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Prioritizing Wildlife Road Crossings in North Carolina

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Wildlands
NETWORK

EXECUTIVE SUMMARY

As we confront the daunting threats facing wildlife and wild places today, conservationists recognize the urgent need to find effective solutions for alleviating the current human-caused extinction crisis. Many researchers have pointed to a strategy focusing on the re-establishment of habitat connectivity as one of the most effective and efficient ways to prevent extinctions. By linking protected natural areas together with a network of habitat corridors, we can create more robust and healthy wildlife populations and provide species with the pathways they need to adapt to changing climates.

While there is great support for this strategy in the conservation community, implementing connectivity is made challenging by the extensive road networks now prevalent across the globe. The state of North Carolina, for example, has constructed one of the largest state-maintained highway networks in the country, accounting for over 79,000 miles of road. Solutions exist, however, for mitigating the impacts of roads on animal species and thus restoring habitat connectivity. By installing structures such as wildlife underpasses and overpasses, we can conserve native wildlife, reduce wildlife-vehicle collisions, and improve public safety. This can be done cost effectively by strategically prioritizing the road segments that are most harmful to wildlife. In this study, we identify priority road segments across North Carolina using a suite of characteristics that predicts where wildlife and transportation conflict is greatest. We did this through the development of large, small, and all-species models that integrate numerous road characteristics, such as traffic volume, species-specific connectivity data, and proximity to protected natural areas. The models provide a comprehensive outlook on roadways most deserving of intervention for wildlife, nuanced enough to help identify which mitigation structures or retrofits would be most appropriate for the particular species involved.

This study adds to a growing body of work of state and regional road prioritization assessments for wildlife, and helps fill the gap in the eastern USA where states have largely neglected wildlife-transportation conflict. Through these models, the North Carolina Department of Transportation (NCDOT) and wildlife conservation groups can more quickly and strategically assess where wildlife mitigation measures should be implemented. As North Carolina continues to develop at a fast pace, NCDOT should better utilize wildlife overpasses, underpasses, and other mitigation strategies to protect native wildlife and residents.

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INTRODUCTION

The most significant threats facing wildlife and wild places today are well known. Unbridled habitat loss, rising human populations, poaching and overharvest, and climate change, among other key factors such as invasive species and disease, have led to what many scientists consider the sixth mass extinction. One of the most frequently cited ways of combating these crises, particularly climate change and habitat loss, is to re-establish habitat connectivity through a network of core protected areas linked together by wildlife corridors (Heller & Zavaleta 2009, Hilty et al. 2006, Taylor et al. 2006). Restoring connectivity can link together small populations into much more viable and robust networks, and can provide many species with the room they need to migrate in response to climate change.

However, one of the most daunting challenges to implementing the connectivity strategy is the extensive road network now found throughout the world. Today, an estimated 4 million miles of public roads exist in the United States alone (Forman et al. 2003). While this infrastructure has provided innumerable benefits to human society, it has come at a severe cost to wildlife. In addition to highway fragmentation of habitat, wildlife-vehicle collisions are estimated to kill one million vertebrates *each day* in the United States – that's 365 million unnecessary wildlife deaths each year (Bissonette & Cramer 2008).

The state of North Carolina has one of the largest state-maintained highway networks in the country, accounting for over 79,000 miles of road. Between 2011 and 2013, the state experienced over 61,000 wildlife-related vehicle crashes, resulting in nearly 20 human fatalities, more than 3,400 injuries, and over $149 million in damages (Oliver 2014). In addition to endangering North Carolinians, wildlife-vehicle collisions also constitute a major threat to survival for some of the state's 10+ federally listed threatened or endangered animal species, including the Carolina northern flying squirrel (*Glaucomys sabrinus coloratus*) and red wolf (*Canis rufus*) (FWS 2016).

There are, however, proven solutions to this issue: mitigation measures, including wildlife underpasses and overpasses, have been shown to reduce wildlife-vehicle collisions by 80 to 90% (Clevenger et al. 2001). Despite their upfront costs, these measures have been shown to pay for themselves over time through cost savings when installed at collision hotspots (Donaldson 2005, Huijser et al. 2009). These measures also improve functional connectivity through local wildlife corridors, which is essential to stemming the extinction crisis. Where mitigation is determined to make sense, such as lengthening a bridge or replacing a culvert, taking steps to prevent collisions and provide safe passage is predicted to save human lives, wildlife, and money.

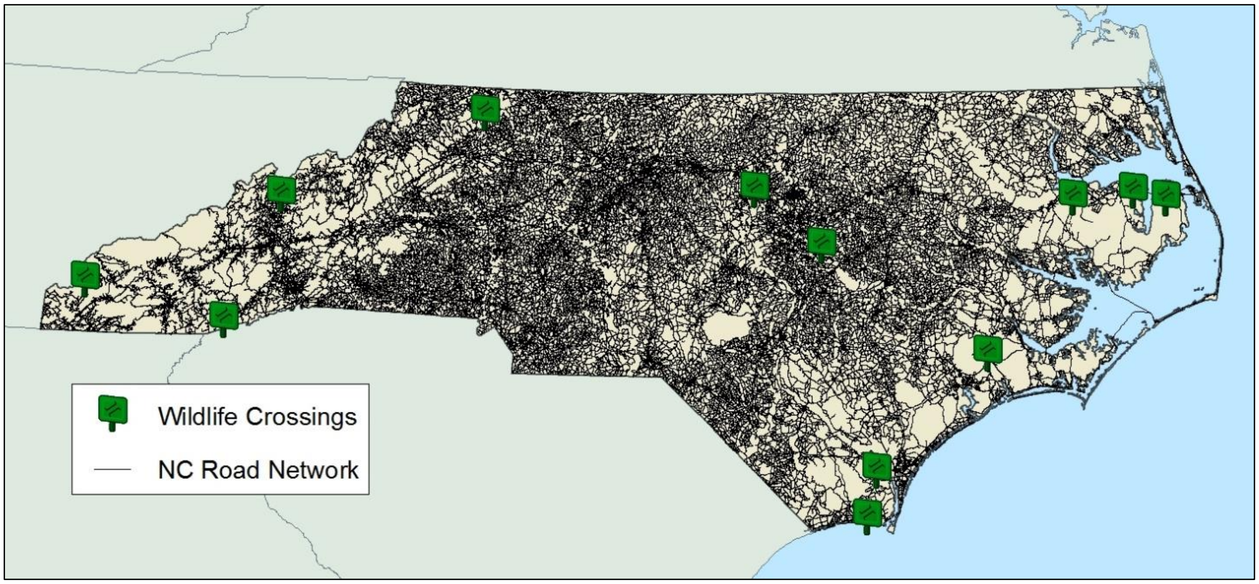


Figure 1. The North Carolina road network accounts for 79,000 miles of roads. According to NCDOT, approximately 12 crossings have been implemented with wildlife in mind.

Figure 2. Bridge lengthening over New Hope Creek on 15-501 in Durham, NC. This underpass was extended on either side of the river to improve wildlife movement through this important habitat corridor.

In this study, we sought to identify road segments throughout North Carolina that should be prioritized for wildlife mitigation measures. Although the North Carolina Department of Transportation (NCDOT) has taken some steps, including building a few wildlife underpasses, this has been largely done opportunistically on a project-by-project basis. While we appreciate the complexity and funding challenges of incorporating mitigation measures into road projects, we also believe that NCDOT is long overdue in prioritizing the most strategic road segments and projects where mitigation efforts are needed for the benefit of the public and our native wildlife. Our prioritization models are driven by available road data, species-specific connectivity models, and expert opinion to define the most strategic road segments worthy of mitigation measures.

MATERIALS & METHODS

Materials

The study was confined to North Carolina, a state that currently has only a very limited set of wildlife underpasses on its extensive highway network. Many data layers were used to develop small and large species models, including a complete North Carolina road layer and wildlife-vehicle collision data points, both freely available through the NCDOT website (NCDOT 2015). In addition, species-specific movement models for black bear (*Ursus americanus*), timber rattlesnake (*Crotalus horridus*), and box turtle (*Terrapene carolina)* were employed to identify pinch-points across roads (Leonard et al. 2016, Sutherland et al. 2015). We identified more generalized hotspots for other rare, endemic, and endangered species using the North Carolina Natural Heritage Program's Element Occurrences dataset, also available from their website (NHP 2016). Wetland landscape features were identified using the National Land Cover Database 2011 dataset (Homer et al. 2015). Finally, a protected area layer was developed from the Protected Area Database of the United States (PAD-US, made available by United States Geological Survey), the National Conservation Easement Database (NCED), and The Nature Conservancy's Secured Areas dataset, all available through their individual websites (USGS 2016, NCED 2015, TNC 2015). The analysis was completed using ArcGIS v 10.3.1 (ESRI 2014).

Methods

The choice to divide the prioritization between two models was driven by the unique set of characteristics that predict whether a certain suite of species will be at risk of mortality or habitat fragmentation from the presence of roads. While some of these layer elements overlap between large and small species groups, we believe splitting these two sets will allow a more nuanced understanding of road crossing priorities, as well as make explicit the specific mitigation measures needed to be most effective.

(1) Road characteristics

While a wide variety of road characteristics affects large species generally, we chose to include only traffic volume, speed limit, and type of median. For small species, we adjusted our characteristics to focus on traffic volume, lane width, and type of median.

With respect to traffic volume, for the large species model, we used a threshold of 10,000 Annual Average Daily Traffic (AADT; meaning that many vehicles use the road segment on an average day), a measure shown to predict road segments of the highest concern and often a complete barrier to large species, such as pronghorn in the southwest United States (Dodd et al. 2011). Since traffic volume, lane width, and number of lanes are typically closely and positively related, and therefore difficult to disentangle, we used AADT only as a proxy for these other measurements (Rico et al. 2007). However, we lowered this threshold for small species to 2,000 AADT. There is a range in the literature suggesting thresholds from 110 to 21,600 AADT (Andrews et al. 2015), but Sutherland et al. (2010) found a threshold of 2,000 AADT in the Sandhills region of North Carolina for amphibians and reptiles. We chose to use this as it most closely represents the species and geographic area of concern.

Roads with speed limits of 60mph or higher were pulled out as a layer for the large species model because these roads represent a barrier to movement even if their traffic volume is not very high (Shilling et al. 2012). We did not use this metric for our small species model because this group is often slow moving or at risk of desiccation compared to larger species. As such, small species are more vulnerable to road mortality regardless of vehicle speed. What does appear to matter, however, is how far these animals need to travel across the road, how long it will take them to cross that distance, and what the weather conditions are at that time. Therefore, we used road width greater than 8 meters, shown to be a barrier for land snails, as a conservative criterion for identifying potential road barriers for small species (Andrews et al. 2015).

Various median structure types are used in North Carolina. Impermeable median barriers for large species include jersey barriers, guardrails, and other positive barriers, determined by expert opinion of the North Carolina Wildlife Road Crossings working group (see Acknowledgements). Generally, a raised median with sloped edge, curb, grass, and painted pavement were determined to be permeable to this group. However, for small species, we determined that all median types except grass were impermeable, and therefore road segments with such medians were highlighted as a layer in our models.

(2) Wildlife-vehicle collision hotspots

As already noted, wildlife-vehicle collisions (WVC) are a major issue for both wildlife and public safety. Unfortunately, data on these collisions are often incomplete and error-prone. This is because most data are collected only when there has been resultant property damage from the collision. Moreover, these reports are not completed by biologists who can positively identify the species involved, but by law enforcement that often are not familiar with this kind of information. Exact locations of these crossings are sometimes recorded incorrectly as well (Gunson et al. 2009). With these limitations in mind, we chose to still include a WVC dataset because while imperfect, it provides the best available information about where large species are being hit on the road and where public safety may be most at risk. Since small species do not cause property damage and therefore do not generate collision reports, this characteristic was only used for the large species group. Data on road mortality for both large and small species is lacking. We urge researchers to focus on collecting this type of information to better inform these models in the future.

We used the 2014 NCDOT WVC dataset (the most recently available dataset), which consists of a large series of point locations recorded for collisions across North Carolina. Since the data were not easily standardized (i.e. by assigning the points to road segments of uniform length), we aggregated the data using the point density function across the entire landscape at 30m resolution, and then looked for road segments that met certain collision density criteria. It is important to note that NCDOT advises that this dataset represents white-tailed deer approximately 90% of the time (Oliver 2014), therefore we can essentially refer to this dataset as deer-vehicle collisions. We used a density of 2.5 deer-vehicle collisions within a quarter mile radius (equivalent to a half-mile stretch of road passing through the middle of a circular search window) to delineate road segments that are the highest priority targets for wildlife mitigation structures. This threshold was chosen because studies have shown that roughly 5 deer-vehicle collisions per mile per year represent the point at which overpasses and underpasses become cost effective to implement (Donaldson 2005, Huijser et al. 2009). The threshold we used is essentially equivalent to this, yet may be even more precise due to its calculation at the half-mile scale of reference.

(3) Species-specific models

We employed three different species-specific connectivity models to help inform our road crossing priorities within the context of regional wildlife movement, all generated by Sutherland et al. (2015). Two of these were based on a circuit theory framework in which each unit area of the landscape is coded with resistance values based on expected suitability for animal movement, and then the flow of animal movement is predicted based on an analogy to electricity moving across an equivalent gridded circuitboard (McRae et al. 2008). Essentially, the "Circuitscape" model injects current into a node, which is an area of least resistance (i.e. a protected area), and that current flows to another node along various potential pathways according to their relative resistance, and the process is repeated for each pair of nodes within a specified distance of one another. These pair-wise models are stacked, providing a layer showing density of predicted animal movement patterns across the landscape. We used black bear and timber rattlesnake models as they both represent habitat generalists for large and small species, respectively. The value of these particular datasets is that they show potential movement across the entire South Atlantic region at a fine resolution of 90m, made possible through the use of a supercomputer (Leonard et al. 2016). This allows users to have fine detail while still keeping regional connectivity priorities in context. To apply these models to our study, we first clipped them to each ecoregion: the Southern Blue Ridge, Piedmont, and Coastal Plain. This was necessary to ensure that the top corridors were not skewed entirely to the Southern Blue Ridge where the majority of North Carolina’s most connected, least-impacted habitat exists. Next, we extracted the top 10% density flow for each ecoregion and intersected these with the roads layer. We used the top 10% because this identifies pinch-points in movement flows, in other words, areas where animals will likely be driven across roads because of surrounding development or other impermeable landscape features.

The third model utilized a slightly different concept, identifying areas with high network centrality rather than connectivity. The model uses "shortest path betweenness centrality," which identifies areas that have the largest influence on movement flow throughout the entire network, in this case, the Atlantic coast (Carroll et al. 2011, Sutherland et al. 2015). We used the box turtle model since small species are typically under-represented in road ecology literature, and we felt it would give us more information as to areas most deserving of road mitigation for the conservation of box turtles and similar species. Again, we extracted the top 10% centrality across the state and found road segments that intersected these areas.

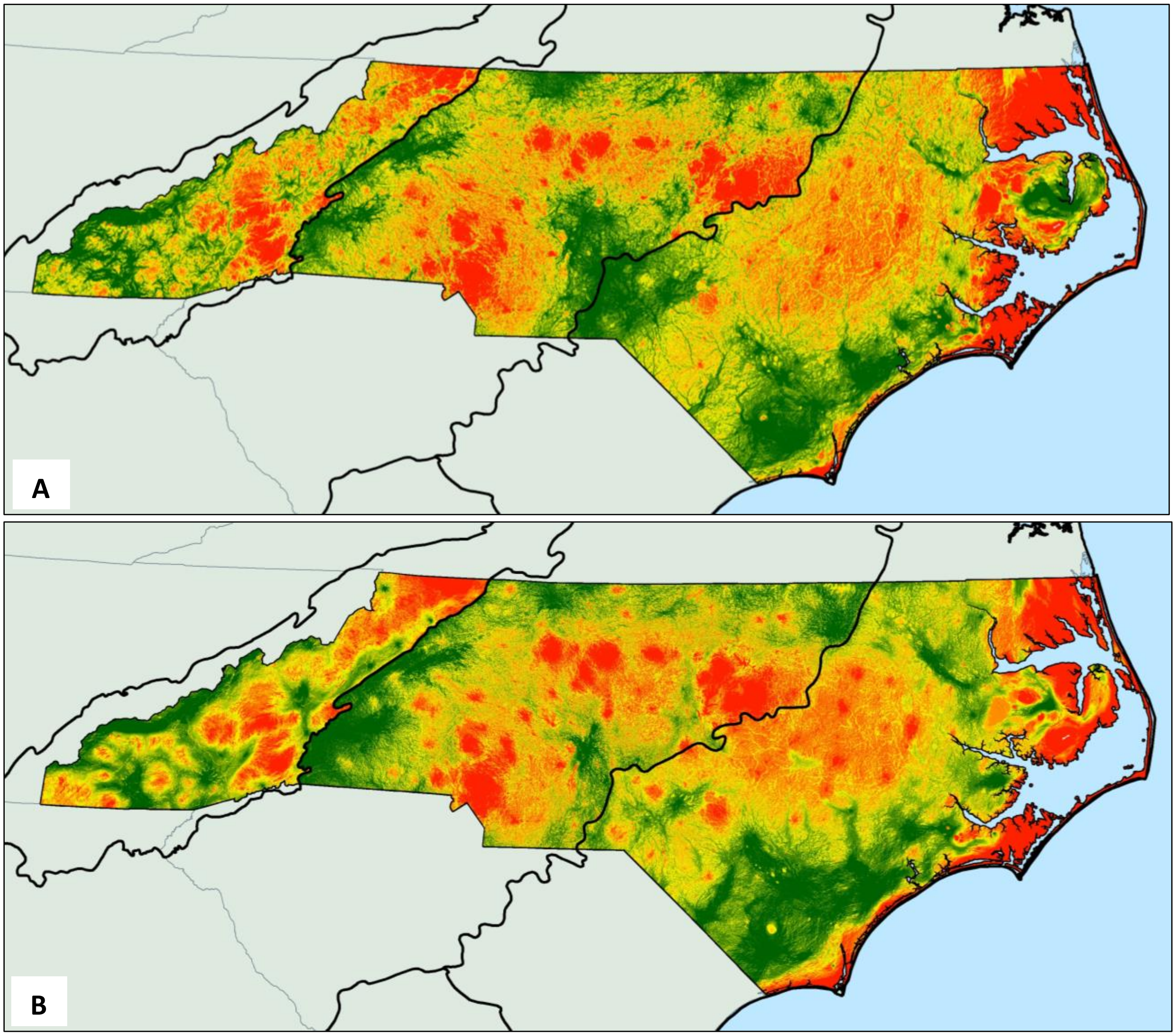


Figure 3. Circuitscape results for timber rattlesnake (A) and black bear (B) relativized by ecoregions (from right to left: Coastal Plain, Piedmont, and Southern Blue Ridge) and displayed in quantiles in each region. The dark green colors denote the top 10% of predicted movement density for each ecoregion for that species.

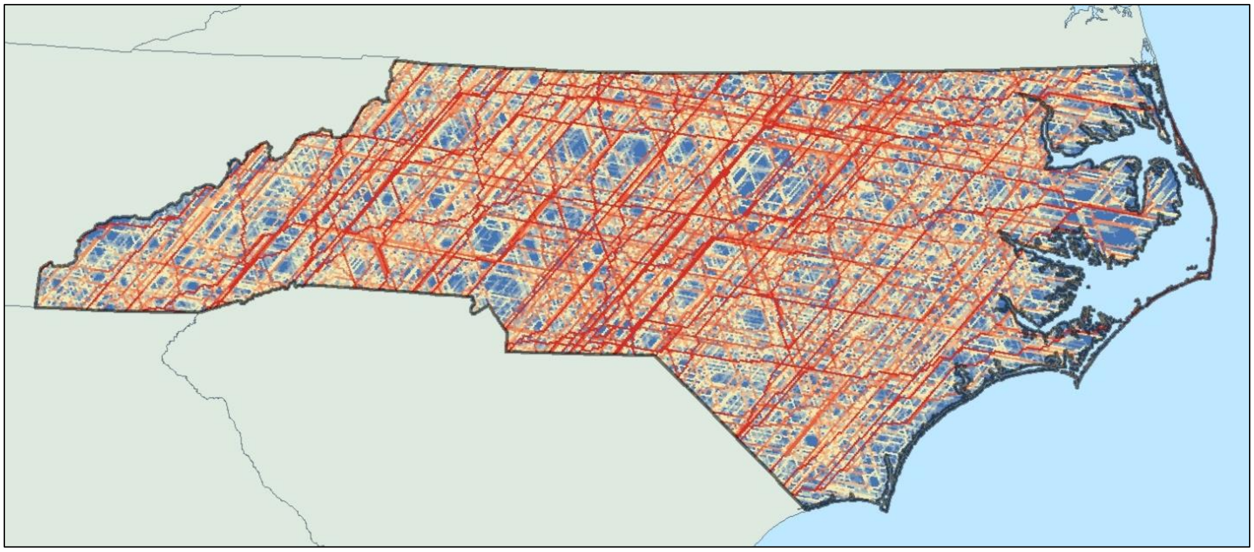


Figure 4. Results from the Connectivity Analysis Toolkit (CAT) for box turtle. Red areas indicate places of highest network centrality.

(4) Hotspots of rare, endangered, and endemic species

The North Carolina Natural Heritage Program (NHP) creates and manages the state's most comprehensive database of the rarest and most outstanding elements of natural diversity by combining on-the-ground surveys with advanced GPS and GIS technologies. Using this dataset enables users to identify areas with rare, endangered, or endemic species. This is important for two reasons. Firstly, the NHP data identify areas of high ecological concern (Spencer et al. 2010). Secondly, they detect areas that will likely trigger an environmental assessment through the National Environmental Policy Act, so transportation departments will need to take this into consideration anyway (Spencer et al. 2010). For the purposes of this analysis, we extracted data points from the Element Occurrences dataset and selected only animal records with the highest accuracy available to overlay with roads. Even though rare, endangered, and endemic plant species are greatly affected by roads, we did not include them because our main focus was on terrestrial animals. Future iterations would benefit from the inclusion of vegetation.

(5) Nearby wetlands

Nearby wetlands was a characteristic included for the small species group. Garrah et al. (2015) found a significant spatial association between multi-year WVC hotspots and wetlands. Therefore, nearby wetlands can be used as a predictor of collision hotspots for small species, at least those associated with wetland and bottomland habitats (Andrews et al. 2015). Using the NLCD data set, we pulled out all of the wetland layers. We then buffered the master roads layer segments by 300 meters, making a buffer polygon for each segment. Next, we fed this data into the Geospatial Modelling Environment's isectpolyrst tool using GME v 0.7.2 RC2 (Beyer 2012). This tool summarizes the raster cell values that are contained in a polygon. In this case, it summarized the percent of wetlands present in the buffered road layer. Because we did not want this characteristic to be overly biased toward the wetland-rich Coastal Plain, we chose to again split the layer up by ecoregion. In the Coastal Plain, we extracted all road segment buffers that had 70% or more wetland pixels. By contrast, in the Piedmont, we extracted all road segment buffers that had 50% or more wetland pixels. In the Southern Blue Ridge, we dropped this down to 30% or more wetland pixels. We combined these road segment buffers together into a wetland priority layer, and then added this information to the master roads layer attributes (as a new field) by selecting the master road segments that fell completely within the wetland priority buffers identified above. This categorizes road segments that likely have or will have high mortality rates for small species, particularly reptiles and amphibians that are often associated with wetland habitats.

(6) Proximity to protected areas

The final characteristic we included in the analysis was proximity to protected areas. Through discussion with NCDOT and other state and federal wildlife agencies, we understand that without nearby protected areas, any wildlife mitigation strategy is perceived as a risky investment by transportation planners. If a wildlife crossing were implemented near unsecured natural areas, there is the possibility that these lands could be converted into agricultural fields or urban development in future years, a scenario that has already taken place at least once in North Carolina (T. Wilson, personal communication, 2015). From NCDOT's perspective, this would make the added cost to construction wasted. We include proximity to protected areas since this is an important metric to making wildlife mitigation feasible in the eyes of NCDOT, and because such protected areas are likely to remain stables sources and targets for dispersing wildlife in North Carolina.

NCDOT prefers to have protected natural areas on both sides of the road in order to consider an area for a wildlife crossing structure (T. Wilson, personal communication, 2015). Therefore, our models attempt to identify road segments with protected areas on both sides. To do this in a fairly simple way, we combined multiple protected area layers including USGS PAD-US, NCED, and The Nature Conservancy's Secured Areas database. After reclassifying this vector dataset to a 30m binary raster (protected [1] or unprotected [0]), we then used focal statistics with a 0.3 mile search radius to determine the presence of protected areas. The 30m raster output scores from the focal statistics ranged from 0-1, so any roads intersecting a raster cell with a score of 0.50 or above indicated the likely presence of protected areas on either side of that piece of road (i.e. more than half of the landscape around the focal pixel with which the road intersects is protected, suggesting that if the road bisects the circular search window, there are likely to be protected areas on both sides of the road). This method isn't perfect, but more elegant solutions were deemed unnecessarily complicated for the purposes of this project.

(7) Integration of layers

The data layers described above were all intersected with the master NCDOT roads layer, which is pre-divided into a set of 416,913 road segments of varying lengths. For each segment, the corresponding road characteristic was given a 1 if the road segment reflected that characteristic and a 0 if it did not. These characteristics were then summed for a total cumulative score. Road segments with higher scores can thus be treated as higher priorities for wildlife mitigation.

RESULTS

The analysis resulted in three spatially-explicit models with accompanying tables. These include a large and small species model as discussed, as well as an all-species model which represents the synthesis of the former two models.

Large species model

In total, the large species model included (1) traffic volume, (2) speed, (3) type of median, (4) WVC hotspots, (5) black bear connectivity, (6) rare, endemic, or endangered species hotspots, and (7) protected areas on both sides of the road. Scores ranged from 0 to 6. All road segments highlighted by the model would benefit from the inclusion of wildlife mitigation, but in particular, higher scores, 4-6, indicate road segments that are in most need of intervention. Fortunately, the flexibility of these models allows the user the option of selecting by score or by characteristics most important for their specific purposes. As such, these models can be utilized by a variety of groups for a variety of purposes. For example, NCDOT may be most concerned with road segments that are WVC hotspots and have protected areas on both sides, whereas a land trust may be most concerned with black bear connectivity and road segments that are not protected. Either way, the model can identify the priority road segments that demonstrate the characteristics required and can help to inform future transportation and conservation planning and advocacy.

Large Species priority road characteristics	*Threshold*
Traffic Volume	10,000 AADT
Speed	60mph or higher
Type of median	Jersey barriers, guardrails, and other positive barriers
WVC hotspots	2.5 collisions per 0.25 mi radius per year
Black Bear connectivity	Top 10% density flow from Circuitscape models
Rare, endemic, or endangered species hotspots	Animal only and high accuracy intersections
Protected areas on both sides	Protected areas on both sides of road segment (>50% protected within 0.3mi search radius)

Table 1. Final characteristics incorporated into the large species prioritization model

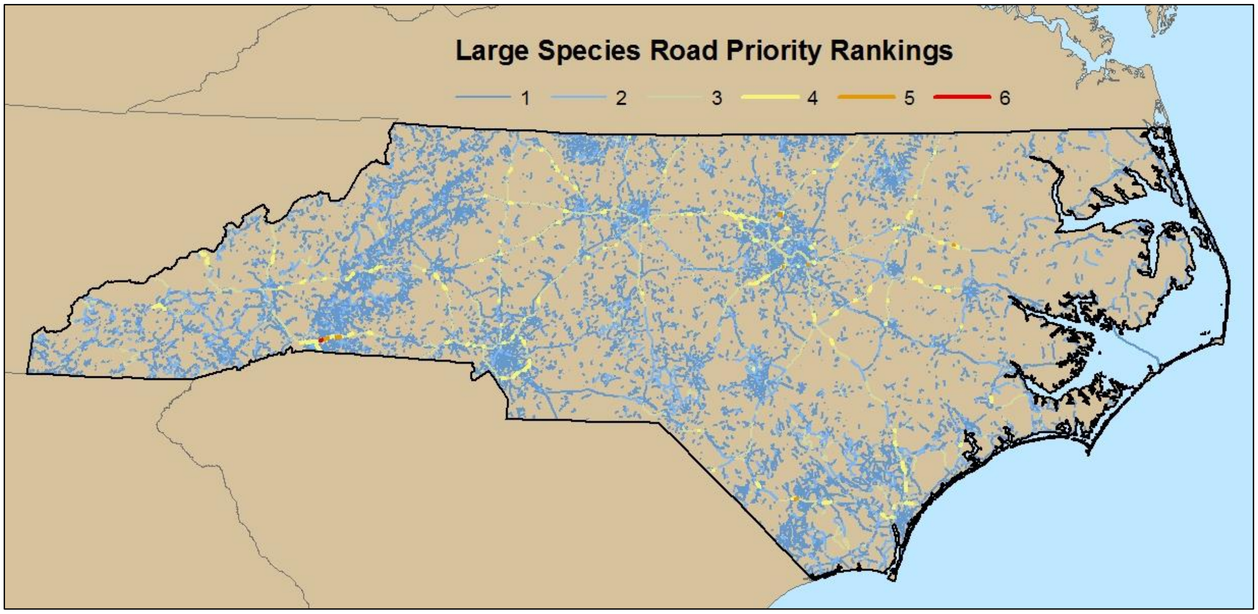
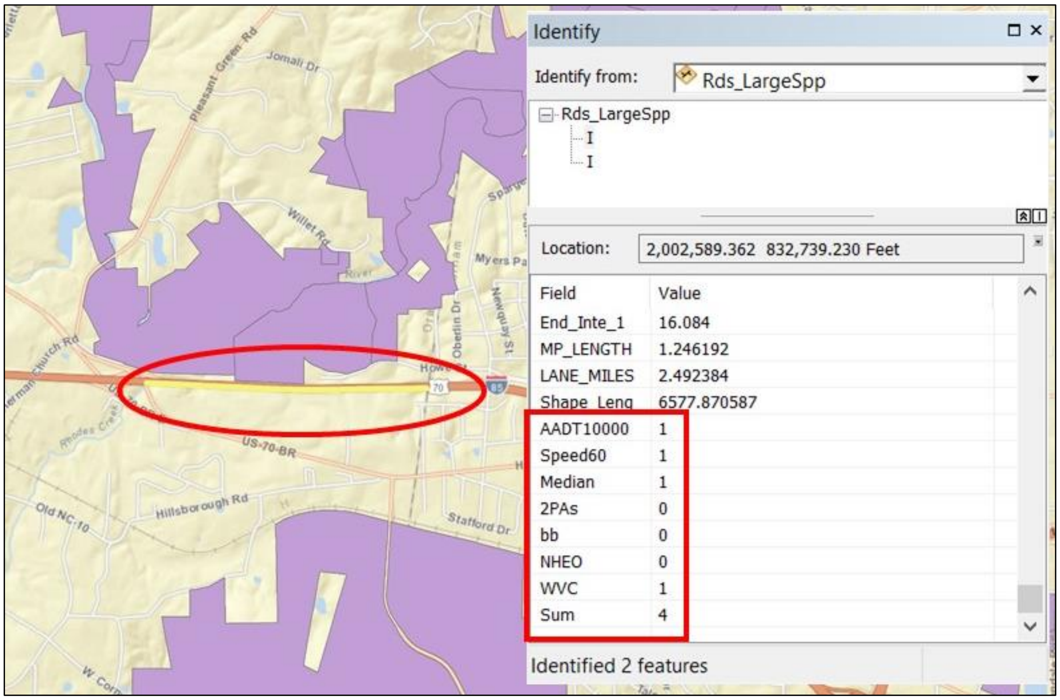


Figure 5. Road crossing priorities for large species generally. Summing a variety of characteristics (see Table 1), high priority road segments (i.e. scores 4-6) reflect candidates for road mitigation strategies, such as bridge lengthening, underpasses, or overpasses.



Identify from: Rds_LargeSpp

Rds_LargeSpp
I
I

Location: 2,002,589.362 832,739.230 Feet

Field	Value
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MP_LENGTH	1.246192
LANE_MILES	2.492384
Shape_Leng	6577.870587
AADT10000	1
Speed60	1
Median	1
2PAs	0
bb	0
NHEO	0
WVC	1
Sum	4

Identified 2 features

Figure 6. In this example, a portion of I-85 through Durham, NC is highlighted as a high priority for wildlife mitigation. The model provides details on what makes this road segment a high priority: high traffic volume, high speeds, an impermeable median, and a wildlife-vehicle collision hotspot. This information can be utilized to determine the best mitigation strategies; in this case, a large wildlife underpass or overpass would facilitate species movement from protected lands (shown in purple) along the Eno River (to the north) to Duke Forest (to the south).

Small species model

The final characteristics included in the small species model integrate (1) traffic volume, (2) road width, (3) type of median, (4) timber rattlesnake connectivity, (5) box turtle centrality, (6) rare, endemic, or endangered species hotspots, (7) nearby wetlands, and (8) protected areas on both sides. Scores again ranged from 0 to 6, with the higher scores identifying road segments most in need of wildlife mitigation measures. As with the large species model, the design allows users to customize how they select priority road segments to reflect their conservation needs and goals.

Small Species priority road characteristics	*Threshold*
Traffic Volume	2,000 AADT or higher
Road Width	8m or greater
Type of median	Jersey barriers, guardrails, and other positive barriers, raised median with sloped edge, curb, and painted pavement
Timber Rattlesnake connectivity	Top 10% density flow from Circuitscape models
Box Turtle centrality	Top 10% centrality from CAT models
Rare, endemic, or endangered species hotspots	Animal only and high accuracy intersects
Nearby wetlands	High nearby wetland percentage (70% in Coastal Plain, 50% in Piedmont, 30% in Southern Blue Ridge)
Protected areas on both sides	Protected areas on both sides of road segment (>50% protected within 0.3mi search radius)

Table 2. Final characteristics incorporated into the small species prioritization model

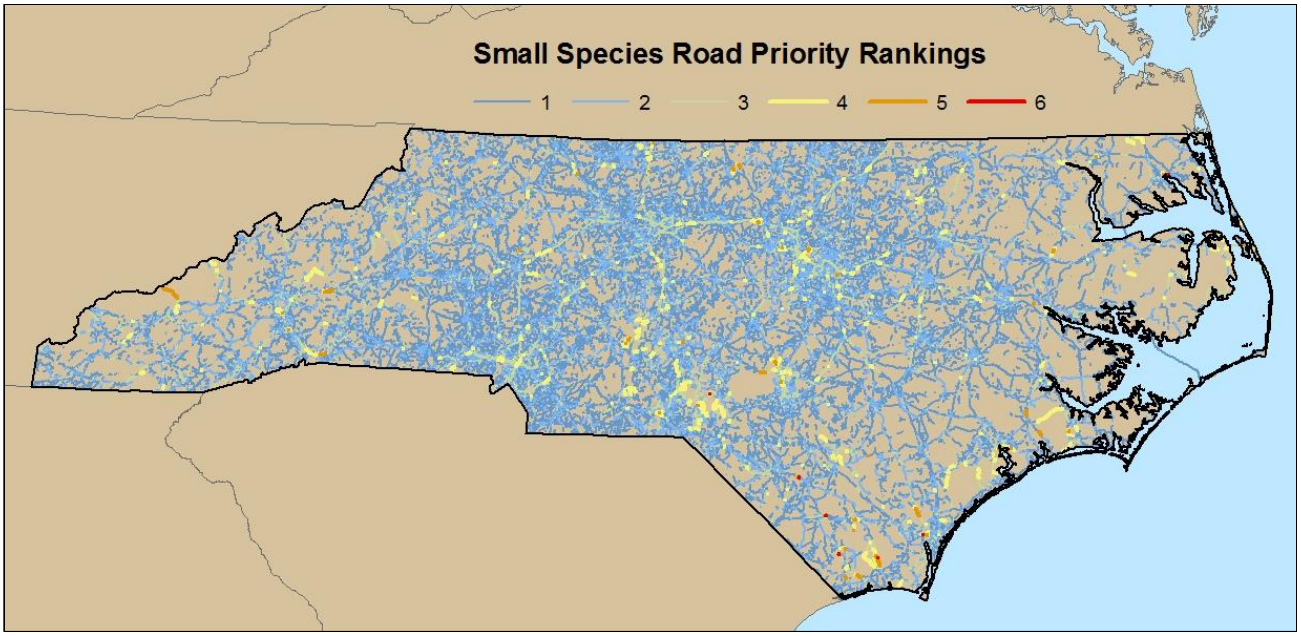
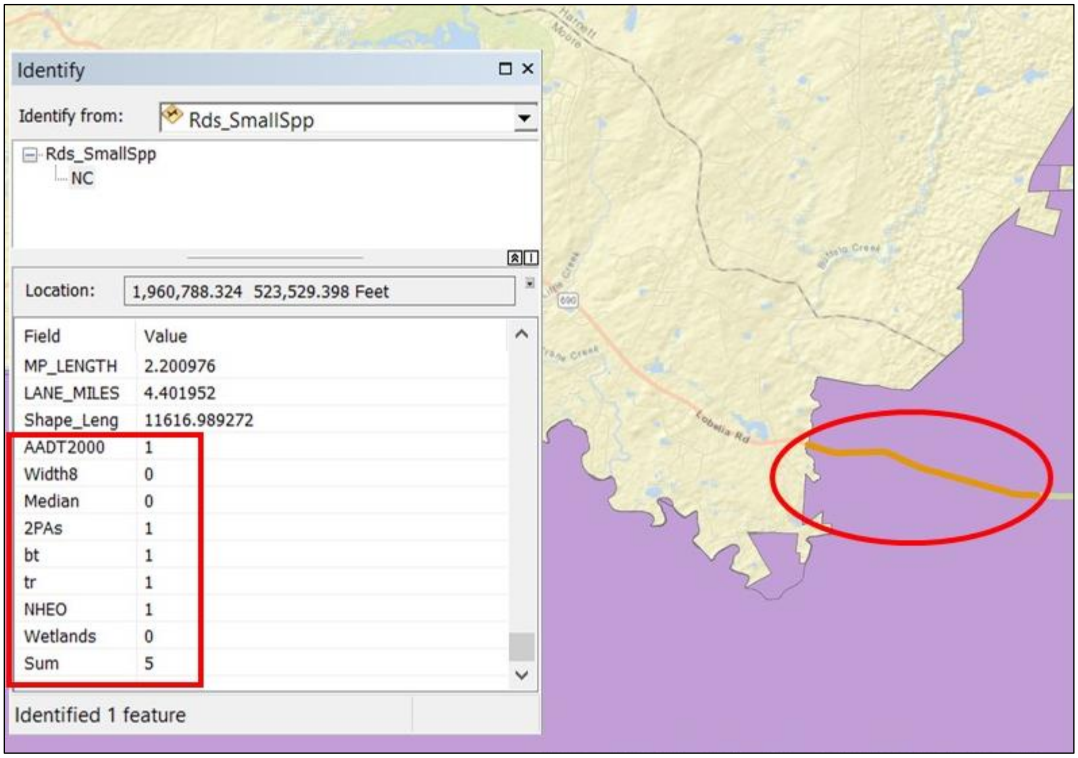


Figure 7. Road crossing priorities for small species generally. Summing a variety of characteristics (see Table 2), high priority road segments (i.e. scores of 4-6) reflect candidates for road mitigation strategies, such as bridge lengthening, culvert widening, or underpasses.



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Rds_SmallSpp
NC

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Shape_Leng	11616.989272
AADT2000	1
Width8	0
Median	0
2PAs	1
bt	1
tr	1
NHEO	1
Wetlands	0
Sum	5

Identified 1 feature

Figure 8. In this example, a portion of NC-690 through Fort Bragg in the Sandhills of North Carolina is highlighted as a top priority for small species. Characteristics of note include high traffic volume, protected area on both sides of the road, high box turtle centrality, high timber rattlesnake connectivity, and the presence of a Natural Heritage Element Occurrence.

All-species model

The all-species model integrates the characteristics in both the large and small species models discussed above. Scores ranged from 0 to 9. While we consider the individual large and small species models to provide a more nuanced outlook on road projects and necessary mitigation strategies, we provide this layer for a more general, but complete overview of potential road segments with high wildlife importance. With this layer, a user can quickly identify road segments that are most important to both large and small species in North Carolina.

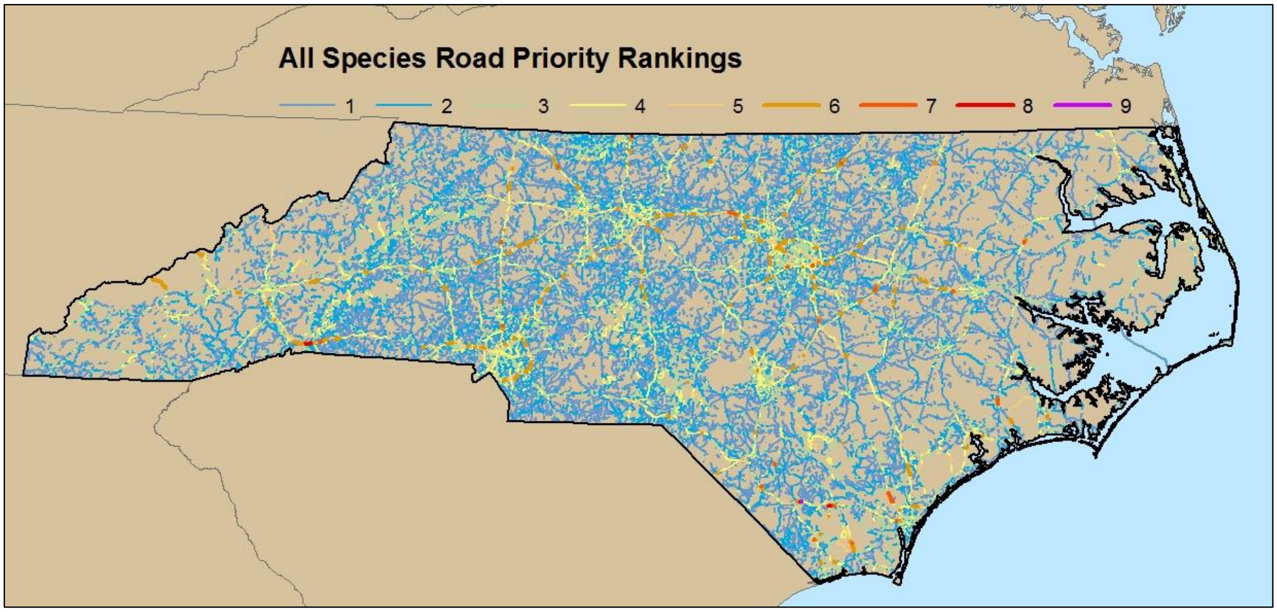
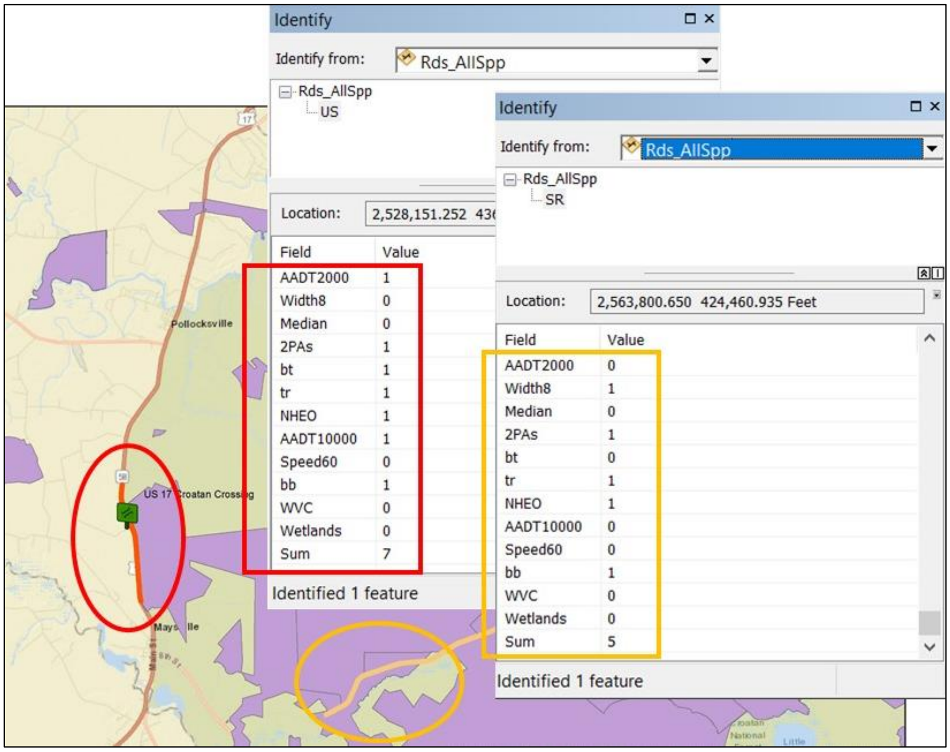


Figure 9. Road crossing priorities for the combined all-species model. Summing all characteristics (see Tables 1 & 2), high priority road segments (i.e. scores of 6-9) reflect candidates for road mitigation strategies, such as wildlife underpasses and overpasses.



Identify from: Rds_AllSpp

Rds_AllSpp
US

Location: 2,528,151.252 43

Field	Value
AADT2000	1
Width8	0
Median	0
2PAs	1
bt	1
tr	1
NHEO	1
AADT10000	1
Speed60	0
bb	1
WVC	0
Wetlands	0
Sum	7

Identified 1 feature

Identify from: Rds_AllSpp

Rds_AllSpp
SR

Location: 2,563,800.650 424,460.935 Feet

Field	Value
AADT2000	0
Width8	1
Median	0
2PAs	1
bt	0
tr	1
NHEO	1
AADT10000	0
Speed60	0
bb	1
WVC	0
Wetlands	0
Sum	5

Identified 1 feature

Figure 10. Here, two priority road segments are highlighted for the combined all-species model. US-17 (red) has a priority ranking of 7 because of high traffic volume (for both large and small species), protected areas (Croatan National Forest and others shown in purple), high box turtle centrality, high timber rattlesnake and black bear connectivity, and a Natural Heritage Element Occurrence. Note that this road section has a wildlife crossing that is currently under construction. SR-1105 (orange) by contrast, has a priority ranking of 5 because of lane width, protected areas on both sides, high timber rattlesnake and black bear connectivity, and the presence of a Natural Heritage Element Occurrence.

DISCUSSION

Road ecology is still a relatively new discipline. However, in the past decade there has been increased understanding and acceptance that wildlife need to be included in transportation planning and decision-making. Several state and regional assessments have been produced for Arizona (Nordhaugen et al. 2006), California (Beier et al. 2005, Spencer et al. 2010), Florida (Smith 1999), the Northern Rocky Mountains (Cushman et al. 2013), Vermont (Leoniak et al. 2009, Shilling et al. 2012), Washington (Singleton et al. 2002), and in 16 western states, the Crucial Habitat Assessment Tool has been developed (Ament et al. 2015). These assessments use differing methodologies, but ultimately have the same goal: to identify priority road segments in need of wildlife mitigation measures. Notably, most of these analyses are based in the western portion of the United States. Outside of Florida and Vermont, the eastern USA suffers from a lack of large-scale road crossing prioritization assessments. Here, we help close that gap by undertaking a statewide prioritization for North Carolina.

In North Carolina, we recognize the importance of preserving wildlife and the critical wildlife corridors they depend on, as the Southeast has been recently designated as a biodiversity hotspot (Noss 2016). Threatening this tremendous natural heritage is a surge in population and development across the region. North Carolina has grown significantly faster than the nation since 2000, and is projected to grow nearly 11% by 2020, reaching a population of roughly 10.6 million (Tippett 2015). This growth will necessitate NCDOT continuing to expand and improve the state's transportation system. We believe this situation creates the opportunity for North Carolina to invest wisely in transportation infrastructure in ways that balance the needs of native wildlife and public safety. One of the easiest applications of these models is to overlay them with NCDOT's Statewide Transportation Improvement Plan (STIP), which is produced biennially and forecasts road project priorities for 10 years. Currently, NCDOT is determining their STIP for 2018-2027.

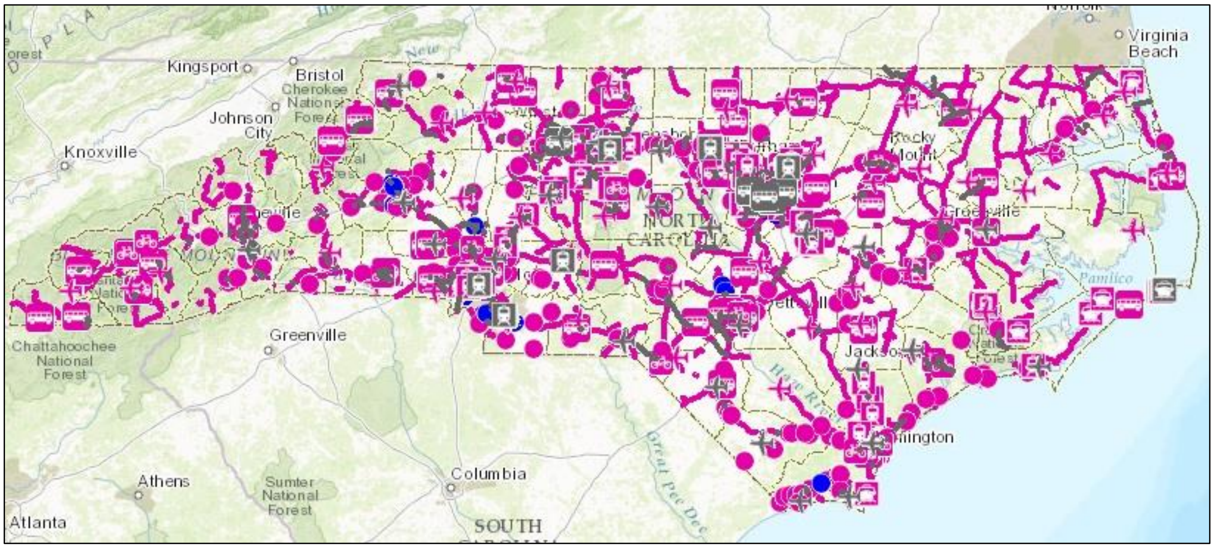
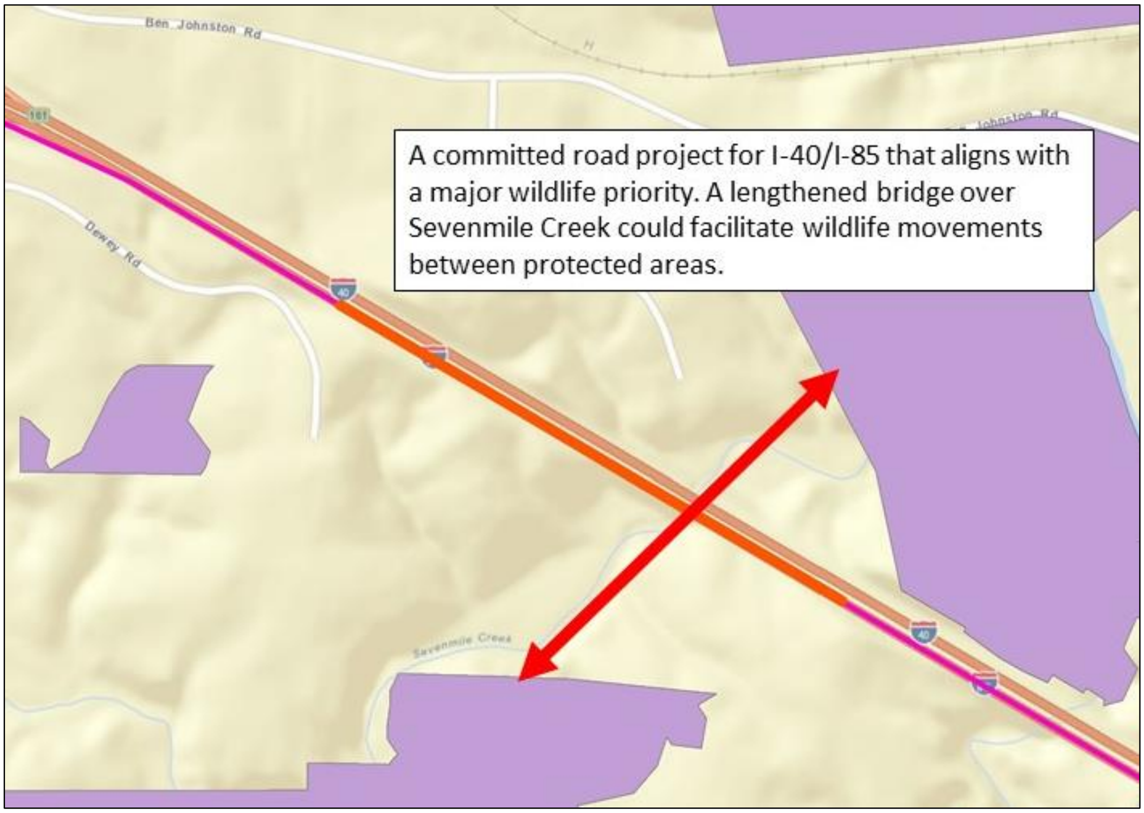


Figure 11. The North Carolina DOT produces a Statewide Transportation Improvement Plan (STIP) biennially. The STIP forecasts road project priorities for the following 10 years, in this example 2018-2027. Recently, NCDOT has made a spatially-explicit version available on their website, which will greatly facilitate the ability of conservation organizations to align DOT project priorities to wildlife considerations. This STIP draft for 2018-2027 will be finalized in 2017. For more information: https://www.ncdot.gov/strategictransportationinvestments/

With our large and small species models, NCDOT has the ability to fold wildlife mitigation measures into future road projects, utilizing the most cost effective approaches. There are many resources available to assist in determining the best wildlife mitigation measure for the type of wildlife species targeted (Huijser et al. 2008a, Huijser et al. 2008b, Kintsch & Cramer 2011). For example, coupling fencing with crossing structures maximizes the effectiveness of those crossings (Clevenger et al. 2001). However, if the crossing is geared toward large species, the emphasis on fencing may be height; in comparison to small species, where the emphasis may be on mesh size (Andrews et al. 2015). Moreover, while the implementation of lengthened bridges, underpasses, and overpasses are most preferable due to their greater expected reductions in collision rates, there are retrofits to existing structures that can help to increase wildlife permeability. For instance, in an existing culvert with no dry passage available, shelves can be installed to assist movement of small and medium-sized animals (Kintsch & Cramer 2011). Using our models will very quickly allow NCDOT, or other groups interested in transportation and wildlife, to identify roads needing mitigation and in combination with the above reports, to determine exactly what measures or retrofits would provide the greatest impact.



A committed road project for I-40/I-85 that aligns with a major wildlife priority. A lengthened bridge over Sevenmile Creek could facilitate wildlife movements between protected areas.

Figure 12. A committed road project on I-40/I-85 for the draft 2018-2027 STIP (pink) aligns with a major road priority in our All-Species model (orange). This road segment scored a 7 due to high traffic volume (for both large and small species), road width, impermeable median, high speed, importance for box turtle centrality, and the presence of a Natural Heritage Element Occurrence. Overlaying this data allows conservation groups to better comment and provide recommendations to NCDOT on how to include appropriate wildlife mitigation into road project design. For example, lengthening a bridge over Sevenmile Creek so that there is terrestrial passage on either side of the waterway would help to facilitate wildlife movement between an Orange County easement to the northeast and Sevenmile Creek Park to the southwest (red arrow).

Limitations

As with all models, there are important limitations to consider. The quality of the WVC dataset is slightly uncertain, as noted in our Methods, and while it can give the user a general sense of where animals are being hit on roads, it may not identify the exact location of WVC hotspots. In addition, species-specific connectivity models can provide us with much useful information, but with a caveat: these models show where species *could* move through the landscape, not necessarily where they *have been observed* to move. Ground-truthing species movement models should continue to be a focus for researchers (Sutherland et al. 2015). Finally, the master roads layer from NCDOT provides information on existing roads, but unfortunately does not include new roads to be constructed, therefore limiting our assessment to what road features currently exist. However, most road projects today deal with existing roads. All new road projects should be vetted for their impact on wildlife and mitigated accordingly, by inclusion of appropriate wildlife crossing structures and by avoiding routes with potential impact on rare wildlife habitats and connectivity.

Next Steps

There are several next steps to take to build on this analysis. First, our models should be vetted by expert biologists and land conservationists from around the state. This would allow us to integrate years of accumulated ecological knowledge in with the results from our data-driven approach, allowing a more comprehensive and robust look at roads and wildlife. Second, our models would benefit from the inclusion of more species-specific data. For example, integration of more connectivity models, preferably ground-truthed or developed from radio-collar data, would provide more targeted road crossing priorities for particular species of note in North Carolina, such as elk, eastern diamondback rattlesnakes, and wild turkey.

Third, as we noted already, there needs to be more emphasis and research on roadkill surveys. Roadkill surveys add precision to wildlife crossing location priorities for key road segments being considered for new transportation projects or retrofits. We hope to find and integrate more roadkill datasets into our analysis, as well as continue to encourage researchers to focus on conducting such surveys. Moreover, we could also use roadkill surveys to test our predictions. For instance, do higher priority roads identified by our assessment actually inflict greater rates of roadkill or WVCs? As demonstrated by Sutherland et al. (2010), surveys of live animals crossing highways can also be highly informative concerning the presence of target species along roads.

Fourth, and complementary to the goal of conducting more roadkill surveys, is the need to better evaluate existing wildlife crossing structures and other projects that were enhanced with wildlife in mind (e.g., bridge lengthening projects). By comparing roadkill rates to successful crossings, either as before and after studies or within mitigated road segments versus control segments, we will be able to get at questions such as whether these mitigation strategies are working as intended, which ones work best, and for what species are they most effective. Such data will improve future wildlife road crossing designs and will help to ensure that NCDOT is using their money effectively to safeguard both wildlife and motorists.

Finally, we recognize that a major challenge to implementing wildlife crossings stems from NCDOT budget restraints. This is a large part of why NCDOT has focused on wildlife mitigation opportunistically, folding wildlife enhancements into already-funded projects. However, there are many road segments that are extremely high priority for wildlife, but in which no immediate construction projects will take place. In these instances, we believe a sustainable funding source must be developed to pay for such retrofits. The public places a high value on both highway safety and reducing wildlife mortality on our roadways, and so even in a tight fiscal environment, a concerted effort to secure steady funding for road crossing structures should be made a priority.

Figure 13. Evidence of wildlife use under the 15-501 underpass for the New Hope Creek corridor. While a pre-construction study was conducted to assess wildlife usage, no follow up study has yet been undertaken. However, this data would provide valuable information on project design to ensure wildlife mitigation is cost effective as well as most effective for local wildlife communities. Wildlands Network is proceeding with plans to monitor this particular bridge and several others like it in the Durham, NC area.

CONCLUSION

North Carolina can and should be a leader in mitigating wildlife-vehicle conflicts along the east coast of the USA. The state has 79,000 miles of opportunity to ensure that its transportation infrastructure is well-designed and connected, safe for its citizens, and allows for coexistence with our natural heritage. The problems faced by wildlife from roads today are widespread; however, in many cases we already know how to solve these problems. By implementing underpasses, overpasses, and other wildlife mitigation measures at priority locations such as the ones we have identified in this project, NCDOT can show their citizens that they care about saving lives – wild and human -- and money. As North Carolina continues to grow and develop, there is no better time to invest in these win-win solutions for its residents.

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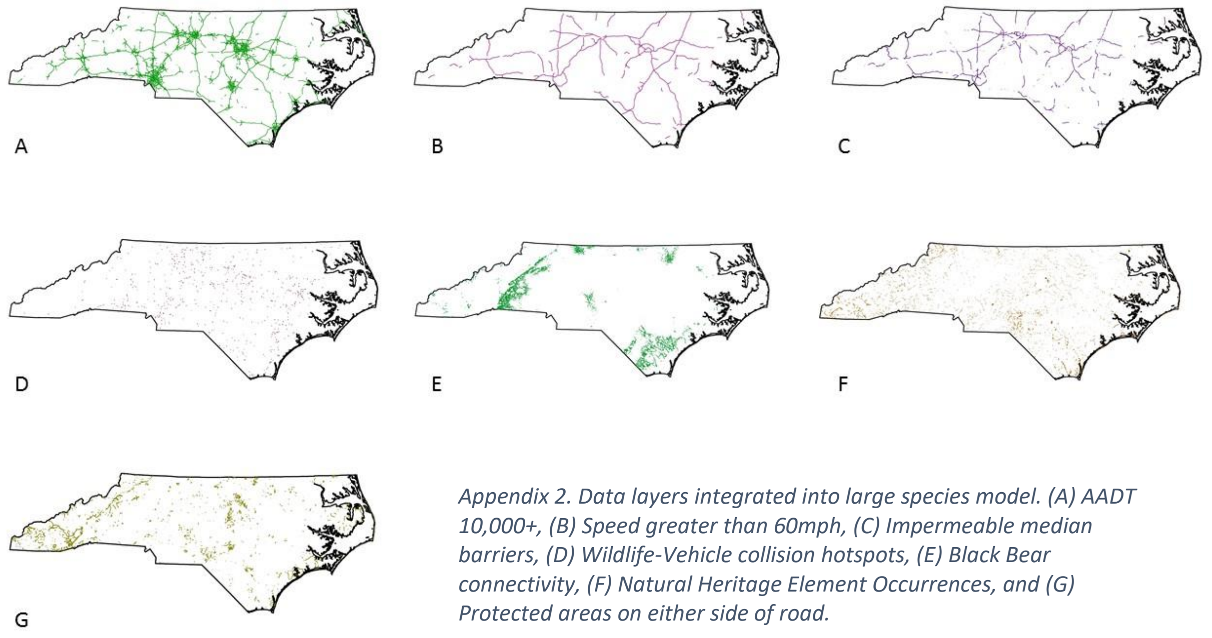
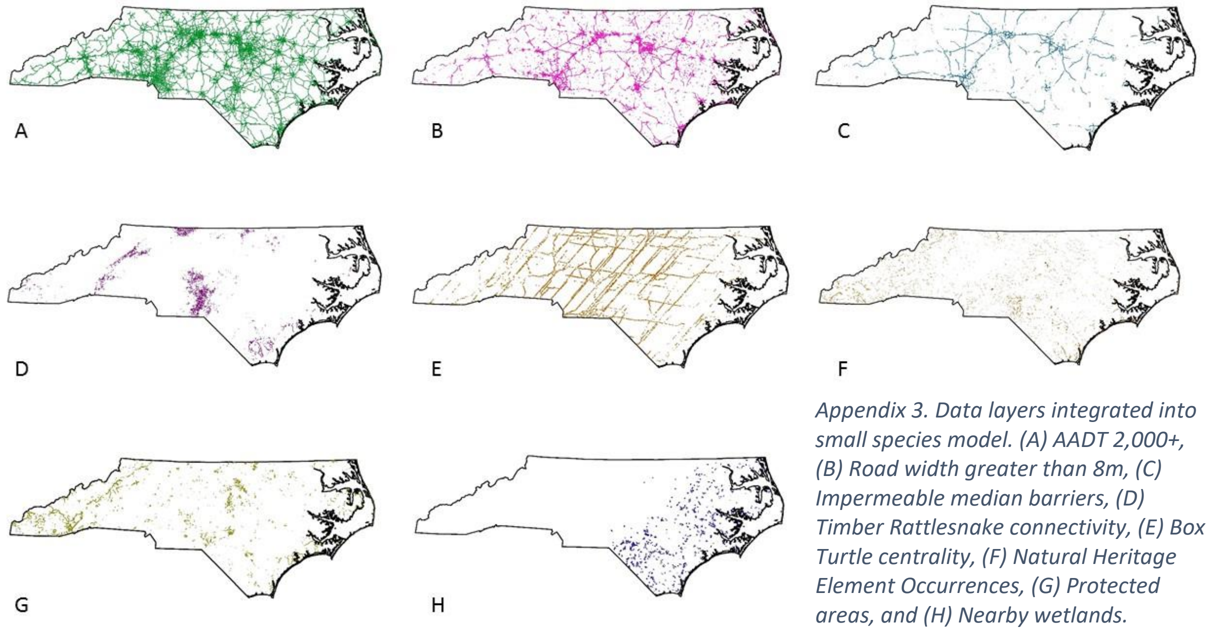
APPENDIX

Data Layer	*Data Source*	*Threshold*	*Threshold Source*
Traffic Volume	NCDOT road layer 2015	• 10,000 • 2,000	Dodd et al. 2011, Sutherland et al. 2010
Speed	NCDOT road layer 2015	• 60mph	Shilling et al. 2012
Road Width	NCDOT road layer 2015	• >8m	Andrews et al. 2015
Type of Median	NCDOT road layer 2015	• Jersey barriers, guardrails, and other positive barriers • Jersey barriers, guardrails, and other positive barriers, raised median with sloped edge, curb, and painted pavement	Expert Opinion
Wildlife-Vehicle collision hotspots	NCDOT WVC data 2015	• 5 or more deer-vehicle collisions per mile per year	Huijser et al. 2009, Donaldson 2005
Black Bear & Timber Rattlesnake connectivity models	Leonard et al. 2016, Sutherland et al. 2015	• Top 10% current density flow	N/A
Box Turtle centrality model	Sutherland et al. 2015	• Top 10% centrality	N/A
Natural Heritage Element Occurrences	NHP NHEO 2016	• Animal only and high accuracy	Spencer et al. 2010
Nearby wetlands	Homer et al. 2015	• Road segments with 70%, 50%, or 30% wetlands (Coastal Plain, Piedmont, and Southern Blue Ridge, respectively)	Andrews et al. 2015, Garrah et al. 2015
Proximity to protected areas	USGS PAD-US 2016, NCED 2015, TNC 2015	• Protected areas on both sides of road	T. Wilson, personal communications, 2015

Appendix 1. Data layers and corresponding thresholds used in prioritization models.



Appendix 2. Data layers integrated into large species model. (A) AADT 10,000+, (B) Speed greater than 60mph, (C) Impermeable median barriers, (D) Wildlife-Vehicle collision hotspots, (E) Black Bear connectivity, (F) Natural Heritage Element Occurrences, and (G) Protected areas on either side of road.



Appendix 3. Data layers integrated into small species model. (A) AADT 2,000+, (B) Road width greater than 8m, (C) Impermeable median barriers, (D) Timber Rattlesnake connectivity, (E) Box Turtle centrality, (F) Natural Heritage Element Occurrences, (G) Protected areas, and (H) Nearby wetlands.

For data email maggie@wildlandsnetwork.org