cross the road. Therefore, even though dispersers travel much further than resident individuals, safe crossing opportunities for dispersers may not allow for a greater distance between safe crossing opportunities compared to safe crossing opportunities for resident individuals.

Full scale population viability analyses can be very helpful to compare the effectiveness of different configurations of safe crossing opportunities. However, for this report the authors choose a simpler approach and suggest the distance between safe crossing opportunities to be equal to the diameter of the home range of the species concerned (Figure 3). In theory, this allows individuals that have the center of their home range on the road to have access to at least one safe crossing opportunity. However, individuals that may have had their home range on both sides of the road do not necessarily have access to a safe crossing opportunity (Figure 4). Finally, this approach assumes homogenous habitat and distribution of the individuals and circular home ranges, while in reality habitat quality may vary greatly, causing variations in density and home range size of individuals and irregular shaped home ranges. Species that have smaller home ranges need the crossing structures to be closer together than species with large home ranges (Figure 3).

This approach does not necessarily result in viable populations for every species of interest, and not every individual who approaches the road and associated wildlife fence will encounter and use a safe crossing opportunity. In addition, the approach described above is not necessarily the only approach or the approach that addresses the barrier effect of the road corridor and associated fencing sufficiently for all species concerned. However, the approach chosen is consistent, practical, can be based on available data, and is likely to result in considerable permeability of the road corridor and associated wildlife fencing for a wide array of species. Note that a mismatch between the spacing of wildlife crossing structures and the distance over which the animals are able and willing to move along a fence can result in severe population decline (Ottburg & van der Grift, 2019). In other words, if an insufficient number of crossing structures is provided, if the distances between consecutive crossing structures is too great, the mitigation can be detrimental rather than helpful to wildlife conservation; doing something is not necessarily better than doing nothing.

Another way to decide on “appropriate distance” between safe crossing opportunities is to evaluate what the spacing is for wildlife crossing structures on other wildlife highway mitigation projects. The average spacing for large mammal crossing structures in Montana (US Hwy 93 North and South), I-75 in Florida, SR 260 in Arizona, Banff National Park in Canada, and ongoing reconstruction on I-90 in Washington State is 1.2 mi (1.9 km) (range for the average spacing of structures in these individual areas is 0.5-1.8 mi (0.8-2.9 km)). However, the 1.2 mi (1.9 km) spacing is simply what people have done elsewhere, and it is not necessarily based on what may be needed ecologically, and the requirements for the target species in one area may be different from what is needed in another area. The distance between suitable crossing structures for amphibians is often much shorter, e.g., only several dozens of feet (12.5 m) (Brehme et al., 2021).

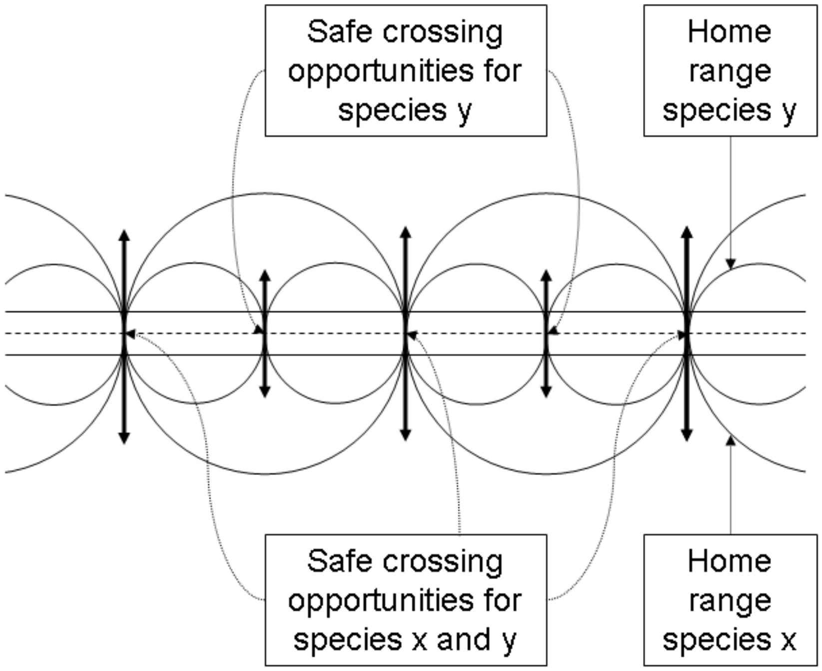

Figure 3. Schematic representation of home ranges for two theoretical species projected on a road and the distance between safe crossing opportunities (distance is equal to the diameter of their home range).

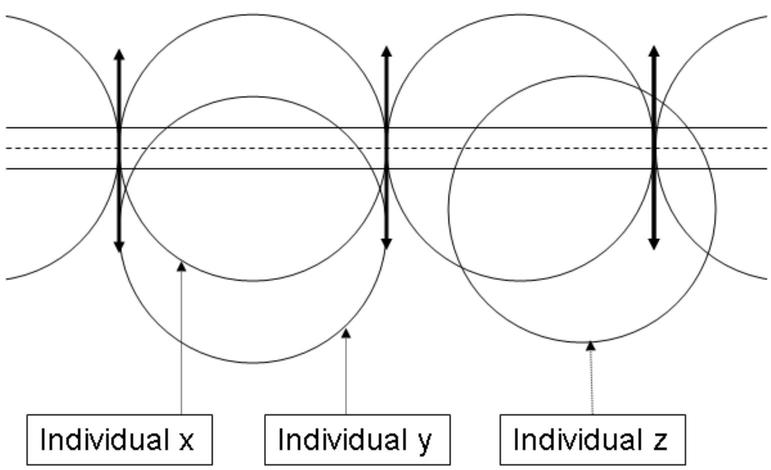

Figure 4. Schematic representation of home range for an individual (x) that has the center of its home range on the center of the road (access to two safe crossing opportunities), an individual (y) that has the center of its home range slightly off the center of the road exactly in between two safe crossing opportunities (no access to safe crossing opportunities), and an individual (z) that has the center of its home range slightly off the center of the road but not exactly in between two safe crossing opportunities (access to one safe crossing opportunity).

6 Selected roads

6.1 Introduction

The West Virginia Department of Transportation (WVDOT) was unable to provide spatially explicit data for wildlife-vehicle crashes recorded by law enforcement personnel or wildlife carcasses that were removed by road maintenance crews for the roads in and around the two protected areas. Therefore, we selected the major highways and selected lower volume roads in and around the two areas for a general assessment only.

6.2 Harpers Ferry National Historical Park

The selected roads include the major highways and roads that cut through the park, are adjacent to it, or that are close to the park and other protected areas (e.g. a state park), regardless of who is responsible for the maintenance of the road (Figure 5). The road sections listed below were selected because of their potential impact on habitat connectivity within the park, adjacent protected lands, and between the Blue Ridge and valleys and the ridges east of there (across the Pleasant Valley and Loudoun Valley).

- US Hwy 340 (William L. Wilson Freeway): From bridge across Koonce Rd to junction with Rohrersville Rd (Route 67) on north bank upper Potomac.
- Route 27 (Bakerton Rd and Millville Rd): From Millville (south end) to junction with Potomac St.
- Potomac St.: From junction with Route 27 (Bakerton Rd) to junction with Shenandoah St.
- Shenandoah St.: From The Point to junction with US Hwy 340 (William L. Wilson Freeway).
- Shoreline Dr.: From junction with US Hwy 340 (William L. Wilson Freeway) to junction with Shenandoah St.
- Washington Ct.: Until junction with Washington St.
- Murphy Rd: From junction with Pointfield Dr. to Murphy Farm.
- Route 32 (Chestnut Hill Rd): From junction with US Hwy 340 (William L. Wilson Freeway) to just south of Silver Grove.
- Harpers Ferry Rd (Route 671): From junction with US Hwy 340 (William L. Wilson Freeway) to junction with Charles Town Pike.
- Charles Town Pike: From junction with Chestnut Hill Rd to Junction with Sagle Rd.
- Harpers Ferry Rd and Sandy Hook Rd (north of Upper Potomac River): From Pleasantville to junction with Keep Tryst Rd.
- Rohrersville Rd (Route 67): From junction with US Hwy 340 (William L. Wilson Freeway) to Appletown.

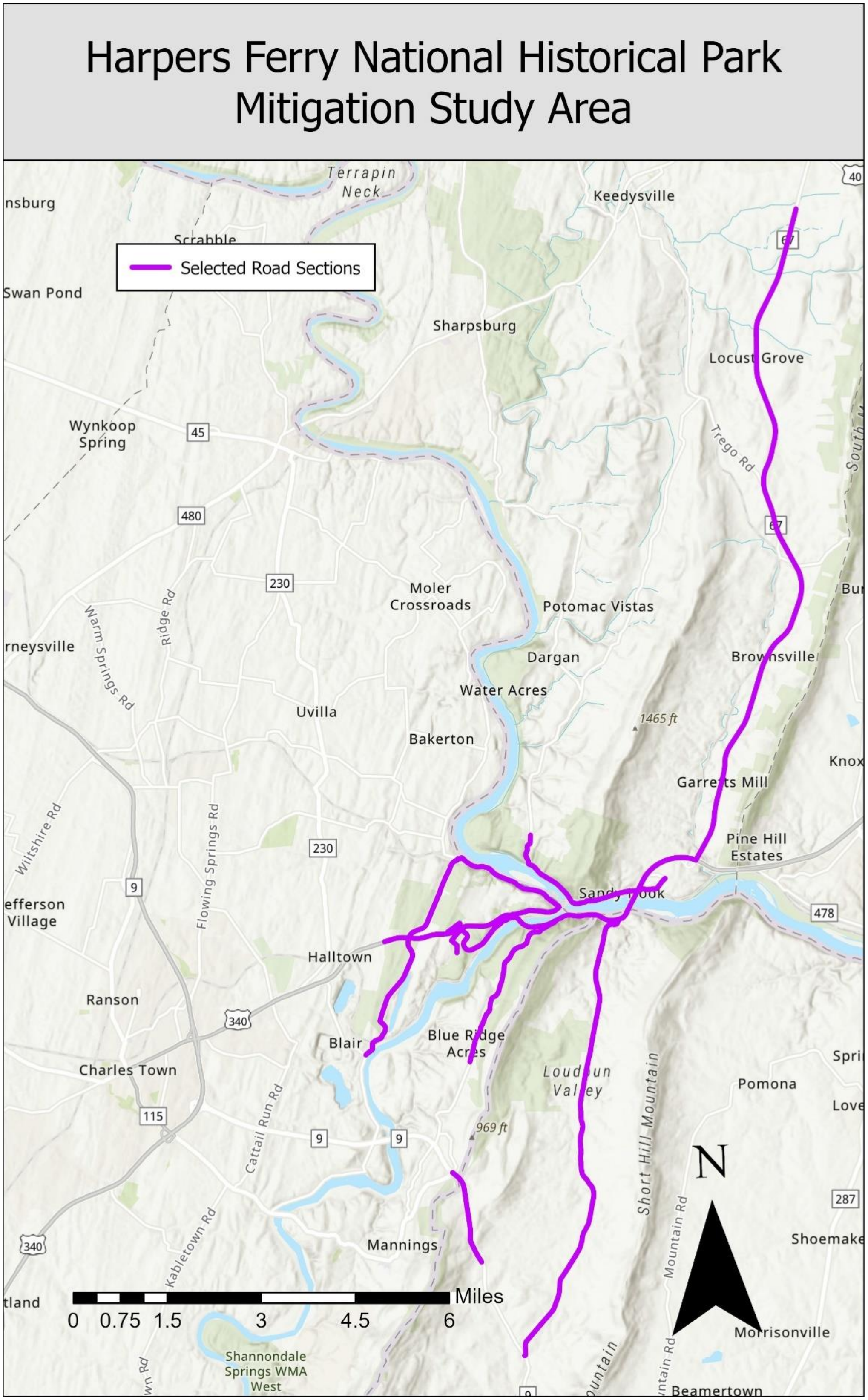

Figure 5: Selected roads through Harpers Ferry National Historical Park.

6.3 New River Gorge National Park and Preserve

The selected roads include the major highways through the park), regardless of who is responsible for the maintenance of the road (Figure 6):

- US Hwy 19
- Route 41
- I-64
- Route 20

The assessment only includes sections of the routes above that cut through the park. The assessment does not include the other roads through the park or in its surroundings. However, based on the suggestions of a herpetologist (Joshua Stover, West Virginia Herpetological Society), we also visited four additional low volume roads in the area where direct road mortality of amphibians and reptiles is a concern (Figure 6).

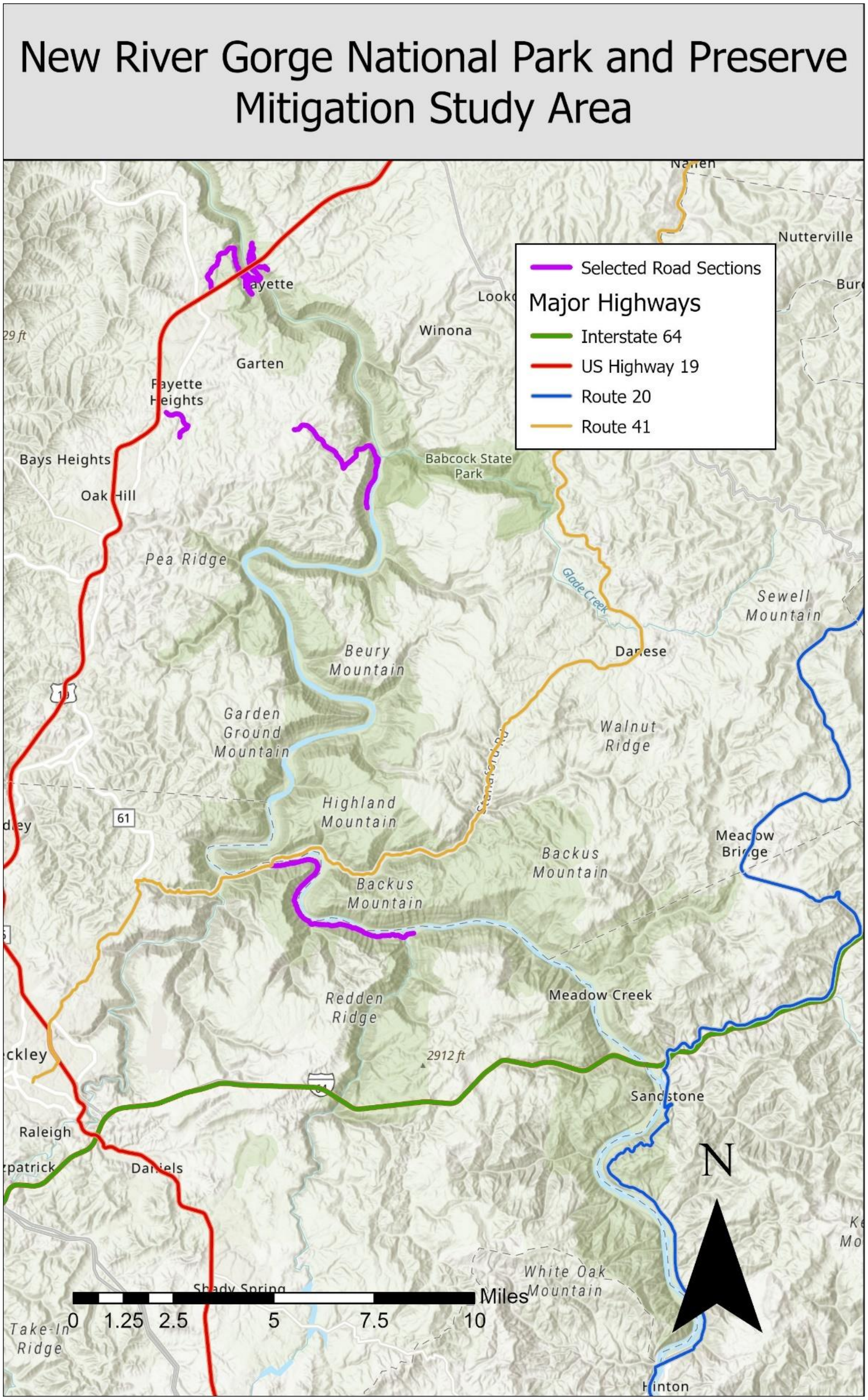

Figure 6: Selected roads through New River Gorge National Park and Preserve.

7 Selected species

7.1 Large wild mammal species

Large wild mammal species (coyote and larger) that may be a concern to human safety in case of a collision and that are known to occur in the two protected areas are listed in Table 1. Mitigation measures aimed at reducing collisions with large wild mammals, and the associated threats to human safety, would need to be targeted at white-tailed deer and American black bear.

Table 1: Large wild mammal species known to occur in and around the two protected areas.

Common name	Scientific name	Harpers Ferry National Historic Park	New River Gorge National Park and Preserve
White-tailed deer	*Odocoileus virginianus*	1	1
American black bear	*Ursus americanus*	2	2, 3

Sources: 1 = National Park Service (2024a; b), 2= iNaturalist (2024), 3 = Personal communication Joshua Stover, West Virginia Herpetological Society

7.2 Species of Greatest Conservation Need (SGCN)

We identified Species of Greatest Conservation Need (SGCN) that are present in the two protected areas (Table 2). We followed the following procedure for species selection:

- The selected species are limited to amphibians, reptiles, and mammals (excluding bats).
- The selected species needed to be categorized as Species of Greatest Conservation Need (SGCN) by one or more of the following sources:
    - In the key wildlife habitat types near Harpers Ferry (within about 10 miles, see Appendix A) in the state of Maryland (Maryland Department of Natural Resources, 2016).
    - In the region of "Northern Virginia" in the state of Virginia (Virginia Department of Game and Inland Fisheries, 2015). This includes the counties of Arlington, Fairfax, Loudoun, and Prince William, cities of Alexandria, Fairfax, Falls Church, Manassas, and Manassas Park, and towns of Dumfries, Herndon, Leesburg, Purcellville, and Vienna.
    - In the region "Greater Shenandoah Valley" and "Gorges" in the state of West Virginia (West Virginia Division of Natural Resources, 2015).

Table 2: Species of Greatest Conservation Need (SGCN) known to occur in and around the two protected areas.

Common species name	Scientific species name	Nearby key habitat types, Maryland	Northern Virginia, Virginia	Gorges, West Virginia	Greater Shenan-doah Valley, West Virginia	Harpers Ferry National Historic Park	New River Gorge National Park and Preserve
Amphibians							
Undetermined siren	*Siren* sp.						
Jefferson salamander	*Ambystoma jeffersonianum*	x		x	x		
Marbled salamander	*Ambystoma opacum*			x			
Tiger salamander	*Ambystoma tigrinum*	x					
Green salamander	*Aneides aeneus*	x		x			2, 3
Eastern hellbender	*Cryptobranchus alleganiensis*	x		x			1
Northern dusky salamander	*Desmognathus fuscus*			x	x	2	2
Seal salamander	*Desmognathus monticola*	x		x	x	2,4	1,2
Allegheny mountain dusky salamander	*Desmognathus ochrophaeus*			x			2
Black-bellied salamander	*Desmognathus quadramaculatus*			x			1
Northern two-lined salamander	*Eurycea bislineata*			x	x	2	
Southern two-lined salamander	*Eurycea cirrigera*						2, 3
Longtail salamander	*Eurycea longicauda*			x	x	2	2, 3
Cave salamander	*Eurycea lucifuga*			x			2, 3
Kentucky spring salamander	*Gyrinophilus porphyriticus duryi*			x			
Northern spring salamander	*Gyrinophilus porphyriticus*	x		x	x		2,3
Mudpuppy	*Necturus maculosus*	x		x			
White-spotted slimy salamander	*Plethodon cylindraceus*			x	x		
Slimy salamander	*Plethodon glutinosus*			x	x		2
Valley and ridge salamander	*Plethodon hoffmani*	x		x	x		
Cumberland plateau salamander	*Plethodon kentucki*			x			2
Wehrle's salamander	*Plethodon wehrlei*	x		x			2,3
Midland mud salamander	*Pseudotriton montanus diastictus*			x			3

Common species name	Scientific species name	Nearby key habitat types, Maryland	Northern Virginia, Virginia	Gorges, West Virginia	Greater Shenan-doah Valley, West Virginia	Harpers Ferry National Historic Park	New River Gorge National Park and Preserve
Northern red salamander	*Pseudotriton ruber*	x			x		2,3
Northern red salamander	*Pseudotriton ruber ruber*			x			
Eastern narrow-mouthed toad	*Gastrophryne carolinensis*	x					
Fowler's Toad	*Anaxyrus fowleri*				x		
Carpenter frog	*Lithobates virgatipes*	x			x		
Northern Cricket Frog	*Acris crepitans*			x	x		
Barking treefrog	*Dryophytes gratiosus*	x					
Mountain chorus frog	*Pseudacris brachyphona*	x		x			2
Upland chorus frog	*Pseudacris feriarum*	x			x		
Reptiles							
River cooter	*Pseudemys concinna*			x			1
Northern Red-bellied Cooter	*Pseudemys rubriventris*				x		
Spotted turtle	*Clemmys guttata*	x			x		
Wood turtle	*Glyptemys insculpta*	x	x		x		
Bog turtle	*Glyptemys muhlenbergii*	x					
Northern map turtle	*Graptemys geographica*	x		x			1
Ouachita map turtle	*Graptemys ouachitensis*			x			
Eastern box turtle	*Terrapene carolina*	x		x	x	1	1, 2, 3
Eastern spiny softshell	*Apalone spinifera*	x					2
Eastern six-lined racerunner	*Aspidoscelis sexlineata*	x					
Northern coal skink	*Plestiodon anthracinus*	x					
Northern coal skink	*Plestiodon anthracinus anthracinus*			x			
Broad-headed skink	*Plestiodon laticeps*			x	x	2	1

Common species name	Scientific species name	Nearby key habitat types, Maryland	Northern Virginia, Virginia	Gorges, West Virginia	Greater Shenan-doah Valley, West Virginia	Harpers Ferry National Historic Park	New River Gorge National Park and Preserve
Little Brown Skink	*Scincella lateralis*				x		
Wormsnake	*Carphophis amoenus*			x	x		1, 2
Northern black racer	*Coluber constrictor*			x	x	2	
North American racer	*Coluber constrictor*					2	2
Northern ring-necked snake	*Diadophis punctatus edwardsii*			x		2	2
Northern scarlet snake	*Cemophora coccinea*	x					
Red corn snake	*Pantherophis guttatus*	x					
Rainbow snake	*Farancia erytrogramma*	x					
Eastern Hog-nosed Snake	*Heterodon platirhinos*				x	4	
Mole kingsnake	*Lampropeltis calligaster rhombomaculata*	x					
Eastern kingsnake	*Lampropeltis getula*	x		x			
Coastal plain milksnake	*Lampropeltis triangulum elapsoides x triangulum*	x					
Eastern milksnake	*Lampropeltis triangulum*					2,4	2
Plain-bellied water snake	*Nerodia erythrogaster*	x					
Rough greensnake	*Opheodrys aestivus*			x	x	2,4	1
Smooth greensnake	*Opheodrys vernalis*	x					2
Northern pinesnake	*Pituophis melanoleucus*	x					
Queen snake	*Regina septemvittata*			x	x		
Common ribbonsnake	*Thamnophis sauritus*	x				4	
Northern copperhead	*Agkistrodon contortrix mokasen*			x	x	4	1
Eastern copperhead	*Agkistrodon contortrix*					2	2, 3
Timber rattlesnake	*Crotalus horridus*	x		x	x	1	1, 2

Common species name	Scientific species name	Nearby key habitat types, Maryland	Northern Virginia, Virginia	Gorges, West Virginia	Greater Shenan-doah Valley, West Virginia	Harpers Ferry National Historic Park	New River Gorge National Park and Preserve
Mammals							
North American porcupine	*Erethizon dorsatum*	x					
Long-tailed shrew	*Sorex dispar*	x		x			
Smoky shrew	*Sorex fumeus*	x					
Southern pygmy shrew	*Sorex hoyi winnemana*	x		x			
Southeastern shrew	*Sorex longirostris*	x					
Southern water shrew	*Sorex palustris punctulatus*	x					
Least shrew	*Cryptotis parva*	x					
Southeastern star-nosed mole	*Condylura cristata parva*	x					
Appalachian cottontail	*Sylvilagus obscurus*	x					
Delmarva fox squirrel	*Sciurus niger cinereus*	x				N/A	N/A
Southern flying squirrel	*Glaucomys volans*					1	
Virginia northern flying squirrel	*Glaucomys sabrinus fuscus*	x					
Eastern harvest mouse	*Reithrodontomys humulis*	x					
Golden mouse	*Ochrotomys nuttalli*			x			
Allegheny woodrat	*Neotoma magister*	x		x		1	1
Southern rock vole	*Microtus chrotorrhinus carolinensis*	x					
Southern bog lemming	*Synaptomys cooperi*	x					
Least weasel	*Mustela nivalis*	x					
American mink	*Neovison vison*	x				1	1
Eastern spotted skunk	*Spilogale putorius*	x					
Bobcat	*Lynx rufus*	x					

Sources: 1 = National Park Service (2024a; b), 2= iNaturalist (2024), 3 = Personal comment Joshua Stover, West Virginia Herpetological Society, 4 = Personal comment Jared Cain, West Virginia Herpetological Society

The list of Species of Greatest Conservation Need (SGCN) present in and around the two protected areas may contain errors. However, we had the species list checked by local experts, especially for SGCN amphibian and reptile species (Personal comment Joshua Stover and Jared Cain, West Virginia Herpetological Society). Regardless, it is evident that the SGCN in and around the two protected areas are predominantly amphibian species (especially salamander species) and reptiles (especially turtles and snakes).

8 Landscape level connectivity

8.1 Introduction

This chapter is based on high level principles and not based on any existing policy or regulation. While the effects of roads and traffic on wildlife are varied (see Chapter 2), the practice of road ecology mostly addresses collisions with large wild mammals (from a human safety perspective), a reduction in direct mortality for wildlife (from a biological conservation perspective) and a reduction in the barrier effect (from a biological conservation perspective). Large and well-connected populations of a species have a lower risk of extirpation than smaller populations that are isolated. In this context it is important to not only reduce unnatural mortality, but it is also important to reduce unnatural barriers in the landscape and connect protected areas to the surrounding landscape and potential other protected areas further away. The landscape features that may allow for connectivity between the two national park units and their surroundings are illustrated below.

8.2 Harpers Ferry National Historical Park

The wider landscape around Harpers Ferry National Historical Park is characterized by forested ridges, valleys with mostly agriculture, and the Shenandoah and Potomac Rivers (Figure 7). Ensuring connectivity along the rivers, including the riparian areas, as well as along the forested ridges are probably the most important landscape features along which provide landscape level connectivity.

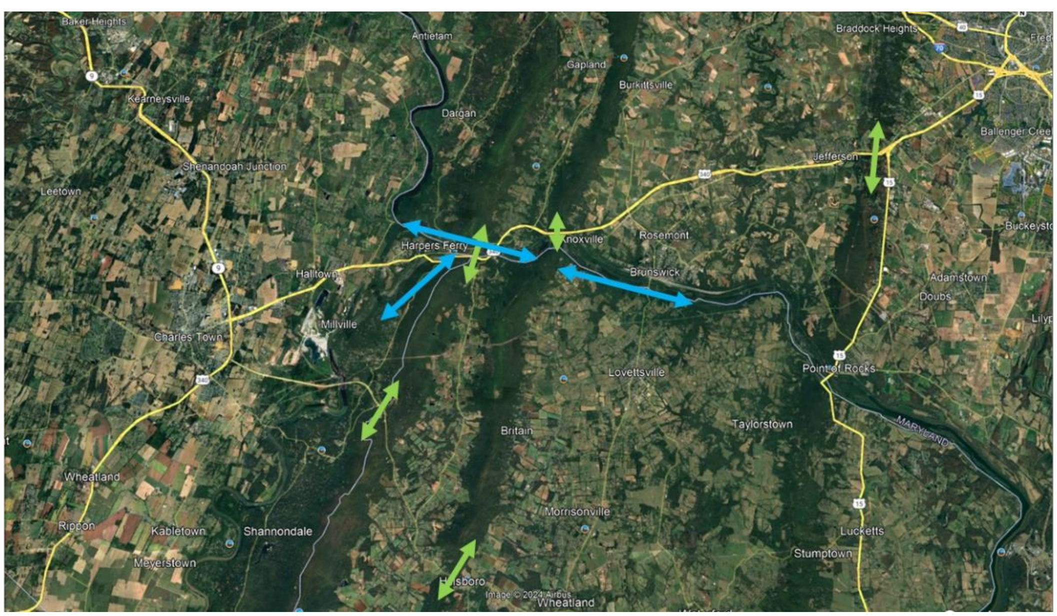

Figure 7: High level landscape connectivity around Harpers Ferry National Historical Park. Green arrows indicate potential terrestrial connectivity needs, blue arrows indicate potential aquatic and riparian connectivity needs.

8.3 New River Gorge National Park and Preserve

The wider landscape around New River Gorge National Park and Preserve is characterized by forests, both on ridges and in valleys, the New River and its gorge, as well as other rivers and streams (Figure 8, Figure 9, Figure 10). Landscape level connectivity is especially important along the New River (e.g. US Highway 19 between Fayetteville and Lansing, and I-64 near Sandstone. Connectivity towards the east and south can be along ridges and valleys, especially those with streams. The options for connectivity towards the west are limited because of the build-up areas and linear development along Hwy 19 and Highway 16.

Figure 8: New River from Grandview, New River Gorge National Park and Preserve, West Virginia.

Figure 9: Road cuts through ridges provide an opportunity for wildlife overpasses. I-64 just east of Glade Creek bridge, New River Gorge National Park and Preserve, Shady Spring, West Virginia.

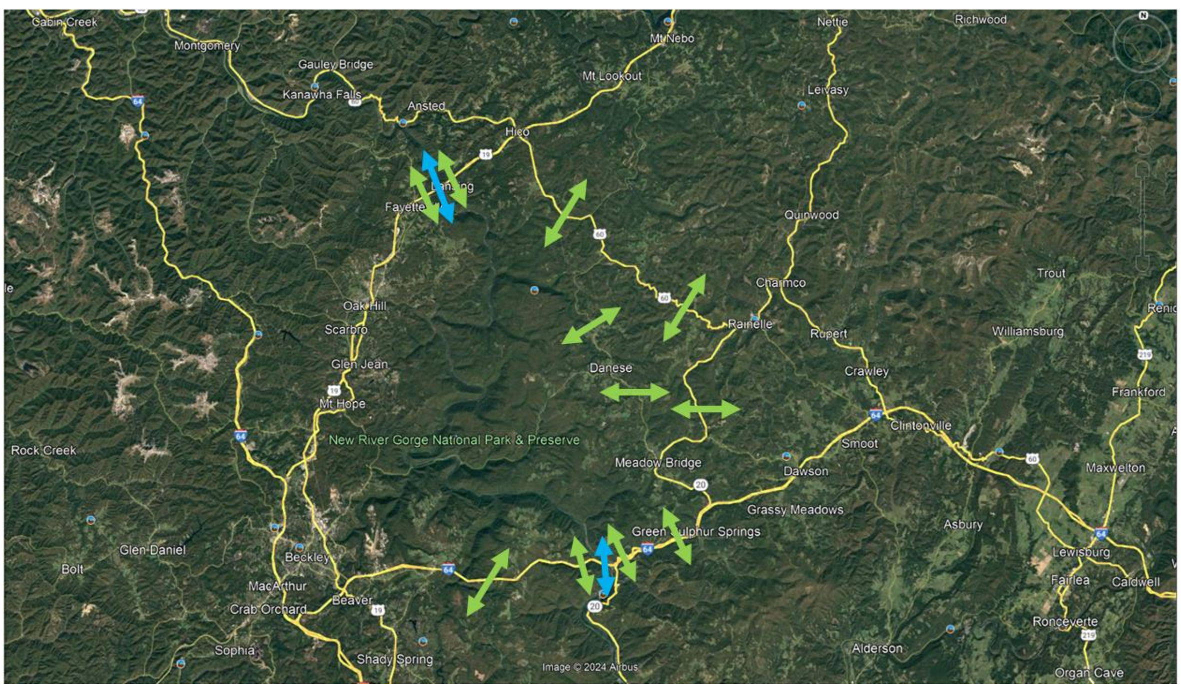

Figure 10: High level landscape connectivity around New River Gorge National Park and Preserve. Green arrows indicate potential terrestrial connectivity needs, blue arrows indicate potential aquatic and riparian connectivity needs.

9 Identification of road sections for human safety and Species of Greatest Conservation Need

9.1 Large wild mammal species

The West Virginia Department of Transportation (WVDOT) was unable to provide spatially explicit data for wildlife-vehicle crashes recorded by law enforcement personnel or wildlife carcasses that were removed by road maintenance crews for the roads in and around the two protected areas.

No other data sources were available for roadkilled mammals for the roads in and around Harpers Ferry National Historical Park. Therefore, no specific road sections could be identified for which mitigation measures could be considered.

For the roads in and around New River Gorge National Park and Preserve, interviewees identified the following roads or general areas as having a relatively high incidence of collisions with wild large mammals:

- US Highway 19 and State Route 16 between Fayetteville and Oak Hill. Species involved include white-tailed deer and black bear (Personal communication Joshua Stover, West Virginia Herpetological Society).
- State Route 9 between I-64 and Grandview overlook (Figure 11). Species involved include white-tailed deer (Personal communication Bryce Wender, National Park Service).

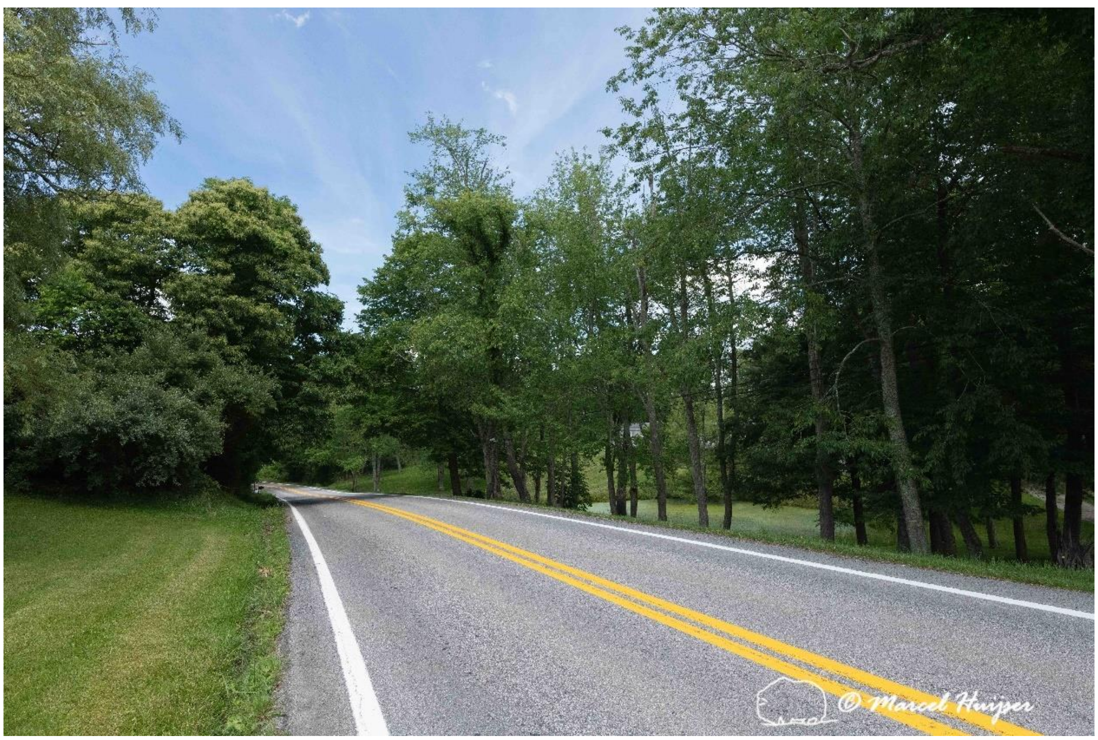

Figure 11: Grandview Road, Grandview, New River Gorge National Park and Preserve, West Virginia.

9.2 Species of Greatest Conservation Need (SGCN)

No spatial explicit information was available on where Species of Greatest Conservation Need may be present in and around Harpers Ferry National Historical Park. Therefore, no specific road sections could be identified for which mitigation measures could be considered. However, Along Shoreline Drive, between Shoreline Drive and the railroad, there are vernal pools that are likely important breeding habitat for amphibians. Spotted salamanders (*Ambystoma maculatum*) have been observed here, and there are likely other species present, including Species of Greatest Conservation need (Personal comment Jared Cain, West Virginia Herpetological Society).

For the roads in and around New River Gorge National Park and Preserve, interviewees identified the following roads or general areas as problematic for Species of Greatest Conservation Need:

- Fayette Station Road (Figure 12, Figure 13, Figure 14, Figure 15, Figure 16, Figure 17)): This is a one-way paved single lane narrow road from Lansing (east side of Gorge) to Fayetteville (west side of gorge). It winds down into the canyon and crosses the New River on a bridge at the bottom of the Gorge. It becomes two-way at the Outpost New River Campground. This road is primarily for tourism. Some people use the road at night, including for night trail running in the gorge, others use it to "hang-out" at night. Observed SGCN roadkilled amphibians and reptiles include Green salamander, Longtail salamander, Cave salamander, Northern spring salamander, Northern red salamander, Eastern copperhead, and Timber rattlesnake) (Personal communication Joshua Stover, West Virginia Herpetological Society). Roadkilled non- SGCN species include rough earth snake or brown snake (*Virginia striatula*) and redbelly snake or the red-bellied snake (*Storeria occipitomaculata*) (Personal communication Joshua Stover, West Virginia Herpetological Society). The number of roadkilled amphibians and reptiles is especially high during rainy nights.

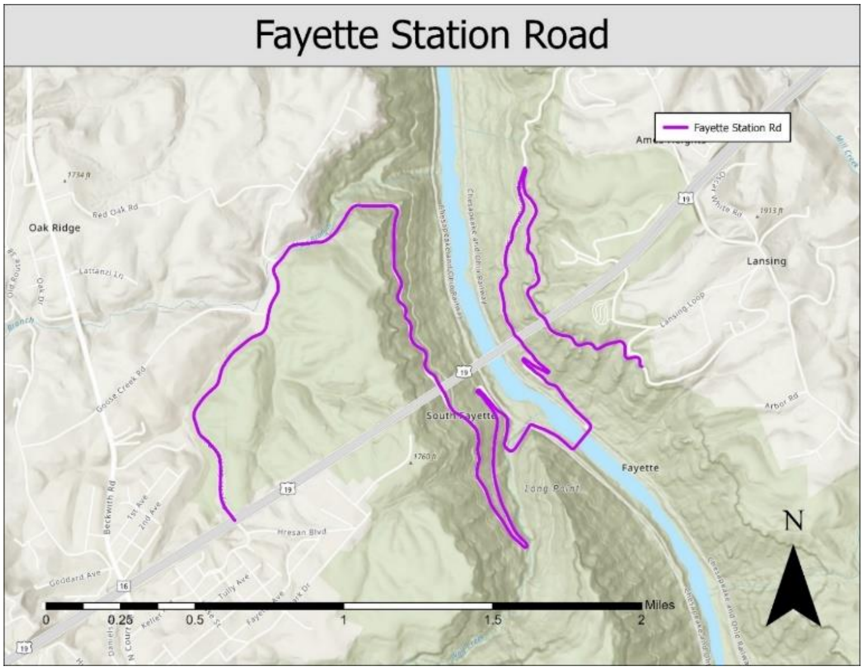

Figure 12: Fayette Station Road winds down the gorge under the New River bridge, New River Gorge National Park and Preserve, Fayetteville, West Virginia.

Figure 13: Fayette Station Road winds down the gorge under the New River bridge and has pull-outs, New River Gorge National Park and Preserve, Fayetteville, West Virginia.

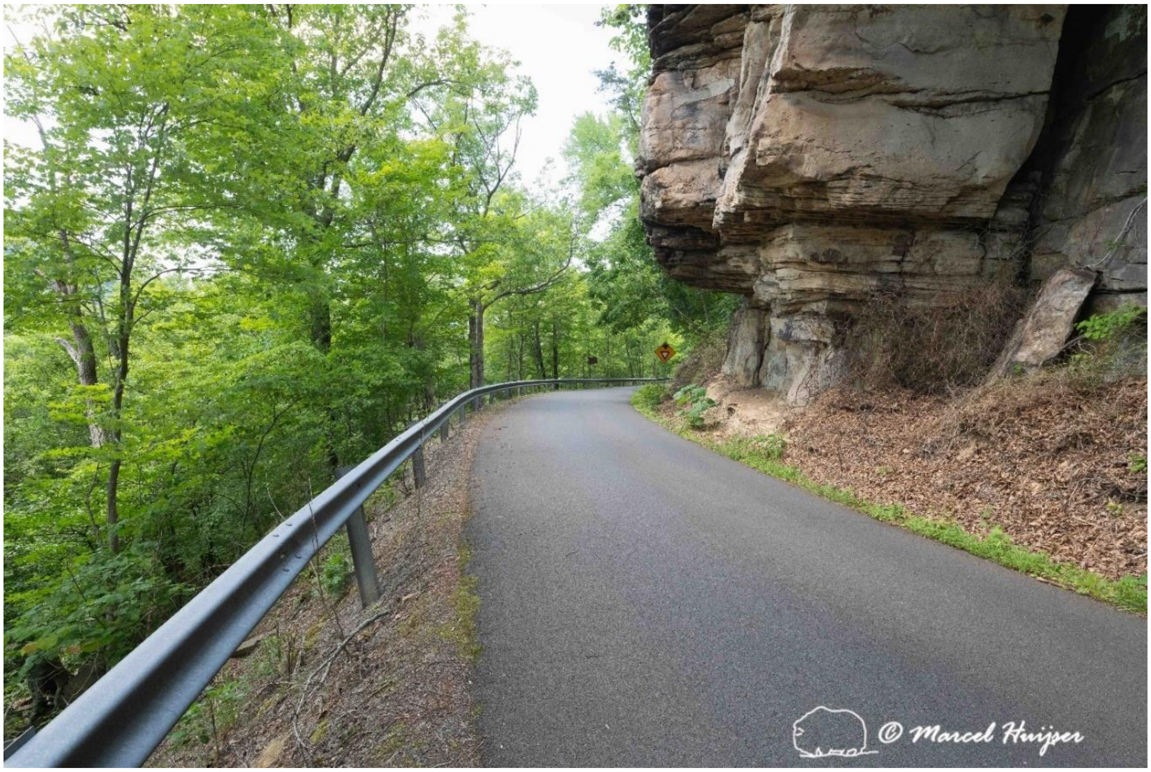

Figure 14: Steep slopes and rock walls are present along the Fayette Station Road, New River Gorge National Park and Preserve, Fayetteville, West Virginia.

Figure 15: Spring feeding into an inboard ditch along Fayette Station Road, New River Gorge National Park and Preserve, Fayetteville, West Virginia.

Figure 16: The railroad crossing and the bridge (in the background to the right) across the New River along the Fayette Station Road, New River Gorge National Park and Preserve, Fayetteville, West Virginia.

Figure 17: Roadkilled eastern rat snake or black rat snake (Pantherophis alleghaniensis), Fayette Station Road, New River Gorge National Park and Preserve, West Virginia.

- Nick Rahall Greenway (Figure 18-22): This is partially a two-lane road, and partially a one-lane road. The biodiversity of herpetofauna is very high in the grasslands and along the creek at the junction with Highway 16; 43 species of amphibians and reptiles (Personal communication Joshua Stover, West Virginia Herpetological Society). Roadkilled species include midland mud salamander (Personal communication Joshua Stover, West Virginia Herpetological Society).

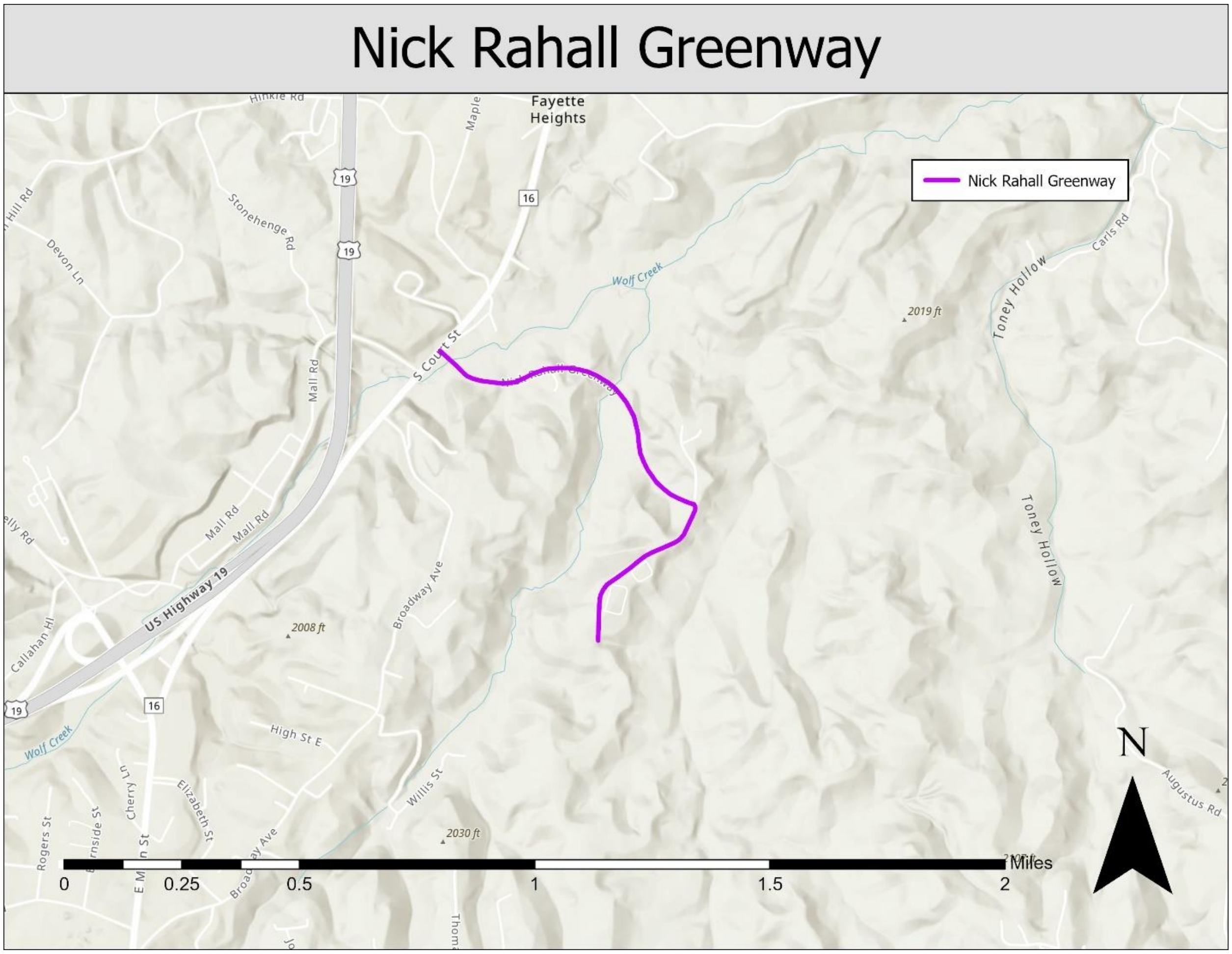

Figure 18: The Nick Rahall Greenway, New River Gorge National Park and Preserve, West Virginia.

Figure 19: Grassland and creek with very high herpetofauna diversity, at the junction with Highway 16, Nick Rahall Greenway, New River Gorge National Park and Preserve, Oak Hill, West Virginia.

Figure 20: Nick Rahall Greenway, New River Gorge National Park and Preserve, Oak Hill, West Virginia.

Figure 21: Nick Rahall Greenway, New River Gorge National Park and Preserve, Oak Hill, West Virginia.

Figure 22: End of road grassland, Nick Rahall Greenway, New River Gorge National Park and Preserve, Oak Hill, West Virginia.

- Cunard River Access Road (Figure 23, Figure 24, Figure 25, Figure 26, Figure 27). The road to Cunard River Access is a two-lane paved road. There are curbs along this road that are likely a barrier to herpetofauna and make it difficult for the animals to leave the road (Figure 21). There are also storm drains that may be a hazard to small animal species as they can act like a pitfall (Figure 22). From Cunard to the Brooklyn campground, the road has a gravel surface. In this area, direct road mortality has been observed for several salamander species, eastern box turtle, eastern copperhead, and timber rattlesnake (Personal communication Joshua Stover, West Virginia Herpetological Society).

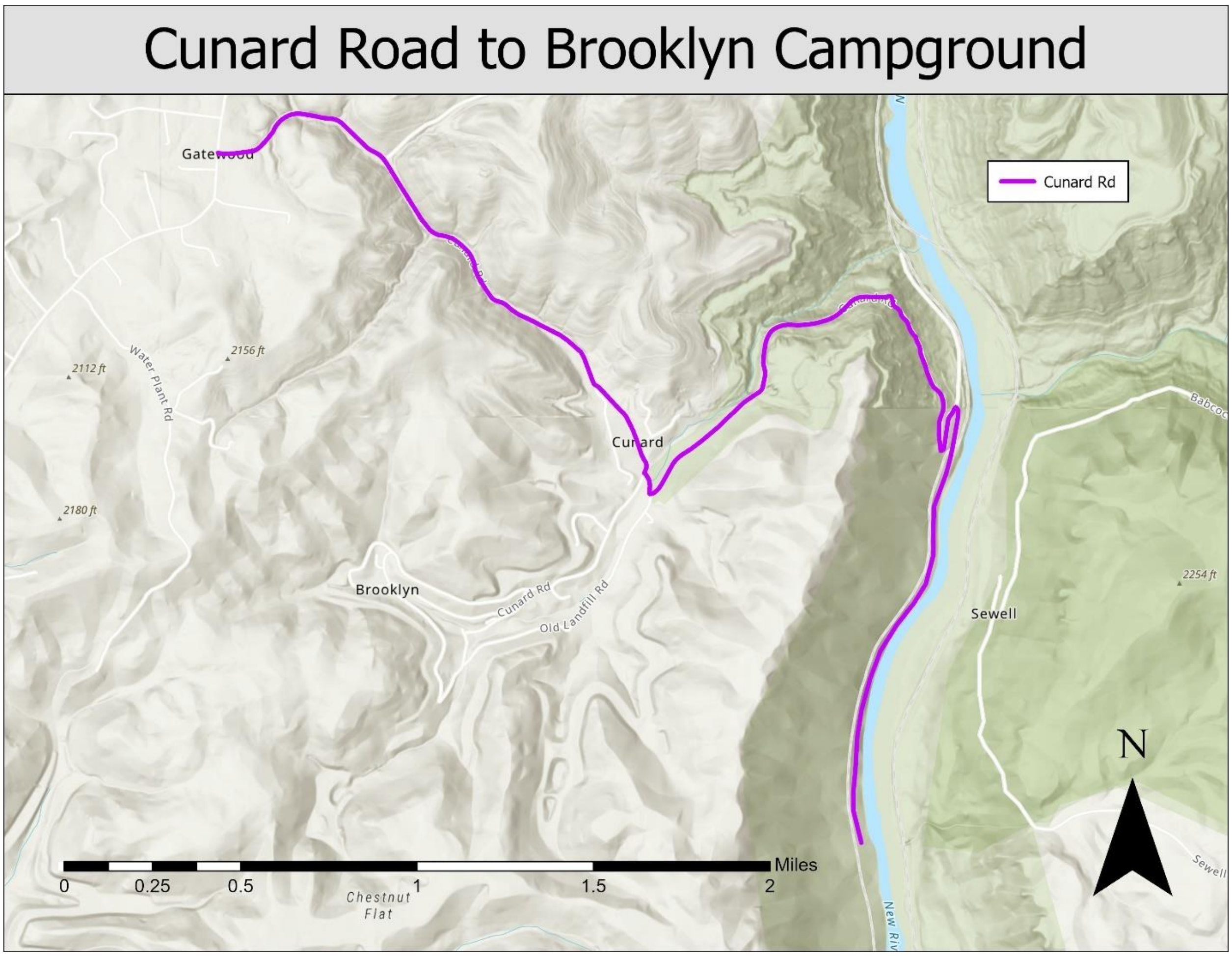

Figure 23: Cunard road, New River Gorge National Park and Preserve, Oak Hill, West Virginia.

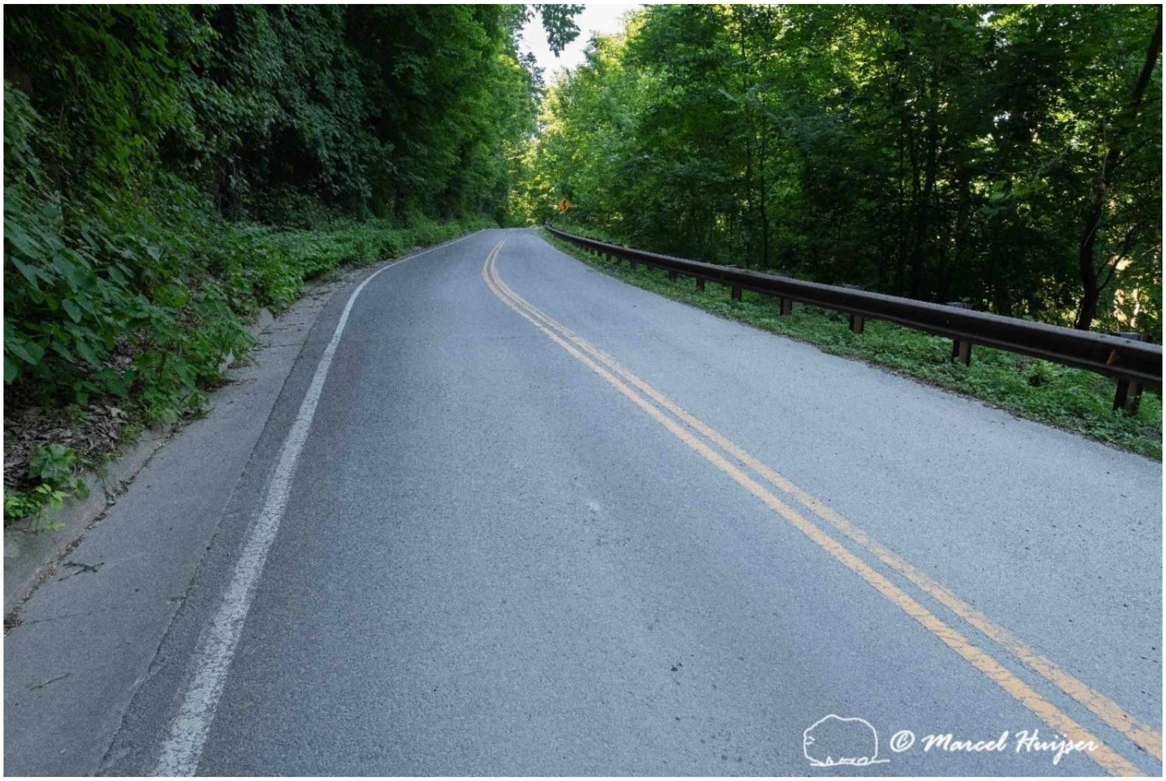

Figure 24: Cunard road, New River Gorge National Park and Preserve, Oak Hill, West Virginia.

Figure 25: Curb presents a barrier to herpetofauna, Cunard road, New River Gorge National Park and Preserve, Oak Hill, West Virginia.

Figure 26: Storm drain presents a hazard (pitfall) to herpetofauna, Cunard road, New River Gorge National Park and Preserve, Oak Hill, West Virginia.

Figure 27: Gravel road between Cunard river access and Brooklyn campground, New River Gorge National Park and Preserve, Oak Hill, West Virginia.

- Glade Creek Road (Figure 28, Figure 29, Figure 30, Figure 31). This is a gravel road between Highway 41 (the bridge across the New River at Prince) and the Glade Creek Trailhead. The road parallels the New River, and there are breeding ponds along the road (Personal communication Joshua Stover, West Virginia Herpetological Society). Roadkilled species include midland mud salamander, eastern box turtle, and multiple snake species (Personal communication Joshua Stover, West Virginia Herpetological Society).

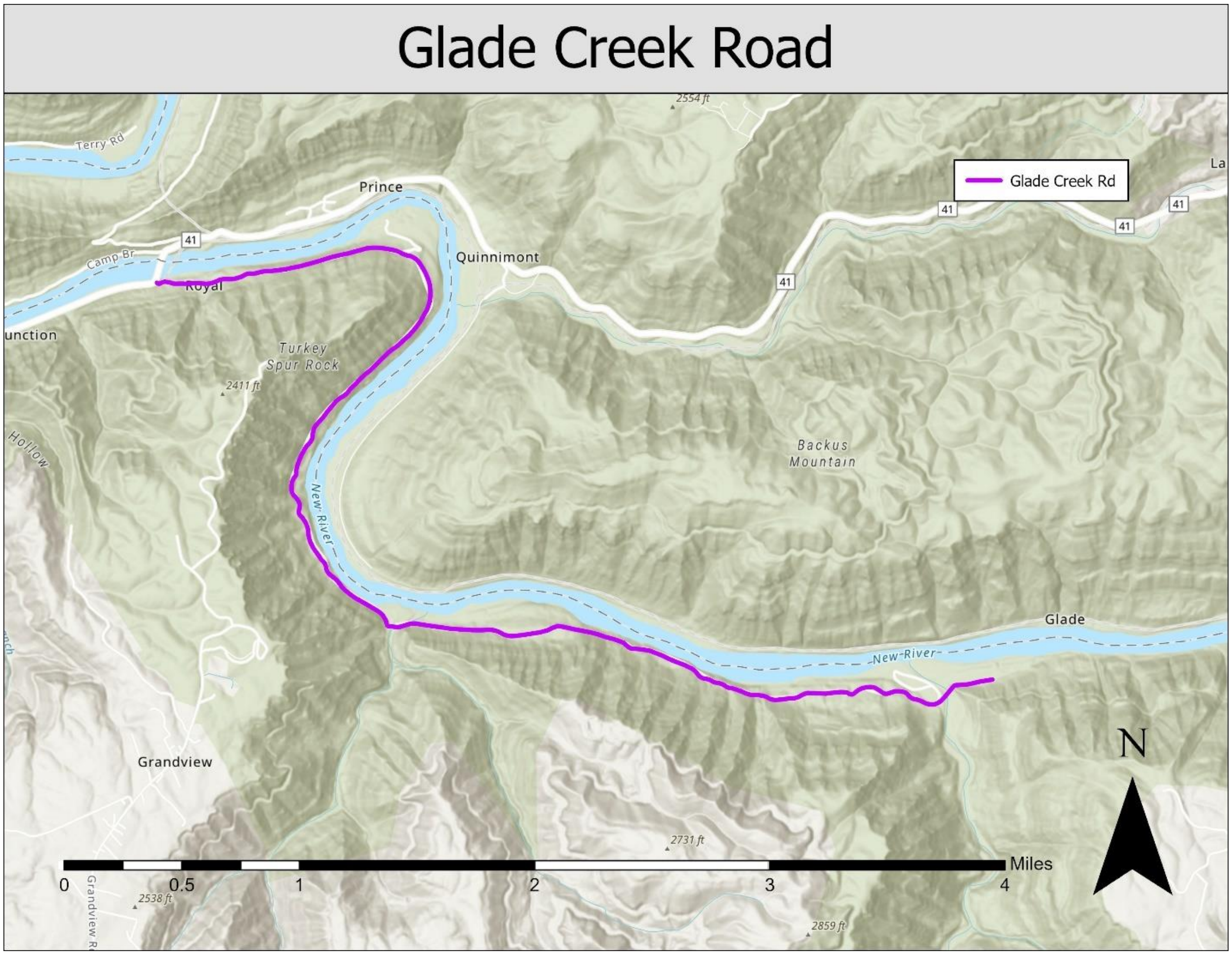

Figure 28: Glade Creek Road, gravel, New River Gorge National Park and Preserve, West Virginia.

Figure 29: Inboard ditch along the grovel Glade Creek Road, New River Gorge National Park and Preserve, West Virginia.

Figure 30: The New River as seen through the trees from the gravel Glade Creek Road, New River Gorge National Park and Preserve, West Virginia.

Figure 31: Storm drain along the gravel Glade Creek Road, New River Gorge National Park and Preserve, West Virginia.

10 Selected trails for non-motorized use

10.1 Harpers Ferry National Historical Park

There are several hiking trails in and around Harpers Ferry National Historical Park (National Park Service 2024c). They include trails within the protected areas as well as a long-distance hiking trail, the Appalachian Trail. Trails have the following road crossings in and around the park:

10.1.1 South of Potomac and Shenandoah River

- Route 9 – Appalachian Trail at Keys Gap (Figure 32). This is a relatively busy two-lane highway with a posted speed limit of 50 MPH, and pedestrian warning signs are in place. This is a potentially dangerous crossing for pedestrians. The trail follows a north-south forested ridge, suggesting there could be ecological benefits for a wildlife crossing structure at this location too.

Figure 32: Appalachian Trail crosses Highway 9 (Charles Town Pike) at Keys Gap, on boundary of West Virginia and Virginia.

- Chestnut Hill Road - Appalachian Trail (Figure 33). This is a low volume two-lane road, a posted speed limit of 35 MPH, limited sight distances, and pedestrian warning signs are in place. This location is considered a "crossing of concern" and is under consideration of measures that would make it safer to cross for people (Pers. com. Melanie Spencer, Appalachian Trail Conservancy). The crossing is on a forested slope, suggesting there could be ecological benefits for a wildlife crossing structure at this location too.

  Potentially activated warning signs that inform drivers about the presence of people on or near the crossing. The warning signs would turn off automatically, e.g. a minute after the last detection of a person.

Figure 33: Appalachian Trail crosses Chestnut Hill Road south of Harpers Ferry, West Virginia.

- US Hwy 340 - Appalachian Trail: goes under bridge, stairs to get on the bridge and across Shenandoah River. This location already has a separated grade; the trail goes under the bridge and then goes up a staircase on the north side of the bridge. The trail is on the bridge and allows pedestrians to cross the Shanandoah River and reach the town of Harpers Ferry. The bridge spans riparian and terrestrial habitat, suggesting wildlife species can move under the bridge as well (Figure 34).

Figure 34: Highway 340 (William L. Wilson Freeway), bridge across Shenandoah River, from the viewpoint of the north bank at Harpers Ferry, West Virginia. The stairs up to the bridge are on the opposite bank.

10.1.2 North of Shenandoah River and south of Potomac River

- Shenandoah Street – Appalachian Trail. This is a relatively low-volume two-lane road with a posted speed limit of 25 MPH, and there is a crosswalk in place. However, the sight distances are short, especially for drivers leaving Highway 340 and turning to Shenandoah Street. Given the proximity of the parking lot on the south east side and the town of Harpers Ferry to the north, there would be limited benefits to increasing ecological connectivity at this location.
- Shenandoah Street – Camp Hill ATC Blue Connector Trail. This is a relatively low-volume road with a 25 MPH posted speed limit. Given the proximity of the Shenandoah River to the south and a forested strip to the north, there could be ecological benefits, but mostly for species with a small home range and need for vertical migration up and down the slopes (e.g. amphibians and reptiles).
- Downtown High Street and Potomac Street - Appalachian Trail. These crossings are downtown setting with very low vehicle speeds. Ecological benefits of mitigation measures would likely be absent or very limited.
- Bakerton road – Parking area Lower Bolivar Heights and parking area Schoolhouse Ridge North and surrounding trails east and west of Bakerton road (Figure 35). This is a two-lane road with a 45 MPH posted speed limit, and pedestrian warning signs are in place. This is a potentially dangerous crossing for pedestrians. This suggests measures that enhance safety for road crossing pedestrians are likely beneficial. The immediate surroundings of the road include grasslands and forest. There are likely benefits mitigation measures aimed at large mammals and small species.

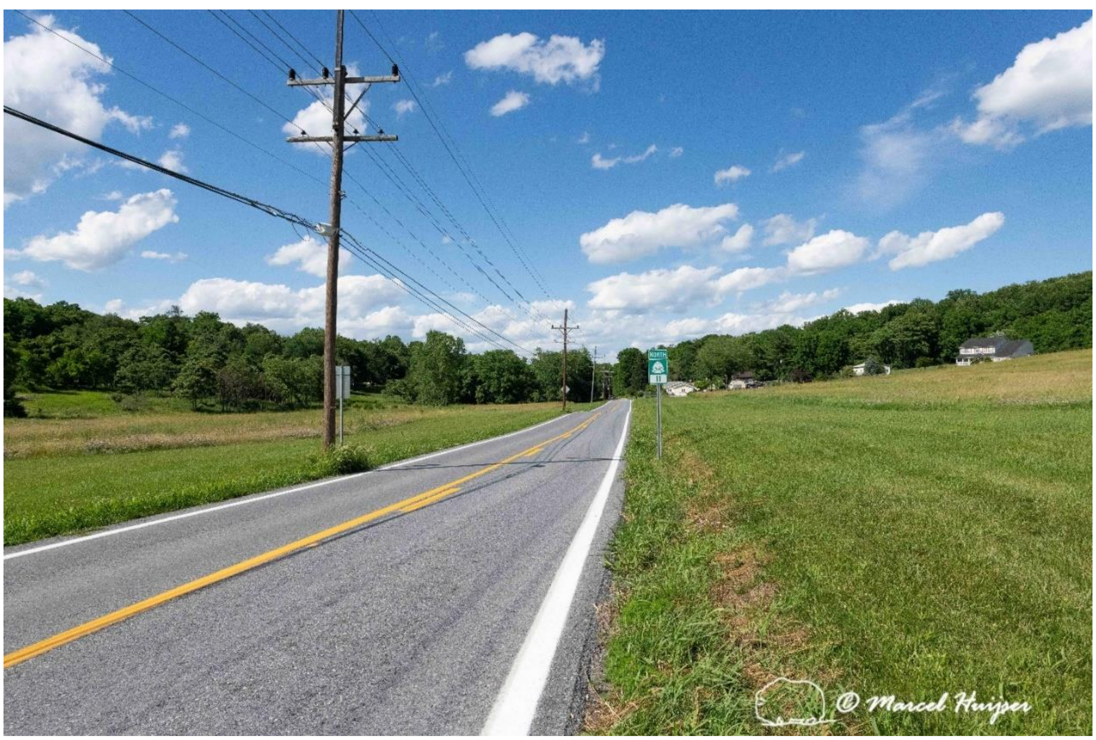

Figure 35: Bakterton Road, just north of Schoolhouse Ridge North, looking north, Harpers Ferry, West Virginia.

- Shoreline Drive – Shoreline Drive Trail (2 crossings). This is a relatively low volume two-lane road, with a 25 MPH posted speed limit, and crosswalks are in place. One of the crossing locations has pedestrian warning signs in place. The immediate surroundings of the road include forest and the Shenandoah River. There are likely benefits mitigation measures aimed at large mammals and small species.

10.1.3 North of Potomac River:

- Harpers Ferry Road – Towpath Potomac Heritage Trail and Maryland Heights Trailhead (trail east of Hoffmaster Road) (Figure 36). This is a relatively low volume two-lane road, with a 35 MPH posted speed limit and a pedestrian warning sign in place. This is a potentially dangerous crossing for pedestrians. To the southwest is the Chesapeake and Ohio Canal and the Potomac River, suggesting there are likely benefits mitigation measures aimed at large mammals and small species.

Figure 36: Maryland Heights Trailhead, Harpers Ferry Road, North Bank of the Potomac River, Maryland.

- US Hwy 340 - Appalachian Trail near Weverton, trail goes under highway. There is a substantial separation of the trail and ecological processes from the main highway.

10.2 New River Gorge National Park and Preserve

There are several hiking trails in and around New River Gorge National Park and Preserve (National Geographic, 2019). Most hiking trails start from a road but do not cross major roads. However, some trails do have road crossings in and around the park:

- US Hwy 19 -Bridge Trail, bridge across the New River, west side. This trail goes under the bridge. This is a very long and tall bridge, allowing for trails and ecological processes to continue under the bridge, almost unaffected by the road and traffic (Figure 37).

Figure 37: New River Gorge Bridge (US Highway 19), as seen from Fayette Station Road, over the New River, West Virginia.

- I-64 bridge across Glade Creek, just north of Upper Glade Creek Trail Head, Shady Spring, West Virginia (Figure 38). This trail goes under the bridge. This is a very long and tall bridge, allowing for trails and ecological processes to continue under the bridge, almost unaffected by the road and traffic.

Figure 38: I-64 bridge across Glade Creek, just north of Upper Glade Creek Trail Head, Shady Spring, West Virginia.

11 Combining wildlife and non-motorized trails

11.1 Why combined use?

People who recreate outside tend to have better physical and mental health (Catalan et al., 2023; Wales et al., 2024). The benefits of spending time outdoors also extend to the overall quality of life and job satisfaction (McFarland, 2017). These principles apply to all settings ranging from urban and suburban to rural and wilderness, including national parks and other protected areas (Stolton & Dudley, 2010; Wolf & Wohlfart, 2014; Catalan et al., 2023). The benefits of physical outdoor activities are greater than those indoors (Niedermeier et al., 2017).

Just like wildlife, people who use trails for non-motorized recreation experience habitat fragmentation because of busy roads, railroads or other linear infrastructure. Crossing structures for hiking, bicycling, and equestrian use across major infrastructure result in larger networks of trails, enhancing recreation opportunities. While it is possible to have separate structures for wildlife and humans using non-motorized trails, there are likely cost savings associated with having wildlife and non-motorized recreation on the same structure rather than two separate structures (van der Ree & van der Grift, 2015). Furthermore, it is possible that more combined use structures would be built than single use structures, potentially allowing for more locations where connectivity for both wildlife and non-motorized recreation by people would be improved.

11.2 General risks of combined use

In general, the non-motorized recreational activities by humans have the potential to disturb wildlife (Taylor & Knight, 2003). Non-motorized activities on trails tend to result in greater behavioral response by large mammals than motorized vehicles on roads (Gump & Thornton, 2023.). Different large ungulates species moved away from humans on trails if the humans were up to several hundreds of meters away (Taylor & Knight, 2003; Lucas, 2020). However, when humans leave or when human use is very low, ungulates can respond quickly and stop avoiding trials (e.g. Longshore et al., 2013). Others found that wildlife may shift the use of areas near trails to the night or delay their return to areas recently used by recreationists (Westekemper et al., 2018; Gump & Thornton, 2023).

Encounters with species that can be dangerous to people can negatively impact visitor experiences (Takahiro & Shoji, 2014). However, species that can pose a risk to humans such as grizzly bears may also choose to avoid areas with relatively high human use (Mace & Waller, 1996).

11.3 Effects of human co-use on wildlife use of crossing structures

Human co-use was negatively associated with large mammal use of wildlife crossing structures in Banff National Park in Canada (Clevenger & Waltho, 2005). This correlation was stronger for large carnivores than ungulates. However, human use tends to be highest close to urban areas which may confound the results. Other studies found mixed effects or no effects of human co-use on wildlife use (review in van der Ree & van der Grift, 2015).

An extensive study on a multi-functional overpass for wildlife and non-motorized use by people in the Netherlands found that people predominantly used the structure during the day (human use was not permitted after sunset to begin with), and human use was higher in the weekends than during week days (van der Grift et al., 2024). On average between 100,000 and 200,000 people used the structure per year. This translated to about 388 bicyclists, 172 pedestrians, and 7 people on horseback per day. The number of crossings by mammal species was not affected by the number of people that used the overpass during the previous day, but there was a tendency for mammals to delay their use of the structure by about 1.5 hours if daytime use by people was high during the previous day. Similar results were found at another multi-functional overpass; mammals crossed the structure on average about 3 hours later on nights following heavy human use (>250 people per day), versus nights following lower human use (<100 people per day) (van der Grift et al., 2022). In multi-functional landscapes almost all mammal species that are present in the wider area were also recorded on crossing structures, but human co-use is associated with animal moving fast across the structure (e.g., running) versus walking and spending more time on the structure (van der Grift et al., 2010).

11.4 Design principles for multi-use crossing structures

Multi-use crossing structures designed for both wildlife species and non-motorized use by people can be especially considered in areas that already have a relatively high human presence and disturbance, and for targets species that are tolerant of human presence and disturbance (van der Ree & van der Grift, 2015). In pristine areas with no or few people and little or no permanent human presence, and for target species that are sensitive to human disturbance and that may be threatened or endangered, separate crossing structures for people and wildlife are probably more appropriate.

If a multi-functional crossing structure is designed for both wildlife and non-motorized use by people, a wider structure is required than what would have been suitable for only wildlife. At a minimum, about 15 ft additional width is required to accommodate a recreational trail and visual and sound barriers between the designated trail and the zone designated for wildlife (van der Ree & van der Grift, 2015) (Figure 39). If the target species are sensitive to human disturbance, or if threatened or endangered species are among the target species, the additional width for human co-use may have to be greater than 15 ft, but one may also consider separate structures for people and wildlife.

If a multi-functional crossing structure is designed for both wildlife and non-motorized use by people, it is recommended to implement explicit design features for both people and wildlife (van der Ree & van der Grift, 2015). This includes a well-maintained designated trail for people on one of the two edges (sides) of a crossing structure, and a designated zone for wildlife on the remainder of the structure (Figure 39, Figure 40, Figure 41). Physical, visual and sound barriers encourage spatial separation of humans and wildlife at the crossing structure. Most importantly, these features discourage people from leaving the trail and venturing out on the designated wildlife zone of a crossing structure. These barriers may include earthen berms, potentially planted with shrubs and small trees, and a fence. Visual and sound barriers should also be installed on the two far edges of crossing structures to reduce noise and visual disturbance from traffic for both wildlife and people. Equestrian use may especially benefit from reducing noise and visual disturbance from traffic. Do not install artificial lighting to discourage people from using the structures at night and to not discourage wildlife at night.

Figure 39. Ecoduct Natuurbrug Zanderij Crailoo, The Netherlands. On the far left is the trail for non-motorized recreation. A fence and vegetated berm separate the trail from the designated zone for wildlife to the right. The corridor is about 50 m wide and 800 m long and connects forests and heathlands on both sides. The corridor consists of embankments and two bridges. One bridge spans a two-lane highway, the other a railroad and railroad yard. The embankment also goes through sports fields.

Figure 40. Hiking and biking trail combined with wildlife overpass across railroad tracks Soest The Netherlands. The designated wildlife area is to the left, on the other side of the fence and vegetated berm.

Figure 41. A provincial road crossed under the 4-lane A27 motorway, near Hilversum, The Netherlands. The structure was made wider to anticipate potential future additional lanes. Instead, this space was used to create habitat for small animal species. Note the black screen on the left that reduces light and other visual disturbance originating from the provincial road. The trail on the right is for non-motorized traffic, including equestrian use.

12 Recommendations

12.1 Large-mammal-vehicle collisions and ecological connectivity

Crash reports, regardless of the type of crash, are collected by law enforcement agencies (Huijser et al., 2007, Nichols et al., 2014). There is typically a threshold in place for the minimum estimated vehicle repair costs, or the occurrence of a human injury or fatality. Crash reports include parameters including the type of crash (e.g., with an animal, a wild animal, or specific animal species), and the date, time, and location (Huijser et al., 2007). These data do exist and if they are made available, they can be used in a project that aims to identify and prioritize locations from the perspective of human safety (see e.g., Nichols et al., 2014).

Carcass removal records are typically collected by road maintenance crews (Huijser et al., 2007, Nichols et al., 2014). However, these carcass removal records mostly relate to large mammal species and carcasses that are on the road or that are considered a danger to traffic (Huijser et al., 2022). While carcass removal data are generally considered to suffer more from inconsistent search and reporting effort than large wild mammal – vehicle crash data, they can also be used in a project that aims to identify and prioritize locations from the perspective of human safety (see e.g., Nichols et al., 2014).

Direct road mortality and habitat fragmentation are considered a substantial concern in most national parks (Ament et al., 2008). Yet very little mitigation has been implemented in national parks to address these concerns, warranting a more systematic approach (Ament et al., 2008).

Our recommendations:

1. Gain access to existing crash and carcass removal data from state agencies.
2. Explore if and how data collection practices may be improved, e.g., through the use of an app and by having employees from multiple agencies, including the National Park Service, use the app (Ament et al., 2018; 2019; 2021).
3. Conduct data analyses to identify and prioritize road section that may require mitigation measures aimed at reducing collisions with large wild ungulates (see e.g., Huijser & Begley 2019; Huijser & Bell, 2024).
4. Identify areas that are important to biological conservation and identify potential corridors between them, especially within national park units and how those units fit into the landscape in the wider region. Overlay these important habitat and corridors with the transportation network to identify and prioritize road sections that may require mitigation measures aimed at increasing habitat connectivity in areas separated by roads.
5. Identify the objectives and the target species for the mitigation measures and design the measures for these species accordingly. The target species influence the barrier (fence) design, as well as the number, location, type and dimensions of crossing structures (i.e. wildlife underpasses and overpasses) (for more details see Huijser et al., 2022) (Figure 42, Figure 43, Figure 44, Figure 45, Figure 46, Figure 47).
6. Implement the mitigation measures at the appropriate spatial scale (see e.g., Huijser & Begley, 2022; Huijser et al., 2022) and ensure there is spatial coherence between the different road

sections that are mitigated. If the objective includes ecological parameters (e.g., improved population viability through reduced unnatural mortality and increased habitat connectivity) we must work on a landscape level. We cannot succeed with only treating roads in certain spots or sections without making the connection to the surrounding landscape.

7. Evaluate the effectiveness of the mitigation measures in terms of reaching the objectives.
8. If the objectives are not reached, investigate why and implement adaptive management.

Figure 42. Typical large ungulate fence in North America, 8 ft tall, wooden posts and mesh-wire fence material, US Hwy 93 North, Montana, USA. Note that there is a dig barrier attached to the main fence material (e.g. for canids).

Figure 43. Fence for Florida panther (Puma concolor coryi), 10 ft tall, metal posts, chain-link fence material, and overhang, SR 29, Florida, USA).

Figure 44. Wildlife fence for amphibians (e.g. common toad (Bufo bufo)), medium sized mammals (e.g. Eurasian badger (meles meles)) and large ungulates (e.g. roe deer (Capreolus capreolus), red deer (Cervus elaphus)) at ecoduct Woeste Hoeve A50 near Apeldoorn, The Netherlands.

Figure 45. Wildlife underpass (width 7-8 m, height 4-5 m) suitable for white-tailed deer and mule deer and black bear. Not suitable for e.g., elk, pronghorn, grizzly bear.

Figure 46. Wildlife underpass with dimensions that would be suitable for most large mammal species. Note the visual barrier. The barrier reduces visual and noise disturbance from traffic for the animals that approach the underpass.

Figure 47. Wildlife overpass with dimensions that would be suitable for most large mammal species. Note the berm on wildlife overpass. The berm with root wads and shrubs provides cover on either side and reduces visual and noise disturbance barrier combined with large mammal fence on an overpass.

12.2 Species of Greatest Conservation Need (SGCN)

General recommendations:

- Crash data from law enforcement agencies and carcass removal data from transportation agencies are generally not suitable for small species or species that are rare (Huijser et al., 2022). Explore if and how data collection practices for small or rare species may be improved or initiated. Examples include using an app, automating date, time, and location recording, and by having NGO's (e.g. West Virginia Herpetological Society) and employees from multiple agencies, including the National Park Service, use the app (Ament et al., 2018; 2019; 2021).
- Conduct data analyses to identify and prioritize road sections that may require mitigation measures aimed at reducing direct road mortality, and other hazards associated with toads and traffic (e.g., impassable curbs, storm drains that act as pitfalls), and where roads may act as a barrier (see e.g., Gunson & Huijser, 2019; Huijser et al., 2022).
- Identify areas that are important to biological conservation and identify potential or existing corridors between them, especially within national park units and how those units fit into the landscape in the wider region. Overlay these important habitat patches and corridors with the transportation network to identify and prioritize road sections that may require mitigation measures aimed at increasing habitat connectivity in areas separated by roads. Rare species may depend on a meta population structure that goes well beyond the boundaries of a single protected area. Small species may not move far or fast and may require mitigation measures at very specific locations, including low volume roads, potentially even gravel roads or dirt roads.
- Identify the objectives and the target species for the mitigation measures and design the measures for these species accordingly. The target species influence the barrier (fence) design, as well as the number, location, type and dimensions of crossing structures (i.e. wildlife underpasses and overpasses) (for more details see Huijser et al., 2021; 2022).
- Implement the mitigation measures at the appropriate spatial scale (see e.g., Huijser & Begley, 2022; Huijser et al., 2022) and ensure there is spatial coherence between the different road sections that are mitigated. If the objective includes ecological parameters (e.g., improved population viability through reduced unnatural mortality and increased habitat connectivity) we must work on a landscape level. We cannot succeed with only treating roads in certain spots or sections without making the connection to the surrounding landscape. If and when mitigation measures are implemented for small species, it is critical to not only implement measures that keep the animals off the road, but to also provide sufficient crossing opportunities that are not too far apart. Mitigation measures that include crossing opportunities that are too far apart can be detrimental to the conservation of a species rather than be helpful (Ottburg & van der Grift, 2019).
- Evaluate the effectiveness of the mitigation measures in terms of reaching the objectives.
- If the objectives are not reached, investigate why and implement adaptive management.

Specific recommendations:

In Harpers Ferry National Historical Park very little information was available on specific road sections impacting Species of Greatest Conservation Need (SGCN) except for Shoreline Drive. This road could be classified as a “park road” as it is inside the national park unit, and it has no apparent function for private residences or businesses. Seasonal or night-time closure could be considered for this road. Alternatively fences or barrier walls with suitable crossing structures at short intervals could be considered for the road section alongside the vernal pools.

The recommendations below are limited to New River Gorge National Park and Preserve and Species of Greatest Conservation Need (SGCN). We recommend Joshua Stover (West Virginia Herpetological Society) is interviewed during the exploration, planning and design process as he knows about the exact locations where the target species occur.

- Fayette Station Road: Night-time closure, especially on rainy nights would be an effective way to substantially reduce direct road mortality of amphibians and reptile species along this road (Figure 48). The night-time closure could be implemented through installing a gate (close to the visitor center of Lansing), and also one just east of the Outpost New River Campground. Park personnel could potentially open and close the gates in the morning and in the evening. Note that the closed road section has no houses or businesses, and that closing the road at night is unlikely to result in substantial problems for people. It is essentially a “park road” for people to enjoy the park, it is not a “through road” used by people to go someplace else. Note that fences (small mammal fences or screens) and crossing structures are not only difficult to implement and maintain along the steep slopes and rocky soils, but the distance that would need to be treated is relatively long, about 5 miles or longer. Furthermore, the steep slopes make the fence or barrier susceptible to erosion and sedimentation which jeopardize the effectiveness of the barrier. This further points to a relatively simple, inexpensive and very effective measure: to substantially reduce direct road mortality by night-time road closure. However, a potential barrier effect of the road is not addressed through night-time road closure.

Figure 48. Night-time road closure Saguaro National Park Arizona USA.

- Nick Rahall Greenway: There are services and businesses along this road, reducing the likelihood of night-time closure. Instead, barriers (fences or sheets) combined with underpasses could be implemented along this road section (Figure 49, Figure 50, Figure 51, Figure 52, Figure 53, Figure 54). The mitigation measures would not only reduce direct road mortality of amphibians and reptile species along this road but could also provide safe crossing opportunities. The relatively short length of this road, and potentially only needing to mitigate one or more sections of this road make fences or screens in combination with underpasses or culverts relatively easy to implement.

Figure 49. Plastic sheeting during installation for amphibians, reptiles, and small mammals, Montana, USA.

Figure 50. Barrier or wall for amphibians integrated into roadbed Deelenseweg between Hoenderloo and Arnhem Gelderland, The Netherlands.

Figure 51. Barrier wall for turtles, alligators, snakes, and amphibians. Lake Jackson Ecopassage Tallahassee Florida USA.

Figure 52. Barrier wall and underpass with slotted roof for common toads, The Netherlands.

Figure 53. Underpass (culvert) for amphibians, including salamander species, Monkton-Vergennes Road Vermont USA.

Figure 54. Underpass for large wild mammals made more suitable for small mammals, amphibians, and mammals by placing cover (branches) along the sides, Montana, USA.

- Cunard River Access Road: The lower portion is a gravel road to a campground. To reduce traffic, one can explore a system where only people who have a reservation at the campground can drive this road. This could be achieved through a gate just after the boat launch that could be opened with a QR code associated with the reservation. Campground guests could be asked to avoid driving in the dark when amphibians are most likely to be active.
- Glade Creek Road: This is a 5-6 mile long gravel road to a trailhead. People headed to the trailhead or returning from the trailhead could be asked to avoid driving in the dark.

12.3 Non-motorized trails

12.3.1 Harpers Ferry National Historical Park

Two road crossings for trails appear the most problematic:

- Route 9 – Appalachian Trail at Keys Gap. Our recommendation is to explore the potential for a multi-functional overpass designed for both non-motorized use by people and by wildlife (Figure 55). The ecological objectives would focus on connectivity associated with the forested ridge and allowing for north-south connectivity along the ridge.

Figure 55. Hiking and biking trail combined with wildlife overpass across railroad tracks, Soest, The Netherlands. The vegetated "wildlife area" on the overpass is further to the left, separated from the trail by a berm and shrubs and trees.

- Chestnut Hill Road - Appalachian Trail (Figure 33). Here the emphasis would be on human safety. We recommend exploring the potential for a push button on the two sides of the road along the trail, potentially set back a bit from the road. Warning signs could be activated for drivers to make them aware of the potential for pedestrians on the road. More than 1 warning sign could be used for each travel direction, including just before blind curves or rises that reduce the sight distance for drivers.

12.3.2 New River Gorge National Park and Preserve

The main trail crossings are under very high and wide bridges; these road crossings already have a spatial separation with the main highways. Almost all other trails start at a trailhead and do not cross any paved roads.

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14 Appendix A

14.1 The key habitat types included:

Hemlock-northern hardwood forests
Cove forests
Montane-Piedmont oak-pine forest
Oak-Hickory Forests
Mesic Mixed Hardwood Forest
Acidic Glade and Barren
Cliff and Rock Outcrop
Montane-Piedmont Floodplain
Montane-Piedmont Acidic Seepage Swamp
Montane-Piedmont Basic Seepage Swamp
Piedmont Seepage Wetland
Piedmont Upland Depression Swamp
Vernal Pool
Spring
Limestone Streams
Highland Streams
Piedmont Streams
Highland Rivers
Caves and Karst
Managed Successional Forests
Managed Grasslands
Artificial Structure - Mine and Tunnel

14.2 The key habitat types excluded:

Basic Mesic Forest
Coastal Plain Oak-Pine Forest
Coastal Plain Pitch Pine Forest
Maritime Forest and Shrubland
Serpentine Barren
Shale Barren
Coastal Bluff
Coastal Beach
Maritime Dune and Grassland
Coastal Plain Floodplain
Montane Bog and Fen
Coastal Plain Flatwood and Depression Swamp
Coastal Plain Seepage Swamp
Coastal Plain Seepage Bog and Fen
Delmarva Bay
Maritime Swamp
Tidal Forest
Tidal Freshwater Marsh and Shrubland
Tidal Brackish Marsh and Shrubland
Tidal Salt Marsh and Shrubland
Intertidal Mudflat and Sand Flat
Coldwater Streams
Coastal Plain Stream
Blackwater Streams
Piedmont Rivers
Coastal Plain Rivers
Shellfish Beds
Hard Bottom
Submerged aquatic vegetation
Macroalgae
Pelagic
Managed Montane Conifer Forest
Roadside and Utility Right-of-Way
Artificial Impoundment and Artificial Wetland
Artificial Structure - Buildings and Other Structures