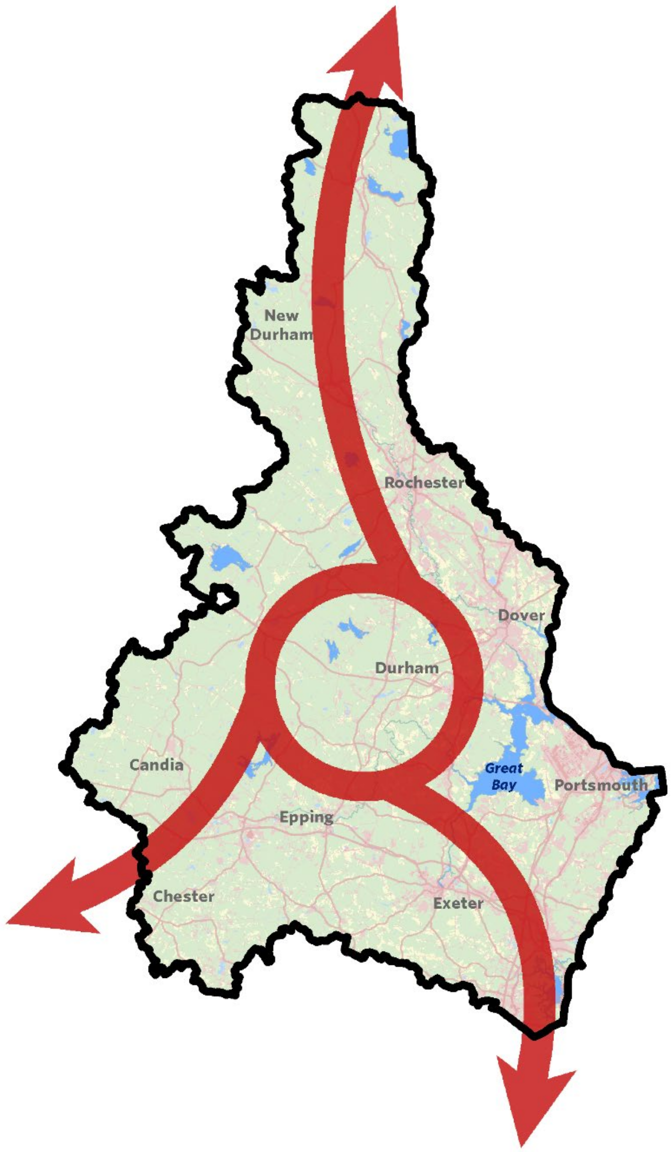
Connect THE Coast

Linking Wildlife Across New Hampshire's Seacoast and Beyond



Final Report: 10/31/2019

Authors: Peter Steckler and Dea Brickner-Wood

The Nature Conservancy New Hampshire

Great Bay Resource Protection Partnership

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Connect THE Coast was developed and completed in partnership with many organizations. An Advisory Committee, comprised of members from the Great Bay Resource Protection Partnership (GBRPP), provided high-level guidance throughout the project. A Technical Committee, comprised of GIS, wildlife, and transportation professionals, guided modeling and prioritization decisions for the project's focal species. Both committees provided invaluable support and guidance from project start to finish. Committee members included:

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Key to Partner Acronyms

BPRG	Bear-Paw Regional Greenways	SPNHF	Society for the Protection of New Hampshire Forests
GBNERR	Great Bay National Estuarine Research Reserve	TNC	The Nature Conservancy
ME DOT	Maine Department of Transportation	UNH	University of New Hampshire
ME IFW	Maine Inland Fisheries and Wildlife	UNHCE	University of New Hampshire Cooperative Extension
NHA	New Hampshire Audubon	US EPA	United States Environmental Protection Agency
NH DOT	New Hampshire Department of Transportation	US FWS	United States Fish and Wildlife Service
NHFG	New Hampshire Fish & Game Department	US NRCS	United States Natural Resource Conservation Service
SELT	Southeast Land Trust		

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Executive Summary

Over the last 25+ years, a concerted effort has helped protect large blocks of wildlife habitat across the seacoast region. However, a rapidly developing landscape and expanding road network is increasingly fragmenting these habitat blocks from one another. This fragmentation threatens the ability for native wildlife to move among areas of suitable and required habitats, which is vital to their survival.

Many of our native species, such as turtles and amphibians, need to access multiple habitat types to complete their life history cycles. Other species maintain large home ranges that cannot be accommodated by a single patch of habitat. With climate change, we are seeing changes in the distribution of suitable habitat; places that once met the needs of a particular species are becoming unsuitable as temperature and precipitation change, whereas other locations are becoming newly suitable. Independently, the challenges to wildlife posed by habitat fragmentation and climate change are daunting enough; together these challenges command an urgent response for landscape planning and management actions. Maintaining a connected network of natural habitats is the best way to ensure our native species can move over time to adapt to these changes.

Connect THE Coast used spatial models to identify connecting lands for wildlife across the 10-mile buffered portion of the Piscataqua-Salmon Falls watershed that drains through New Hampshire. As a result, identified wildlife corridors (i.e. connecting lands and waters with suitable and intact dispersal habitat) encompass just ten percent of the project area. However, only 13 percent of these wildlife corridors are conserved. Nineteen percent of the project area is prioritized as unfragmented habitat for wildlife, that is, the large unfragmented blocks of natural habitat that the corridors run between. Nearly half of these core habitats are conserved.

Priority road segments were identified at the intersection of the region's road network with Connect THE Coast wildlife corridors and prioritized habitat blocks. These are places where transportation best management practices should be deployed to facilitate safe and reliable road crossings for wildlife and motorists. Nearly 680 (7.1%) of the project area's 9,523 miles of road network (all road classes including private) are identified as high priorities for wildlife passage. Of the 7.1%, 324 miles (3.4%) are associated with wildlife corridors, while 355 miles (3.7%) are associated with prioritized habitat blocks.

Connect THE Coast priorities provide the necessary information for stakeholders, whether land trusts, town planning and conservation boards, state regulators, road managers, project funders, or landowners, to identify the places to protect that will maintain opportunities for wildlife to move across the landscape, both now and into the future. While meaningful protection has begun, more focused and deliberate protection is required to secure a connected network of lands for sustainable wildlife populations.

1. Introduction

Southeastern New Hampshire offers a rich mix of natural landscapes. Beaches, barrier islands, rocky coasts and estuaries to the east grade into Appalachian oak-pine and hemlock-hardwood-pine forests to the west. Freshwater streams, both large and small, run eastward through wetland complexes, lakes and ponds. These diverse habitats support a broad suite of wildlife, including white tailed deer, black bear, bobcat, coyote, fox, fisher, mink, and otter, to name a few. Rare, threatened and endangered species, such as Blanding's and Spotted turtles, New England cottontail, and black racer are conservation priorities here.

The natural landscapes that support the region's wildlife—both common and uncommon—have also proved desirable to people. Rockingham and Strafford counties have some of the highest population growth rates in the state (Piscataqua Region Estuaries Partnership 2018). The resulting land conversion and development continues to eat away at high-quality habitat areas, and an expanding transportation network further fragments remaining natural areas. While discreet blocks of important wildlife habitat are permanently protected, the critical connections between them for wildlife to persist and thrive are increasingly at risk.

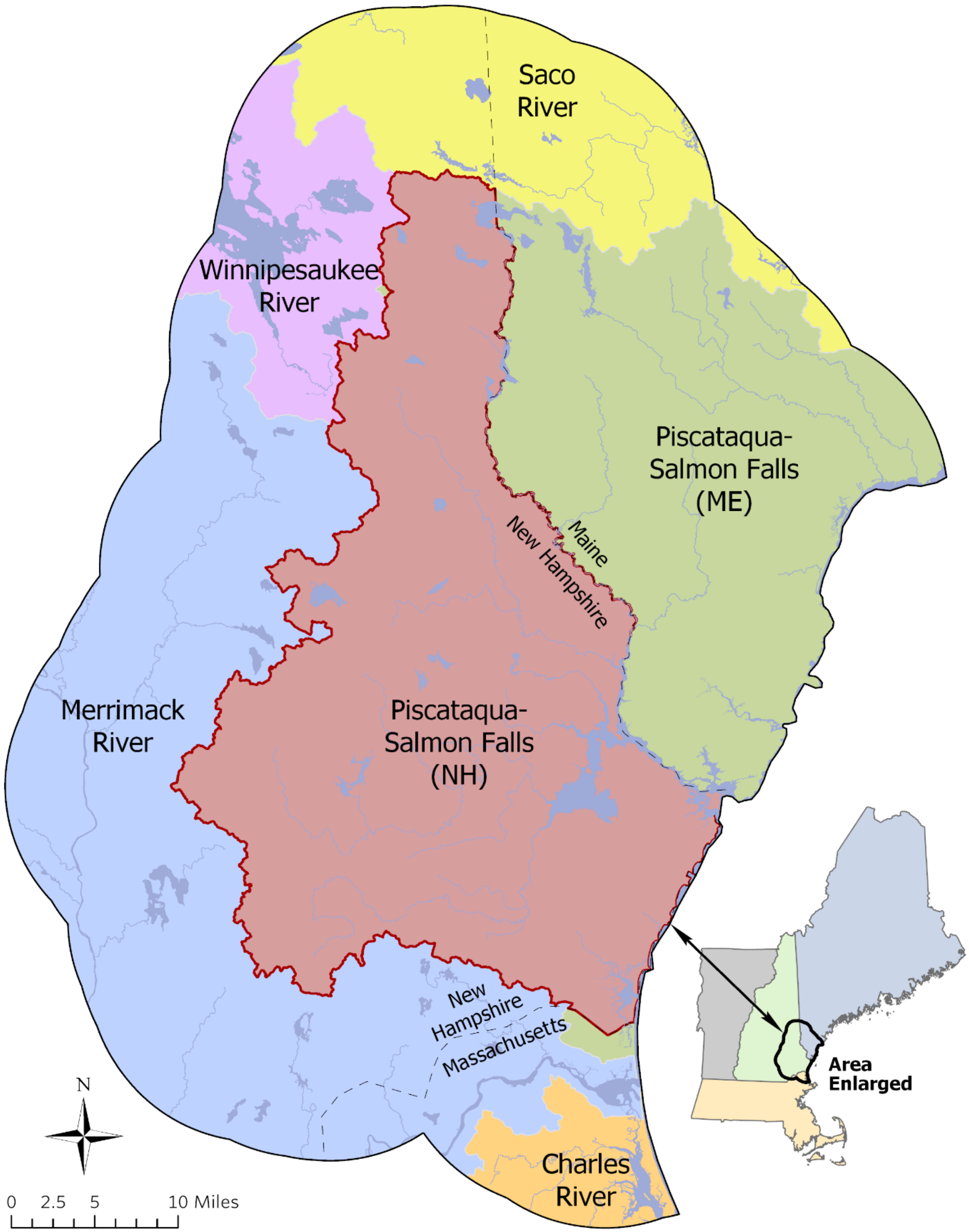
Connect THE Coast is an initiative to identify networks of connecting lands for wildlife across southeastern New Hampshire, including connections into Massachusetts and Maine, in response to increasing habitat fragmentation. The project is centered on New Hampshire's coastal watershed, which includes Atlantic coast drainages along the outer coast and the Salmon Falls-Piscataqua Rivers watershed. Connections to adjacent watersheds to the south, west, and north were identified to facilitate cross-watershed wildlife connectivity planning and implementation.

This report describes the context and need for Connect THE Coast, details project methods, presents results, and identifies next steps.

Project Area

The Connect THE Coast project area is centered on the Piscataqua-Salmon Falls watershed that drains through New Hampshire. The project area was expanded to include a 10-mile buffer around the coastal watershed to facilitate cross-watershed wildlife connectivity planning and implementation. As a result, wildlife connections were addressed into the Charles, Merrimack, Winnipesauke, and Saco River watersheds to the south, west, north, and east, respectively. Figure 1 shows the project area.

Figure 1: The Connect THE Coast project area is centered around NH's coastal watershed, with connections into adjacent watersheds including the Charles, Merrimack, Winnipesaukee, Saco, and the Maine portion of the Piscataqua-Salmon Falls watersheds.



In total, the Connect THE Coast project area totals nearly 1.7 million acres spread across Massachusetts, New Hampshire, and Maine. Table 1 details the area of each state within the Connect THE Coast project area, and each state's relative percent of the project area.

Table 1: Connect THE Coast project area's geographic distribution in each state, and each state's relative percent of the project area.

State	Project Area (Acres)	Percent of Project Area
MA	108,179	6.4%
NH	1,126,205	66.6%
ME	455,582	27.0%
TOTAL	*1,689,966*	-

Conservation Context

There is a long history of conservation accomplishments protecting critical lands in New Hampshire's coastal watershed, with over 82,000-acres (15.4%) permanently protected (NH GRANIT 2018). At the heart of New Hampshire's coastal watershed is Great Bay, an estuarine ecosystem recognized for its significance from local to national scales. The Great Bay estuary has been designated a conservation priority by the National Oceanic and Atmospheric Administration through designation of the Great Bay National Estuarine Research Reserve, Important Bird Area, NH Wildlife Action Plan, North American Wetland Conservation Plan (International Focus Area), and the U.S. Environmental Protection Agency's NH Resource Protection Project.

Since 1994 the Great Bay Resource Protection Partnership (GBRPP), a group of regional conservation partners, has led a collaborative effort to increase the pace of conservation to protect the region's most significant natural resources. The GBRPP and conservation partners have strategically focused protection efforts based on focus areas identified over multiple conservation planning cycles. Focus areas were initially identified in the 1997 *Habitat Protection Plan* (Brickner-Wood 1997) and subsequent field inventories, and further refined by the 2006 *Land Conservation Plan for New Hampshire's Coastal Watersheds* (Zankel, et al. 2006), referred to as the "Coastal Plan". A supplement to the 2006 plan was developed in 2016 titled *Land Conservation Priorities for the Protection of Coastal Water Resources* (Steckler, Glode and Flanagan 2016).

The 2006 *Coastal Plan's* conservation focus areas were identified as the most critical conservation priorities at the time and have been a major driver of regional land protection. These focus areas provide habitat for many of the wildlife species that occur across southern New Hampshire, and are well represented by wildlife habitat protection priorities identified in NH's Wildlife Action Plan (New Hampshire Fish and Game Department 2015). Seventy two percent of the *Coastal Plan's* core conservation focus areas are also tier 1 or tier 2 wildlife action plan priorities (highest ranking in the state and biological region, respectively). In total, 44,678

(33%) of the 136,551 acres of core conservation focus areas from the 2006 *Coastal Plan* are permanently protected.

Despite intensive land conservation efforts to protect the 2006 core conservation focus areas, estimated to exceed one hundred million dollars in habitat protection, there is a real threat that conserved areas across New Hampshire's coastal watershed will become a series of isolated habitat islands or blocks. Habitat blocks are typically separated by intersecting roads and associated land development, such as homes, businesses, and industry. As land conversion expands and roads are upgraded accordingly, these fragmenting features become increasingly difficult for wildlife to reliably and safely navigate. Fragmenting features are both perceived barriers that wildlife avoid and physical barriers where wildlife are blocked or killed, such as by vehicle collisions.

It is critical to maintain connections between habitat areas to support the long-term sustainability of wildlife populations. For example, many of our native species, such as turtles and amphibians, need to access multiple habitat types to complete their life history cycles (i.e. breeding habitat, overwintering sites, etc.). Other species maintain large home ranges for hunting, foraging, or seasonal movements that cannot be accommodated in single patches of habitat. In addition, individuals need to be able to find others of their kind to maintain viable populations, and individuals moving among populations can help to rescue populations close to local extinction, or restart extinct local populations.

With climate change, the distribution of suitable habitat is shifting; places that once met the needs of a particular species are becoming unsuitable as temperature and precipitation change, whereas other locations are becoming newly suitable. Migration pathways must enable species to move and re-distribute to newly suitable habitat. Maintaining a connected network of natural habitat is the best way to ensure our native species can move over time to adapt to these changes.

To-date, there has been a lack of wildlife connectivity conservation priorities or vision for New Hampshire's coastal watershed. The Connect THE Coast project utilized the best available science to develop a comprehensive connectivity plan to benefit wildlife now and well into the future.

Historic Context of Land Use in the Coastal Watershed

The historic and cultural resources of the region have long been shaped by the natural landscape. For thousands of years, Native Americans of the Abenaki and other nations inhabited ancient villages throughout the coastal region, sustained by abundant natural resources including fish, shellfish, waterfowl and mammals.

In the early 1600's European explorers, followed by settlers, discovered the region's rich natural resources that had supported the Native Americans. Early settlements were established in Rye, Portsmouth and Dover Point, and expanded along the river corridors. The region became an important fishing area, with other natural resource trades following. Goods such as fish, furs, and lumber were transported along tidal rivers. The region's forests were replaced by farms, and industries for ship building, brickyards and sawmills developed.

The late 1700s and early 1800s brought manufacturing to the shores of tidal towns such as Exeter and Newmarket. Advances and shifts in modes of transportation, from waterways to the introduction of the Boston and Maine railroad around 1840, and eventually the introduction of roads, directed patterns of growth in the region that are still prominent today. Beginning in 1926, U.S. Route 4 connected the southern and central part of the State from Portsmouth to Vermont. In 1950, U.S. Route 95 was completed as part of the Interstate Highway System. I-95 provided a highway corridor connecting points north in Maine and south in Massachusetts.

Conversion of the predominantly agricultural landscape to other uses was in full swing by the mid to late 1900s. From 1962 to 1998, in the coastal communities surrounding Great Bay, land devoted to agriculture declined by 40%. Forest cover increased by 9%, while lands used for residential and commercial development increased by 46%. During that same period, land devoted to transportation infrastructure increased by 18%. Population growth, fueled by the expansion of transportation systems and other economic drivers over this period, drove sprawling residential and commercial development. Land conversion patterns resulted in an increase in impervious surfaces, habitat loss and fragmentation, and loss of productive agricultural and forest lands (Mills 2011).

Current Connectivity Challenges

More recently, the region's attractive quality of life, geographic position, and natural landscape continues to attract residents, businesses, and industry. The state's transportation network has expanded to accommodate this growth, through both upgrades to existing roads and the construction of new roads and bypasses. For example, the expansion of NH Route 101 in 2001 to a 4-lane divided highway introduced the watershed's most prominent east-west transportation corridor with high-speed access between Manchester and Hampton. That same year high speed rail was introduced connecting Dover, Durham, and Exeter to Boston and Portland. Increased access to major economic hubs such as the greater Boston area and Manchester, and economic expansion and modernization within the watershed in places like Portsmouth, are fueling growth and development in this desirable region to live, work, and visit.

The Piscataqua Region Estuaries Project, through their State of the Estuaries Report (2018) tracks 23 indicators that relate to estuary health. Two indicators, changes in population and housing, are also indicators of development pressure, demand for resources, and loss of open space, which can drive habitat fragmentation and loss of landscape connectivity. Key findings include:

- Between 1990 and 2015, the combined population of the 52 Maine and New Hampshire towns in the Piscataqua Region watershed grew by 38% from 280,205 to 386,658. During that time, Strafford County became one of the fastest growing counties with the highest percent increase (9.7%).

- Between 2000 and 2015, a total of 19,483 multi-family and single-family new housing permits were issued in the 42-New Hampshire communities of the coastal watershed. Ten coastal watershed towns had the largest absolute changes in housing units in New Hampshire. Growth was distributed throughout the region – in communities along the coast and around Great Bay, and in the upper reaches of the watershed.
- Between 1990 and 2010, impervious surfaces in the watershed increased by 120%, and has continued to increase from 2010 to 2015.

The indicators above describe rapid population growth and development pressure within the project area, and there is no end in sight. Population projections indicate a continued pattern of steady growth looking forward. Over the twenty-five year period between 2015 and 2040, the population in the three-county coastal watershed region of New Hampshire is projected to grow by 9.4% (Office of State Planning 2016). This growth is expected to further threaten wildlife's ability to move and redistribute through increased habitat loss and fragmentation.

Independently, the challenges to wildlife posed by habitat fragmentation and climate change are daunting enough; together these challenges command an urgent response for landscape planning and management actions. Securing wildlife connectivity pathways now, before they are lost to expanding development, is a critical need for the protection of New Hampshire wildlife. While meaningful protection has begun, more focused and deliberate protection is required to secure a connected network of lands for sustainable wildlife populations.

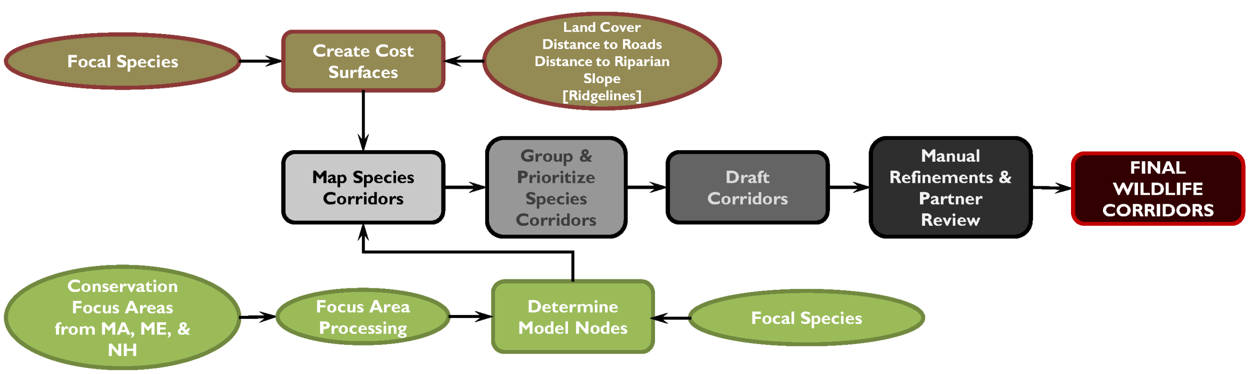
2. Methods

This section details the methods undertaken to complete connectivity modeling efforts. Project committees were established to advise and guide project activities. An Advisory Committee was comprised of members of the Great Bay Resource Protection Partnership, which provided high-level guidance regarding the project goal, project partners to engage, and were a sounding board for project ideas and methodologies. A Technical Committee was comprised of GIS, wildlife, and transportation professionals, which provided support in the selection of focal species, data inputs and development, modeling approach, selecting prioritizing habitat blocks for corridor modeling, and reviewed project results.

Modeling Overview

Computer models were used to identify intact wildlife movement corridors across the project area. Figure 2 provides an overview of the corridor development process. The Linkage Mapper (McRae and Kavanagh 2016) software program was used to identify wildlife corridors for eleven representative focal species between 153 prioritized habitat blocks. This approach uses "cost surfaces", which define areas that are permeable or resistant to movement across the landscape. The Wildlife Connectivity Model for New Hampshire (NH Audubon and NH Fish and Game Department 2016) is the basis for identifying movement and dispersal parameters that are incorporated into each of the focal species cost surfaces. The Wildlife Connectivity Model for New Hampshire's documentation is included in Appendix A.

Figure 2: A conceptual depiction of the wildlife corridor development process. The top row represents the construction of species cost surfaces. The bottom row represents the determination of nodes (i.e. start/end destinations) for modeling corridors. The middle row represents the process of mapping, prioritizing, and refining wildlife corridors.



Once run in Linkage mapper, corridors for each species were combined and prioritized to identify areas on the landscape permeable to the largest number of focal species. Ultimately, the goal was to identify the essential network of corridors necessary to maintain connectivity between the prioritized habitat blocks. Intensive quality control was completed to verify that the resulting prioritized corridors are intact; manual refinements were undertaken as necessary to adjust corridors where modeling results and underlying land use conflicted. Additional details about the steps in the modeling process are provided in the following sections.

Focal Species

Eleven focal species were selected to represent the dispersal characteristics of the broader suite of wildlife that occur or might occur in the future within the project area. Generalist species included black bear (*Ursus americanus*), bobcat (*Felis rufus*), fisher (*Martes pennant*), porcupine (*Erethizon dorsatum*), and black racer (*Coluber constrictor*). Riparian-associated or dependent species include long-tailed weasel (*Mustela frenata*), mink (*Neovison vison*), otter (*Lutra canadensis*), Blanding's turtle (*Emydoidea blandingii*), and spotted turtle (*Clemmys guttata*). New England Cottontail (*Sylvilagus tranisitionalis*) was also included as a habitat specialist species.

Selecting Prioritized Habitat Blocks used as Modeling Nodes for Corridor Mapping

Existing conservation plans were used in the selection of prioritized habitat blocks, referred to in this section as "nodes", to use in the connectivity modeling process. For Massachusetts the *BioMap2* (MassGIS et al. 2017) focus areas were used. *Beginning with Habitat* (Maine Department of Inland Fisheries and Wildlife 2017) focus areas were used in Maine. Regional watershed-based plans were used for the New Hampshire portion of the project area. These included core areas from the *Land Conservation Plan for New Hampshire's Coastal Watersheds* (Zankel, et al. 2006), the highest scoring conservation focus areas from *A Land Conservation Plan for the Merrimack River Watershed of New Hampshire and Massachusetts* (Sundquist and Deely 2014), and a selection of the larger core conservation focus areas from the *Lakes Region Conservation Plan Update* (Sundquist 2018).

Where conservation plan priorities overlapped, the following decisions were made: (1) BioMap2 superseded the Merrimack River Watershed Plan, and the Land Conservation Plan for New Hampshire's Coastal Watershed superseded all other overlapping plans. All nodes were checked against NH's Wildlife Action Plan tier one and two priorities and expanded within roadless blocks to match. All nodes less than 50-acres were removed.

Additional processing of nodes was undertaken to improve the efficiency and effectiveness of the model. These included the following steps:

- All nodes were initially trimmed by a 100-meter buffer of the untransformed average annual daily traffic rate (University of Massachusetts 2017) roads layer with an annual average daily traffic rate of greater than 100 vehicles per day. This step was undertaken to allow the least-cost corridor model to evaluate the most suitable dispersal habitat on both sides of a road-bounded node, not just the outside area.
- Each node was reviewed using the latest available aerial photos. Small isolated patches of nodes fragmented by roads were removed, especially if not connected through conserved land. Nodes were trimmed to exclude recent areas of development.

- Node boundaries were adjusted in some cases to help identify key connections. For example, Pawtuckaway Lake was removed from its node so the model could run from the forested edge of conserved land rather than from the opposite side of lake that is developed. In some cases, nodes were split into two separate nodes if fragmented by a road without connecting conservation land on both sides. This allowed the model to identify key connections across the fragmenting feature.
- For large nodes with significant contiguous conserved land (i.e. Bear Brook and Blue Hills), nodes were shrunk to match the conserved land area. This was done to prioritize connectivity to the existing conservation block rather than to the edge of an unprotected area.
- For large nodes with significant conserved land in discrete assemblages (i.e. Mount Agamenticus and Blue Hills), the existing conservation lands were used to divide the focus area into separate nodes. This was done to prioritize connectivity opportunities within the larger conservation focus area.
- Nodes were merged together if they are already connected by abutting conservation land across a road. Merging of these connected lands reduces the number of modeled connections run through the Linkage Mapper (McRae and Kavanagh 2016) tool, allowing the modeling process to identify the least costly connection to one node rather than to two or more.
- Nodes were merged where a clear and contiguous wetland connection exists and other habitat connections are limited because of development.
- Existing conservation lands that extended beyond node boundaries were merged to build upon the existing network of protected and connected lands. Not all conservation lands were added in, such as when a conserved land addition would favor a shorter pathway through a more fragmented area with limited or no opportunities for connectivity. In these areas the conservation lands were not added to let the model determine the most appropriate connections.
- Stepping stone nodes were added in cases where long distances (i.e. >30,000 Euclidean distance value based on the bobcat cost surface) separated nodes from the source conservation plans. Stepping stone nodes were added in these areas based on larger assemblages of conservation land, Wildlife Action Plan tier one and two areas in New Hampshire, or unfragmented habitat blocks.

Species-Specific Modeling Nodes

The entire extent of the prioritized habitat blocks, or nodes, were used as start and end locations for generalist species corridors, which include bobcat, bear, fisher, porcupine, black racer, and long-tailed weasel. That is, least-cost corridors were run from the outer edge of these nodes regardless of dispersal habitat within the node. The remainder of the species are more dependent upon certain habitat types. Modeling a pathway to the edge of a node may be insufficient for these species if their required habitat is unavailable there. Table 2 details how model nodes were refined to identify connecting corridors to the habitat required by the specialist species.

Table 2: Model node refinement details for specialist species.

Species	Species-specific model node refinements for specialist species
Mink/otter	Limited to low cost patches (<12.3) greater than 10 acres in size
Blanding's turtle	Limited to suitable NWI wetland types* greater than two acres in size
Spotted turtle	Limited to suitable NWI wetland types* greater than two acres in size
New England Cottontail	Limited to low cost patches (<16.5) greater than 5 acres in size

* Suitable NWI wetland types include freshwater emergent wetland, freshwater forested/shrub wetland, freshwater pond, or riverine.

Cost Surface Development and Data Inputs

Species cost surfaces were developed according to the Wildlife Connectivity Model for New Hampshire (NH Audubon and NH Fish and Game Department 2016), which is included in Appendix A. This modeling approach computes a wall-to-wall raster dataset (30-meter resolution) that represent different levels of resistance to a species moving across the landscape. Each raster cell is computed based on underlying landscape factors related to land cover, proximity to roads, proximity to riparian areas, slopes, and for some species, ridgelines. In each of the cost surfaces, low resistance habitats for dispersal have low values (i.e. low cost) and high resistance areas have high values (i.e. high costs). Table 3 details the data inputs and sources used to build the focal species' cost surfaces.

Table 3: Data input factors by geographic extent and source used to generate species cost surfaces.

Data Input Factor	Geographic Extent	Data Source
Land Cover	Project Area	2011 National Land Cover Dataset (U.S. Geological Survey 2014)
Wetlands	Piscataqua-Salmon Falls and Merrimack watersheds	National Wetlands Inventory (NWI) Plus (New Hampshire Department of Environmental Services 2017)
Wetlands	Remaining project area in New Hampshire, Maine and Massachusetts not covered by NWIPlus extent	National Wetlands Inventory Version 2 (U. S. Fish and Wildlife Service 2017)
Surface Water	USGS National Hydrography Dataset Plus High Resolution	USGS National Hydrography Dataset Plus High Resolution (U.S. Geological Survey 2017)
Roads	Entire project area	Untransformed average annual daily traffic rate (McGarical, et al. 2018)
Railroads	Massachusetts Maine New Hampshire	Trains (MassGIS 2014) RailRouteSys (Maine Dept. of Transportation 2011) NH Railroads (NH Department of Transportation 2017)

Elevation	United States & Canada	USGS NED 1/3 arc-second ArcGrid 2017 (U.S. Geological Survey 2017)

Because of the similarities in landscape factors identified for the dispersal of black bear and bobcat, and mink and otter, respectively, these species were combined during the modeling process. The Technical Committee agreed that when combining species, the higher cost parameters would be used when input parameters differed.

Land Cover Factor

The Wildlife Connectivity Model for New Hampshire (NH Audubon and NH Fish and Game Department 2016) was developed using land cover classes from the 2001 Land Cover Assessment. 2011 National Land Cover (U.S. Geological Survey 2014) data was used for Connect THE Coast modeling, so species dispersal values needed to be translated from the 2001 land cover classes to 2011 classes. Table 4 details the cross-walked land cover classes and additional land cover updates applied from other data sources.

Table 4: Cross-walked land cover classes from 2001 NH Land Cover Assessment classes to 2011 National Land Cover Dataset classes, with additional land cover updates applied from other data sources.

2001 NH Land Cover Assessment Classes	2011 National Land Cover Dataset Classes	Comments
Developed - High	Developed High Intensity	
Developed - Medium	Developed, Medium Intensity	
Developed - Low	Developed, Low Intensity	
Developed - Low	Developed, Open Space	
Agriculture	Cultivated Crops	
Orchard	Pasture/Hay	Used orchard values for greater permeability
Orchard	Grassland/Herbaceous	Used orchard values for greater permeability
Hardwoods	Deciduous Forest	
Softwoods	Evergreen Forest	
Mixed forest	Mixed Forest	
Transitional-Successional	Shrub/Scrub	
Forested wetland	Woody Wetlands	
Open wetland	Emergent Herbaceous Wetlands	
Developed - Low	Barren Land	Based on 2015 aerial review, Barren Lands are maintained open or developed. Appropriate to assign a higher cost than “bedrock-vegetated”, but not as high as Developed-High or Medium
Open water	Open Water	
Updates from Other Sources		

Open Water >.25mi wide	Open Water >.25mi wide	Added in from NHDPlus
Forested wetland	NWI PFO	Added in from NWI
Open wetland	NWI PEM & PSS	Added in from NWI
Tidal wetland	NWI E2	Added in from NWI

Distance to Roads Factor

Resistance curves were applied to categories of untransformed average annual daily traffic rates (UMASS 2017) and active railroads according to the Wildlife Connectivity Model for New Hampshire (NH Audubon and NH Fish and Game Department 2016). Applying a resistance curve to a road centerline creates a raster dataset with higher costs directly adjacent to the road that diminish at specified rates moving away from the road until no effects are predicted. The curves predict the severity of effects of different road classes. For example, some species' movements are primarily affected in close proximity to roads while other species are sensitive to roads even from a distance.

Distance to Riparian Areas Factor

Resistance curves from the Wildlife Connectivity Model for New Hampshire (NH Audubon and NH Fish and Game Department 2016) were applied to riparian areas to predict how focal species will disperse across the landscape in relation to riparian habitats. Riparian associated or dependent species are predicted to disperse in closer proximity to riparian areas based on their assigned resistance curve, whereas generalist species are predicted to have a slight preference for traveling through riparian areas but are not restricted to them.

Slope Factor

Resistance curves from the Connectivity Model for New Hampshire (NH Audubon and NH Fish and Game Department 2016) were applied to slopes generated from a 10-meter digital elevation model (U.S. Geological Survey 2017). Some species are much more sensitive to slopes when dispersing, which is represented by the curves. For example, the curves indicate that the turtle species are very slope sensitive, while most of the other focal species, with the exception of New England cottontail and porcupine, are quite tolerant of steep slopes when dispersing.

Combining Factors into Species Cost Surfaces

The landscape factors described above were combined in ArcGIS 10.3 (ESRI 2014) using the Weighted Sum tool to create species cost surfaces. The Connectivity Model for New Hampshire (NH Audubon and NH Fish and Game Department 2016) specifies the species-specific relative influence of each of the factors during the weighted sum process.

Applying the Ridgeline Modifier

A ridgeline modifier was developed to identify generalized ridge features on the landscape. Applying a ridgeline modifier slightly lowers the cost surface values along ridge areas for ridge-using species. For these ridge-using species, the model is more likely to route predicted species movements through the lower cost ridge features if they provide a lower cost alternative to the non-ridge surrounding landscape. The ridgeline modifier reduced cost surface values by two points within ridge areas and it had no effect on the remainder of cost surface values.

To develop the ridgeline modifier, the topographic position tool from the Corridor Designer (Majka, Jenness and Beier 2007) modeling package was run in ArcGIS 10.3 (ESRI 2014). The tool was run on the 10-meter digital elevation model (U.S. Geological Survey 2017) using a 200-meter circle radius search window, with canyons set at -12, ridgetops set at 10, and slopes set at 6. The resulting ridge features represent cells with elevations more than 10 cell values, or meters, higher than the average cell value within the analysis window; these were used to modify the cost surfaces of the ridge-using species.

Mapping Species Corridors using Linkage Mapper

The Linkage Mapper (McRae and Kavanagh 2016) program was used to map least-cost corridors for each of the species within ArcGIS 10.3 (ESRI 2014). The “Build Network and Map Linkages” tool was run for each of the focal species, which uses the species-specific modeling nodes (see above) and species-specific cost surfaces to map corridors between the nodes. Default program settings were used, with an optional setting of Maximum Euclidean Corridor Distance set at 30,0000 to limit excessively long-distance corridors.

Corridor Prioritization Process

Results from the “Build Network and Map Linkages” tool (see above) for each focal species were prioritized to identify overlapping least-costly corridors for the suite of focal species. The truncated 200K outputs were sliced (equal area, 100) and then reclassified using a weighted index score so that the least costly 1% grid cells were assigned a value of 20, 2% a value of 19, 3% a value of 18, and so on until the 20% grid cells were assigned a value of 1 point. All grid cells greater than 20% least costly were not included in the prioritization process. The re-assigned (or weighted) values for each species were summed together to identify co-occurring areas of least-costly movement zones. A threshold value of 50 was selected to convert co-occurring least-costly areas to a first draft of corridors.

Quality Control and Manual Refinements

Manual refinements were undertaken to ground-truth model results with underlying habitat features and land characteristics. Feasibility was a driver through this effort, with a goal of identifying the minimum and best-connected network of habitats to secure for sustained wildlife connectivity across the project area. Manual refinements were made to the corridor areas that emerged from the corridor prioritization process. Refinements were based on basic clean-up of polygon boundaries, altering boundaries using aerial photography to remove developed areas, and through reviews and feedback from the Advisory and Technical Committees.

Refinements were also made based on guiding principles agreed upon by the Technical Committee. The Technical Committee agreed that, all things being equal, riparian corridors were to be prioritized over upland corridors. This is because generalist species are likely to utilize both upland and riparian corridors, whereas riparian species are more limited to riparian corridors. Riparian corridors offer more promising road barrier mitigation opportunities through under-road passage at culverts and bridges. In addition, riparian corridors generally offer more intact habitat connections because of development limitations associated with flooding and wet conditions.

Headwater wetlands, especially those that flow across watershed boundaries in both directions, were prioritized to facilitate riparian species across watershed divides. Watershed divides typically do not have strong connections for riparian species, so these features are especially important for facilitating cross-watershed dispersal. The existing network of conservation lands was also consulted, and in some places incorporated, into the corridor refinement process.

Identifying the Intersection of Roads and Wildlife Corridors

Finalized wildlife corridors and prioritized habitat blocks were intersected with the region's road network to identify priority road crossings for wildlife connectivity. All features within the road network maintained by the state departments of transportation were included in this analysis, which includes federal, state, municipal, and private roads.

Priority road segments were attributed separately based on their intersection with a corridor or a prioritized habitat block. Review of the priority road segments was completed to ensure all relevant road features are represented and non-critical road segments were removed (such as road segments on the edge of a prioritized habitat block not influential to the broader connectivity network).

3. Results

Connect THE Coast project results are comprised of the following geospatial data layers: (1) Prioritized Habitat Blocks, (2) Wildlife Corridors, and (3) Priority Road Segments. The areas represented by these data layers represent where focused efforts can secure opportunities for wildlife to move and disperse regionally across the landscape over time. Each of these spatial products are described in the following sections.

It is important to note that the primary focus of Connect the Coast is regional scale connectivity for wildlife. An area not identified as a prioritized habitat block or a wildlife corridor does not mean that it isn't important at a local scale or as a municipal priority. Justification for impacts to wildlife habitats or wildlife corridors in areas not identified by this study is a gross misuse of its data products.

Prioritized Habitat Blocks

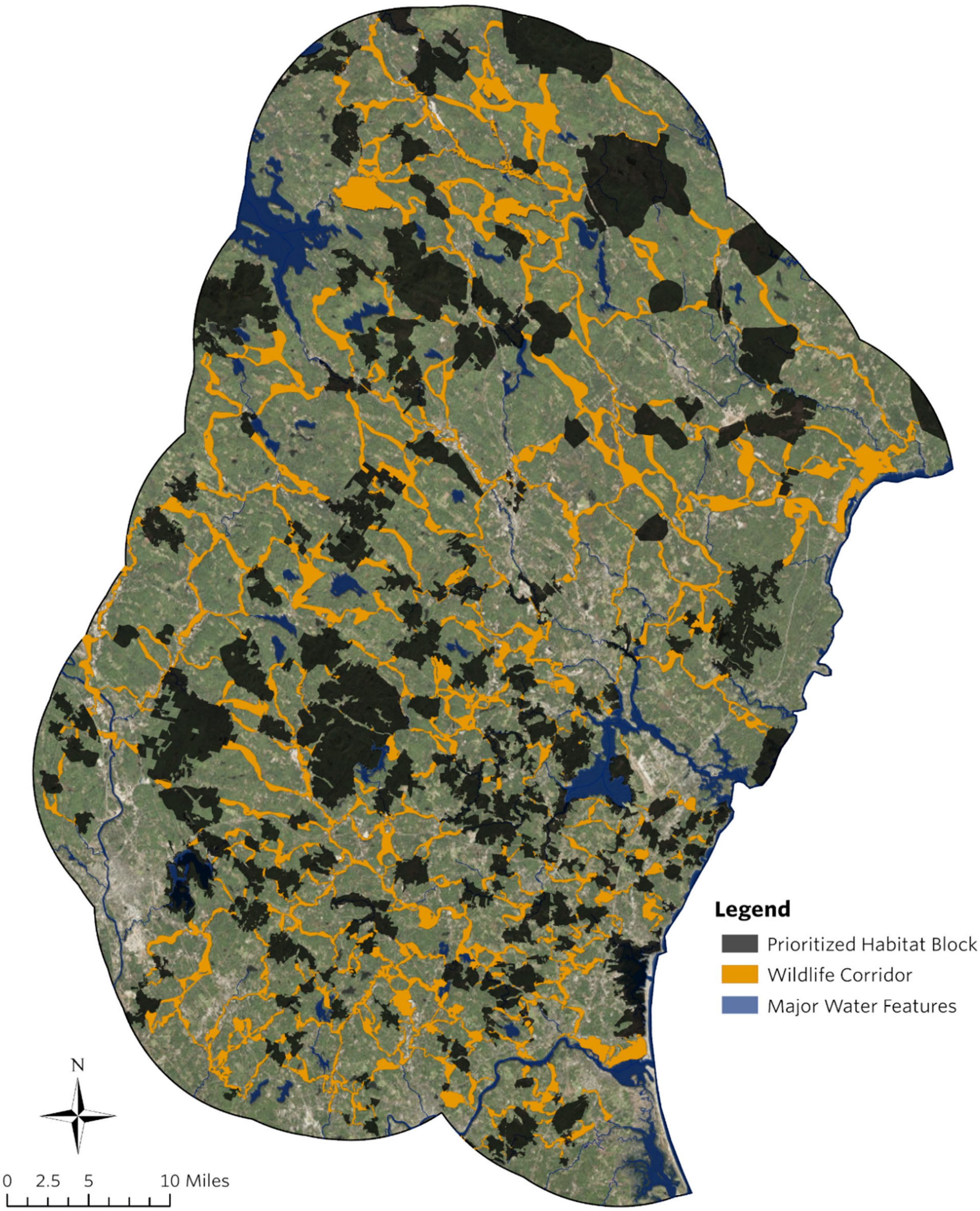
Nearly 19 percent of the project area is included in the network of prioritized habitat blocks; half of these unfragmented core habitats are conserved leaving the remaining half vulnerable to habitat loss or degradation. Figure 3 depicts the extent and pattern of prioritized habitat blocks, as well as the connecting wildlife corridors between them. Table 5 summarizes the extent of prioritized habitat blocks used as model nodes within the Connect THE Coast project area by state, in addition to the conservation status of the focus areas.

Table 5: Summary of the extent and percent of prioritized habitat blocks used as model nodes within the Connect THE Coast (CTC) project area by state, and their conservation status.

State	Area of Prioritized Habitat Blocks (Acres)	Percent of State's CTC Project Area	Area of Prioritized Habitat Block Conserved* (Acres)	Percent of Prioritized Habitat Block Conserved*
MA	10,761	9.9%	6,421	59.7%
NH	230,478	20.5%	115,248	50.0%
ME	78,903	17.3%	37,176	47.1%
PROJECT AREA	***320,142***	***18.9%***	***158,845***	***49.6%***

*Based on GAP Status codes of 1, 2, and 3's. GAP Status codes were updated for unattributed records using other conservation land attributes where possible.

Figure 3: Depiction of Connect THE Coast's prioritized habitat blocks and the wildlife corridors that connect them.



Wildlife Corridors

The total network of wildlife corridors encompasses ten percent of the project area; only 13 percent of these corridors are conserved. These corridors represent a network of connecting wildlife habitat between priority habitat blocks (see Figure 3). Table 6 summarizes the extent of corridor areas within the Connect THE Coast project area by state, in addition to the conservation status of the corridors.

Table 6: Summary of the extent and percent of wildlife corridor areas within the Connect THE Coast project area by state, and the conservation status of the corridors.

State	CTC Corridor Area (Acres)	Percent of State's CTC Project Area	Corridor Area Conserved* (Acres)	Percent of Corridor Area Conserved*
MA	10,249	9.5%	2,596	25.3%
NH	114,410	10.2%	14,652	12.8%
ME	45,109	9.9%	5,374	11.9%
PROJECT AREA	***169,767***	***10.0%***	**22,621**	***13.3%***

*Based on GAP Status codes of 1, 2, and 3's. GAP Status codes were updated for unattributed records using other conservation land attributes where possible.

Priority Road Segments

In total, nearly 680 (7.1%) of the project area's 9,521 miles of roads are identified as high priority crossings for wildlife. Figure 4 depicts the priority road segments for addressing regional wildlife connectivity, which is where prioritized habitat blocks and wildlife corridors intersect the region's road network (black and red lines in Figure 4, respectively).

Priority road segments are differentiated by their intersection with prioritized habitat blocks and wildlife corridors for three primary reasons. First, there may be a false sense of security that wildlife connectivity is not threatened within prioritized habitat blocks, especially those that are largely conserved. Yet, if prioritized habitat blocks include roads, connectivity could be threated either now or in the future through the expansion of those roads. Second, priority road segments that intersect prioritized habitat blocks have not been analyzed using habitat characteristics to prioritize the best opportunity areas for wildlife crossings in the same manner as was completed for wildlife corridors. It is likely that that the priority road segments within prioritized habitat blocks are more expansive than a narrower selection of road segments that coincide with internal wildlife movement corridors. Finally, and as detailed below, differentiating prioritized habitat blocks from wildlife corridors allows for a better understanding of the road classes that intersect these two types of resource areas.

Of the priority road segments, 355 miles (3.7%) are associated with prioritized habitat blocks and 324 miles (3.4%) are associated with wildlife corridors. Table 7 summarizes the length of project area roads by state and road class that intersect prioritized habitat blocks, wildlife corridors, a summation of the two (i.e. total priority road segment length), the total length of the respective road network, and the percentage of the respective road network designated as a priority road segment.

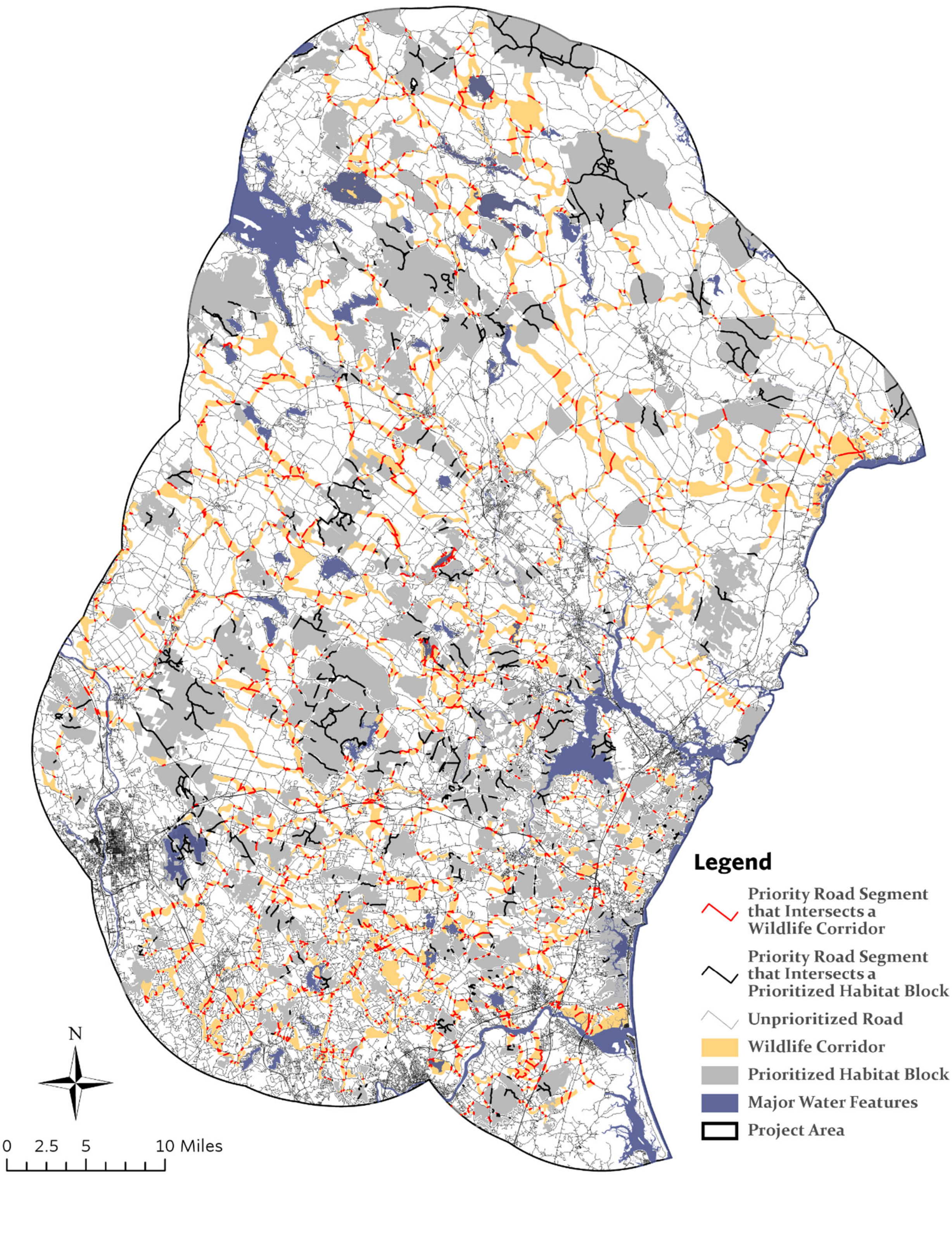
As an example, Table 7 details that there are a total of 1,483.3 miles of state roads in New Hampshire, of which just 93.6 (6.3%) are identified as priority road segments for wildlife. Of the nearly 4,000 miles of local roads in New Hampshire, just 171 miles (4.3%) are identified as priority road segments for wildlife. A higher percentage of "other" road classes are identified as priority road segments for wildlife across each of the states, especially that coincide with prioritized habitat blocks. This is likely because these undeveloped forested areas include higher densities of unmaintained (class VI), recreation, reservation, and private roads.

Table 7: The length of project area roads by state that intersect prioritized habitat blocks, wildlife corridors, a summation of the two (i.e. total priority road segment length), the total length of the road network, and the percentage of the total road network designated as a priority for wildlife.

State	Road Class	Road Length within Prioritized Habitat Blocks (Miles)	Road Length within Wildlife Corridors (Miles)	Total Priority Road Segment Length (Miles)	Total Study Area Length of Road by State and Class (Miles)	Percent of Priority Road Segment by State and Class
MA	State	0.4	7.6	8.1	144.2	5.6%
	Local	6.5	18.9	25.3	710.9	3.6%
	Other*	5.1	5.6	10.7	149.0	7.2%
NH	State	22.9	70.7	93.6	1,483.3	6.3%
	Local	66.7	104.3	171.0	3,986.2	4.3%
	Other*	164.2	70.6	234.8	1,511.2	15.5%
ME	State	16.9	16.5	33.4	442.4	7.6%
	Local	63.3	29.8	93.1	1,081.1	8.6%
	Other*	8.8	-	8.8	13.0	67.7%
PROJECT AREA		*354.8 (3.7%)*	*323.9 (3.4%)*	*678.7*	*9,521.3*	*7.1%*
COMBINED MA, NH, ME	State	40.3	94.8	135.1	2,070.0	6.5%
	Local	136.5	152.9	289.4	5,778.2	5.0%
	Other*	178.0	76.2	254.2	1,673.2	15.2%

* Other roads include all classes not categorized as state or local. These include, for example, private, recreation, reservation, and non-maintained roads.

Figure 4: Depiction of Connect THE Coast's priority road segments in conjunction with wildlife corridors and prioritized habitat blocks.



Project Data and Maps

Connect THE Coast data and maps are currently available in two formats to maximize accessibility and use. Portable Document Format (PDF) maps for every town in the study area are posted to an online file sharing site. These maps display prioritized habitat blocks, wildlife corridors, and priority road segments by road type, in addition to tax map parcels (where available), conservation lands, surface waters and wetlands, and an aerial photo background. Appendix B provides a list of towns organized by state with an internet link to download the Connect THE Coast map for each respective town. Figure 5 is an example of the town-scale maps available through Appendix B.

Online viewing and download of Connect THE Coast data is also available from the NH Coastal Viewer, an online mapping tool. The NH Coastal Viewer allows users to interact with a variety of spatial data layers in conjunction with Connect THE Coast data, such as tax parcel data, USGS topographic maps, and aerial photos. A 10-minute getting started video is recommended for users new to the NH Coastal Viewer platform.

Once on the NH Coastal Viewer, Connect THE Coast wildlife corridors and prioritized habitat blocks can be accessed from the "Layers" tab on the bottom left of the NH Coastal Viewer window. Then, follow these steps:

1. Click on the "+" mark to the left of the "Environment and Conservation" heading.
2. Click on the "+" mark to the left of the "Other Wildlife Data".
3. Click to check the box to the left of "Other Wildlife Data". This will enable the underlying layers for "Wildlife Corridor" and "Prioritized Habitat Blocks"; they will change color from gray to black.
4. To view the "Wildlife Corridor" layer, click the check box to its left.
5. To view the "Prioritized Habitat Blocks" layer, click the check box to its left.

Figure 6 is an example image of the NH Coastal Viewer. All of the viewable data layers are listed in the "Layers" tab on the left side of the image. The example image shows the order of layers that must be expanded and activated to view Connect THE Coast data layers.

Figure 5: An example of a Connect THE Coast result map generated for every project area town. These maps display prioritized habitat blocks, wildlife corridors, and priority road segments. Appendix B lists links for each town.

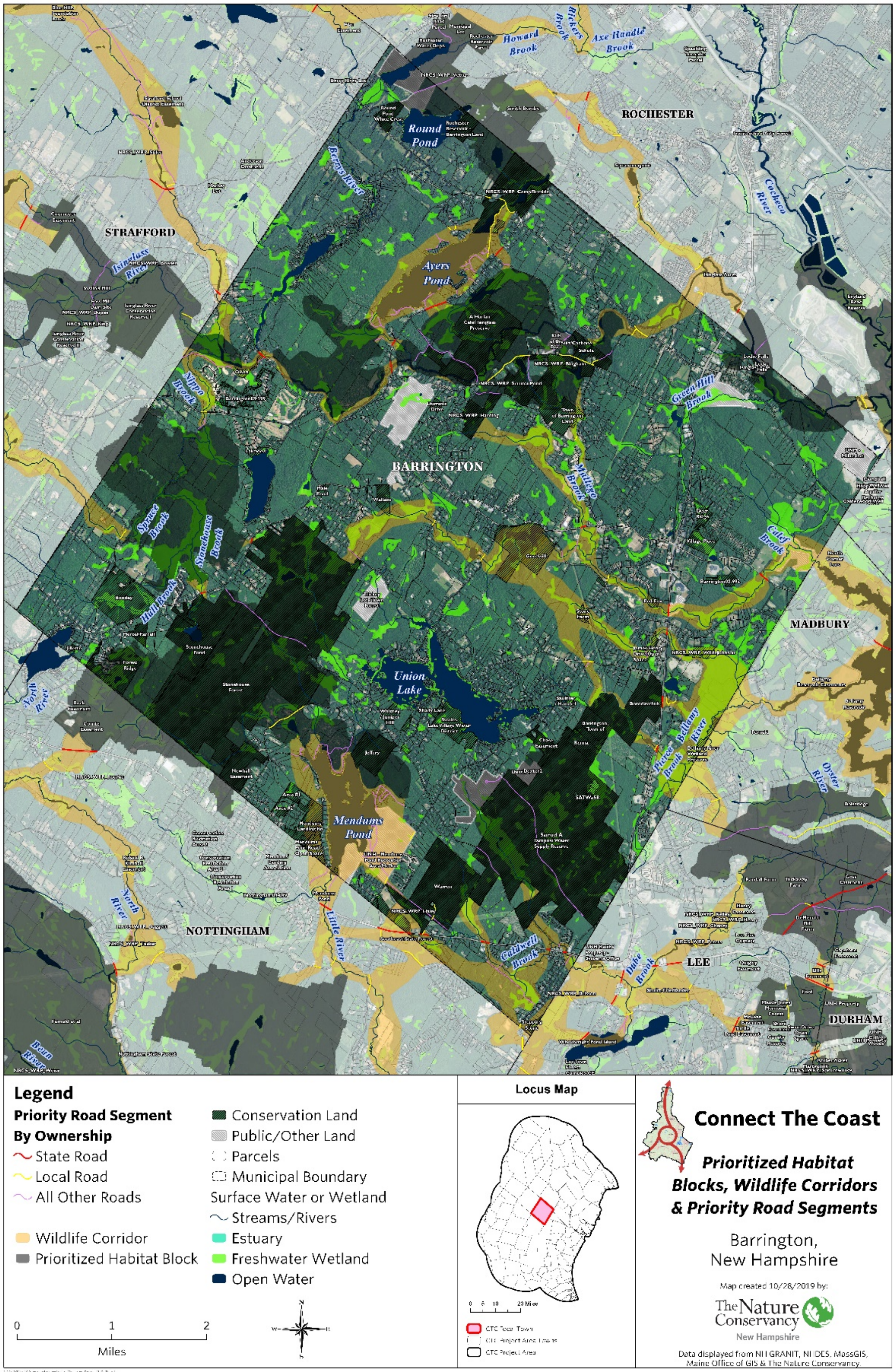
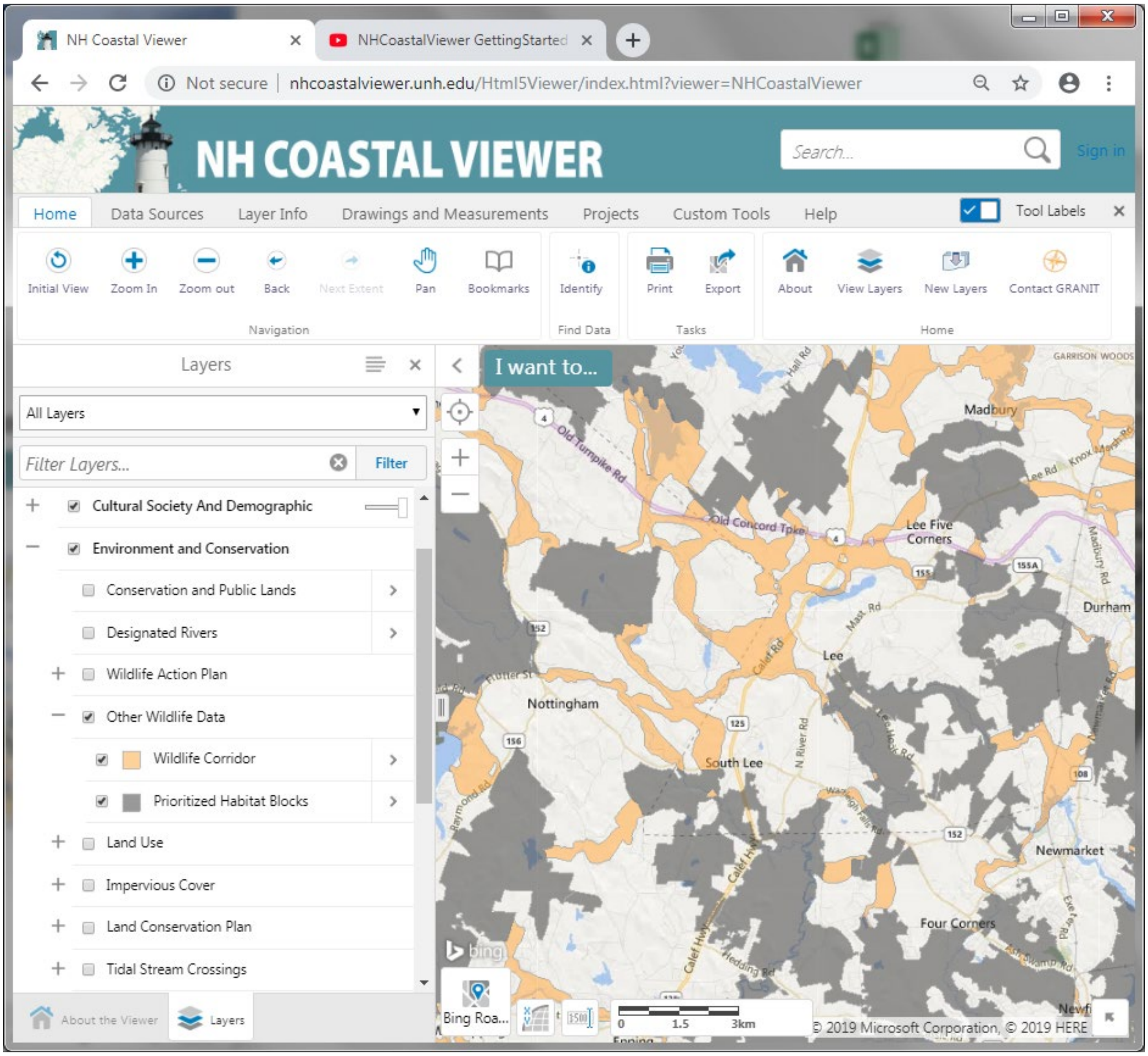


Figure 6: An example image of the NH Coastal Viewer with the Connect THE Coast data layers activated for viewing.



4. Next Steps

The Connect THE Coast project identifies spatially explicit wildlife corridors and priority road segments within and beyond New Hampshire's coastal watershed. With this foundational step complete, a series of next steps are needed to transition from planning to implementation. For the planning work of Connect THE Coast to be of real value for wildlife on the ground, it has to guide resource allocation and result in a deliberate effort to secure a connected network of lands. This section details critical next steps that will help foster this implementation.

Outreach

Land conservation through traditional fee and easement acquisitions are important and necessary implementation tactics for Connect THE Coast. However, a "buy it all" approach, especially in the near-term, is impractical to secure the entire wildlife corridor and prioritized habitat block network needed to maintain opportunities for wildlife to move across the landscape over time. Other tactics must also be deployed, such as incorporating Connect THE Coast conservation science into planning documents at state, regional, and local scales. Therefore, a broad group of decision makers, planners, funders, land trusts, resource managers, and landowners will need to work in concert to achieve the goal of a connected landscape for wildlife to persist and thrive.

Outreach activities are essential to deliver the "why" and "where" messaging about wildlife connectivity to stakeholders. How to protect landscape connectivity is equally important, but many of this initiative's stakeholders understand how to protect, regulate, or manage valuable resources once they know where they are located (see the Implementation section below for addition information). This report provides the context for why wildlife connectivity is important (see Introduction section), and the Results section details the minimum connectivity network to protect. Targeted outreach, focusing on why, where, and even how in some cases, should be conducted to the following audiences across the three-state project area:

- Land use decision makers and regulators at the state level, such as for large-scale development projects or projects with wetland impacts (e.g. in New Hampshire, the NHDES Alteration of Terrain Bureau and Wetlands Bureau).
- Regional Planning Commissions, who work both regionally and locally with municipalities, including on long and short-range transportation planning.
- Transportation managers, both at the state and municipal levels.
- Municipal planning and conservation departments, boards, and commissions.
- Land trusts that prioritize land conservation for wildlife habitat protection.
- Technical assistance organizations, such as Cooperative Extension service providers.
- Land conservation and habitat restoration funders. In NH these include the Land and Community Heritage Investment Program, The NH Department of Environmental Services' Aquatic Resource Mitigation Program, NH's Conservation & Heritage License Plate Program, and Natural Resource Conservation Service programs.

- Natural Resource professionals, who work to minimize or mitigate natural resource impacts of projects that are subject to state and/or local regulations.
- Policy makers, to support funding and initiatives that advance wildlife and landscape connectivity.

Implementation

Securing wildlife connectivity will necessitate a range of actions undertaken by Connect THE Coast stakeholders. Table 8 details these implementation actions and the relevant stakeholders necessary to advance them.

Table 8: Connect THE Coast implementation actions and the relevant stakeholders to advance them.

Implementation Action	Relevant Stakeholders
Incorporate Connect THE Coast priorities into decision making frameworks and screening tools regarding regulated resources.	• Regulators • Land use decision makers (e.g. planning boards) • Departments of Transportation (state and local) • Policy makers
Incorporate Connect THE Coast priorities into transportation, build-out, and municipal plans.	• Departments of Transportation (federal, state, local) • Regional Planning Commissions • Municipal planning departments and boards
Incorporate Connect THE Coast priorities into local planning documents such as master plans, natural resource inventories, zoning, and land use ordinances.	• Municipal planning and conservation departments
Permanently protect land that will build out the network of connected lands through fee acquisition, conservation easement, or deed restriction.	• Land trusts • State and federal land conservation programs • Land owners
Advocate for and support communities to incorporate Connect THE Coast priorities into local planning documents.	• Land Trusts • Technical assistance providers • Residents and landowners
Inform landowners of the connectivity values that their land provides at both local and regional scales	• Technical assistance providers • Land trusts • Conservation commissions

Implementation Action	Relevant Stakeholders
Provide advice/consultation on land management activities that benefit connectivity	• Technical assistance providers • State wildlife departments • Land trusts
Align conservation program funding to drive investments toward projects that build landscape connectivity.	• Land conservation and habitat restoration funders (e.g. NRCS, State programs, private foundations)
Incorporate Connect THE Coast priorities into development projects to secure wildlife connectivity, or reduce/mitigate threats to wildlife connectivity.	• Natural resource professionals
Incorporate best management practices for wildlife road barrier mitigation at priority road segments.	• Departments of Transportation (state and local)
Develop policies to maintain and enhance wildlife connectivity, such as conservation and transportation funding mechanisms.	• Policy makers

Additional Planning

Additional planning steps have been identified by project partners to integrate, prioritize and enhance Connect THE Coast results. These planning steps include:

- Complete a comprehensive update to the 2006 *Land Conservation Plan for New Hampshire's Coastal Watersheds*. Supplemental conservation planning for wildlife connectivity and water resource protection are newly available since the release of the 2006 Coastal Plan. Under the guidance of the Great Bay Resource Protection Partnership, The Nature Conservancy is beginning to undertake an effort to integrate the spatial priorities from the 2006 plan with these more recent planning efforts. Once synthesized and further prioritized, effective end-user and outreach products will be developed.
- Integrate Connect THE Coast products with State Wildlife Action Plans and their outreach programs (e.g. Taking Action for Wildlife Program in New Hampshire).
- Combine Connect THE Coast priority road segments with road-stream crossing assessment data to identify immediate opportunities for multi-benefit projects that address both terrestrial and aquatic connectivity.
- Consider how to further prioritize the network of wildlife corridors. For example, are there certain corridors that are disproportionately important to the entire network that should be focused on first?
- Build a partnership of stakeholders to pilot a local wildlife corridor protection effort. A pilot would be helpful to develop a stepwise process that other local partnerships could use as a model for initiating corridor protection throughout (and beyond) the Connect THE Coast project area.

- Connect THE Coast identified wildlife corridors into adjacent regional conservation partnership areas, such as the Merrimack watershed and the Lakes Region. For broader effectiveness beyond just the Connect THE Coast region, similar wildlife connectivity plans should be developed across adjacent geographies to the south, west, north and northeast.

5. Conclusion

Connect THE Coast is a spatially explicit vision for wildlife to persist and thrive across a connected landscape, both now and well into the future in New Hampshire's Coastal Watershed. While the rigorous mapping and modeling phase of Connect THE Coast is complete, the hard work of implementation is still to come.

Achieving long-term landscape connectivity for wildlife will require deliberate, focused, and sustained investments from a broad group of stakeholders. These efforts must start immediately—before the remaining network of connected lands are severed by further land use changes. With only 13% of wildlife corridors and half of prioritized habitat blocks currently protected, the conservation community must secure as much of the remaining network of connected lands through land conservation as possible. Yet, a "buy it all" approach is not feasible, especially in the near-term when action is most critical. Land use laws and regulations, both at the state and municipal levels, must be updated to protect landscape connectivity for wildlife, and incorporate Connect THE Coast priorities. Regulators, planners, planning boards, and conservation commissions must hold proposed projects accountable to maintaining functional wildlife corridors and fully mitigating connectivity impacts.

Landscape fragmentation by roads adds an additional layer of challenges and complexities for wildlife. Roads present both real and perceived barriers—where wildlife-vehicle collisions result in mortality and where risk avoidance restricts movement. While local wildlife crossings are important, Connect THE Coast priority road segments significantly narrows the focus for expensive road barrier mitigation along high traffic volume roads to areas most important to broader-scale wildlife movement. Out of the 2,070 miles of state-maintained road network, just 135.1 (6.5%) are priority road segments for wildlife. It is essential that transportation managers implement best management practices for wildlife crossings at these key locations. Best management practices are detailed in the Wildlife Crossings Structures Handbook (Clevenger and Huijser 2011) and the Environmental Guide for Mitigating Road Impacts to Wildlife (Ontario Ministry of Transportation 2016). Examples of best management practices include upsizing road-stream crossings for under-road passage, reduced speed limits, signage, and guardrail and curbing options, among others. Partnerships between road and resource managers to promote, fund, and construct wildlife crossings at priority road segments is necessary to enhance connectivity for wildlife in these key places and across the broader landscape.

Time is of the essence to address landscape connectivity for wildlife before it is lost. The challenges for connectivity grows every passing year, with increasing development and road traffic. Once lost, connectivity is significantly harder, and maybe impossible, to get back and serve the species that currently depend upon it. Whether on land or along roadways, the time for wildlife connectivity action is now. With deliberate, focused, and sustained action, we can achieve a lasting legacy for wildlife of today and the future.

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Appendix A: Wildlife Connectivity Model for NH Documentation

- Data notes
- Species costs
- Resistance equations

NH Audubon and NH Fish & Game Department
Spatial Data Notes

DATA LAYER:	Wildlife Connectivity Model for New Hampshire
COVER NAME:	***sppcost*** (one cost surface per species); **meancost2016** (mean cost all 16 species); **meancostnrip** (mean cost for just the species not obligate to riparian areas)
COVER CONTENTS:	landscape permeability (cost surfaces) for 16 NH wildlife species
COVER TYPE:	raster
SOURCE:	**NH Audubon and NH Fish and Game Department**
SOURCE SCALE:	30 meter 2001/2012 NH land cover data, 30m 2011 National Land Cover Data; 10m USGS digital elevation model; 1:24,000 NHD hydrography; NWI; and Roads
SOURCE MEDIA:	digital
COORDINATE SYSTEM:	NH State Plane feet, horizontal datum NAD83
TILE:	State
AUTOMATED BY:	NH Fish & Game Department, GIS Program
LAST REVISION:	**July 2016**
CONTACT:	Katie Callahan, NHFG (603) 271-3014 E-mail: Catherine.Callahan@doit.nh.gov

This data set represents the third update to the original 2006 NH wildlife connectivity model. Changes reflect updates to land cover, roads, and NWI wetlands. Model parameters are the same as 2010.

General Description of the Data

Introduction

The purpose of this project is to identify wildlife connectivity zones in New Hampshire to inform conservation and land use planning.

Project Goals:

- To create a model for identifying wildlife connectivity zones at multiple scales.
- To identify wildlife connectivity zones in New Hampshire.
- To make information on New Hampshire's wildlife connectivity zones available to land-use planners.

The NH Wildlife Action Plan (WAP) provides the first comprehensive, state-wide analysis of wildlife habitat. This analysis has identified the highest quality landscape patches of 19 terrestrial habitat types at state and ecoregional scales. Maps from the WAP are available on GRANIT and are already informing conservation planning and land use decisions in many levels of government as well as in conservation NGOs. However, identification and protection of landscape linkages between key habitat blocks is equally important to the long-term sustainability of New Hampshire's wildlife populations.

In developing the WAP, NH Fish and Game (NHFG) biologists, with input from NH Audubon (NHA) biologists, created a basic, GIS-based, landscape permeability model to predict broad-scale wildlife connectivity zones across the state. However, further development was required before this model would be suitable for planning applications. Planners from all levels (e.g. municipalities, Regional Planning Commissions, NH Dept. of Transportation, NH Dept. of Environmental Services) expressed a desire to incorporate wildlife connectivity into their considerations. This analysis can identify both key areas for land protection efforts and strategic locations for restoring connectivity in currently fragmented landscapes.

As a result of our presentation on this project at the Northeast Transportation and Wildlife Conference in 2008, we have collaborated with colleagues in Maine to ensure compatibility of connectivity models for the two states. We replaced functional road categories with traffic volume in the model. The main obstacle we encountered was the lack of traffic count data for some road categories. We overcame this obstacle by using municipal population data to estimate traffic counts on rural and suburban roads, based on comparable traffic count data from Maine.

Key terms:
Pixel = smallest unit of area in a raster GIS map (in NH model this is 30mx30m or approx 0.2 acre)
Factor = a pixel attribute such as land cover, distance to road, distance to riparian, percent slope
Cost = a pixel attribute that represents the relative difficulty (resistance) of moving through the pixel
Cost distance = distance between two locations that reflects the difficulty of moving between them
Permeability = compliments resistance such that a perfectly permeable landscape has zero resistance
Corridor = a continuous swath of land estimated to be the best route for one or more species to use for travel

August 25, 2016
Spatial Data Notes: Connectivity Model for NH

Methods

Step 1: Selected sixteen focal species to provide an umbrella for connectivity analysis. Habitat generalists (G), habitat specialists (S), area sensitive (A), and barrier sensitive (B) species were included to capture the range of variation in dispersal behavior:

Blanding's turtle (B)	Mink (S)
Spotted turtle (B)	Otter (S)
Wood turtle (B)	Long-tailed weasel (G)
Black racer (B)	Fisher (G)
Eastern hognose (S,B)	American marten (S,A)
Snowshoe hare (S)	Bobcat (A)
New England cottontail (S)	Canada lynx (S,A)
Porcupine (G,B)	Black bear (G)

Step 2: Selected four landscape factors to include in the cost surface and determined relative influence based on literature review. Selection criteria included relevance to wildlife dispersal behavior and data availability.

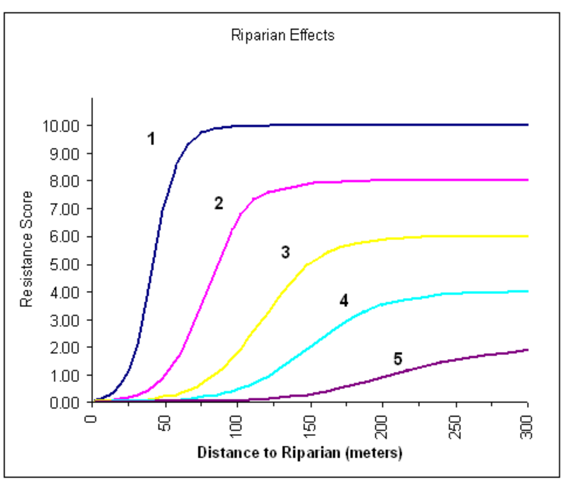
Relative (riparian dependent species relative influence in blue font, 3-3-3-1 weight)

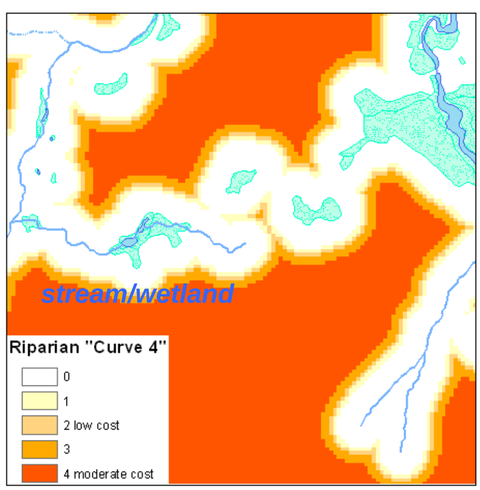
Influence:	Factor:
40% 30%	Land cover (2001 NH Land Cover Assessment data and 2006 National Land Cover data)
40% 30%	Distance to road (all roads classified by traffic volume based on AADT counts or estimates)
10% 30%	Distance to riparian areas (50m horiz. or 5m vertical buffer of NHD water bodies/NWI wetlands)
10% 10%	Slope (derived from USGS 10m digital elevation model)

Step 3: Developed custom raster data layers for the four landscape factors.
The 2001 NH Land Cover data/2012 Northern NH land cover data was adjusted as follows:

1. 2011 National Land Cover developed classes (developed high intensity, developed medium intensity, and developed low intensity) were used to update the raster
2. Remaining land cover grouped into 14 classes: agriculture, orchards, hardwood, softwood, mixed forest, alpine, open water, forested wetland, open wetland, tidal wetland, disturbed, bedrock, dunes, cleared.
3. NWI palustrine wetlands were added: predominantly emergent and scrub/shrub wetland polygons became a raster value of 620 (open wetland) and predominantly forested wetland polygons became a raster value of 610 (forested wetland)
4. Any portion of a water body wider than ¼ mile was used to update the open water land cover class.

Resistance curves were used to model intense, moderate, and mild road effects. Similar curves were developed for distance to riparian areas and slope. These logistic functions describe the cost of movement across the landscape and were based on maximum possible effect (highest cost), half-life of effect (distance), and rate of change in effect. COST = (max cost / (1+ (half life * EXP(-attenuation rate * distance)))



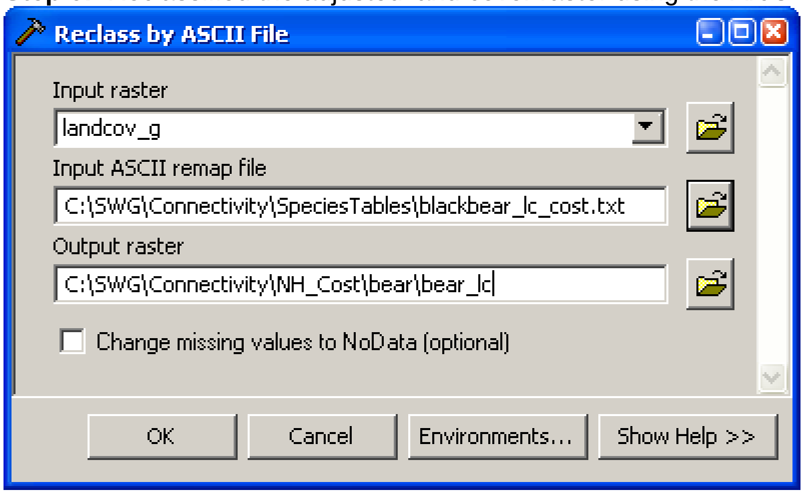


Example: Curve 1 represents a species that is obligate to riparian areas.
Sample equation used in Raster Calculator C:\Temp\rip_4 = 4 / (1 + (400 * (exp(-0.04 * ([distrip_g])))))

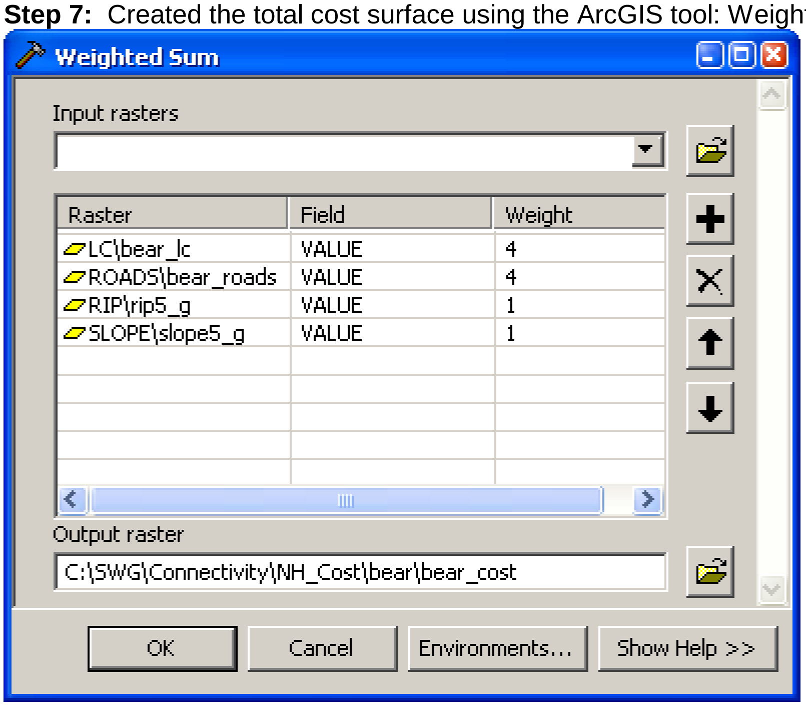
Step 4: Resistance scores were assigned to each class level for each species and input raster: Relative land cover cost (1-10, low-high) and resistance curves were initially assigned by NH Audubon/NHFG biologists based on literature reviews. A table was then prepared for each of the 16 species and distributed for independent peer-review. Reviewers adjusted the land cover cost scores and selected resistance curves for the other three factors. Slope was weighted less and received a relative influence of 10% because its effects on movement were not well documented in the literature.

Step 5: Peer review of species cost tables
We distributed the resistance scores to biologists familiar with the species and revised scores as recommended.

Step 6: Reclassified the adjusted land cover raster using the ArcGIS tool: Reclass by ASCII file



Step 7: Created the total cost surface using the ArcGIS tool: Weighted Sum overlay



Step 8: Ridgeline modifier
The final cost surfaces for: American marten, black bear, bobcat, Canada lynx, and fisher had a ridgeline modifier applied, where 2 points were subtracted from the cost surface in locations where fine-scale ridgeline features were present. Ridgelines were identified from the USGS 10m dem using flow accumulation tools (combination of both flow_acc = zero in original dem and flow_acc > 20 in the inverted dem).

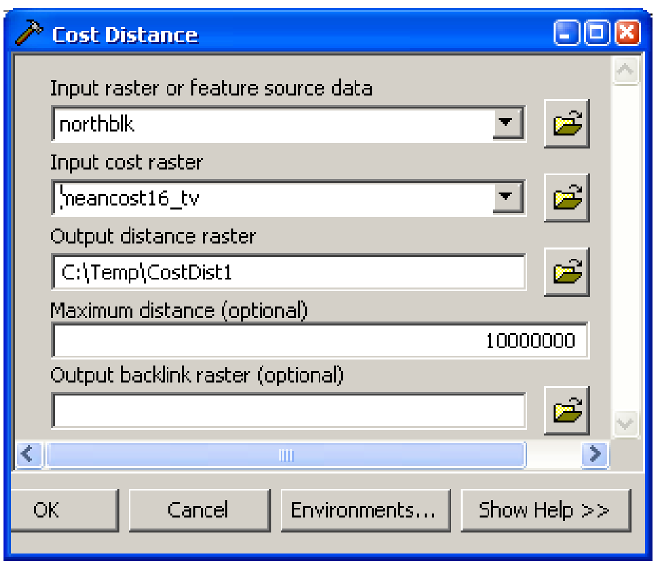
Step 9: Validation of the cost surface
Preliminary model validation utilized available data from tracking and telemetry studies. Visual assessment of these data provided a sufficient level of confidence in the model to accept the resulting cost surface for general conservation planning purposes.

Step 10: Applications – interpreting the cost surface and identifying movement corridors

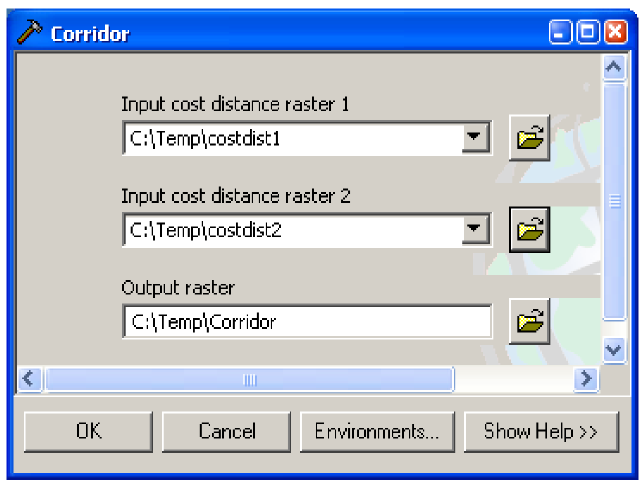
Cost Allocation calculates nearest neighbors in terms of accumulated travel cost. The tool has an optional output distance raster that measures for each cell the least accumulative cost distance over the cost surface to the identified source location(s). A threshold or maximum cost distance can be defined; and existing telemetry and/or tracking data may be used to help set this value. Determination of poor, fair, good connectivity of any landscape feature/habitat polygon/or location could be made using this tool. NOTE: If the identity of the nearest source(s) is not required, then using just the Cost Distance tool would be sufficient.

Corridors between wildland blocks, conservation lands, or known species home ranges/or probability models can be identified using the CORRIDOR function. Corridors may be identified using individual species cost surfaces or a single statewide cost surface averaged for all species (as appropriate to their distribution). Output is NOT actual location of a wildlife corridor but a display of how a model of habitat suitability and movement behavior translates into patterns of landscape connectivity.

First set the extent to the start/end points between which the corridor will be analyzed. Next, run the Cost Distance tool twice, once to habitat block 1 (start), and again to habitat block 2 (end) – where block 1 and block 2 are separate data layers (polygon or raster data may be used).



Final step = use the two resulting cost distance surfaces in the Corridor tool:



The NH species cost surfaces may be used for modeling potential wildlife corridors using GIS software. To iteratively step through identifying corridors between multiple nodes, try **Linkage Mapper** Connectivity Analysis Software available at: http://www.circuitscape.org/linkagemapper

Users are also encouraged to try **Circuitscape** (http://www.circuitscape.org); or **CorridorDesigner** (free ArcGIS tools for designing and evaluating corridors http://corridordesign.org). The NH connectivity data has been applied using both corridor modeling (in areas of high-contrast in the cost surface) and Circuitscape (in areas of low-contrast, because it identifies pinch-points of dispersal patterns) to identify potential patterns of movement. Other software tools are available (e.g. Resistant Kernel estimator, used by NHFG to identify connectivity between locations of optimal stream habitat for wood turtles).

NOTE: Land cover data is based on 30m resolution Landsat Thematic Mapper imagery 1999-2005 (2010 in northern NH). Traffic volume data for local roads was estimated by comparing human population to road class parameters determined for Maine municipalities because data from actual traffic counters placed on NH roads was limited. It is strongly encouraged that users incorporate best available local data sources wherever possible and ground-truth the results of corridor analyses, which is essential for identifying critical connectivity zones.

August 25, 2016
Spatial Data Notes: Connectivity Model for NH

Process for delineating riparian areas:
All vector features in the 1:24,000-scale NHD hydrography and NWI wetlands data layers were combined and converted to a raster. This raster was expanded to a horizontal distance of 50m. Next, streams/rivers fourth order or higher were converted (from NHDflowline) to raster and used to extract elevation values from the USGS dem. Euclidean Allocation was run on the 4th order raster, to a maximum horizontal distance of 900m. The Euclidean Allocation result was then subtracted from the USGS dem. The resulting values give the elevations of the nearest hydrographic or NWI feature location to each cell. Using a suitable Map Algebra expression, all dem values within 5m of the Euclidean Allocation result were converted to a true-false grid (value=1). These areas represent a 5m vertical buffer of 4th order streams and were combined with the 50m horizontal buffer of all NHD and NWI features to create the riparian raster.

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- New Hampshire Land Cover assessment 2001. NHLC 30m raster data available from GRANIT, Complex Systems Research Center at University of New Hampshire Online URL http://www.granit.unh.edu
- National Wetlands Inventory, developed by US Fish & Wildlife Service 1985-1986; digitized by Complex Systems Research Center, University of New Hampshire.
- New Hampshire Hydrography Dataset. NHHD developed at 1:24,000-scale extracted from the high-resolution USGS National Hydrography Dataset

NOAA Coastal Services Center and U.S. Geological Survey. National Land Cover Database 2011 produced through a cooperative project conducted by the Multi-Resolution Land Characteristics (MRLC) Consortium. Accessed through the USGS Seamless Data Distribution System. Online URL http://seamless.usgs.gov

United States Geological Survey. Date varies. *National Elevation Dataset*.
10m raster data accessed through the USGS Seamless Data Distribution System, accessed June 2014.

Vermont TransRoad_RDS (accessed June 2016 VCGI). VT Transportation.Online URL: http://www.vcgi.org/

Connectivity Model for NH: Species Costs

Variable	American Marten	Black Bear	Black Racer	Blandings Turtle	Bobcat	Canada Lynx	Fisher	Hognose Snake	LT Weasel	Mink	NEC	Otter	Porcupine	SSH	Spotted Turtle	Wood Turtle
RELATIVE INFLUENCE (weight)																
Land Cover	4	4	4	3	4	4	4	4	3	3	4	3	4	4	3	3
Road	4	4	4	3	4	4	4	4	3	3	4	3	4	4	3	3
Riparian	1	1	1	3	1	1	1	1	3	3	1	3	1	1	3	3
Slope	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
LAND COVER (2001 NH Land Cover Assessment data and 2010 Northern NHLC data; with 2011 NLCD developed classes added, and NWI palustrine wetlands added to forested and open wetland classes)																
Developed22 - Low; Disturbed 71(	5	5	6	9	5	5	5	7	5	5	5	5	5	5	9	9
Developed23 - Medium	8	8	8	10	8	8	8	8	8	8	8	8	8	8	9	10
Developed24 - High	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Agriculture 210	9	5	1	4	5	5	5	3	5	4	3	4	6	7	4	4
Orchards 220	9	5	1	3	5	5	5	3	5	3	4	3	3	3	3	3
Hardwoods 410	4	1	1	2	1	2	2	3	1	3	5	2	1	2	2	2
Softwoods 420	1	1	2	3	1	1	2	3	1	3	6	2	1	1	3	3
Mixed forest 430	2	1	1	2	1	1	2	3	1	3	5	2	1	1	2	2
Alpine 440; Tundra 800	2	8	10	10	7	2	7	10	9	9	10	10	10	4	10	10
Open water 500	8	5	9	7	7	7	7	9	7	2	9	1	10	7	7	7
Open water > 1/4 mile wide 510	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Forested wetland 610	1	1	2	1	1	1	1	3	1	1	1	1	1	1	1	2
Open wetland 620	9	3	2	1	5	5	3	4	3	1	3	1	8	5	1	2
Tidal wetland 630	10	7	4	5	7	10	9	10	7	1	9	1	10	10	5	10
Cleared 790; Transitional-Success	4	2	1	2	5	5	5	3	5	5	1	5	5	5	2	2
Bedrock-vegetated 720	2	2	1	2	2	2	2	3	2	3	5	3	3	3	2	2
Sand dunes 730	10	8	1	4	5	10	5	1	5	5	3	5	8	9	4	4
DISTANCE TO ROAD																
Interstate & Arterial	H2	H3	H1	H1	H3	H4	H2	H1	H2	H2	H1	H2	H1	H1	H1	H1
Collector & Paved Local	M3	M2	M1	M1	M4	H3	M3	M1	M3	M3	M2	M3	M2	M2	M1	M1
Unpaved & Private; Railroad	L1	L1	M1	M1	L2	L2	L1	M1	L1	L1	L1	L1	L1	L1	M1	M1
TrafficVolume6 (10,000+)	tv6_h3	tv6_h3	tv6_h1	tv6_h1	tv6_h3	tv6_h4	tv6_h2	tv6_h1	tv6_h2	tv6_h2	tv6_h1	tv6_h2	tv6_h1	tv6_h1	tv6_h1	tv6_h1
TrafficVolume5 (6,000-9,999)	tv5_h3	tv5_h3	tv5_h1	tv5_h1	tv5_h3	tv5_h4	tv5_h2	tv5_h1	tv5_h2	tv5_h2	tv5_h1	tv5_h2	tv5_h1	tv5_h1	tv5_h1	tv5_h1
TrafficVolume4 (3,000-5,999)	tv4_h3	tv4_h3	tv4_h1	tv4_h1	tv4_h3	tv4_h4	tv4_h2	tv4_h1	tv4_h2	tv4_h2	tv4_m2	tv4_h2	tv4_h1	tv4_m2	tv4_h1	tv4_h1
TrafficVolume3 (500-2,999)	tv3_m3	tv3_m2	tv3_h1	tv3_h1	tv3_m2	tv3_m3	tv3_m2	tv3_h1	tv3_m2	tv3_m2	tv3_m2	tv3_m2	tv3_h1	tv3_m2	tv3_h1	tv3_h1
TrafficVolume2 (100-499)	tv2_m2	tv2_m2	tv2_m1	tv2_m1	tv2_m2	tv2_m3	tv2_m1	tv2_m1	tv2_m1	tv2_m1	tv2_m1	tv2_m1	tv2_m1	tv2_m1	tv2_m1	tv2_m1
TrafficVolume1 (< 100)	tv1_l1	tv1_l1	tv1_l1	tv1_l1	tv1_l1	tv1_l1	tv1_l1	tv1_l1	tv1_l1	tv1_l1	tv1_l1	tv1_l1	tv1_l1	tv1_l1	tv1_l1	tv1_l1
Railroads (turtles addl' cost)				**8**											**8**	**8**
DISTANCE TO RIPARIAN																
	R4	R5	R5	R4	R4	R5	R4	R5	R4	R3	R4	R3	R5	R5	R3	R2
SLOPE (percent)																
	S4	S5	S4	S1	S4	S4	S4	S1	S4	S4	S2	S4	S3	S2	S1	S1
RIDGELINE MODIFIER																
	Yes	**Yes**			**Yes**	**Yes**	**Yes**									
SPECIES RANGE LIMIT																
(if blank, species model is statewide)	**Yes**		**Yes**	**Yes**		**Yes**		**Yes**			**Yes**				**Yes**	
	American Marten	Black Bear	Black Racer	Blandings Turtle	Bobcat	Canada Lynx	Fisher	Hognose Snake	LT Weasel	Mink	NEC	Otter	Porcupine	SSH	Spotted Turtle	Wood Turtle

Connectivity Model for NH: Resistance Equations

Distance to riparian

Riparian = a 50m horizontal buffer of all 1:24,000-scale NHD hydrography and NWI wetlands, plus 5m vertical buffer of all streams 4^{th}-order or higher.

General equation:

COST = (max cost / (1+ (half life * EXP(-attenuation rate * distance)))

Cost is increasing as you move away from the riparian area.

Actual cost equations used in Raster Calculator:

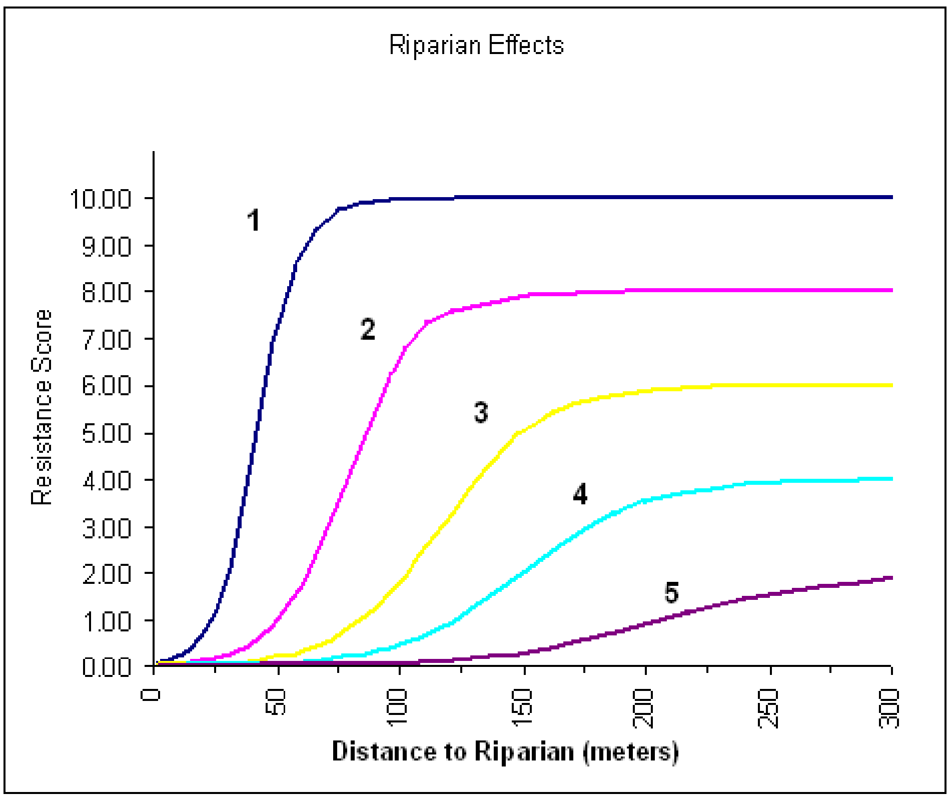
C:\SWG\NH_Cost\rip_1 = 10 / (1 + (150 * (exp(-0.12 * ([distrip_g])))))

C:\SWG\NH_Cost\rip_2 = 8 / (1 + (250 * (exp(-0.07 * ([distrip_g])))))

C:\SWG\NH_Cost\rip_3 = 6 / (1 + (350 * (exp(-0.05 * ([distrip_g])))))

C:\SWG\NH_Cost\rip_4 = 4 / (1 + (400 * (exp(-0.04 * ([distrip_g])))))

C:\SWG\NH_Cost\rip_5 = 2 / (1 + (500 * (exp(-0.03 * ([distrip_g])))))



Slope (percent, derived from 10m dem)

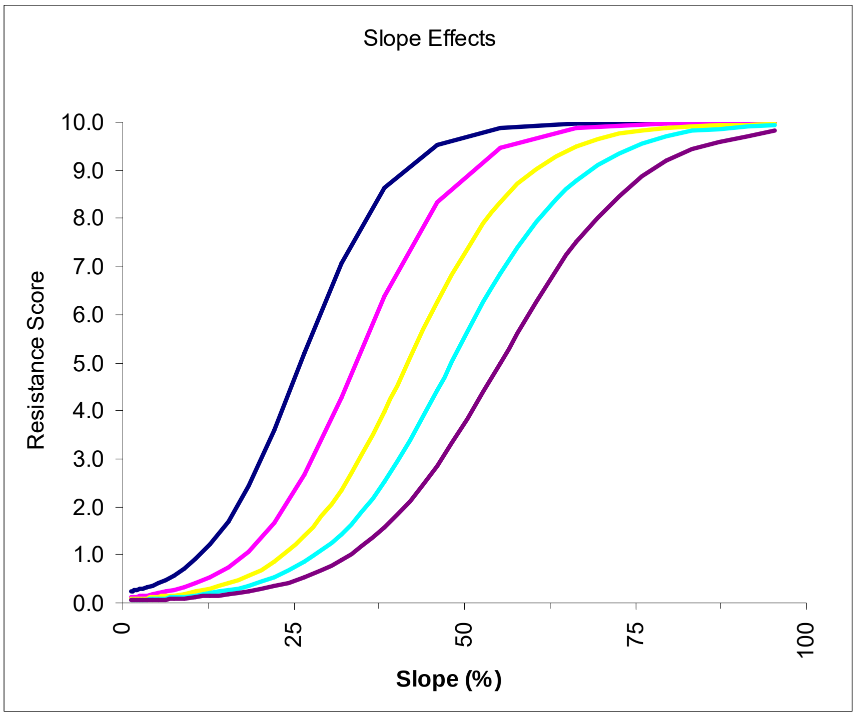
C:\SWG\NH_Cost\slope_1 = 10 / (1 + (50 * (exp(-0.15 * ([slope_pct])))))

C:\SWG\NH_Cost\slope_2 = 10 / (1 + (100 * (exp(-0.135 * ([slope_pct])))))

C:\SWG\NH_Cost\slope_3 = 10 / (1 + (150 * (exp(-0.12 * ([slope_pct])))))

C:\SWG\NH_Cost\slope_4 = 10 / (1 + (200 * (exp(-0.11 * ([slope_pct])))))

C:\SWG\NH_Cost\slope_5 = 10 / (1 + (250 * (exp(-0.1 * ([slope_pct])))))



Optional equation for slope, from FunConn user manual – I personally find this easier to visualize, in part because I think of slope in degrees not percent, but we ended up going with the equations on the previous page. In the end, …probably all comes out the same.

A negative logistic function was used to create the example slope-cost raster. Two parameters determine the shape of the curve: the inflection point (d_{50}) and the scaling factor (d_s). The inflection point is the value of x where y = 0.5. The scaling factor is the distance along the x-axis from d_{50} to the point at which y = 0.75 (McGarigal 2001).

$$\text{Permeability} = 1.0 - (\ 1.0 / (1.0 + e^{(-(\text{slope} - d50)) / ds})\ )$$

$d_{50} = 30$
$d_s = 7$

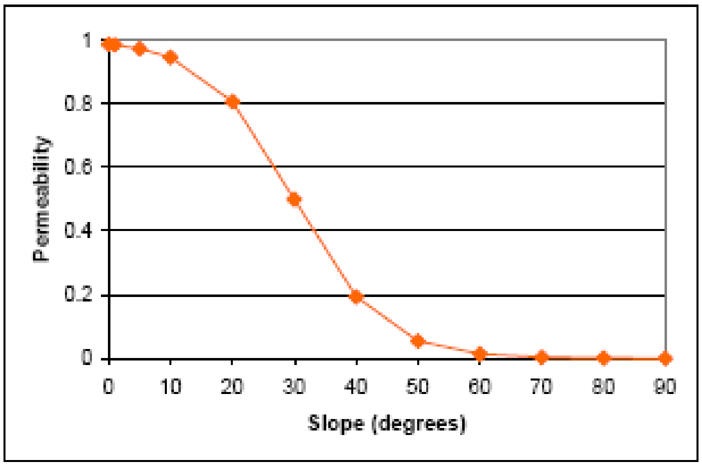


Figure 4. Permeability logistic function.

As with the permeability reclass table, the range of values is 0-1, with 1 being the most readily moved through. The slope-cost is multiplied by the permeability raster to get a total permeability raster. The final resistance, or cost, surface is simply the inverse of the permeability raster.

Distance from roads (based on Traffic Volume category)

Cost is decreasing as you move away from the road.

TVcategory	Vehicle Trips per day
1	Fewer than 100 AADT
2	100 to 499
3	500 to 2,999
4	3,000 to 5,999
5	6,000 to 9,999
6	Over 10,000 AADT

Cost equations used in Raster Calculator ("**x**" is traffic volume category):

Intense road effects (High cost):

C:\SWG\NH_Cost\TV**x**_H1 = 10 / (1 + (0.01 * (exp(0.09 * ([dist_TV**x**_m])))))
C:\SWG\NH_Cost\TV**x**_H2 = 10 / (1 + (0.001 * (exp(0.06 * ([dist_TV**x**_m])))))
C:\SWG\NH_Cost\TV**x**_H3 = 10 / (1 + (0.0025 * (exp(0.02 * ([dist_TV**x**_m])))))
C:\SWG\NH_Cost\TV**x**_H4 = 10 / (1 + (0.009 * (exp(0.006 * ([dist_TV**x**_m])))))

Moderate road effects (Medium cost):

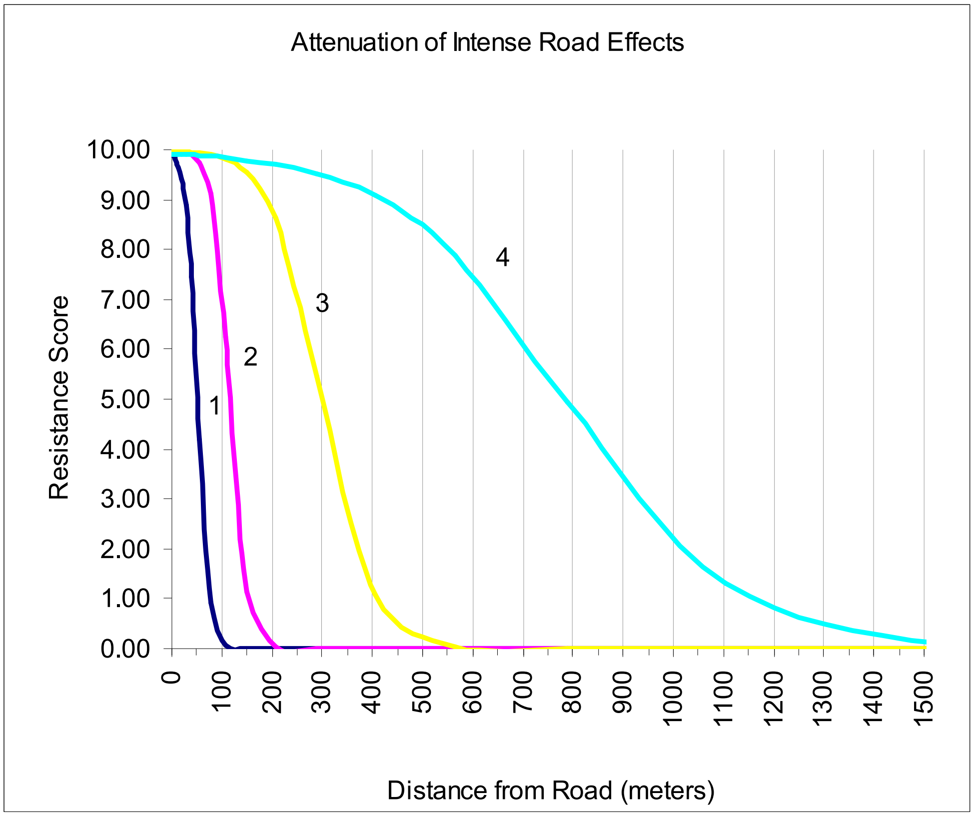
C:\SWG\NH_Cost\TV**x**_M1 = 6 / (1 + (0.08 * (exp(0.09 * ([dist_TV**x**_m])))))
C:\SWG\NH_Cost\TV**x**_M2 = 6 / (1 + (0.04 * (exp(0.06 * ([dist_TV**x**_m])))))
C:\SWG\NH_Cost\TV**x**_M3 = 6 / (1 + (0.001 * (exp(0.06 * ([dist_TV**x**_m])))))
C:\SWG\NH_Cost\TV**x**_M4 = 6 / (1 + (0.004 * (exp(0.02 * ([dist_TV**x**_m])))))

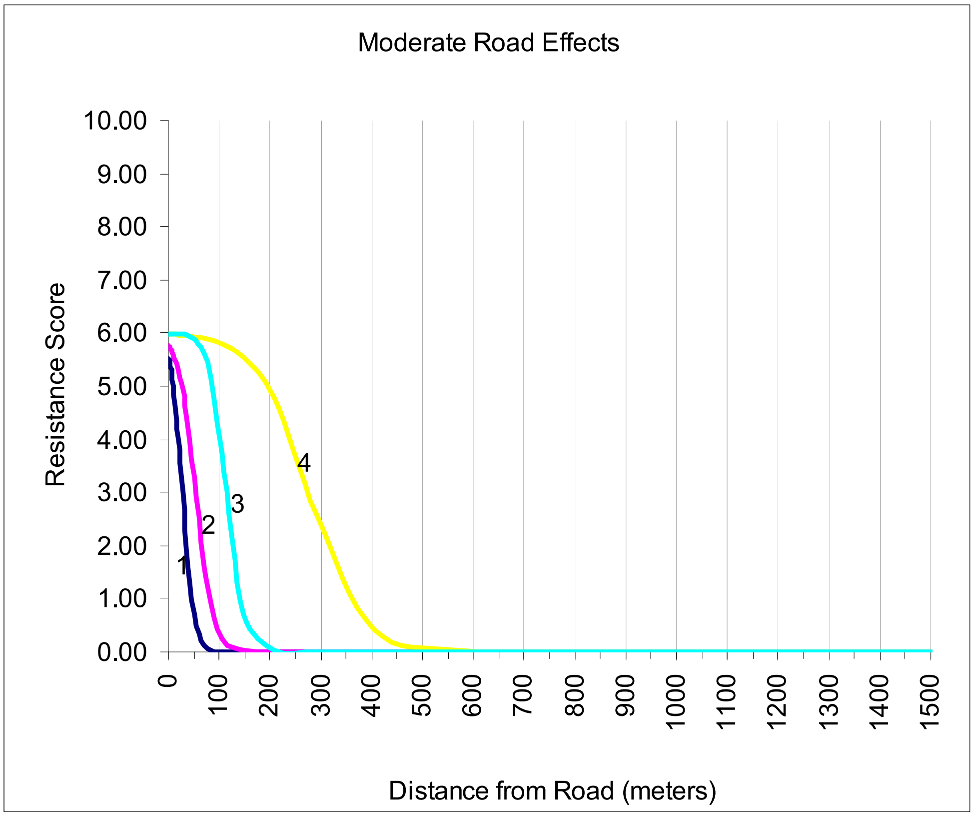
Mild road effects (Low cost):

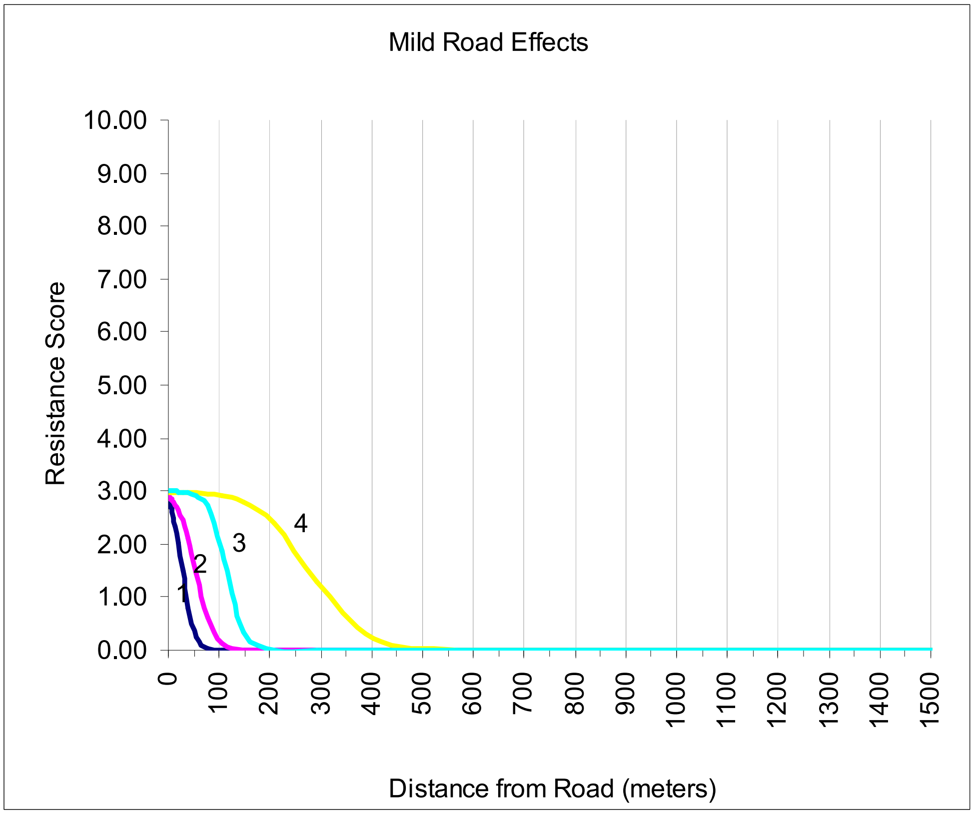
Note: the L1 curve was the only resistance curve applied for mild road effects, and only to roads with traffic volume category of "1" – for all species.

C:\SWG\NH_Cost\TV**1**_L1 = 3 / (1 + (0.08 * (exp(0.09 * ([dist_TV**1**_m])))))
C:\SWG\NH_Cost\TV**x**_L2 = 3 / (1 + (0.04 * (exp(0.06 * ([dist_TV**x**_m])))))
C:\SWG\NH_Cost\TV**x**_L3 = 3 / (1 + (0.001 * (exp(0.06 * ([dist_TV**x**_m])))))
C:\SWG\NH_Cost\TV**x**_L4 = 3 / (1 + (0.004 * (exp(0.02 * ([dist_TV**x**_m])))))

Turtles: applied additional cost (value = 8) for a 1-cell (30m) width along active railroads.


Attenuation of Intense Road Effects
Resistance Score
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1
2
3
4
Distance from Road (meters)


Moderate Road Effects
Resistance Score
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1
2
3
4
Distance from Road (meters)



Mild Road Effects
Resistance Score
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1
2
3
4
Distance from Road (meters)

Appendix B: Links to Online Connect THE Coast Maps by State and Town

Massachusetts

Amesbury	Haverhill	Newbury	Salisbury
Georgetown	Merrimac	Newburyport	West Newbury
Groveland	Methuen	Rowley	

New Hampshire

Allenstown	Derry	Hampstead	Newfields	Rye
Alton	Dover	Hampton	Newington	Salem
Atkinson	Dunbarton	Hampton Falls	Newmarket	Sandown
Auburn	Durham	Hooksett	Newton	Seabrook
Barnstead	East Kingston	Kensington	North Hampton	Somersworth
Barrington	Effingham	Kingston	Northwood	South Hampton
Bow	Epping	Lee	Nottingham	Strafford
Brentwood	Epsom	Litchfield	Ossipee	Stratham
Brookfield	Exeter	Londonderry	Pembroke	Tuftonboro
Candia	Farmington	Loudon	Pittsfield	Wakefield
Chester	Fremont	Madbury	Plaistow	Windham
Chichester	Gilford	Manchester	Portsmouth	Wolfeboro
Concord	Gilmanton	Middleton	Raymond	
Danville	Goffstown	Milton	Rochester	
Deerfield	Greenland	New Durham	Rollinsford	

Maine

Acton	Kennebunk	Lyman	Sanford	York
Alfred	Kennebunkport	Newfield	Shapleigh	
Arundel	Kittery	North Berwick	South Berwick	
Berwick	Lebanon	Ogunquit	Waterboro	
Eliot	Limerick	Parsonsfield	Wells	