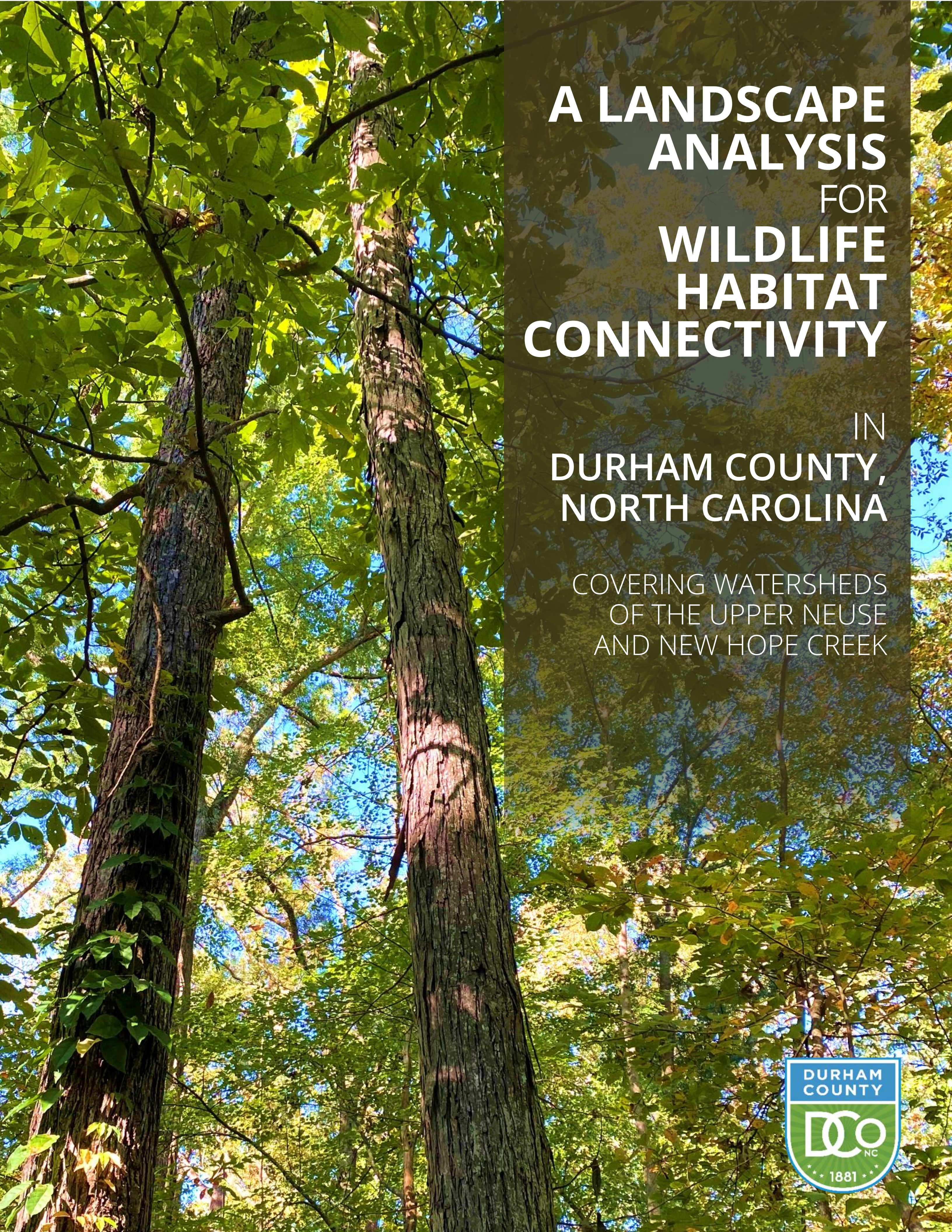

A LANDSCAPE ANALYSIS FOR WILDLIFE HABITAT CONNECTIVITY

IN DURHAM COUNTY, NORTH CAROLINA

COVERING WATERSHEDS OF THE UPPER NEUSE AND NEW HOPE CREEK

DURHAM COUNTY
DCO NC
1881

A Durham County Open Space Program project funded by the Burt's Bees Foundation

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February 2023

Front and back cover photo credits: Celeste Burns

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ACKNOWLEDGEMENTS

We gratefully acknowledge:

The Burt's Bees Foundation for their generous funding of this project.

John Fay of Duke University for sharing his expertise and tools for landscape connectivity analysis.

Members of the Durham Landscape Analysis Advisory Committee for sharing their time, expertise, insight, and advice on this project:

Jane Korest	**Project Administrator**; Durham County Open Space Program
Celeste Burns	**Project Administrator**; Durham County Open Space Program
Misty Buchanan	North Carolina Natural Heritage Program
Sara Childs	Office of the Duke Forest, Duke University
Jennifer Costanza	Southern Research Station, US Forest Service
John Fay	Nicholas School of the Environment, Duke University
Bo Howes	Triangle Land Conservancy
Kim Livingston	Eno River Association
Brooke Massa	North Carolina Wildlife Resources Commission
Ron Sutherland	Wildlands Network
Rickie White	Ellerbe Creek Watershed Association

The agencies, organizations, and individuals who shared critical data inputs to this project, including:

The Durham County Open Space Program, City of Durham GIS Services; the North Carolina Natural Heritage Program; NatureServe; the North Carolina Wildlife Resources Commission; Stephen Hall and the North Carolina Biodiversity Project; Jim Smith (The Nature Conservancy project lead for LANDFIRE) and Inga La Puma (KBR technical lead for LANDFIRE); North Carolina State Parks; Camp Butner National Guard Training Center; Person County GIS Department; Granville County Addressing & GIS Department; Duke Forest Teaching and Research Laboratory; Triangle Land Conservancy; Wildlands Network; HerpMapper; the Box Turtle Connection project; Piedmont Wildlife Center and the Turtle Trekkers project; Duke University (former) graduate students Julia Geschke and Kendra Sultzer; Eno-New Hope Landscape Conservation Group members Deborah Fowler, Bo Howes, Brooke Massa, Olivia Munzer, Milo Pyne, Bradley Saul, Pete Schubert, and Allison Weakley; community members Suzanne Cadwell, Barbara Driscoll, Tom Driscoll, Phil May, and Barbara Stenross; iNaturalist contributors; and the Counties, Towns, North Carolina state agencies, and Federal agencies who share their open GIS data online.

Because this project and the report build on the previous Eno-New Hope Landscape Conservation Project, we also gratefully acknowledge:

The co-authors of the Eno-New Hope landscape conservation report and plan (Tuttle et al. 2019), including Julie Tuttle, Brooke Massa, Olivia Munzer, Rich Shaw, Sara Childs, and Johnny Randall, and other members of the Eno-New Hope Landscape Conservation Group.

Michelle Benham for generous donation of her expertise and time in the design and creation of promotional materials for the Eno-New Hope Project, some of which have been reused in this report.

Blake Tedder from the Office of the Duke Forest at Duke University for assistance with formatting of the 2019 Eno-New Hope report, which has been adapted for this report.

INTRODUCTION

THE IMPORTANCE OF LANDSCAPE CONNECTIVITY

We understand the critical importance of access – for our communities, our families, and ourselves – to basic resources, diverse and resilient livelihoods and communities, and healthy (and health-giving) environments. We strive to suitably locate and connect our human landscapes to provide this access to all. Similarly, wildlife communities living in the natural landscapes around us rely on a mosaic of diverse, healthy, and connected natural *habitats* to survive, thrive, and persist.

Movement of animal species within and between priority habitats is necessary for their survival. With increasing habitat loss and *fragmentation* from development and roads, along with other threats related to environmental change, wildlife species need an intact, connected network of *suitable habitats*, *movement corridors,* and *wildlife crossings* that maintain ecosystem functions and processes (Rudnick et al. 2012). Without suitable habitats and a connected natural landscape, wildlife populations and *natural communities* decline and cannot persist (Crooks and Sanjayan 2006).

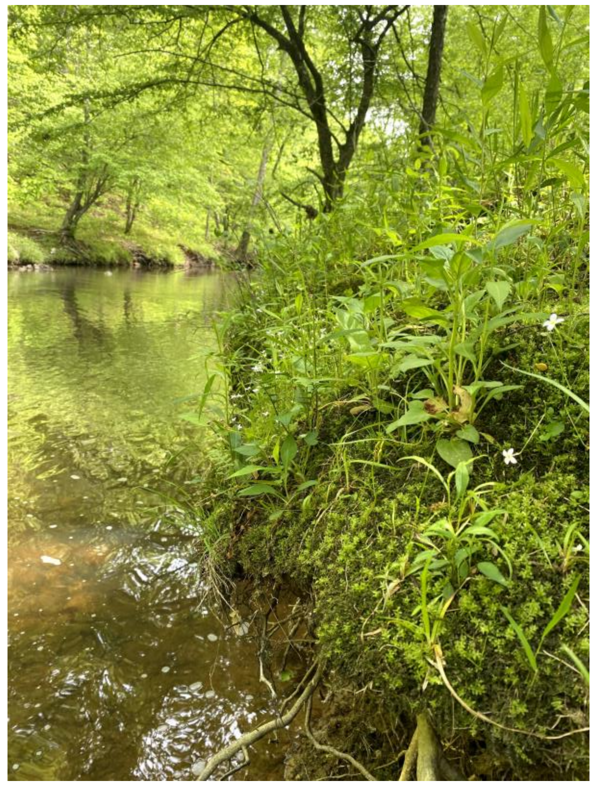


Figure 1. *Riparian forested habitat along the Little River in Little River Regional Park, Durham County, NC. Photo credit Celeste Burns.*

We depend on these *ecosystems*, too – conserving and connecting wildlife habitats (such as in Figure 1) not only benefits wildlife populations but also supports native plants and pollinators, helps maintain clean water and air, reduces hazards such as flooding and urban heating, supports public health and recreation, and helps drive our local economy (through, for example, working farms and forests) (Mitchell et al. 2013, NRCS 2004).

KEEPING THE NATURAL LANDSCAPE CONNECTED

Extensive biological inventory and conservation planning have fueled decades of successful land, water, and biodiversity conservation in Durham and surrounding counties. Increasingly, this work has been informed by the *landscape conservation* approach, focused on preserving the *ecological integrity* of our remaining natural landscapes by keeping them functionally connected for wildlife, natural communities, and ecosystem processes. This approach recognizes that a connected landscape includes a mosaic of high-quality, natural and semi-natural habitat areas, connected by movement corridors that may also include working farms and forests, public and private open space, and – crucially – road crossing structures (wildlife crossings) that enable safe wildlife passage within and between habitat areas. In the North Carolina Piedmont, the landscape mosaic includes habitats in riparian corridors, floodplains, and upland areas that connect ecosystems within and between watersheds.

As part of its mission, the Durham County Open Space Program focuses on the protection of key open space properties. Since the early 1990s with the development and adoption of the New Hope Corridor Open Space Master Plan (Coulter Associates and New Hope Corridor Advisory Committee 1991), protection has focused on habitats and properties that connect them. In developing the New Hope Corridor Open Space plan more than 30 years ago, the advisory committee was charged with "…creating an open space corridor linking the Eno River State Park, the New Hope Creek, Corps Lands, and the growing communities of Durham and Chapel Hill…"

Subsequent open space plans, coordinated by Durham's Planning Department, also include a prioritization of habitat and wildlife corridors. These plans are implemented by Durham's Open Space Program, housed in the Open Space and Real Estate Division of the Durham County Engineering and Environmental Services Department. The Open Space Program uses the open space plans, along with current data from the North Carolina Natural Heritage Program (NCNHP), regional water quality parcel analyses (City of Raleigh, City of Durham), other community and conservation metrics, and data provided by projects such as this one to guide prioritization of protection projects.

In Durham and surrounding areas, local governments, land trusts, state and national agencies, and educational institutions have invested countless hours and financial commitment to protect important wildlife habitat areas, including many natural areas prioritized by NCNHP (2022a, b) and the North Carolina Wildlife Resources Commission (NCWRC 2015, 2020). These natural areas also serve as open space, parks, and green refuges that are valued and beloved by communities in this rapidly developing region, but their long-term sustainability and resilience depend on their connectedness with each other and with habitats in surrounding regions. As Durham and the surrounding communities continue to grow and develop, these wildlife habitats and the connections between them will not be maintained without intentional efforts to identify them and ensure their protection.

Mapping a connected landscape for Durham County

Landscape connectivity analysis aims to identify wildlife habitat areas, how they are connected for wildlife movement, and landscape-level priorities for conserving, managing, or restoring a functional *habitat-corridor network* that will help ensure long-term persistence of biodiversity, ecosystems, and the beneficial services they provide. Results of the analysis can help answer key questions (Table 1) and inform efforts to maintain and improve landscape habitat connectivity.

Table 1. Some key questions informed by landscape connectivity analysis.
Where are the important habitat areas and potential movement corridors in this landscape?
Which habitat-corridor pathways are most important for maintaining a connected landscape?
Where is landscape resilience supported by alternative movement pathways?
Which pathways are vulnerable because of, for example, connectivity pinch-points or potential gaps in connectivity?
Which habitat areas are isolated from other parts of the landscape?
Where might restoration support increased wildlife movement and landscape connectivity?

To identify a prioritized habitat-corridor network for the Eno River and Jordan Lake-New Hope watersheds, a landscape connectivity analysis was conducted as part of the 2019 Eno-New Hope Landscape Conservation Plan (Tuttle et al. 2019), which was developed with funding from NCWRC's Green Growth Program and Orange County. Seventeen organizations, including the Durham County Open Space Program, came together over concerns about the pace of development and habitat fragmentation affecting these watersheds and developed the plan to help inform conservation priorities, land use decision-making, and transportation infrastructure siting and improvements. This collaboration was also intended to foster coordination on shared landscape conservation goals that require planning based on ecological systems rather than jurisdictional boundaries.

However, the Eno River and Jordan Lake-New Hope watersheds cover only portions of western and southwestern Durham County (Figure 2). As a result, the Durham County Open Space Program obtained funding from the Burt's Bees Foundation to identify priority wildlife habitats and connections between them for the entirety of Durham County. The Durham Landscape Connectivity Analysis updates and expands the Eno-New Hope analysis to include additional portions of the Upper Neuse watershed and provides habitat connectivity data that encompass all of Durham County. The objective of the analysis is to identify and map priority wildlife habitat and corridors connecting a network of natural communities and species populations, within and between the Upper Neuse and New Hope watersheds.

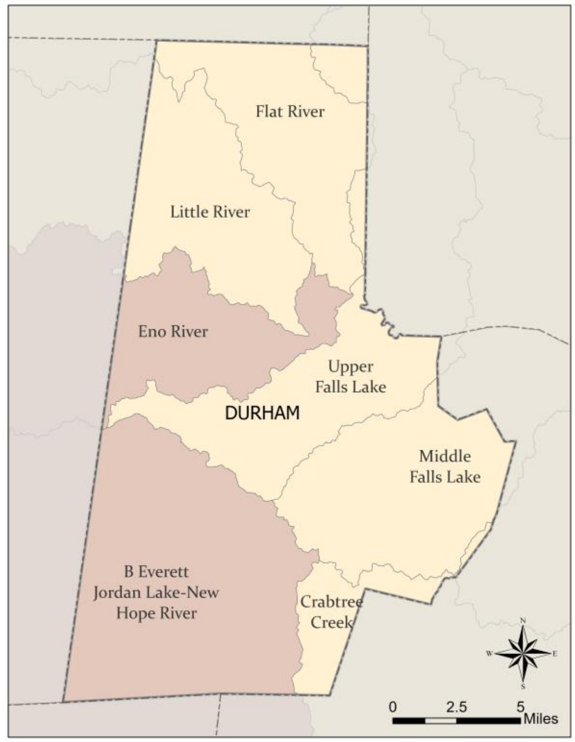


Figure 2. *Durham County watersheds.*

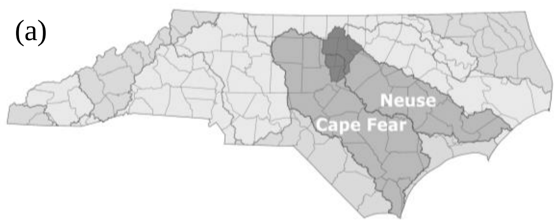
The analysis focuses on the habitat and movement needs of development-sensitive terrestrial wildlife species known to occur in the project area (such as the Eastern Box Turtle, Figure 3), identified from NCNHP data (Ratcliffe 2020) and the North Carolina Wildlife Action Plan (NCWRC 2015, 2020). The analysis brings together principles from landscape ecology, scientific knowledge of species' biology and ecology, data on landscape conditions in our area, and current GIS-based connectivity modeling techniques to inform the analysis. An advisory committee of local ecological experts and conservation stakeholders supported completion of the project through regular consultation.

Figure 3. *Eastern Box Turtle (Terrapene carolina). Photo credit NCWRC.*

The resulting connectivity dataset, when combined with other natural resource data, will assist with planning and prioritizing land, water quality, and habitat protection efforts in Durham County. The results of the analysis are specific to Durham County and can assist with County-wide land use planning and environmental policy development, particularly for the Durham Comprehensive Plan (https://www.durhamnc.gov/346/Comprehensive-Plan) and subsequent ordinances. Moreover, sharing results of the project with the community will help increase understanding of the importance and relevance of Durham County's conservation areas, wildlife habitats, and their connections across the landscape. Because the project area includes the Upper Neuse and Jordan Lake-New Hope watersheds, the results provide an updated dataset for the Eno-New Hope Landscape Conservation Plan (Tuttle et al. 2019) as well as data that may be useful for portions of surrounding counties within the Upper Neuse watersheds.

THE UPPER NEUSE AND NEW HOPE WATERSHEDS

Durham County is in the Eastern Piedmont of North Carolina within the Neuse and Cape Fear River basins (Figure 4a). The County spans the northeast portion of the Jordan Lake-New Hope River ("New Hope") watershed, along with portions of the Upper Neuse watersheds (including Eno River, Little River, Flat River, Upper and Middle Falls Lake, and Crabtree Creek) (Figures 2 and 4b). These watersheds also cover portions of neighboring Chatham, Granville, Orange, Person, and Wake counties.



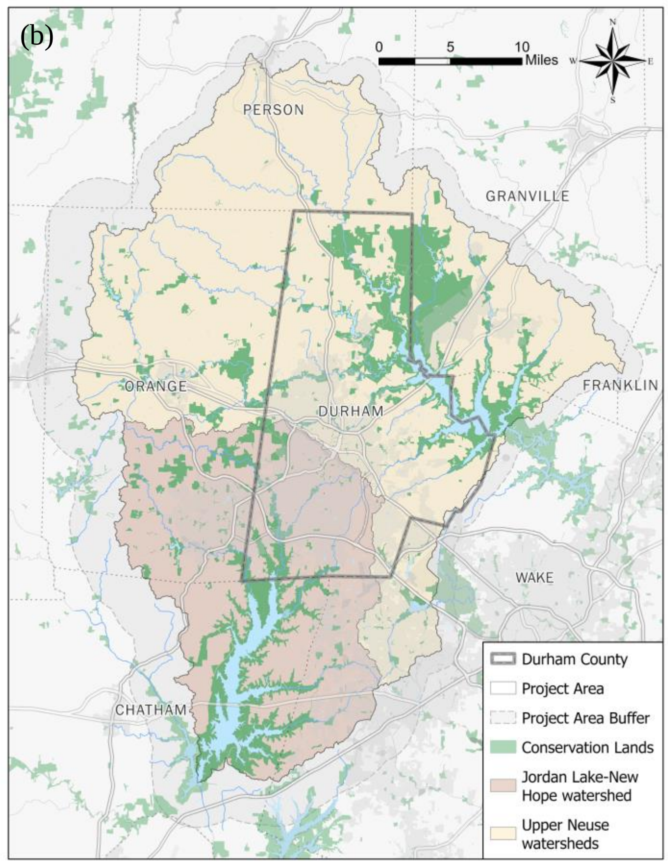


Figure 4. *(a) The project area (darkest gray) within the Neuse and Cape Fear River basins of North Carolina. (b) Project area watersheds with existing conservation lands[1] (NCNHP 2023).*

The Upper Neuse and New Hope watersheds ("the Project Area") are home to ecologically significant forests, wetlands, and other habitats that support a rich diversity of plant and animal species, natural communities, and wildlife habitats. In these watersheds, the NCNHP has identified 114 Natural Heritage Natural Areas (NHNA), 38 of which are in Durham County (NCNHP 2022a). NHNAs are terrestrial or aquatic sites "of special biodiversity significance…due to the presence of rare species, exemplary natural communities, or important animal assemblages" (NCNHP 2020).

Thirty-eight natural community types recognized by NCNHP occur in the project area, 30 of which occur in Durham County (NCNHP 2022b). Natural communities are defined as "distinct and recurring assemblage[s] of populations of plants, animals, bacteria, and fungi naturally associated with each other and their physical environment" (Schafale 2012). Natural communities in Durham County and throughout the project area span upland, riparian, and wetland communities, including but not limited to several types of oak-hickory forest, upland depression swamps, diabase glades, hardpan forests, bottomland hardwood forests, rich mesic slopes, heath bluffs, mesic mixed hardwood forests, numerous riparian forest variants, and more (NCNHP 2022b , Schafale 2012, Schafale and Weakley 1990). These natural communities provide habitat for a number of rare plant and animal species (both terrestrial and aquatic) and support a rich fauna of birds,

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[1] Conservation lands as used in this report refer to NCNHP Managed Areas (2023) designated as having some level of permanent protection from conversion of natural land cover for most or all of the property (see NCNHP's help document for more information, available from https://ncnhde.natureserve.org/help).

mammals, amphibians, reptiles, and many other wildlife taxonomic groups (North Carolina Biodiversity Project, NCBP 2022).

Local, state, and national agencies, land trusts, universities, and private landowners (such as Durham and surrounding counties, Eno River State Park, Eno River Association, Triangle Land Conservancy, North Carolina Plant Conservation Program, Duke University, North Carolina Botanical Garden Foundation, UNC Chapel Hill, US Army Corps of Engineers, and others) hold thousands of acres of wildlands and natural open space in the project area (Figure 4b). Since the Durham County Open Space Program was formally created in 2003, the County has preserved over 3600 acres of permanent conservation lands for habitat protection, water quality protection, working lands, and recreation (Figure 5).

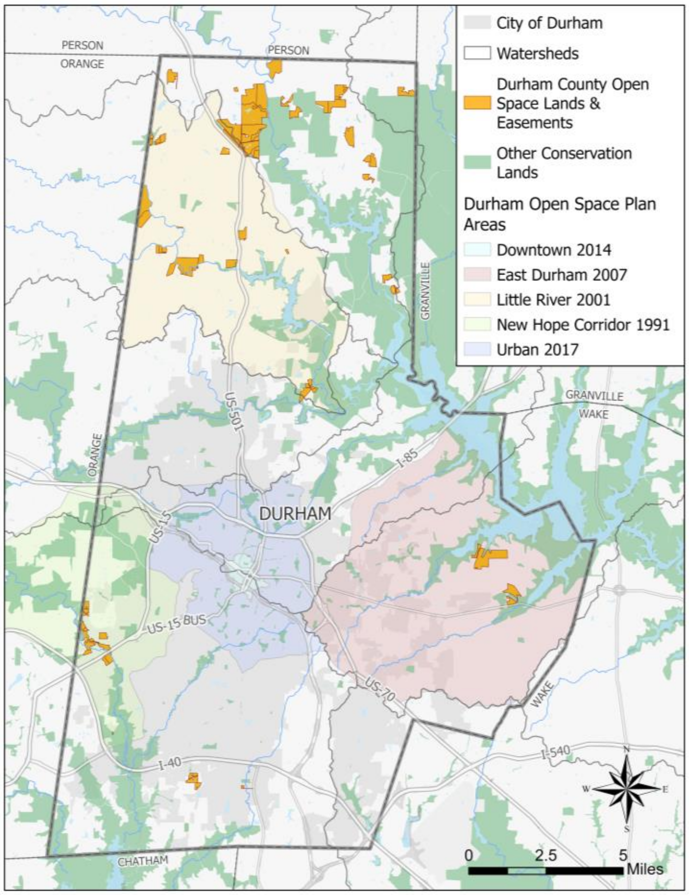


Figure 5. *Durham County Open Space lands, easements, and planning areas.*

More detail on the significant biodiversity, natural and environmental features, and history of the project area may be found in NCNHP's natural area inventories for Durham and adjacent counties, ongoing data collected and managed by NCNHP (https://www.ncnhp.org/data), the NC Wildlife Action Plan (NCWRC 2015, 2020), the Durham County Open Space Plans, and assessments for specific sites, adjacent jurisdictions, or the region.

BACKGROUND

WHY WE NEED LANDSCAPE HABITAT CONNECTIVITY

Movement of wildlife within and between habitats is essential for the short-term and long-term survival of individuals, species, and populations. Animals need to move across the landscape to find food, shelter, water, and mates, as well as to maintain genetic diversity and adapt to climate change (Cosgrove et al. 2018). However, as human population density increases, the natural contiguous landscape is fragmented by development into smaller, isolated patches or "islands" of natural habitat (Hilty et al. 2006) (Figure 6). Roads and development can make wildlife travel difficult or impossible (National Research Council 2005), while semi-natural landscapes such as working farms and forests are more conducive to movement by some species (NCWRC 2017). In North Carolina, as elsewhere, habitat loss and fragmentation are caused by changing human land uses from natural and semi-natural to developed land uses.

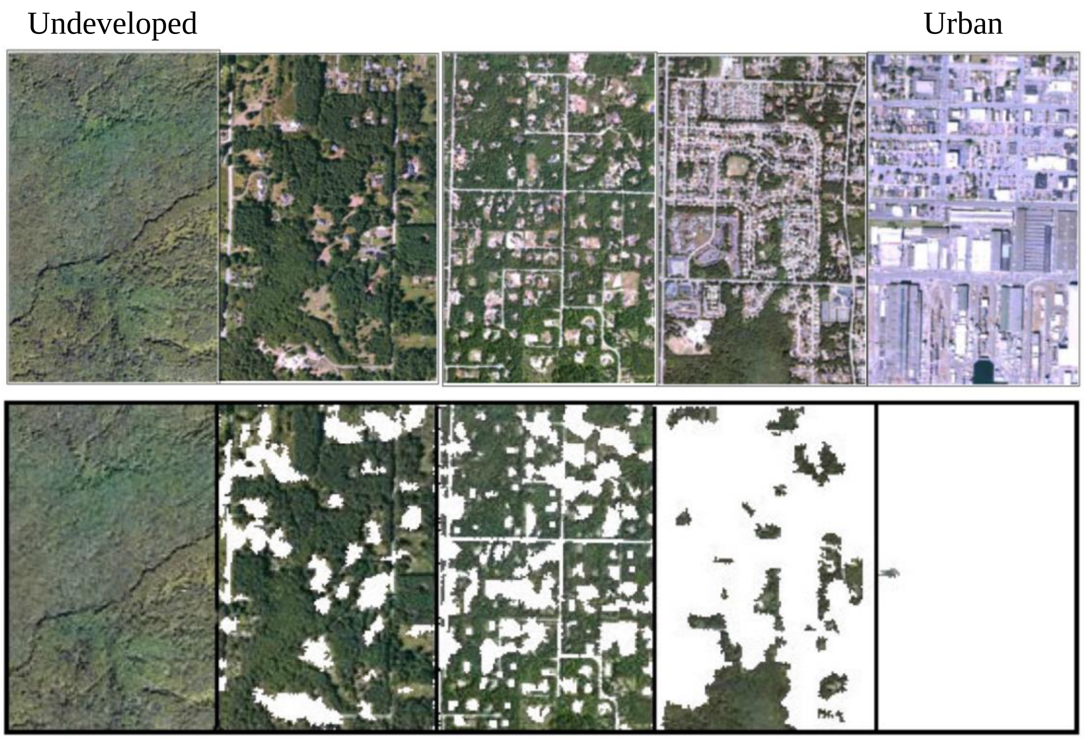


Figure 6. *Reproduced from Washington Department of Fish and Wildlife (2009): "An aerial depiction of the undeveloped to urban gradient...The bottom panel highlights how forest habitat (shown here in green) decreases, and how forest patches become smaller and more dispersed as development intensity increases."*

In addition to direct loss of wildlife populations from conversion of habitat to human land uses, development actions such as land clearing, development, and road-building (along with resulting increases in traffic volume) can be understood as stressors that negatively affect development-sensitive wildlife populations, overall biodiversity, and ecosystems (Washington Department of Fish and Wildlife 2009) (Figure 7). For example, along New Hope Creek in Durham County, habitat fragmentation caused by US Highway 15-501 creates an artificial edge to the forest that alters or halts the movement behavior of wildlife species that are wary of open or developed areas. This *habitat edge* also contributes to habitat degradation and increased threats to wildlife (such as predation by other species) through changes in natural community composition and structure, as the road carries edge-dependent (often non-native and/or invasive) plant and animal species into the bottomland hardwood forests in the floodplain.

In addition to these and other *edge effects* of habitat fragmentation (Hilty et al. 2006, 2019), US Highway 15-501 is a direct cause of mortality for wildlife that try to cross, and the road creates a behavioral or physical barrier for less mobile animals that will not cross a paved road or cannot cross a road with curbs or other structures (National Research Council 2005). Over time, loss and isolation of habitat, blocked animal movements, and increased mortality contribute to decline of wildlife populations (Haddad et al. 2015).

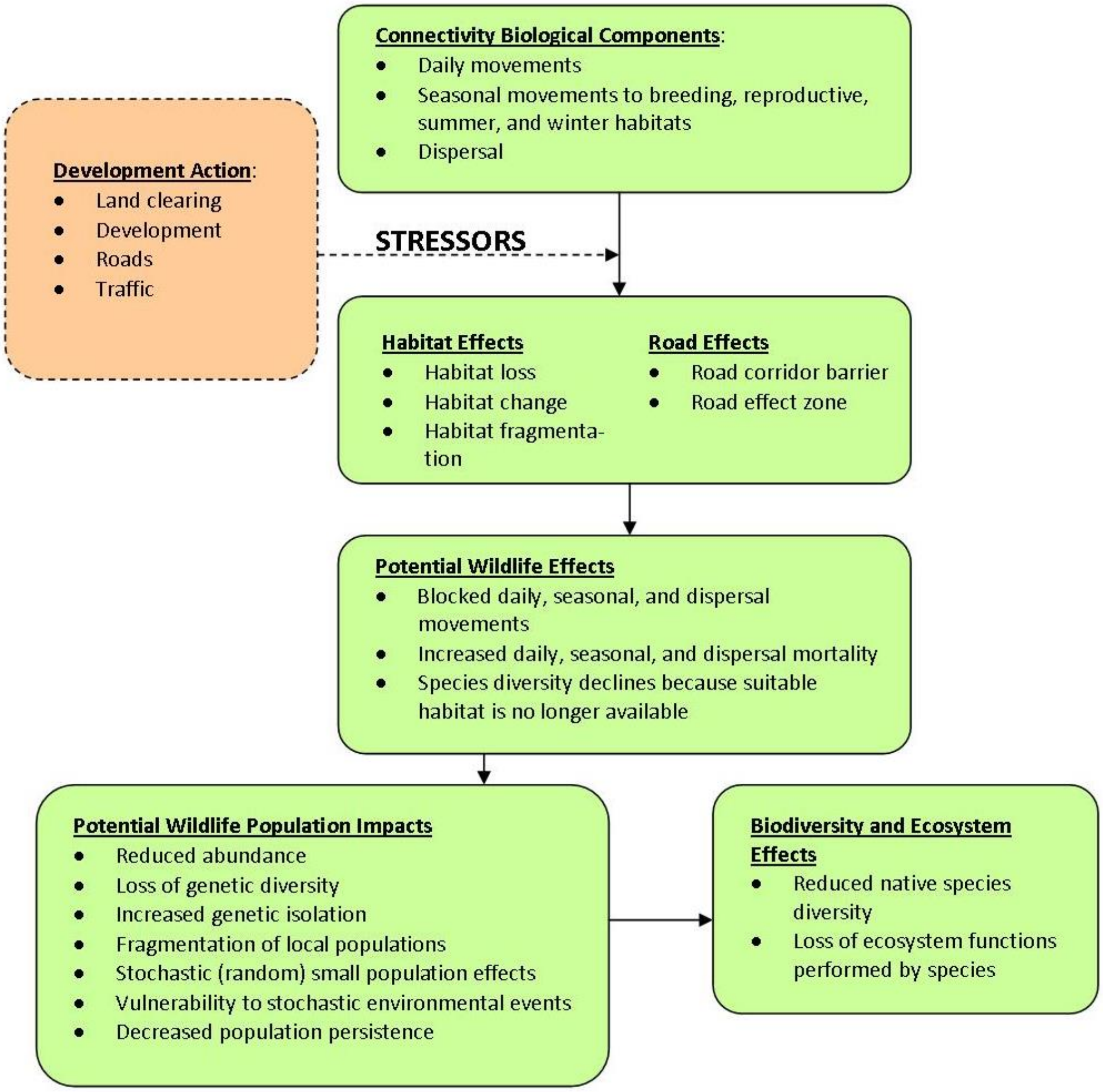


Figure 7. *Reproduced from Washington Department of Fish and Wildlife (2009): "Potential impacts to wildlife from loss of connectivity in developed landscapes. Includes impacts of the 'road effect zone,' or area of impact extending beyond the roadway and including traffic noise and lights."*

Ultimately, local wildlife populations and species diversity are not sustainable in a landscape with isolated patches of habitat (Crooks and Sanjayan 2006, Haddad et al. 2015). Interconnected networks of habitat are necessary for maintaining wildlife populations, natural communities, genetic and species diversity, and natural ecological processes (Bennett 1999, Cosgrove et al. 2018). Maintaining connectivity of natural communities and ecosystem processes also benefits humans by maintaining beneficial *ecosystem services*, such as clean water and air, native plant and pollinator diversity, carbon sequestration and climate regulation, benefits to our local economy (through working farms and forests, recreation, and tourism), benefits to public health, and more (Millennium Ecosystem Assessment 2005, Mitchell et al. 2013, NRCS 2004).

In fragmented landscapes, habitat connectivity can be achieved through naturally occurring or created habitat *corridors* (Gilbert-Norton et al. 2010), defined as "patch[es] of habitat (often linear) that link two or more other natural habitat patches, providing habitat for animals as they disperse or migrate" (NCWRC 2012) (see Appendix B: Glossary for more detailed definition). Corridors must include crossing structures that enable wildlife to cross barriers such as roads, reducing wildlife collisions with vehicles (Bennett 1999). Corridors allow wildlife populations to move to meet daily and seasonal resource needs, to interbreed with other populations, and to colonize new or former habitat areas (such as after recovery from disturbance or disease) by increasing the potential for dispersal from one habitat patch to another (Hilty et al. 2006, NRCS 2004). Maintaining habitat connectivity reduces the susceptibility of wildlife populations and species to decline and local extinction that can occur through, for example, the deleterious effects of increased predation, disease, and natural catastrophes when there are no avenues for escape or recovery through movement of individuals between populations and habitat areas (Rudnick et al. 2012).

Transportation Planning for Wildlife

Roads contribute to wildlife habitat fragmentation and often function as barriers to wildlife movement or sources of wildlife mortality from wildlife-vehicle collisions (WVC) (National Research Council 2005) (Figure 8). In the US, over one million vertebrates are killed each day due to WVC (Bissonette and Cramer 2008 *in* Ernest and Sutherland 2017). Human safety is also at issue, with nearly 60,000 animal-related vehicle crashes recorded in North Carolina from 2019 to 2021 (even with reduced traffic volume in 2020 due to the COVID-19 pandemic), causing 11 human fatalities, nearly 2700 injuries, and more than $173 million in damages (Cowhig 2022). Durham, Orange, Chatham, and Wake Counties ranked in approximately the top one-third of North Carolina counties for number of animal-related crashes during this period.

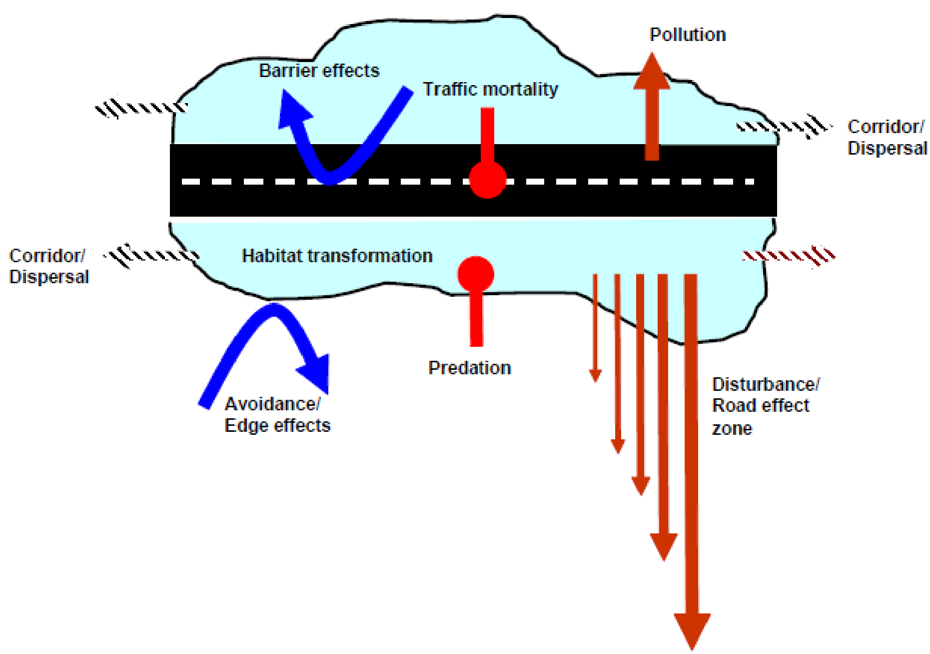


Figure 8. *Schematic showing the primary effects of roads on wildlife species and populations (reproduced from National Research Council 2005).*

Wildlife crossings, including underpasses, overpasses, and wildlife-friendly culverts, can facilitate wildlife movements and have been shown to reduce WVC (Clevenger et al. 2001 *in* Ernest and Sutherland 2017). Indeed, properly designed wildlife crossing structures installed or retrofitted at priority locations within the landscape are a necessary component of a landscape habitat-corridor network that functions to maintain wildlife populations. To determine where wildlife crossings should be prioritized and what type of crossing is most suitable for a given location, knowledge of WVC, species' biological requirements, and landscape corridor data are required (Huijser et al. 2008). Other road design elements such as guard rails, fencing, and vegetation barriers are also important considerations for designing successful wildlife crossings. As our understanding of wildlife movement behavior and wildlife use of crossing structures improves, detailed structural specifications and implementation guidelines for effective crossing structures are increasingly available for different wildlife taxonomic groups (such as mammals, turtles, or salamanders) (Clevenger and Huijser 2011).

North Carolina has nearly 80,000 miles of roads (Ernest and Sutherland 2017), and as of 2022, the NC Department of Transportation (NCDOT) had installed or modified approximately 13 crossings for wildlife statewide (NCDOT 2022). The improved US 15-501 bridge over New Hope Creek (Figure 9), installed in 2007, is an example of a transportation improvement project in the project area that included modification of the bridge height and length to improve its use as a wildlife underpass. Analyses from camera trap data show that the new bridge has increased safe passage under the highway for a variety of wildlife species (Ron Sutherland, Wildlands Network, pers. comm.).

Figure 9. *The improved US 15-501 bridge over New Hope Creek in Durham County, NC. Photo credit Ron Sutherland, Wildlands Network.*

In 2017, Ernest and Sutherland produced a statewide map of roads that are high-priority candidates for wildlife crossing structures to mitigate WVC, based on data from NCDOT on traffic volume, WVC, and road structural characteristics. More recently, with increased federal funding available to support wildlife crossing infrastructure and improvements, Sutherland et al. (2022) identified the highest priority crossing sites for North Carolina, including 5 sites in the project area. Their data, in combination with the results of this project and other conservation data layers, provide an opportunity for NCDOT and local governments to integrate wildlife crossing structures into transportation improvement projects at selected locations where they will be most effective for reducing WVC, promoting landscape connectivity, and helping to maintain healthy, diverse ecosystems.

THE DURHAM LANDSCAPE CONNECTIVITY ANALYSIS

APPROACH AND TOOLS

This project builds on the previous Eno-New Hope Landscape Conservation Project, which generally followed the steps outlined in NatureServe's Landscope America guide, "Connecting Landscapes: A Practitioner's Resource for Assessing and Planning for Habitat Connectivity" (Figure 10) (NatureServe/Landscope America 2019). Following the approach used in the Eno-New Hope project, this project used a spatially explicit, GIS-based approach to map habitat areas, identify corridors, and analyze connectivity in the project area. Within this broad approach, a variety of methods and tools exist to accommodate different objectives and scales of analysis (see examples at Conservation Corridor: Programs and Tools, https://conservationcorridor.org/corridor-toolbox/programs-and-tools/).

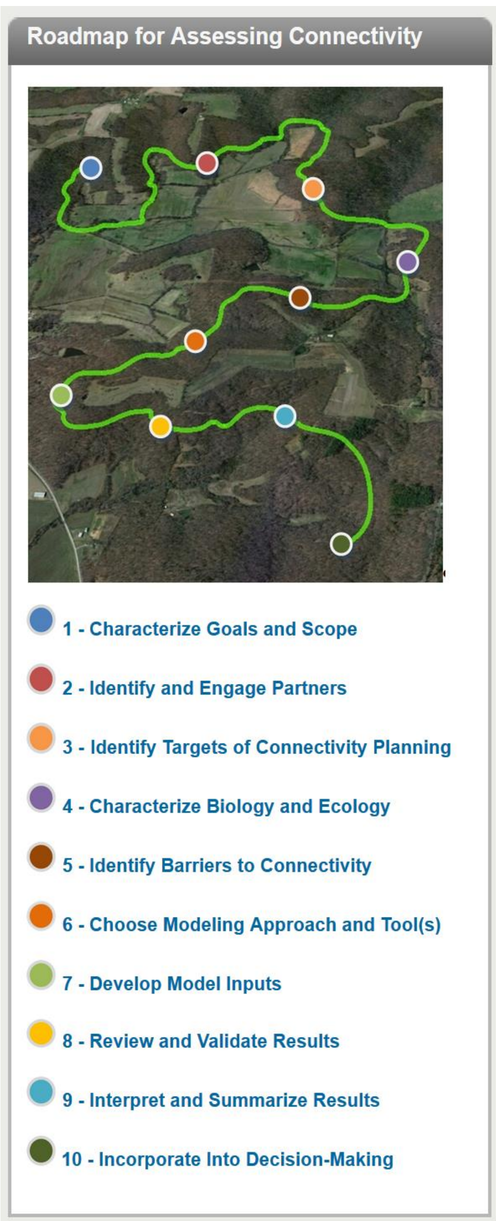
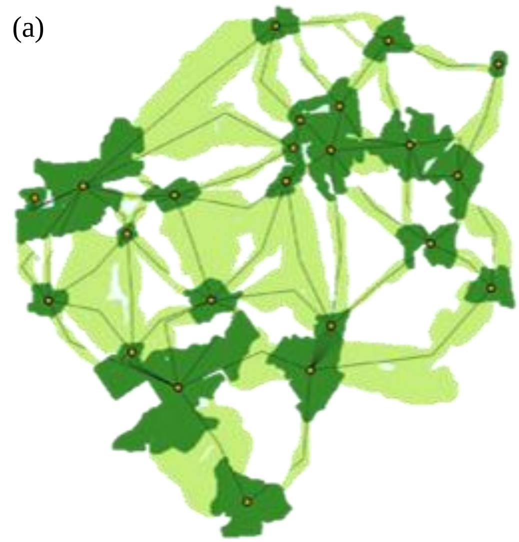


Figure 10. *An outline of the Landscope America Roadmap for Assessing Connectivity (Reproduced from NatureServe/ Landscope America 2019).*

Based on the scale of the project area, the project objective, and the need for compatibility with other planning tools, the project used resistance-surface-based connectivity modeling (Wade et al. 2015) to identify a *habitat-corridor network* across the project area, defined as a connected set of discrete wildlife *habitat patches* and *least cost corridors* between them (Figure 11a). Least cost corridor mapping (Etherington 2016, Wade et al. 2015) uses knowledge of species' habitat needs and movement behaviors to map pathways of different relative *movement cost* for a species across a given landscape, using a *cost surface* (or resistance surface) that excludes *movement barriers*. Rather than using a single *least cost path*, a cost threshold is used to identify the areas of lowest movement cost (least cost corridors) connecting pairs of discrete habitat areas (Wade et al. 2015) (Figure 11b).

Least cost corridors are intended to represent areas that, over time, are most hospitable or conducive to successful movement of a species between habitat areas. For example, a Spotted Salamander living in a moist forest habitat may typically stay within several hundred meters of its breeding pond; however, its offspring may disperse several kilometers across the landscape to find mates and new breeding ponds (NatureServe 2019c). For this *dispersal* to be successful, an individual salamander must choose a movement path that is safe (from predation by other species) and has environmental conditions it can tolerate (sufficient moisture, sufficient food and shelter for the journey, or a relatively short journey between habitat patches). The salamander may actively avoid moving into or across areas that it perceives as threatening (roads with traffic) or inhospitable (open fields or dry, sunny conditions), and will be unable to move across areas that it cannot physically traverse (a barrier across or alongside a road, or a built-up area). A particular least cost corridor will preferentially include any areas similar to the salamander's habitat (whether small or large) and will exclude movement barriers and minimize expanses of threatening or inhospitable habitat. Over time, a connected landscape of habitat patches and functional least cost corridors can promote successful movement of individuals between a network of populations (a *metapopulation*) (Gilbert-Norton et al. 2010), which ultimately supports long-term persistence, health, and *resilience* of species and ecosystems.



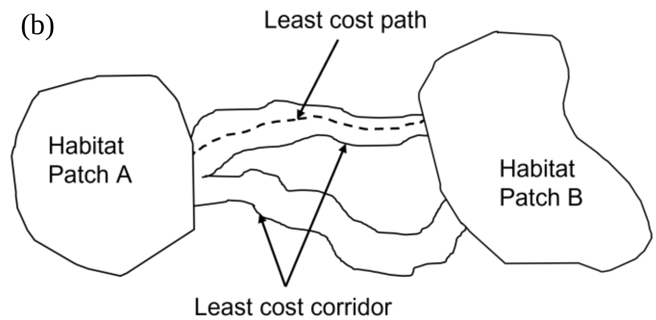


Figure 11. *(a) Depiction of a habitat-corridor network with habitat patches in dark green and corridors in light green (reproduced from Rudnick et al. 2012). (b) Two habitat patches connected by areas of lowest movement cost for a given species across a cost (or resistance) surface, defined by a threshold of maximum movement cost.*

To create the habitat-corridor network, Tuttle used ArcGIS 10.4 (ESRI 2015), ArcGIS Pro 2.9 (ESRI 2021), the GeoHAT Toolbox for ArcGIS (Geospatial Habitat Assessment Toolkit) (Fay 2012), the PatchConnect Toolbox for ArcGIS Pro (Fay 2021), customized ArcGIS models and Python scripts developed by Tuttle (unpublished), and NetworkX (software for network analysis using the Python programming language) (Hagberg et al. 2008). During the analysis process, the Advisory Committee reviewed and provided guidance on data inputs and intermediate results.

PRIORITY SPECIES AND HABITATS

The project focuses on connectivity for preservation of terrestrial wildlife species, natural communities, and existing conservation lands. Building on biodiversity and habitat assessments developed by NCWRC and NCNHP, the project focuses on priority species (and their habitats) identified in the North Carolina Wildlife Action Plan (NCWRC 2015, 2020) and in NCNHP's List of Rare Animal Species of North Carolina (Ratcliffe 2020). Hall's previous work on *Landscape/Habitat Indicator Guilds* (LHIG) (Hall 2008, 2009, 2018) helped focus the project on the function and movement of species groups (*indicator guilds*) within and between habitat types in a landscape network. In the LHIG framework, species are grouped into guilds by similar habitat needs and responses to habitat fragmentation and development. Because of their sensitivity to fragmentation, these indicator guilds can represent the conservation needs of many species that rely on these habitats or, put another way, that collectively represent these natural communities. Hall's work on LHIG for the Eastern Piedmont of North Carolina (Hall 2008, 2009, 2018) informed the definition of priority indicator guilds and their associated habitats for the project area.

To identify the priority species and indicator guilds known to occur in the project area, species lists and occurrence data were compiled from a number of sources (Table 2).

Table 2. *Species lists and occurrence data used to identify priority species and indicator guilds for the project area.*

Species list or dataset	***Date***
NCNHP's List of Rare Animal Species of North Carolina (Ratcliffe)	2020
NCWRC's List of Species of Greatest Conservation Need (SGCN), Taxa Team Evaluation Results, and Terrestrial Species Habitat Associations (appendices to the NC Wildlife Action Plan)	2020, 2015
NCNHP's Element Occurrence database	2021, 2022b
Hall's species guild database, compiled from various sources, including NCNHP county inventories and the NC State Parks Natural Resources Inventory Database (NRID)	2017
North Carolina Biodiversity Project (NCBP)	2022
HerpMapper	2021
Box Turtle Connection (NCWRC)	2021
Piedmont Wildlife Center (Turtle Trekkers project and fauna database)	2021, 2018
Camp Butner Training Center faunal survey (Jackson Group)	2019
Herpetofauna of the Duke Forest (Duke Forest Teaching and Research Laboratory)	2020
Julia Geschke and Kendra Sultzer (Duke University former graduate students)	2019, 2021
Eno-New Hope Group members: Deborah Fowler, Bo Howes, Brooke Massa, Olivia Munzer, Milo Pyne, Bradley Saul, Pete Schubert, and Allison Weakley	2017-2022
Community members: Suzanne Cadwell, Tom Driscoll, Barbara Driscoll, Phil May, and Barbara Stenross	2019-2021
Contributors to iNaturalist.org	2021

The NC Wildlife Action Plan (with its appendices) provides a list of *Species of Greatest Conservation Need* (SGCN)[2] and Knowledge Gap species known to occur in the Piedmont of NC and, where possible, relates species to Hall's guild habitats for the Eastern Piedmont region (NCWRC 2015, 2020). County-level occurrences for NCNHP's rare and watch list animal species are summarized by species in Ratcliffe (2020) and can be downloaded by county (https://www.ncnhp.org/data/species-community-search). For the Eno-New Hope project, the NCWRC and NCNHP species lists were combined, and inconsistent species taxonomy was corrected. This combined species list was updated for the expanded project area and used to filter all available georeferenced species occurrences (from the additional sources listed above) within the project area boundary, yielding a list of priority animal species known to occur in the project area. The final species list included only terrestrial species known to occur in the project area within the last 30 years and with year-round resident or breeding populations in the project area. Classification of species into habitat guilds followed the classification designated by Hall in his work on LHIG (Hall 2008, 2009, 2017) with some updates derived from Hall's ongoing work (NCBP 2022).

Eighty-nine priority terrestrial wildlife species in more than 25 habitat indicator guilds were identified for the project area (Appendix C). Based on the desire to identify specific habitat and corridor areas, the availability of spatial data for mapping habitat, and other methodological constraints, connectivity analysis and mapping included habitat types for three guilds. The three guild habitats broadly encompass wet-to-mesic and mesic (moist) hardwood forests, dry-to-wet hardwood and mixed hardwood-pine forests, and sparsely settled forested areas. Collectively, they include a total of 19 terrestrial wildlife indicator species, 14 of which are non-flying species that rely on ground-based habitat connectivity.

The three guild habitat types are often spatially nested on the landscape – for example, as floodplain or riparian forests (Figure 12a) that are surrounded and connected by adjacent upland forests (Figure 12b)

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[2] SGCN for North Carolina and the southeast region are included; regional SGCN are designated by the Southeast Association of Fish and Wildlife Agencies (SEAFWA) (NCWRC 2020).

and, in some areas, embedded in or adjacent to sparsely settled landscapes with a mix of natural and working forests. These three habitat types encompass most of the remaining natural habitats in the project area as well as some managed forests that can support native wildlife populations. Many localized habitat types, such as wetlands (Figure 12c), are further nested within the three selected habitat types, supporting additional priority wildlife species (Appendix C). In addition, many priority aquatic communities and species identified by NCNHP and NCWRC are embedded within or associated with the three selected habitat types. As a result, conserving and maintaining connectivity for these habitats will support the persistence of many additional terrestrial and aquatic natural communities and wildlife species.

(a)

(b)

(c)

Figure 12. *(a) Riparian hardwood forest along the Little River in Durham County, NC. Photo credit Jane Korest. (b) Upland hardwood forest along the Eno River in Durham County. Photo credit Julie Tuttle. (c) Bottomland forested wetland along New Hope Creek in Durham County. Photo credit Celeste Burns.*

Biological and ecological information for guild species on the final list was compiled primarily from information in Biotics, NatureServe's web-enabled biodiversity information management system (which includes NC-specific data from NCNHP) (NatureServe 2019c, also publicly available online by species from NatureServe Explorer 2.0 at https://explorer.natureserve.org/); the NC Wildlife Action Plan (NCWRC 2015, 2020); and NCBP (2022). Where species-level information was not available, information was compiled for the Element Group (NatureServe 2019d) to which the species belongs. Each Element Group represents species that are related taxonomically, functionally, or by habitat and that have similar habitat needs and movement behaviors.

CONCEPTS, PARAMETERS, AND INPUTS

Resistance-surface-based connectivity modeling, a common approach to GIS-based connectivity analysis, involves conceptualizing the landscape as habitat, barriers to movement, and a cost surface (or resistance surface) intended to represent species' ability to move within and between habitat areas on the landscape. Types of habitat can be distinguished and assigned higher or lower movement costs, and the *cost distance* that species can move on the landscape can be specified, based on knowledge of species' habitat and movement needs, limitations, and behaviors. Potential corridors can be identified and overall landscape connectivity assessed from this mapping based on the quantity and arrangement of habitat types and barriers, and the ease, difficulty, or obstruction of movement over the cost surface.

Habitat. For this project, we used the concepts of suitable and unsuitable habitat as defined by NatureServe and the Natural Heritage Network (NatureServe 2019a, b). The landscape was divided into habitat suitable for occupancy (by individuals or populations; *suitable habitat*), habitat unsuitable for long-term occupancy but suitable for movement (*unsuitable habitat*[3]), and barriers to movement.

Suitable habitat was further divided into *habitat patches* – contiguous areas of suitable habitat above a size threshold – and smaller fragments of suitable habitat dispersed on the landscape. Habitat patch size thresholds for each guild (Table 3) were determined from information on home range size, daily and seasonal movement behaviors, and habitat characteristics for species or Element Groups as compiled in Biotics (NatureServe 2019c) and other sources. Where habitat patch size differed for species or Element Groups within guilds, the more limiting (larger) patch size was used.

To classify the landscape of the project area into suitable and unsuitable habitat, we used the Existing Vegetation Type layer (EVT) from the 2016 LANDFIRE vegetation classification as the base land cover layer (LANDFIRE 2016a). For the publicly released version of EVT (LANDFIRE 2016b), the LANDFIRE team applied a post-classification ruleset that reduced the level of useful information for this project. To address this issue, LANDFIRE generously provided the original modeled EVT layer for use in this project. The EVT layer was modified with several 2019 National Land Cover Database layers (NLCD; Dewitz and USGS 2021): NLCD Forest Disturbance Date was used to update EVT with areas of forest conversion between 2016 and 2019. Road location errors in LANDFIRE 2016 were corrected using the NLCD 2019 Developed Impervious Descriptor and NLCD 2019 Land Cover layers. In addition, the vegetation classification within several land parcels in Chapel Hill (the Greene Tract) was updated using vegetation types mapped in 2020 (SynTerra 2020).

Vegetation types representing suitable or unsuitable habitat for priority species in each guild were identified from information in reports by Hall (2008, 2009) and in Biotics (NatureServe 2019c) (Table 3). The modified EVT land cover classes (NatureServe 2017, 2018) were then matched to these vegetation types. This habitat "crosswalk" was calibrated and verified using Hall's previous mapping of guild habitat for the project area (from finer-resolution aerial photography than that used for the EVT 30 m x 30 m classification) along with the locations of guild species occurrences compiled for the project area.

The resulting habitat classification was refined and updated using overlays of floodplains from the NC Floodplain Mapping Program (NCFMP 2021), wetlands from the National Wetlands Inventory (NWI) (US Fish and Wildlife Service 2021), floodplain and riparian areas from The Nature Conservancy's

[3] In maps of the analysis results, unsuitable habitat is referred to as "non-habitat", indicating areas that are not barriers (usually with some type of vegetation) and not suitable habitat for the guild species.

Active River Area layer (ARA) (Smith et al. 2008, TNC 2015a), and riparian areas from the US Environmental Protection Agency's EnviroAtlas Hydrologically Connected Zones layer (HCZ) (USEPA 2016). For instance, in areas mapped as floodplain but incorrectly classified as an upland hardwood forest type (usually because of the relatively coarse scale of the EVT layer), the vegetation type was updated to floodplain hardwood forest.

Table 3. *Guild/species biological and ecological information related to habitat and connectivity needs, derived primarily from information in Biotics (NatureServe 2019c) with additional sources noted. Focal species are selected indicator species used to refine the priority habitat-corridor network (see Analysis and interpretation section).*

Guild name (habitat type)	Example taxonomic groups in guild	Focal species (species observation network)	Habitat and movement characteristics				Barriers to movement	Sensitivity to development and fragmentation	Primary stressors
			Patch size	*Habitat composition (focal species)*	Separation distance: *Unsuitable habitat*	Separation distance: *Suitable habitat*			
Wet-Mesic and Mesic Hardwood Forests	amphibians, (riparian breeding birds and odonates)	Four-toed Salamander	3 ha[a]	**breeding:** boggy streams, ephemeral wetlands, usually in floodplains or uplands near headwater streams **non-breeding:** mesic hardwood forests, mixed hardwood/pine near wetlands	1 km	3 km	Large streams, rivers, and lakes; roads; suburban and urban development	High sensitivity	Floodplain and wetland modification, human disturbances, water pollution, roads
		White-spotted Slimy Salamander	3 ha[a]	**breeding:** not specified **non-breeding:** mesic hardwood forests with leaf litter and cover objects such as fallen logs, often near water sources[b]	1 km	3 km			Habitat modification and loss, human disturbances, water pollution, roads
Dry-Wet Hardwood and Mixed Forests	reptiles, amphibians, (forest breeding birds)	Eastern Box Turtle	10 ha[c]	**breeding**: upland mixed hardwood/pine, successional (herb, shrub, and woody) **non-breeding**: bottomland hardwood, successional	1 km	3-5 km (minimum of 3 km used)	High-traffic-volume roads, large rivers, urban development	Moderate sensitivity	Roads, habitat loss
Sparsely Settled Mixed Habitats	generalist species of large and small mammals, reptiles, (birds)	Bobcat	60 ha[d]	**breeding:** upland and bottomland mixed hardwood/ pine, successional, with logs, fallen trees, or rock shelters for denning **non-breeding:** upland and bottomland mixed hardwood/pine, successional	50 km[e]	200 km[e]	None; avoidance of buildings and development	Moderate sensitivity	Roads, dense development, human disturbances

[a]Data in Biotics (NatureServe 2019c) indicate home range size of less than 1 ha; however, to avoid including spurious patches and to avoid excessive GIS computation time, the observed minimum patch size of approximately 5 ha (based on species observations in the project area) was used in the Eno-New Hope project. For this project, additional species observations and improved methods enabled a minimum patch size of 3 ha.
[b]From species information compiled by Beamer and Lannoo on AmphibiaWeb (2022).
[c]Revised from 20 ha used in the Eno-New Hope project. Additional species observations in the project area and improved methods enabled an updated minimum patch size of approximately 10 ha for this project.
[d]Derived from minimum Bobcat home range provided in FEIS (Abrahamson nd).
[e]Derived from Bobcat dispersal information in Biotics (NatureServe 2019c). Dispersal distances for Timber Rattlesnake are lower (7 and 1 km for suitable and unsuitable habitat, respectively), but species observation data currently support the presence of very few and widely separated Timber Rattlesnake populations in the project area.

Barriers. By definition, characteristics of barriers are similar for terrestrial species within the same guild. Information in Biotics indicates that developed areas, some roads, and some water bodies are the primary barriers to movement for the focal species and habitat guilds in this project (Table 3).

Developed areas were identified from developed land cover classes in the modified EVT layer (Dewitz and USGS 2021, LANDFIRE 2016a) and building footprint layers combined across the project area (Chatham County 2020, City of Raleigh 2021, Durham City-County 2020, Fuquay-Varina 2021, Granville County 2020 and 2021, Microsoft 2018, NCFMP 2012, Orange County 2020, OSM 2021, Person County 2020, Town of Cary 2013 and 2021, Wake County 2021). To update to more current conditions, aerial imagery was used to identify and digitize building footprints within the project area that were missing from the combined building footprints layer. The missing building footprints were created as open-source contributions to OpenStreetMap and then downloaded for use in the project (OSM 2021).

Areas of open water (large rivers, lakes, and ponds) were identified from the EVT and NWI layers. Several ponds and small lakes missing from the NWI layer were identified using the water bodies layer in the National Hydrography Dataset (NHD; USGS 2020). Streams and river areas that were not wide enough to be identified as open water in the EVT classification were not considered barriers.

To classify roads as either barriers or non-barriers, the scientific literature (as compiled in Ernest & Sutherland 2017) provides details on traffic volume, road characteristics, and roadway structures that likely represent barriers to movement for large- and small-animal species groups (adapted for this project as in Table 4). Roads, road characteristics, roadway structures, and traffic volume data for the project area were obtained from NCDOT (2021a).

To represent known or potential wildlife crossing locations, barrier roads were considered *permeable* to wildlife passage via known and presumed crossing structures (such as bridges, culverts, or pipes). Bridge, culvert, and pipe location data were obtained from NCDOT (2021b). Ultimately, however, potential wildlife crossings were represented primarily as intersections between barrier roads and permanent streams from NHD (USGS 2020) because of incomplete mapping of bridge, culvert, and pipe locations throughout the project area. Bridge locations over non-barrier roads, railroads, and ground-level pedestrian pathways (such as the American Tobacco Trail) were included as potential crossing locations. For major rivers and lakes, bridges were evaluated using imagery, and potential crossing locations under one or both ends of each bridge were mapped. Causeways over open water do not provide dry passage underneath the roadway and were treated as barriers.

Table 4. *Criteria for identifying barrier roads and potential crossing locations for each habitat guild, adapted from criteria provided in Ernest and Sutherland (2017) based on biological/ecological information for priority species in this project area. The traffic volume criteria for two guilds were increased from the levels used in the Eno-New Hope project, based on evaluation of species observations for the project area.*

<table>
<tr><th>Habitat guild</th><th>Barrier road characteristics</th><th>Potential crossing locations</th></tr>
<tr><td>Wet-Mesic and Mesic Hardwood Forests
(Salamanders)</td><td>Surface width ≥ 26 feet
Shoulder curb present
Median barrier or curb present
Striped median present
Traffic volume ≥ 2000
Causeway over open water</td><td rowspan="3">Intersections between barrier roads and streams

Bridges over non-barrier roads, railroads, and pedestrian pathways</td></tr>
<tr><td>Dry-Wet Hardwood and Mixed Forests
(Box turtle, amphibians)</td><td>Surface width ≥ 26 feet
Shoulder curb present
Median barrier or curb present
Striped median present
Traffic volume > 12000
Causeway over open water</td></tr>
<tr><td>Sparsely Settled Mixed Habitats
(Bobcat, medium-sized mammals, snakes)</td><td>Speed limit ≥ 60 miles per hour
Median barrier present
Traffic volume > 12,000
Causeway over open water</td></tr>
</table>

Movement cost and distance. Cost distance thresholds and the costs for movement through suitable or unsuitable habitat were derived from NatureServe's concept of *separation distance* (NatureServe nd). For NCNHP mapping of known species occurrences, the distance between two or more occurrences and the quality of the intervening habitat (suitable or unsuitable) determines whether the occurrences are mapped as distinct populations or as connected sub-populations. These separation distances for suitable and unsuitable habitat are determined from knowledge of species' biology and ecology, including typical or maximum dispersal distances within and between areas of suitable habitat.

For each guild, separation distances for suitable and unsuitable habitat were derived from information for species or Element Groups in Biotics (NatureServe 2019c), supplemented by information from additional scientific literature (Table 3). Where suitable or unsuitable separation distance differed for species or Element Groups within guilds, the more limiting (lower) distance was used. A guild's cost distance threshold was scaled to the unsuitable separation distance, so that each unit of distance traveled in unsuitable habitat represented a unit of cost toward the distance threshold for unsuitable habitat. The lower movement cost in suitable habitat was then calculated as the ratio of unsuitable to suitable separation distance, so that for the same cost distance threshold, the actual distance on the ground would equal the larger suitable separation distance.

Cost surface and habitat patches. The cost surface for each guild was derived by first rasterizing (where necessary), reclassifying, and combining the following GIS layers into a single raster GIS layer:

- habitat (modified EVT, riparian areas, floodplains, wetlands, and non-barrier roads)
- barriers (developed areas, building footprints, open water, and barrier roads)
- potential wildlife crossing areas (barrier road—stream intersections and bridges over non-barrier roads, railroads, or pedestrian pathways)

The combined raster layer was then reclassified so that barriers were removed, and each unique habitat class was assigned the guild's unit movement cost value for suitable or unsuitable habitat according to a reclassification table. Potential wildlife crossing areas were also assigned the movement cost value for unsuitable habitat. Discrete areas of suitable habitat above the threshold patch size were identified and extracted as a separate habitat patch layer (shown in Figure 13 overlaid on the cost surface).

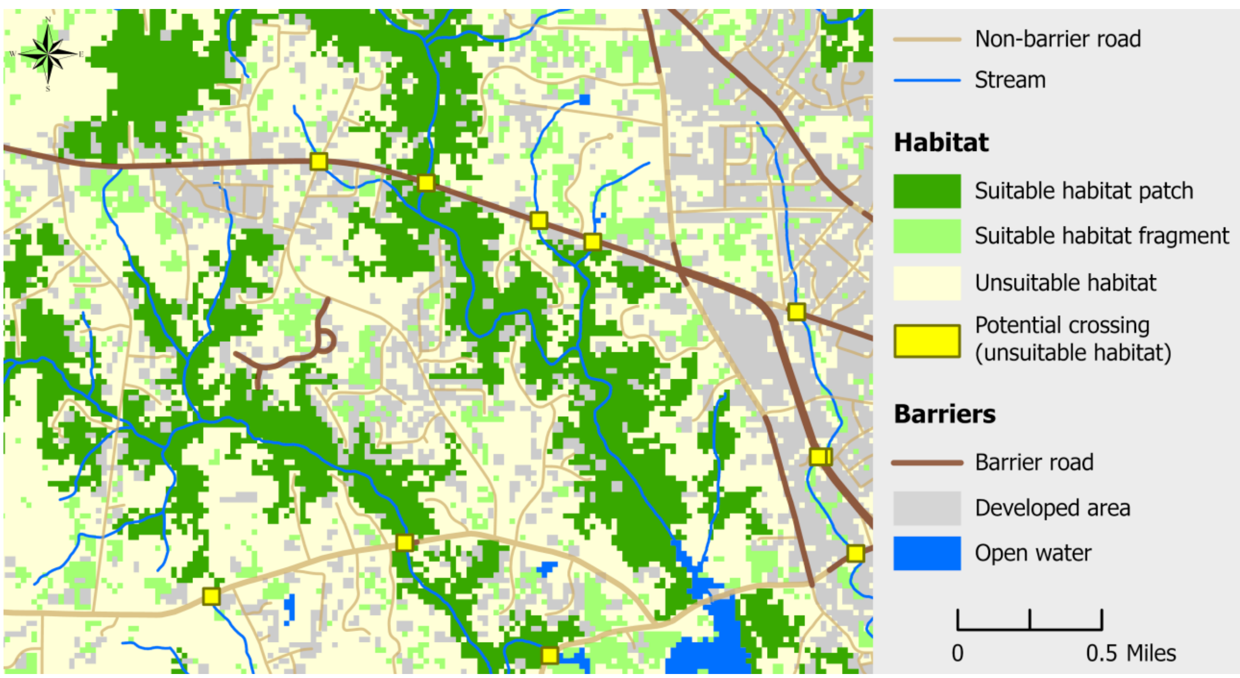

Figure 13. *A portion of the cost surface for the Dry-Wet Hardwood and Mixed Forests guild. Unsuitable habitat areas, including potential crossing locations, are assigned a cost of 1 distance unit. Suitable habitat fragment areas are assigned a cost of 1/3 distance unit, to reflect the lower cost and species' ability to move greater distances through suitable habitat. In the modeling approach for this project, movement proceeds from the edge of one habitat patch to the edge of another patch, such that there is no movement cost associated with areas within habitat patches.*

ANALYSIS AND INTERPRETATION

Using a combination of tools and scripts from ArcGIS Pro 2.9 (ESRI 2021), GeoHAT (Fay 2012), PatchConnect (Fay 2021), Tuttle's custom toolbox for this project (Tuttle unpublished), and NetworkX (Hagberg et al. 2008), a network of habitat patches connected by least cost corridors (the habitat-corridor network) was identified for each guild. The relative *connectivity importance value* was then calculated for each corridor segment between two habitat patches. We used the cost-weighted *edge betweenness centrality* (EBC) metric (NetworkX Developers 2019) to represent connectivity importance value for corridor segments (referred to as "edges" in NetworkX). EBC represents the proportion of least cost paths between all patches in the connected network that include a particular corridor segment, and the value ranges from 0 to 1 (Wade et al. 2015). To assign a connectivity importance value to each patch, the maximum EBC value for all corridor segments connected to the patch was assigned to the patch. In this way, the most important habitat-corridor pathways for overall landscape connectivity were mapped.

EBC identifies the most important pathways for keeping a given landscape connected, and the relative importance of particular pathways can shift depending on the landscape that is defined. This project is focused on wildlife habitat connectivity within and between major watershed areas. For this reason, connectivity importance values were calculated separately for three defined landscapes of interest: the entire project area, the set of Upper Neuse watersheds, and the New Hope watershed. For each landscape, the resulting set of values was rescaled to a common maximum EBC value of 1, to enable comparison.

To refine results for the above *habitat-only networks*, species occurrence data for 1-2 focal indicator species in each guild (Table 3, Figure 14) were used to develop a subnetwork of corridor connections between species occurrences, and the EBC-based connectivity importance values for these *species observation networks* were calculated. For each species, a species observation network was identified for the three landscapes defined above, and the resulting sets of values were rescaled to a maximum EBC value of 1.

Figure 14. *Focal indicator species selected from each of the three habitat types for development of the species observation networks, which were used to refine the priority habitat-corridor network for the project area. Photo credits: NCWRC (Eastern Box Turtle), Summer Trimble (Bobcat), Todd Pierson (salamanders).*

Calculating connectivity importance values for each guild's *habitat-only network* and *species observation network(s)* across the three defined landscapes yielded several sets of relative connectivity importance values. For each guild, the maximum relative connectivity importance value across all sets was applied to each corridor segment and habitat patch to represent the final prioritized habitat-corridor network.

The habitat-corridor network for each guild was classified into 4 ranked priority groups based on natural breaks between the final set of maximum connectivity importance values. The guild networks were combined for viewing in GIS using a semi-transparent overlay of all three guild networks in which the maximum-ranked elements of the network are always displayed on top (as shown in the Results section of this report). Unranked corridors and patches were retained in the GIS dataset. Unranked corridors are areas identified by the model as having a cost greater than the movement cost threshold. Unranked patches consist of habitat areas isolated from the habitat-corridor network as a result of barriers surrounding the patch or only unranked corridors connecting the area to other habitat. Final results were provided to the Advisory Committee for review and discussion.

RESULTS AND DISCUSSION

OVERVIEW

The Durham landscape connectivity analysis provides a significant update and expansion of the recent Eno-New Hope analysis (Tuttle et al. 2019), including updated data sources, improved methods, and – most importantly – expansion of the project area to include the entirety of Durham County and its connections to surrounding counties in the Upper Neuse watershed.

Key results of the analysis, described and illustrated in the following sections, include identification of:

- Important habitat-corridor areas that connect forested habitats for priority wildlife across Durham County.
- Habitat "anchors" within Durham County, and opportunities to conserve connectivity between these and other protected and managed lands.
- Connectivity "pinch-points" along major landscape corridors that are critically important for maintaining habitat connectivity across Durham and the Upper Neuse-New Hope watersheds.
- Opportunities to restore functional habitat connectivity across Durham's urban environments, supporting landscape connectivity while providing co-benefits to urban communities.
- Important considerations for using and interpreting the results.

LANDSCAPE HABITAT CONNECTIVITY IN DURHAM COUNTY

The landscape connectivity analysis identifies and prioritizes forested habitat areas and connections between them for priority wildlife populations in Durham County (Figure 15). Durham's habitat-corridor areas are part of the broader connectivity network for the Upper Neuse and New Hope watersheds (Figure 15 inset map), and habitat-corridor areas are prioritized based on their importance for keeping the overall network connected.

The results represent a system of major habitat-corridor pathways within watersheds ("generalized landscape corridors"), along with the riparian and upland pathways that connect them to each other ("connections between corridors") (Figure 16). The results for the full project area also highlight potential habitat-corridor connections to watersheds beyond the project area.

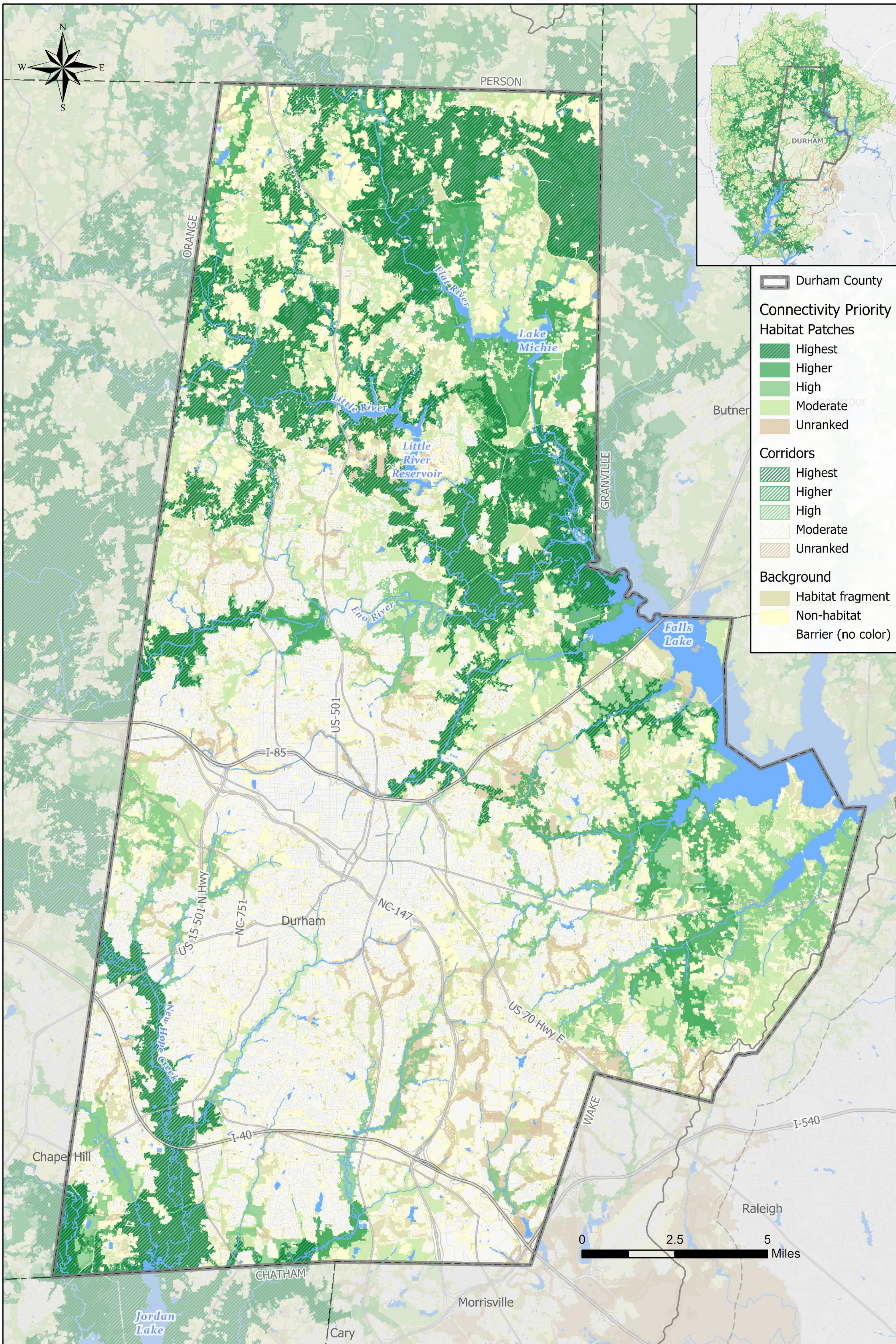

Figure 15. *Durham habitat connectivity priority areas within the Upper Neuse-New Hope habitat-corridor network (inset map).*

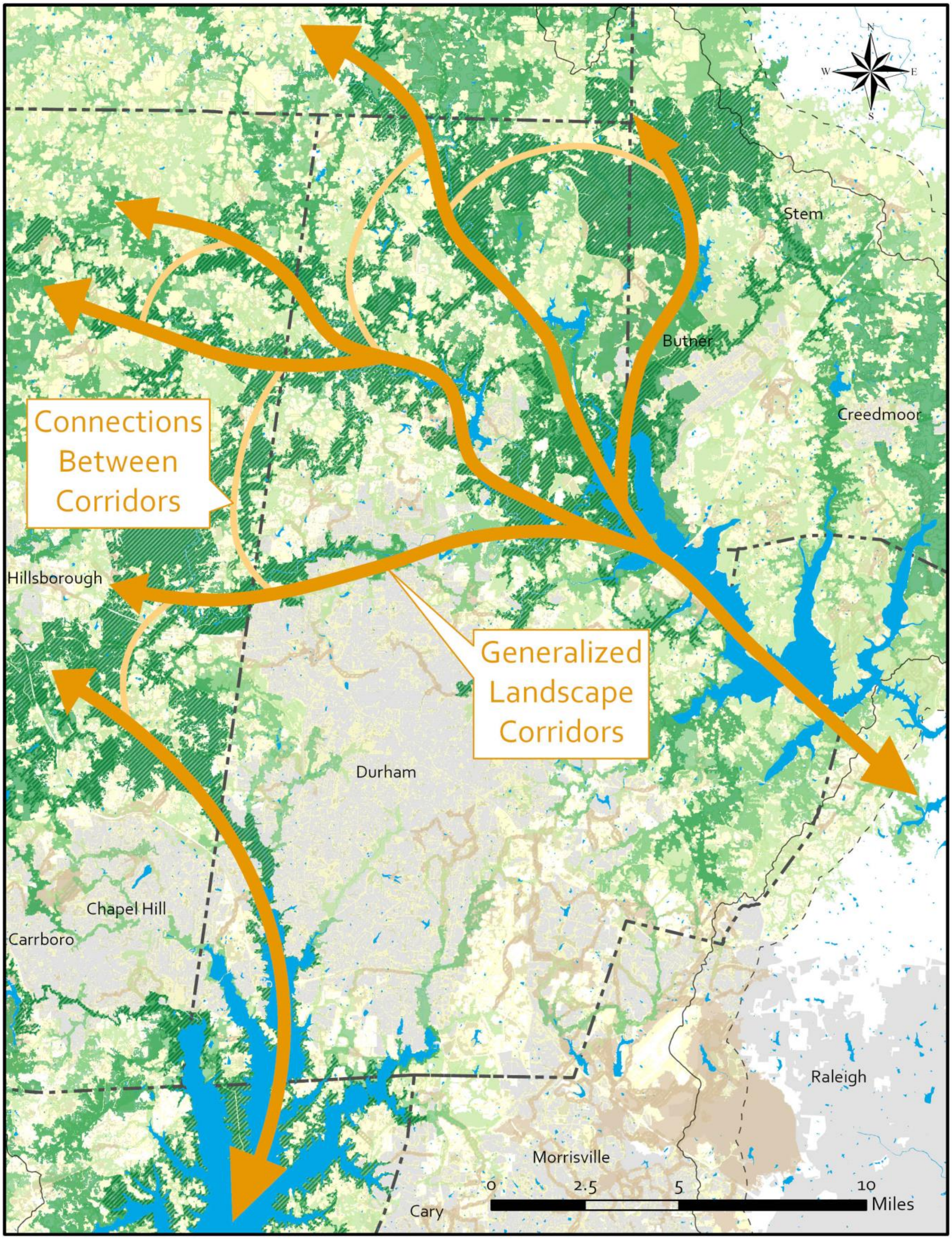

Figure 16. *Generalized landscape corridors (major habitat-corridor pathways) based on the Durham landscape habitat connectivity analysis. The habitat-corridor network is depicted in shades of green, and unranked areas are tan.*

Habitat anchors and protection opportunities

Several areas in Durham County emerge as important habitat anchors, which are contiguous areas of natural, semi-natural, and working forests distinguished by their size, their importance for keeping the overall network connected (connectivity priority), and their conservation status. Habitat anchors include forested areas of:

- Eno River State Park
- Duke Forest
- North Carolina State University's Hill Demonstration Forest
- portions of the Camp Butner National Guard Training Center
- City of Durham Open Space lands around Lake Michie
- US Army Corps of Engineers (USACE) lands around Falls Lake and Jordan Lake (with associated game lands managed by NCWRC)

These lands cover more than 29,000 acres in Durham County (of more than 92,000 acres in the project area) and are held by both public and private landowners, with various levels of protection and management for conservation of biodiversity, natural communities, wildlife habitats and human uses (NCNHP 2023).

The overlay of conservation lands (NCNHP 2023) on the prioritized connectivity network (Figure 17) illustrates the importance of the habitat anchors and provides a guide for conservation and restoration to keep existing conservation lands, watersheds, and the entire landscape connected. Major areas of opportunity to connect habitat anchors (Figure 17, A-F) correspond to the generalized landscape corridors and connections between them (Figure 16).

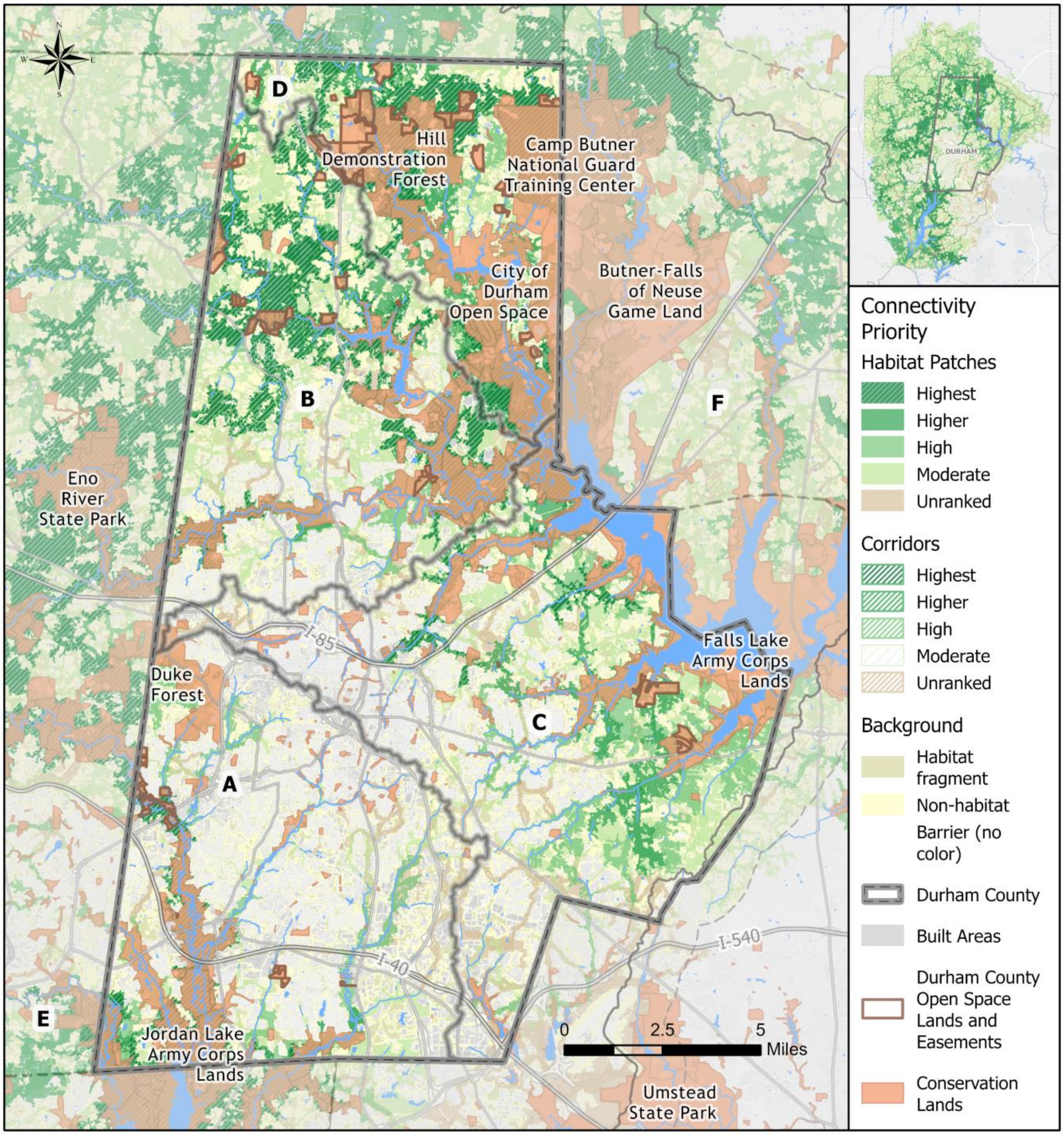

Figure 17. *Durham habitat anchors and connectivity priority areas, with major areas of opportunity to conserve connectivity: A. New Hope Creek Corridor. B. Eno River and Little River corridors with connections between them. C. Upper-middle Falls Lake and tributaries in eastern Durham. D. Flat River corridor. E. Jordan Lake and tributaries in Orange, Chatham, and Wake Counties. F. Upper and Middle Falls Lake in Granville County.*

CONNECTIVITY PINCH-POINTS

Connectivity pinch-points are “portion[s] of the landscape where movement is funneled through a narrow area” with few to no alternative pathways, and where the loss of a small habitat area or corridor can disconnect much larger portions of the landscape (Singleton and McRae 2013, WHCWG 2013). The analysis reveals connectivity pinch-points within Durham County along New Hope Creek, the Eno River, and the west side of Falls Lake.

New Hope Creek Corridor. The paramount importance of the New Hope Creek landscape corridor for wildlife populations and habitat connectivity, along with its vulnerability because of high development pressure, has long been recognized by local and regional governments, land trusts, and conservation organizations (for example, in Coulter Associates and New Hope Corridor Advisory Committee 1991). The importance of this corridor is affirmed in this analysis (Figure 15 inset map) and in broader regional analyses such as the Southeast Conservation Blueprint (https://secassoutheast.org/blueprint.html).

A connectivity pinch-point occurs where the New Hope Creek bottomland and adjacent upland habitats are surrounded by development and crossed by the major transportation corridors of US Highway 15-501 and I-40 (Figure 18). Significant interjurisdictional planning and collaboration, sustained public input, and coordination with private landowners have enabled some permanent conservation along this area of New Hope Creek, despite high development pressure. In particular, the Durham County Open Space program has protected approximately 322 acres between the Jordan Lake Army Corps lands and Duke Forest. The results of this analysis highlight areas where additional protection and management would prevent further habitat loss and degradation to help ensure the long-term integrity and function of this crucial landscape corridor.

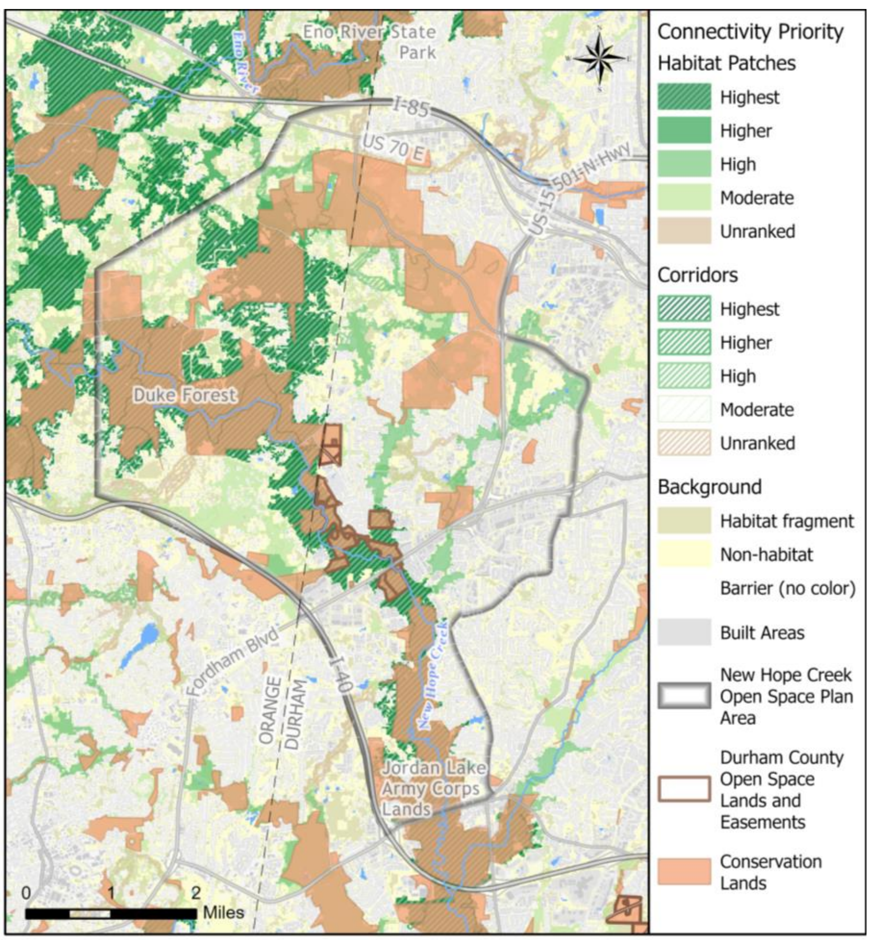

Figure 18. *Habitat connectivity priority and conservation in the New Hope Creek Corridor.*

Eno River in north-central Durham. Land protection efforts that led to the creation of Eno River State Park and other significant conservation lands along the Eno River corridor began in the 1960s (https://www.enoriver.org/features/formation-of-the-eno-river-association/), and conservation of this major landscape corridor is ongoing. In Durham County, lands along the river are protected as conservation land or managed as open space by a mix of state, local, and federal government agencies. This connectivity analysis and broader regional analyses affirm the critical conservation importance of the Eno River corridor.

A connectivity pinch-point occurs along the Eno River in north-central Durham between habitat areas in the City of Durham's West Point Park and other open space lands east of US Highway 501 (N. Roxboro Rd.) (Figure 19a, b). Just east of the highway crossing, the analysis does not identify a corridor on either the north or south side of the river. As a result, the analysis identifies prioritized connections between Eno River and Little River habitats via tributaries and uplands west of US Highway 501, primarily in Orange County. Along US Highway 501 just south of the Eno River crossing, results identify the potential for a wildlife crossing between habitat areas on each side of the highway; however, the habitat area on the east side of the highway has been largely cleared for development recently (not shown).

Closer inspection of the Eno River pinch-point area (Figure 19c) reveals narrow strips of open space vegetation surrounded by development on each side of the river, including grading and clearing for sewer infrastructure. The connectivity analysis relies on land cover data at a resolution of 30 m x 30 m blocks, and in developed areas, blocks along the river may contain, for example, a mix of buildings, impervious surface, river, and semi-natural vegetation. However, each block is classified as habitat (vegetation, whether suitable or unsuitable) or barrier (developed areas or open water). As a result, the analysis at this resolution identifies only scattered, disconnected habitat blocks.

In spite of this limitation, this result of the analysis yields several insights useful for conservation assessment and planning, particularly when considering scientific guidelines and best practices for wildlife corridors:

- The distance along the open space corridors is roughly 1.2 km (3/4 mile) on the north side and 2-3 km (greater than 1 mile) on the south side of the river, both of which are longer than the movement distance threshold (in unsuitable habitat/non-habitat) for priority wildlife species that need to move between habitats in this area.
- Likewise, the open space corridors on both sides are narrower than the minimum width of forest zone recommended for riparian and floodplain wildlife travel corridors (300-1000 ft depending on species) and lack wider habitat nodes or stepping stones that could mitigate the effects of narrower corridors (NCWRC 2012, 2017).
- Corridor improvements and habitat restoration could effectively "shorten" the movement distance for wildlife between the larger, higher-quality habitat areas to the west and east and could mitigate degradation resulting from adjacent development (NCWRC 2012, 2017).
- Floodplain hazard mitigation buyouts (small parcels in Figure 19c) and other nature-based hazard mitigation and watershed improvement solutions that provide community benefits can also support improved wildlife corridor quality and function.

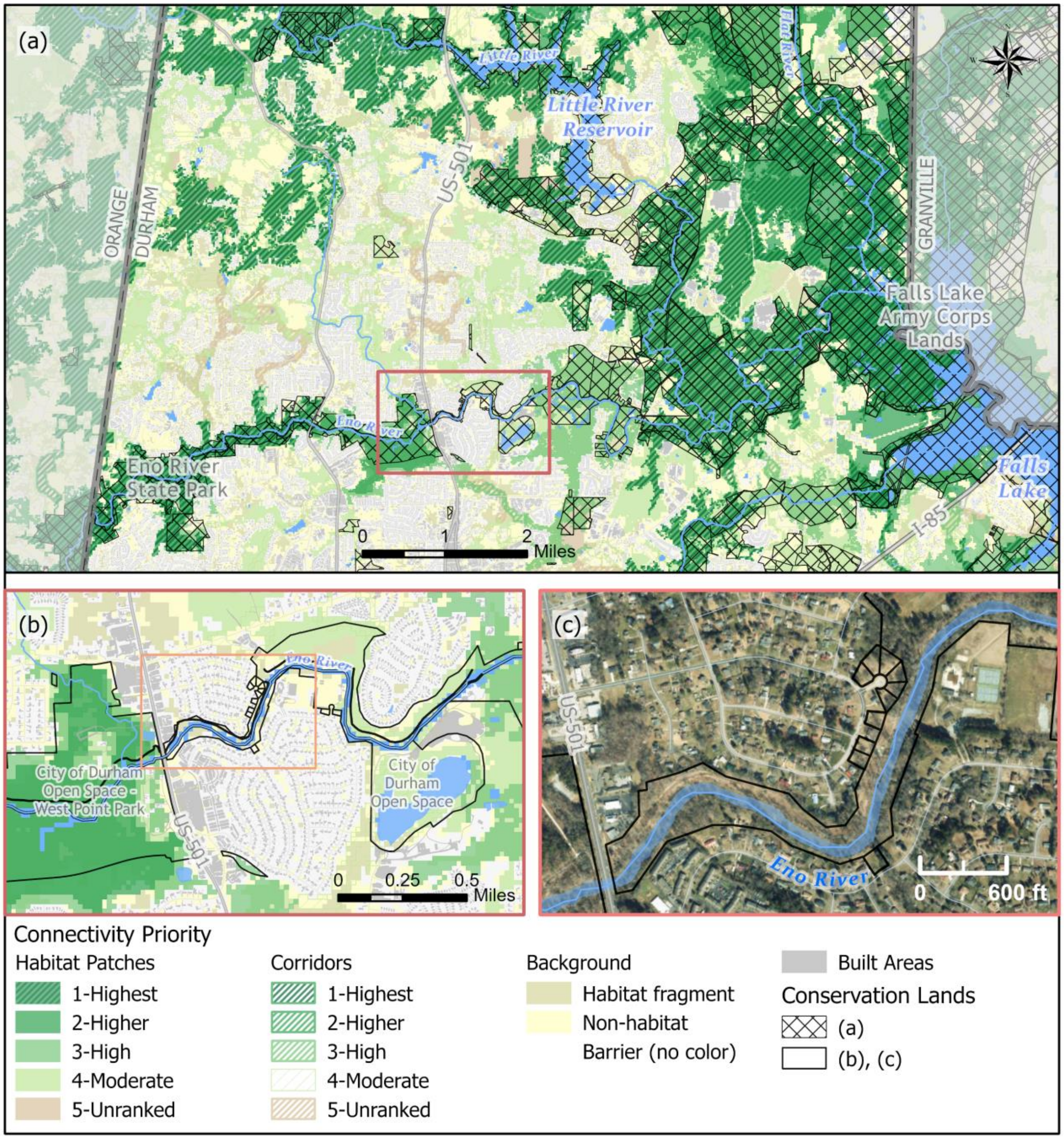

Figure 19. *(a) Habitat connectivity priority in north-central Durham, including the Eno River. (b) Connectivity pinch-point along the Eno River in north-central Durham. (c) Close-up showing land cover for a portion of the Eno River pinch-point. The smaller managed-area parcels are hazard mitigation buyout properties owned by NC DPS, Division of Emergency Management (NCNHP 2023).*

Upper-middle Falls Lake in eastern Durham. The major landscape corridor along Falls Lake and its tributaries is anchored by Falls Lake Army Corps lands and connects habitats in watersheds of the Neuse River and adjacent river basins. The importance of this area for wildlife and natural communities is reflected in the designation of several NHNAs (NCNHP 2022a) in the upper-middle Falls Lake area.

Results for the west side of Falls Lake in eastern Durham may highlight one or more connectivity pinch-points or gaps in this major landscape corridor (Figure 20). At first glance, the prioritized pathways identified in this area might seem counterintuitive. For instance, one might expect the highest-priority pathway to follow lands along the shore of Falls Lake. Instead, the results emphasize relatively narrow riparian and overland connections between tributaries as the most important pathways for keeping the entire landscape connected. Closer inspection of the results and aerial imagery (not shown) reveals habitat-corridor gaps and unranked (disconnected) habitat areas along some parts of the Falls Lake shoreline. In addition, I-85 represents a major road barrier across this area, including and especially the I-85 causeway over Falls Lake, which does not enable passage underneath the road for terrestrial wildlife. The prioritized pathways in this area rely on potential wildlife crossings along I-85 at stream-road intersections or bridges that carry I-85 over non-barrier roads in the vicinity of habitat areas. Consideration of the results in this area can help identify locations where habitat restoration, management, and protection along with functional wildlife crossings would best reconnect habitats along the western side of Falls Lake to ensure the long-term integrity of this major landscape corridor.

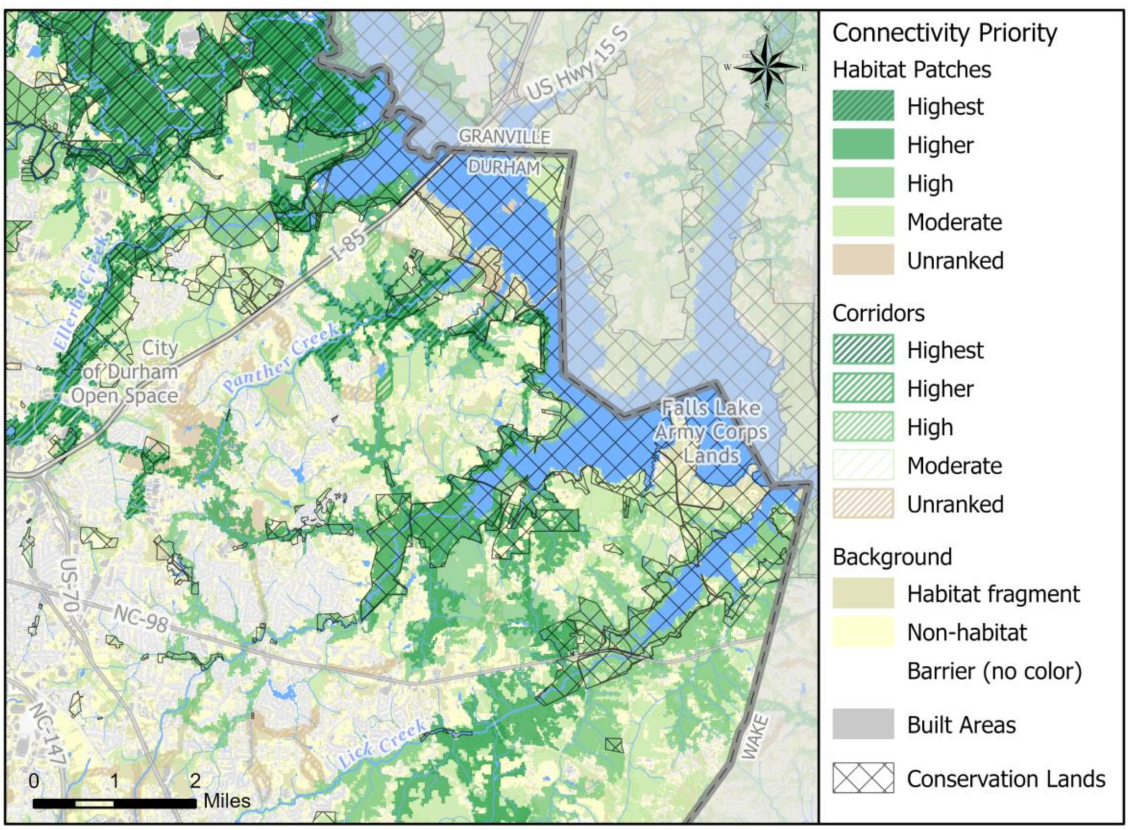

Figure 20. *Habitat connectivity priority along upper-middle Falls Lake in eastern Durham.*

Opportunities to restore urban connectivity

The results also help identify urban and developed areas where habitat-corridor restoration efforts could have significant impact on landscape habitat connectivity. Unranked habitat, which largely occurs in developed areas, represents known or potential habitat that may be isolated from the connected habitat-corridor network. Similarly, unranked corridors represent connections between habitat areas that may not function for wildlife movement because of distance, habitat quality, or both. These unranked habitat and corridor areas, when considered in context, can highlight opportunities for further assessment and restoration of connectivity across urban and developed areas.

Ellerbe Creek in central Durham. For instance, unranked habitat and corridor areas in central Durham (Figure 21) illustrate potential pathways for priority wildlife along Ellerbe Creek, potentially connecting this area with City of Durham Open Space and Falls Lake Army Corps lands to the east as well as Duke Forest and Eno River State Park to the west. Further assessment of these unranked areas could help identify whether or not priority wildlife populations are using and moving between habitat areas, as well as sites that would benefit from habitat or corridor restoration.

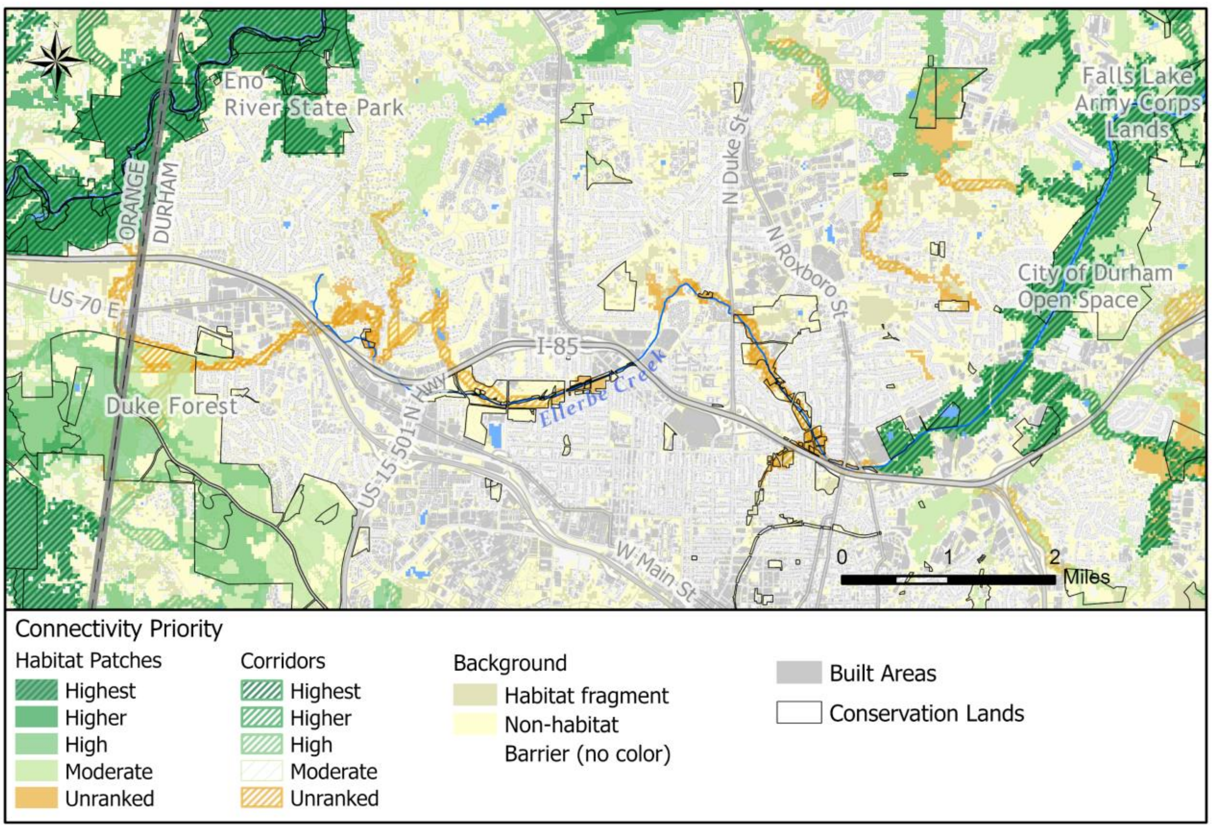

Figure 21. *Habitat connectivity priority and restoration opportunities along Ellerbe Creek in Durham.*

Falls Lake in southeastern Durham. Similarly, further assessment of unranked habitat-corridor areas between Falls Lake in southeastern Durham and Umstead State Park in Wake County (Figure 22) could help identify potential pathways and opportunities for restoration. Umstead State Park in Wake County represents an important anchor of known habitats for priority wildlife. The habitat areas within and around Umstead State Park are recognized as an NHNA (NCNHP 2022a), and this area likely represents a localized habitat-corridor network. However, the analysis identifies the Umstead area as isolated from the broader Upper Neuse-New Hope connectivity network, with only unranked corridors between Umstead and the adjacent watersheds in the project area (Middle Falls Lake and Jordan Lake-New Hope).

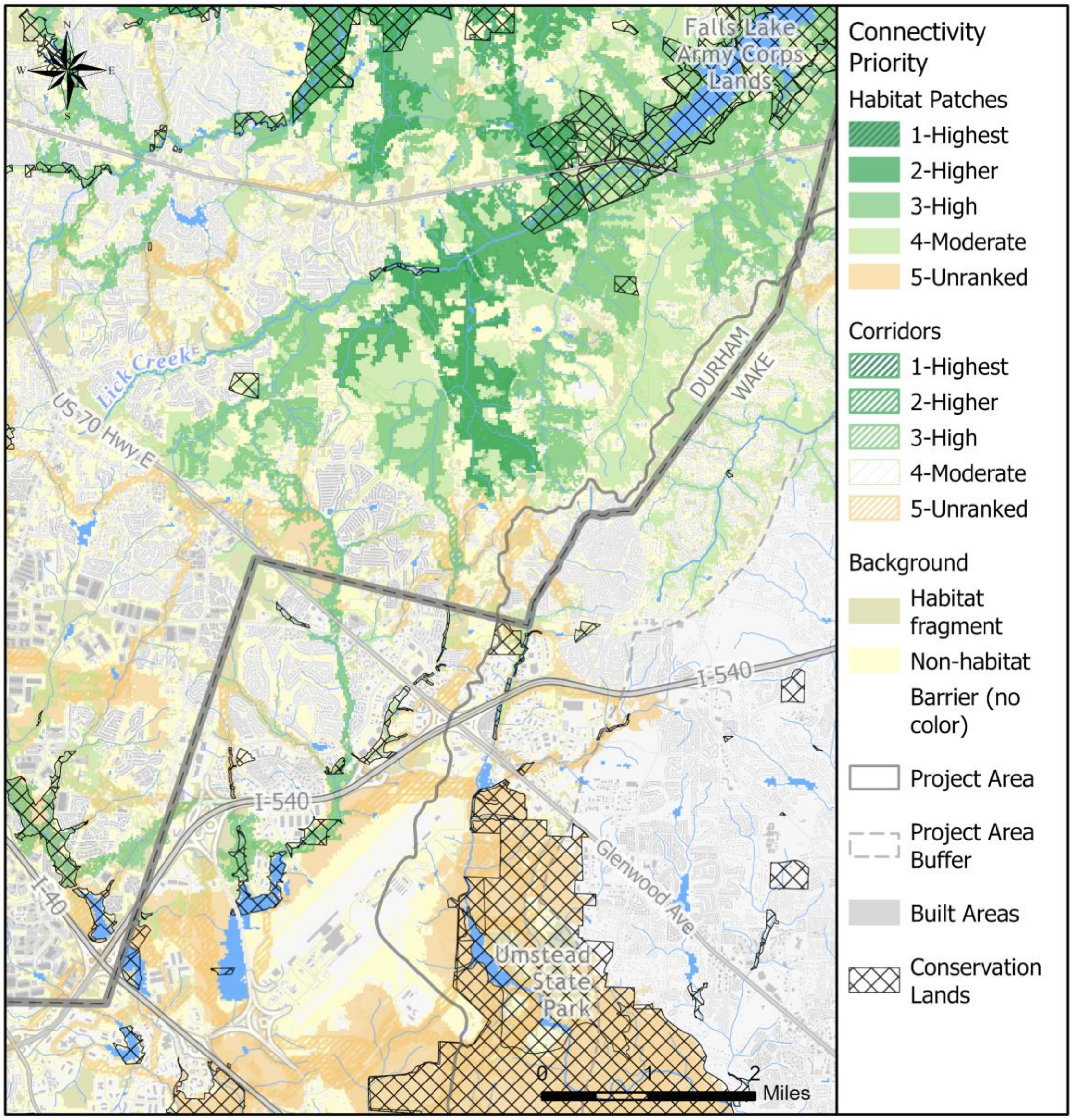

Figure 22. *Habitat connectivity priority and restoration opportunities between Falls Lake in Durham and Umstead State Park in Wake County.*

CONSIDERATIONS FOR USING AND INTERPRETING RESULTS

Care should be taken to consider how the assumptions and limitations of both the analysis methods and the input datasets influence the results. In particular, the analysis relies on land cover classifications and other spatial data layers that may not be current and/or may contain classification and location errors. (Land cover is changing rapidly in Durham County as new development occurs.) In addition, the selection of model parameters appropriate for the project objectives uses best available science, local biological/ecological expertise, and empirical data for the project area. Refined knowledge and updated data inputs could provide useful updates to the parameters and the results. Indeed, review and use of these project results for connectivity planning and conservation will provide important information for improving their interpretation and usefulness.

When using and interpreting the results, keep in mind the following:

- The need for field-based verification of current land cover as well as habitat-corridor location, quality, and function. This applies to areas within the prioritized network, unranked areas, and finer-scale patterns not identified in the analysis.
- The need to verify and/or improve the location, status, and function of bridges, culverts, and road-stream intersections identified as potential wildlife crossing areas in priority corridors.
- The potential that finer-scale, often narrow habitat-corridor areas were missed by the spatial resolution of the base land cover layer (30 m x 30 m, or 98.425 ft x 98.425 ft), particularly in urban areas. However, even if fine-scale habitat-corridor areas are identified, the function and viability of such small or narrow areas should be evaluated, with attention to best available science and established guidelines on habitat and corridor criteria that meet the needs of priority wildlife (NCWRC 2012, 2017; also see resources in Appendix D).

When carefully considered and reviewed alongside other relevant data, the results of this analysis represent an important tool for local decision-making and regional collaboration to support landscape connectivity conservation within and beyond Durham County.

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Appendix A: List of abbreviations

ARA	TNC Active River Area
CCSG	Connectivity Conservation Specialist Group
CMS	Convention on Migratory Species
EBC	Edge betweenness centrality
ELI	Environmental Law Institute
EVT	LANDFIRE Existing Vegetation Type
FEIS	Fire Effects Information System
GeoHAT	Geospatial Habitat Assessment Toolkit
GIS	Geographic information system(s)
HCZ	EnviroAtlas Hydrologically Connected Zone
IUCN	International Union for Conservation of Nature
LHIG	Landscape/Habitat Indicator Guild
NCDNCR	North Carolina Department of Natural and Cultural Resources
NCDOT	North Carolina Department of Transportation
NCFMP	North Carolina Floodplain Mapping Program
NCNHP	North Carolina Natural Heritage Program
NCWRC	North Carolina Wildlife Resources Commission
NHD	USGS National Hydrography Dataset
NHNA	Natural Heritage Natural Area
NRCS	Natural Resources Conservation Service
NRID	North Carolina State Parks Natural Resources Inventory Database
NWI	National Wetlands Inventory
OSM	OpenStreetMap
SGCN	Species of Greatest Conservation Need
UNC Chapel Hill	University of North Carolina at Chapel Hill
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WCPA	World Commission on Protected Areas
WHCWG	Washington Wildlife Habitat Connectivity Working Group
WVC	Wildlife-vehicle collision

Appendix B: Glossary

Active River Area: A spatially explicit framework for modeling rivers and their dynamic interaction with the land through which they flow. Key features of the ARA include the meander belt, riparian wetlands, floodplains, terraces, and material contribution areas. The ARA is different from, but was calibrated to and compared against, the FEMA 100-year floodplain. (TNC 2015b)

Connectivity (landscape, habitat, or ecological connectivity, landscape permeability): The degree to which the landscape facilitates or impedes movement of organisms or processes (Wade et al. 2015). The extent to which a species or population can move among landscape elements in a mosaic of habitats. This necessitates linkages among individuals, species, communities, and ecosystems at appropriate spatial and temporal scales. Corridors are one means of achieving connectivity (Hilty et al. 2006). A measure of the ability of organisms, gametes, and propagules to move among separated patches of suitable habitat. Ideally, corridors serve to facilitate connectivity over time and can operate at a range of spatial scales (Hilty et al. 2019). The unimpeded movement of species and the flow of natural processes that sustain life on Earth (CMS 2019).

Connectivity conservation: The action of individuals, communities, institutions, and businesses to maintain, enhance, and restore ecological flows, species movement, and dynamic processes across intact and fragmented environments. Moreover, it is an innovative strategy that is bringing together a growing global movement to protect the vital interconnections of nature by providing a coordinated response for safeguarding biodiversity and increasing resilience to climate change. (CCSG 2016)

Conservation planning: The process that occurs when a group of stakeholders consider the status of an area's natural environment and identify goals and strategies for conserving the area's natural heritage and biological diversity (NCWRC 2017).

Conservation threshold: The minimum level of any characteristic of a species' habitat that is needed in order for local populations to persist over time (NCWRC 2012).

Corridor (landscape, habitat, or wildlife corridor): Avenues along which wide-ranging animals can travel, plants can propagate, genetic interchange can occur, populations can move in response to environmental changes and natural disasters, and threatened species can be replenished from other areas (The Ninth US Circuit Court of Appeals 1997 *in* Walker and Craighead 1997). Any space that facilitates the movement of populations, individuals, gametes or propagules, and plant parts capable of vegetative reproduction in a matter of minutes, hours, or over multiple generations of a species. Corridors may encompass altered or natural areas of vegetation and provide connectivity that allows biota to spread or move among habitat fragments through areas otherwise devoid of preferred habitat. Landscape elements that function as corridors may also serve multiple other purposes, providing aesthetic amenities, ecosystem service values, cultural heritage protection, and recreational opportunities. (Hilty et al. 2019)

Cost surface (resistance surface): A mapped surface representing the degree to which some landscape feature impedes or facilitates some movement process, typically represented as a cell (pixel) value in a grid (raster) within a GIS. Corridors are then modeled in areas with lowest resistance to the movement process considered. The models are relatively easy to apply given existing data, and the approach offers the flexibility to develop models ranging from simple to complex, tailored to the specific conservation needs, and able to be refined as better data become available. A resistance surface is conceptually related to the idea of travel costs from behavioral ecology, and can therefore be designed to integrate ecological concepts important to successful wildlife movement, such as an organism's perceptual range and susceptibility to competition and predation. Resistance-surface connectivity modeling assumes a relationship between surficial proxy measures (such as habitat type or quality) and ease of animal movement. It is important that resistance surfaces be considered hypotheses reflecting a solid consideration of causal biology. (Wade et al. 2015)

Dispersal: Movements that occur within the lifetime of the individual, as, for example, when it leaves its natal site (NCWRC 2015).

Ecological integrity: A system's wholeness, including presence of all appropriate elements and occurrence of all processes at appropriate rates, that is able to maintain itself through time (ELI 2003). The ability of an ecological system to support and maintain a community of organisms that has a species composition, diversity, and functional organization comparable to those of natural habitats within a region. An ecological system has integrity, or a species population is viable, when its dominant ecological characteristics (such as elements of composition, structure, function, and ecological processes) occur within their natural ranges of variation and can withstand and recover from most perturbations imposed by natural environmental dynamics or human disruptions (Parrish et al. 2003).

Ecosystem: An ecosystem is a community of living organisms (plants, animals, and microbes) in conjunction with the nonliving components of their environment (air, water, and mineral soil), interacting as a system. It is a system of environmental conditions, habitats, natural communities, and species that interact (NCWRC 2015).

Ecosystem services: The benefits people obtain, directly or indirectly, from ecosystems. These include *provisioning services* such as food, water, timber, and fiber; *regulating services* that affect climate, floods, disease, wastes, and water quality; *cultural services* that provide recreational, aesthetic, and spiritual benefits; and *supporting services* such as soil formation, photosynthesis, and nutrient cycling. The human species, while buffered against environmental changes by culture and technology, is fundamentally dependent on the flow of ecosystem services. (Millennium Ecosystem Assessment 2005)

Edge effects: The negative influence of habitat or ecosystem edges on interior conditions of the habitat or on associated species. Edge effects can include profound modification of biological and physical conditions. (ELI 2003)

Habitat: The physical features (such as topography, geology, stream flow) and biological characteristics (such as vegetation cover and other species) needed to provide food, shelter, and reproductive needs of animal or plant species (ELI 2003).

Habitat edge: The edge of a habitat adjoining incompatible land. Habitat edge causes "edge effects" whereby species are negatively impacted due to edge conditions, such as a higher number of predators. The width of edge effects differs for different species. (NCWRC 2017) The portion of a habitat patch near its perimeter where environmental conditions are more affected by the surrounding *matrix* as compared to the patch core (Wade et al. 2015). A boundary between different natural communities, or between a patch and matrix, along which movement of non-living materials, organisms, and information between the two areas may occur (Hilty et al. 2006). Edges can naturally occur or can be the result of human activities, and species responses may differ. (Hilty et al. 2019)

Habitat fragmentation: The breaking up of previously continuous habitat (or ecosystem) into spatially separated and smaller parcels. Habitat fragmentation results from human land use associated with forestry, agriculture, and settlement, but can also be caused by natural disturbances like wildfire, wind, or flooding. Suburban and rural development commonly changes patterns of habitat fragmentation of natural forests, grasslands, wetlands, and coastal areas as a result of adding fences, roads, houses, landscaping, and other development activities. (ELI 2003)

Habitat loss: Reduction in total area of habitat (Wade et al. 2015).

Habitat patch: A relatively homogeneous type of habitat that is spatially separated from other similar habitat and differs from its surroundings (ELI 2003). A discrete area of contiguous habitat, often above a size threshold representing the habitat needs of an organism or species, or the functional needs of a natural community.

Habitat-corridor network: A connected set of discrete habitat patches and corridors between them.

Home range: Area used by an animal in its normal daily activities. Not defended. (NCWRC 2015).

Indicator guild: A group of species that show similar patterns of response to specific types of environmental change (Hall 2008).

Indicator species: A species that is closely associated with a particular habitat type, and whose presence indicates quality habitat (NCWRC 2012).

Invasive species: Any species that does not occur naturally in North Carolina and poses serious threats to native ecosystems, due to the species' propensity to spread rapidly and out-compete native species (adapted from NCWRC 2017).

Landscape (ecological landscape): For the scale of this project, a large heterogeneous land area (for example, multiple square miles or several thousand hectares) consisting of a cluster of interacting ecosystems repeated in similar form (such as a watershed) (ELI 2003).

Landscape conservation: An approach that brings people together across geographies, sectors, and cultures to collaborate on conserving our important landscapes and the myriad ecological, cultural, and economic benefits they provide (Network for Landscape Conservation, http://landscapeconservation.org/about/what-is-landscape-conservation/)

Landscape/Habitat Indicator Guild: A group of species that have similar habitat and movement needs, respond in similar ways to landscape fragmentation, and collectively serve as indicators of landscape habitat integrity (Hall 2008).

Landscape habitat integrity: Defined by Hall (2008) as simply the inverse of the degree of landscape fragmentation.

Least cost corridor: A corridor representing areas of lowest movement cost between two discrete endpoints (habitat patches), determined by a threshold of total movement cost above the cost of the least cost path.

Least cost path (shortest path): In cost distance analysis (or shortest path modeling), the single path with the lowest total sum between two endpoints (habitat patches). In raster-based GIS analysis, the least cost path is only a single pixel wide, which is unlikely to represent the exact path taken by an organism. (Wade et al. 2015)

Matrix: A component of the landscape, often altered from its original state by human land use, which may vary in attributes from human-dominated to natural, and in which corridors and habitat patches are embedded (Hilty et al. 2019).

Metapopulation: A network of semi-isolated populations with some level of regular or intermittent migration and gene flow among them, in which individual populations may be extinct but then be recolonized from other subpopulations (ELI 2003).

Movement barrier: A physical object or environmental condition that obstructs or prohibits animal movement from one part of the landscape to another.

Natural community: A distinct and recurring assemblage of populations of plants, animals, bacteria, and fungi naturally associated with each other and their physical environment (Schafale 2012).

Natural Heritage Element Occurrence (NHEO): Occurrences of rare plants and animals, exemplary or unique natural communities, and important animal groupings, as tracked and documented by NCNHP. Collectively, these plants, animals, natural communities, and animal assemblages are referred to as "elements of natural diversity" or simply as "elements." Maps of NHEOs are maintained and distributed by NCNHP and are updated quarterly (NCWRC 2017).

Natural Heritage Natural Area (NHNA): Terrestrial or aquatic sites that are of special biodiversity significance as defined by NCNHP. A site's conservation priority rating or significance may be due to the presence of rare species, rare or high-quality natural communities or other important ecological features. Maps of NHNAs are updated quarterly. (NCNHP 2020, NCWRC 2017)

Non-native species: Any species that has been introduced (either intentionally or accidentally) to an area outside its natural past or present distribution. This includes any part (gametes, seeds, eggs, or propagules) of such species that might survive and subsequently reproduce. Non-native species can be invasive, injurious, or beneficial where they occur. (NCWRC 2015)

Pinch-point (connectivity pinch-point): Portions of the landscape where movement is funneled through a narrow area with few to no alternative pathways, and where the loss of a small habitat area can disconnect much larger portions of the landscape (Singleton and McRae 2013, WHCWG 2013).

Resilience: The ability to retain essential processes in the face of disturbances or expected shifts in ambient conditions; ecosystem resilience provides the ability to support native diversity (NCWRC 2015).

Separation distance for suitable habitat: Distance of intervening suitable habitat not known to be occupied that is great enough to effectively separate occurrences by limiting movement or dispersal of individuals between them (NatureServe 2019a).

Separation distance for unsuitable habitat: Distance of intervening unsuitable habitat that is great enough to effectively separate occurrences by restricting movement or dispersal of individuals between them (NatureServe 2019b).

Species of Greatest Conservation Need (SGCN): In North Carolina, SGCN have been defined as species that are currently rare or have been designated as at-risk of extinction; those for which we have knowledge deficiencies; and those that have not received adequate conservation attention in the past. In addition to these species for which there is high conservation concern, SGCN may also include those species for which we are unable to determine true status in the state and are therefore a priority for research due to these knowledge gaps. (NCWRC 2015)

Succession: The process of replacement of one community with another, typically after disturbance (adapted from NCWRC 2015).

Suitable habitat: Habitat capable of supporting reproduction or used regularly for feeding or other essential life history functions; a habitat in which you would expect to find the species (assuming appropriate season and conditions) (NatureServe 2019a). Habitat that meets the survival and reproductive needs of a species, allowing for a stable or growing population over time (ELI 2003).

Unsuitable habitat: In most cases, unsuitable habitat is habitat through which individuals may move, but that does not support reproduction or long-term survival (NatureServe 2019b).

Wetland: An area of land with soil that is either permanently or temporarily saturated with water (NCWRC 2012).

Wildlife crossing (wildlife road crossing, wildlife crossing structure): Any structure that allows wildlife to pass over or under a roadway without crossing without crossing the flow of traffic, reconnecting severed habitat and reducing wildlife-vehicle collisions (Sutherland et al. 2022).

Appendix C: List of Landscape/Habitat Indicator Guilds in the Upper Neuse-New Hope watersheds

Priority terrestrial (or semi-terrestrial) wildlife indicator species known to occur in the Upper Neuse and New Hope watersheds, grouped according to Hall's Landscape/Habitat Indicator Guilds (LHIG) (Hall 2008, 2009, with some updates from Hall's recent work with NCBP, 2022). The three LHIG habitat types selected for connectivity analysis include Wet-Mesic and Mesic Hardwood Forests, Dry-Wet Hardwood and Mixed Forests, and Sparsely Settled Mixed Habitats. The four focal species selected for additional *species occurrence network* analysis are marked with an asterisk. See report text for explanation of how priority indicator species were identified.

Habitat Guild	Taxonomic Group	Common Name	Scientific Name
Wet-Mesic and Mesic Hardwood Forests	Amphibian	Eastern Mud Salamander	*Pseudotriton montanus*
	Amphibian	Four-toed Salamander*	*Hemidactylium scutatum*
	Amphibian	Red Salamander	*Pseudotriton ruber*
	Amphibian	White-spotted Slimy Salamander*	*Plethodon cylindraceus*
	Bird	Acadian Flycatcher	*Empidonax virescens*
	Bird	Kentucky Warbler	*Geothlypis Formosa*
	Reptile	Smooth Earthsnake	*Virginia valeriae*
Dry-Wet Hardwood and Mixed Forests	Amphibian	Marbled Salamander	*Ambystoma opacum*
	Amphibian	Mole Salamander	*Ambystoma talpoideum*
	Amphibian	Spotted Salamander	*Ambystoma maculatum*
	Bird	Eastern Whip-poor-will	*Antrostomus vociferus*
	Bird	Yellow-throated Warbler	*Setophaga dominica*
	Moth	Straw Besma	*Besma endropiaria*
	Reptile	Eastern Box Turtle*	*Terrapene carolina*
Sparsely Settled Mixed Habitats	Mammal	Bobcat*	*Lynx rufus*
	Mammal	Long-tailed Weasel	*Neogale frenata*
	Reptile	Timber Rattlesnake	*Crotalus horridus*
	Reptile	Eastern Hognose Snake	*Heterodon platirhinos*
	Reptile	Eastern Kingsnake	*Lampropeltis getula*
Wet-Hydric Forests	Bird	Prothonotary Warbler	*Protonotaria citrea*
	Dragonfly or Damselfly	Regal Darner	*Coryphaeschna ingens*
Wet Hardwood Forests	Bird	Louisiana Waterthrush	*Parkesia motacilla*
	Moth	Broadly Pectinate Hypomecis Moth	*Hypomecis longipectinaria*
Cool Mesic Slopes	Amphibian	Eastern Red-backed Salamander	*Plethodon cinereus*
Cool Heath Bluffs	Butterfly	Brown Elfin	*Callophrys augustinus*
Wet-Dry Hardwood Forests	Bird	Yellow-billed Cuckoo	*Coccyzus americanus*
	Bird	Warbling Vireo	*Vireo gilvus*
	Bird	Wood Thrush	*Hylocichla mustelina*
Rich Wet-Dry Hardwood Forests	Moth	Franck's Sphinx	*Sphinx franckii*

Habitat Guild	Taxonomic Group	Common Name	Scientific Name
Hardwood Forests	Amphibian	Cope’s Gray Treefrog	*Hyla chrysoscelis*
	Amphibian	Gray Treefrog	*Hyla versicolor*
Dry-Xeric Hardwood Forests	Butterfly	A Geometrid Moth	*Lytrosis permagnaria*
	Butterfly	Northern Oak Hairstreak	*Satyrium Favonius*
Dry-Xeric Pine Forests and Woodlands	Bird	Chuck-will’s-widow	*Antrostomus carolinensis*
	Butterfly	Confused Cloudywing	*Thorybes confusis*
	Reptile	Scarlet Kingsnake	*Lampropeltis elapsoides*
	Reptile	Corn Snake	*Pantherophis guttatus*
	Reptile	Scarlet Snake	*Cemophora coccinea*
Semi-Natural Pine Forests and Woodlands	Bird	Brown-headed Nuthatch	*Sitta pusilla*
	Orthopteran	Pine Katydid	*Hubbellia marginifera*
Forest-Field Ecotones and Groves	Bird	American Woodcock	*Scolopax minor*
	Bird	Cooper’s Hawk	*Accipiter cooperii*
	Bird	Red-headed Woodpecker	*Melanerpes erythrocephalus*
	Bird	Sharp-shinned Hawk	*Accipiter striatus*
	Bird	American Kestrel	*Falco sparverius*
	Bird	Northern Bobwhite	*Colinus virginianus*
	Mammal	Golden Mouse	*Ochrotomys nuttalli*
Mix of open and forested habitats	Amphibian	Eastern Spadefoot	*Scaphiopus holbrookii*
	Reptile	Mole Kingsnake	*Lampropeltis rhombomaculata*
Reservoirs	Bird	Bald Eagle	*Haliaeetus leucocephalus*
Shallow Wetlands	Reptile	Spotted Turtle	*Clemmys guttata*
Beaver Ponds and Successional Wetlands	Bird	Hooded Merganser	*Lophodytes cucullatus*
Canebrakes	Bird	Swainson's Warbler	*Limnothlypis swainsonii*
Waters and Shorelines	Bird	Green Heron	*Butorides virescens*
	Reptile	Eastern Ribbonsnake	*Thamnophis sauritus*
	Reptile	Eastern Musk Turtle	*Sternotherus odoratus*
Inland Freshwater Marshes	Bird	King Rail	*Rallus elegans*
	Bird	Least Bittern	*Ixobrychus exilis*
	Moth	Louisiana Owlet Moth	*Macrochilo louisiana*
Piedmont and Rocky Rivers	Dragonfly or Damselfly	Septima’s Clubtail	*Gomphurus septima*
	Dragonfly or Damselfly	Splendid Clubtail	*Gomphurus lineatifrons*
	Dragonfly or Damselfly	Cinnamon Shadowdragon	*Neurocordulia virginiensis*
	Reptile	Queen Snake	*Regina septemvittata*
Semi-Natural Grasslands	Bird	Barn Owl	*Tyto alba*
	Bird	Grasshopper Sparrow	*Ammodramus savannarum*
	Bird	Eastern Meadowlark	*Sturnella magna*
	Bird	Dickcissel	*Spiza americana*
	Butterfly	Cobweb Skipoper	*Hesperia metea*
	Reptile	Slender Glass Lizard	*Ophisaurus attenuates*
Successional Fields	Bird	Loggerhead Shrike	*Lanius ludovicianus*
	Bird	Prairie Warbler	*Setophaga discolor*
	Butterfly	Monarch	*Danaus plexippus*

Habitat Guild	Taxonomic Group	Common Name	Scientific Name
	Butterfly	Checkered White	*Pontia protodice*
	Butterfly	Leonard's Skipper	*Hesperia leonardus*
	Mammal	Eastern Harvest Mouse	*Reithrodontomys humulis*
Urban Areas	Bird	Chimney Swift	*Chaetura pelagica*
	Bird	Common Nighthawk	*Chordeiles minor*
Habitat guild not yet determined	Bird	Gadwall	*Anas strepera*
	Bird	Yellow-crowned Night Heron	*Nyctanassa violacea*
	Dragonfly or Damselfly	Amber-winged Spreadwing	*Lestes eurinus*
	Dragonfly or Damselfly	Laura's Clubtail	*Stylurus laurae*
	Mammal	Tricolored Bat	*Perimyotis subflavus*
	Mammal	Northern Long-eared Bat	*Myotis septentrionalis*
	Mammal	Seminole Bat	*Lasiurus seminolus*
	Mammal	Little Brown Bat	*Myotis lucifugus*
	Mammal	Hoary Bat	*Lasiurus cinereus*
	Moth	Doris Tiger Moth	*Grammia doris*
	Reptile	Rough Earthsnake	*Virginia striatula*
	Sawfly, Wasp, Bee, Ant	American Bumblebee	*Bombus pensylvanicus*

Appendix D: List of resources for landscape connectivity analysis and planning

North Carolina landscape conservation planning guides, data, and assistance

Ernest, M and R Sutherland. 2017. Prioritizing wildlife road crossings in North Carolina. Wildlands Network, Durham, NC. Available from https://wildlandsnetwork.org/resources/prioritizing-wildlife-road-crossings-in-north-carolina.

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NCWRC. 2017. Green Growth Toolbox: wildlife and natural resource stewardship in planning. Green Growth Toolbox handbook 2017 edition. NCWRC, Raleigh, NC. Available from https://www.ncwildlife.org/Conserving/Programs/Green-Growth-Toolbox/Download-Handbook

NCWRC Green Growth Toolbox, including workshops, data, technical assistance, site assessment, and other resources: https://www.ncwildlife.org/conserving/programs/Green-Growth-Toolbox.

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The Southeast Conservation Adaptation Strategy (SECAS). 2022. The Southeast Conservation Blueprint. SECAS, Raleigh, NC. Available from https://secassoutheast.org/blueprint.

Corridor ecology and conservation

Conservation Corridor: Connecting Science to Conservation. https://conservationcorridor.org/.

Hilty, JA, ATH Keeley, WZ Lidicker, Jr, AM Merenlender, editors. 2019. Corridor ecology: linking landscapes for biodiversity conservation and climate adaptation. Second edition. Island Press, Washington, DC.

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LANDSCAPE CONSERVATION AND CONNECTIVITY PLANNING

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Bentrup, G. 2008. Conservation buffers: design guidelines for buffers, corridors, and greenways. General Technical Report SRS-109. US Department of Agriculture, Forest Service, Southern Research Station, Asheville, NC. Available from https://www.fs.usda.gov/nac/buffers/index.html.

Breuer, A, B Hance, R Callahan, R Ament, Z Wurtzebach, A Wearm. 2022. Ecological connectivity policy compendium: U.S. policies to conserve ecological connectivity, 2007-2021. Center for Large Landscape Conservation, Bozeman, MT. Available from https://doi.org/10.53847/KBWT3277.

Conservation Corridor: Corridor Policy Digest. https://conservationcorridor.org/category/digests/corridor-policy/.

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Conservation Corridor: Corridor Toolbox. https://conservationcorridor.org/corridor-toolbox/.

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LANDSCAPE CONSERVATION AND CONNECTIVITY PLANS FROM OTHER REGIONS

Conservation Corridor: Connectivity Plans Library. https://conservationcorridor.org/connectivity-plans-library/.

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Southeast Aquatic Resources Partnership. Resources for culvert assessment. https://southeastaquatics.net/ and https://southeastaquatics.net/sarps-programs/southeast-aquatic-connectivity-assessment-program-seacap/culvert-assessments/sarp-culvert-assessment-manual.

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For more information on this project, please contact the Durham County Open Space Program.