ecoConnect: Ecosystem-based Regional Connectivity to Inform Conservation Networks at Multiple Scales

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For data and more info:
https://umassdsl.org/data/ecoConnect/

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Summary

Regional landscape connectivity is essential for gene flow and the movement of organisms to maintain connected networks of refugia, and to facilitate range shifts in response to climate change. Metrics of regional connectivity are typically based on pre-designated conservation cores, and may not be appropriate when applied to alternative or changing conservation priorities. We developed ecoConnect, an approach for estimating multi-scale, ecosystem-specific, regional connectivity that is independent of pre-designated cores, and applied it to a 13-state region in the northeastern U.S. Our hybrid approach combines random low-cost paths with a graph theory metric. Results can be used at multiple scales to preserve and restore ecological connectivity through land conservation and mitigate the fragmenting effects of transportation infrastructure.

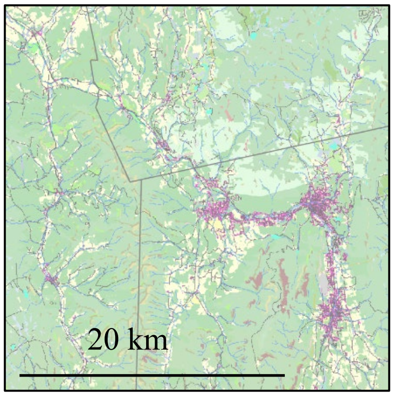
Introduction

Regional connectivity supports the persistence of metapopulations, genetic rescue and dispersal, and is necessary for species range shifts over time. Long-distance dispersal is particularly important in the face of climate change, as warming temperatures, changing precipitation patterns, shifts in seasonal phenology, and novel assemblages of species are likely to change the distribution of suitable habitat and will force wildlife populations to disperse to new areas.

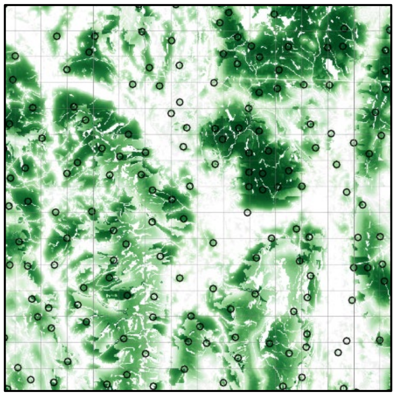
In recent decades, conservation practitioners have become increasingly effective at identifying and protecting natural communities with high ecological integrity and resilience. Likewise, more effort is being directed at connecting protected land to form viable conservation networks. In the northeastern U.S., much land conservation is implemented at the local (town) or sub-regional (multi-town or county) level, and road/highway mitigation projects are identified based on impacts to local wildlife populations. Given the magnitude of anticipated climate change impacts, we need to ensure that protected land is connected at regional scales, in a redundant network that stretches for hundreds of miles.

We have developed an approach to estimating regional connectivity that has four defining features: (1) it is truly regional (as opposed to local or medium-scale connectivity tiled or chained together), (2) it is ecosystem-based, providing assessments for selected groups of ecological systems (e.g., forests, wetlands, or more-narrowly defined groups, such as ridgetop systems or floodplain forests) connected through areas most similar to the target systems, (3) it is independent of pre-defined conservation cores or targets, instead connecting all areas of the landscape, and (4) it is multi-scale, with results that are meaningful across a few kilometers, tens of kilometers, and the entire northeastern U.S.

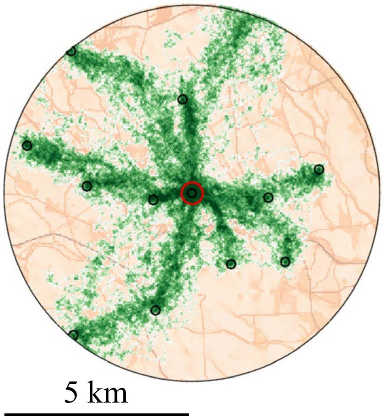
Methods



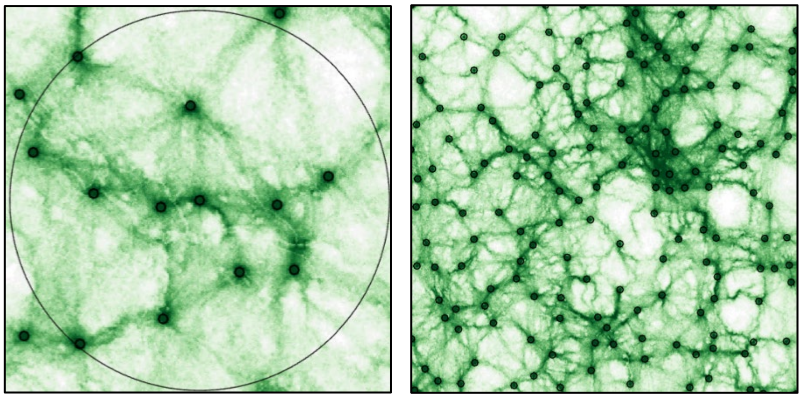
Example area, on the New York-Vermont-Massachusetts border. Greens represent forest, beige is agriculture, and pinks are development.



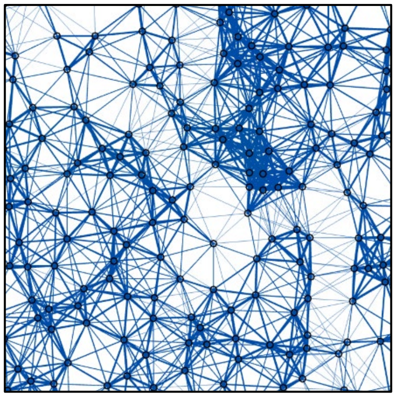
The first step in the analysis was to place a point within the target ecological system in each 2 km tile across the landscape. These points were spaced closely enough to reasonably represent the entire landscape at all but the most local scales. We placed these points at the 30 m cell with the highest Index of Ecological Integrity (IEI; McGarigal et al. 2018) in each tile. Ties were broken by taking the high-IEI cell closest to the tile center. We dropped all but one point in clusters within 1 km of each other.



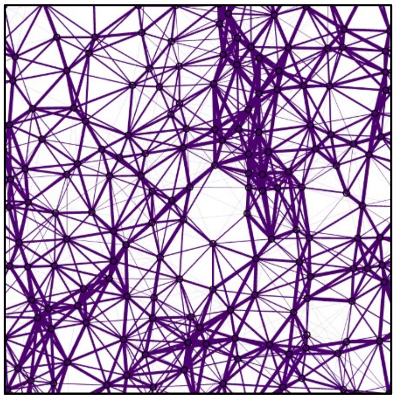
Each point was connected to each other point within 5 km using 30 Random Low-Cost Paths (RLCPs), an approach that adds stochasticity to least cost paths (McGarigal et al. 2013). RLCPs generally follow low-resistance routes, but explore multiple sub-optimal alternatives. The RLCPs used landscape resistance derived from multivariate ecological distance between points calculated using 24 natural and anthropogenic ecological settings variables, such as wetness, slope, percent impervious, and traffic rates (McGarigal el al. 2018).



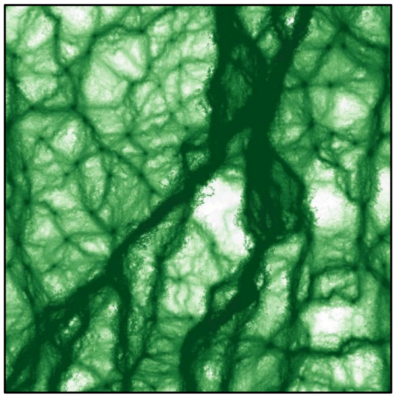
A total of 60 RLCPs between every pair of points within 5 km gave an estimate of local connectivity.



A graph was built from the points. Graph theory (Urban and Keitt 2001) represents the world as points connected by “edges,” each with an assigned cost. A number of highly efficient algorithms can assess connectivity within large graphs. We used the median cost-distance between each pair of points as edge costs.



We used the graph metric *edge betweenness* (Csardi and Nepusz 2006) to count the number of times each edge was used when connecting every pair of edges in the landscape with least-cost routes through the graph. Similar to our approach with RLCPs, we introduced stochasticity into this process by adding a small normal random deviate to each edge cost and iterating 30 times, then using the mean for each edge. This approach avoids tilting results to optimal paths, instead focusing on an array of plausible suboptimal routes across the landscape.



Finally, we recreated 100 RLCPs (to get more detailed results), using the edge weights from the graph metric to weight RLCPs between each pair of neighboring points, yielding regional connectivity. Regional connectivity metrics were created separately for groups of ecological systems (e.g., forests, wetlands, or more-narrowly defined groups, such as ridgetop systems or large river floodplain forests).

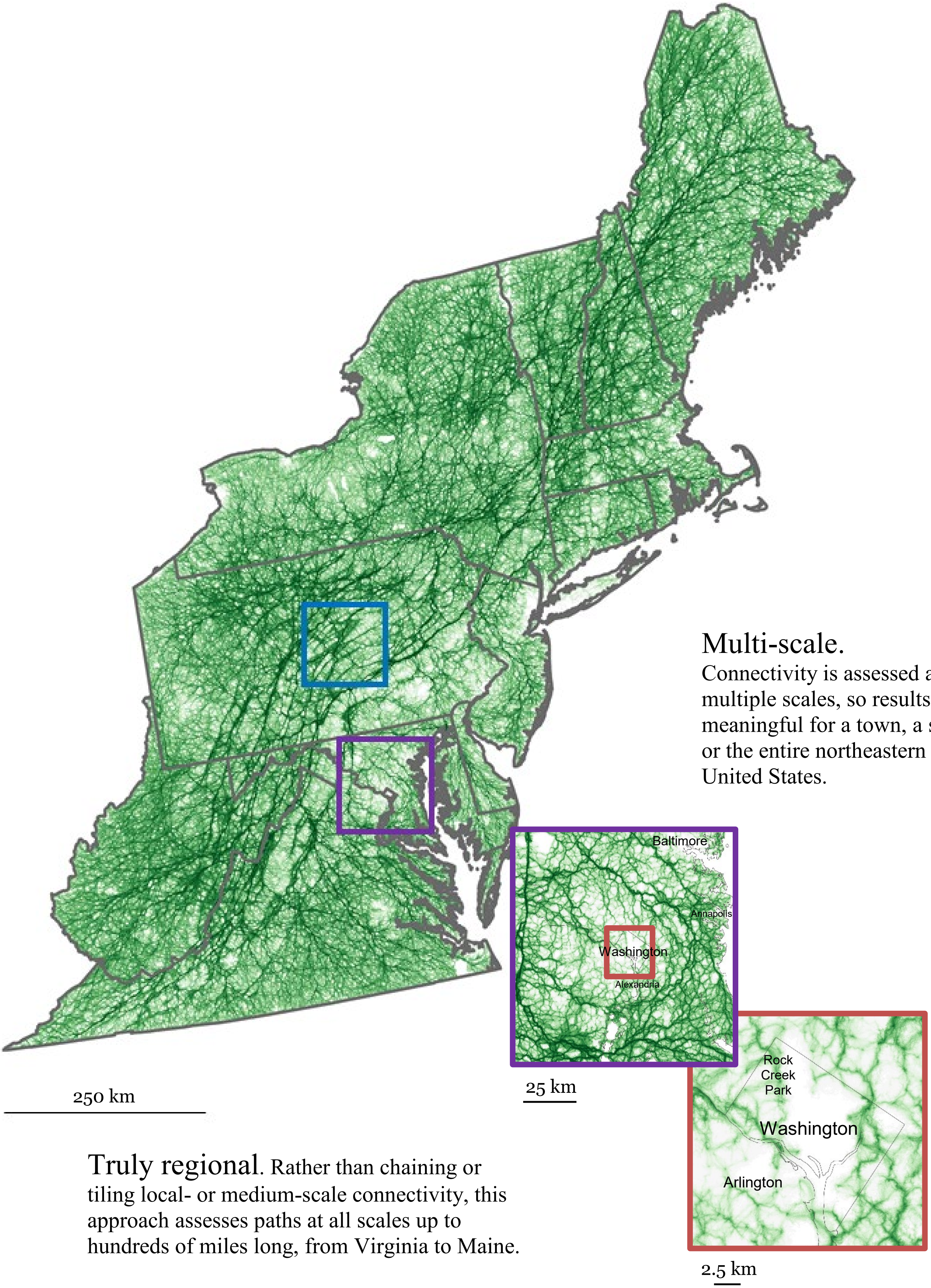
Results and Discussion

The ecoConnect model provides estimates of connectivity that are *truly regional*, *multi-scale*, *ecosystem-aware*, and *independent of pre-defined conservation targets* (figs 1 and 2).

Results are available for four ecosystems: forests (including forested wetlands), non-forested wetlands, ridgetop systems, and large river floodplain forests. Values of ecoConnect range from 0 (no contribution to connectivity) to 100 (highest contribution) for each ecosystem. Values are not comparable between different ecosystems, as (for example) forests are naturally more connected than wetlands in the Northeast. Results are primarily visual rather than quantitative, although summarizing means or sums of ecoConnect for parcels or other conservation targets provides a relative comparison. Higher-valued (darker) and wider bands of ecoConnect indicate higher connectivity.

Achieving true regional connectivity will require the protection of redundant networks of connections for a variety of ecological systems. Such connections will require protecting land important for connectivity that might not otherwise be protected because it is not highly rated for habitat quality or ecological integrity (e.g., undeveloped land in developed areas). Such connectivity also requires taking ecosystems into account, as connectivity for wetlands is very different from connectivity for forests.

Fig. 1

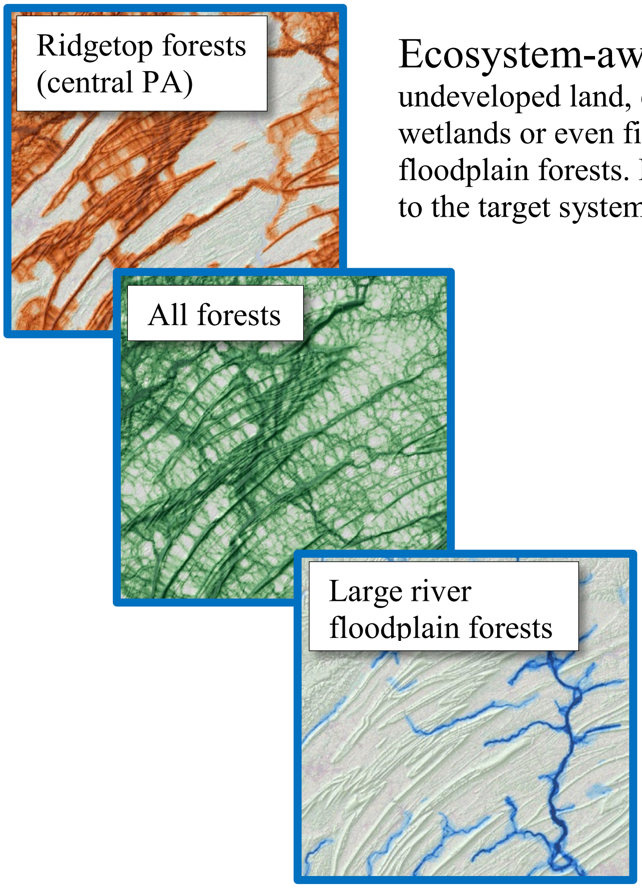


Multi-scale.

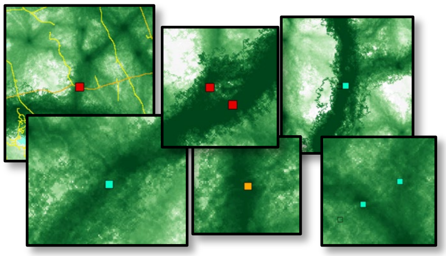
Connectivity is assessed at multiple scales, so results are meaningful for a town, a state, or the entire northeastern United States.

Truly regional. Rather than chaining or tiling local- or medium-scale connectivity, this approach assesses paths at all scales up to hundreds of miles long, from Virginia to Maine.

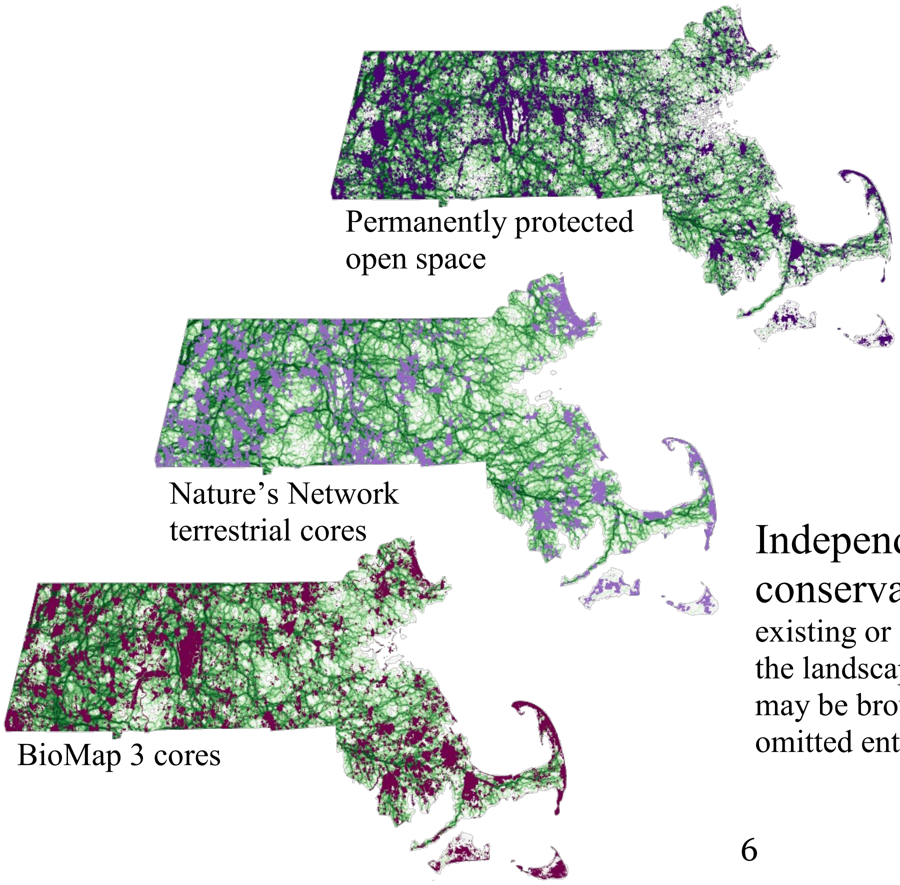
Fig. 2



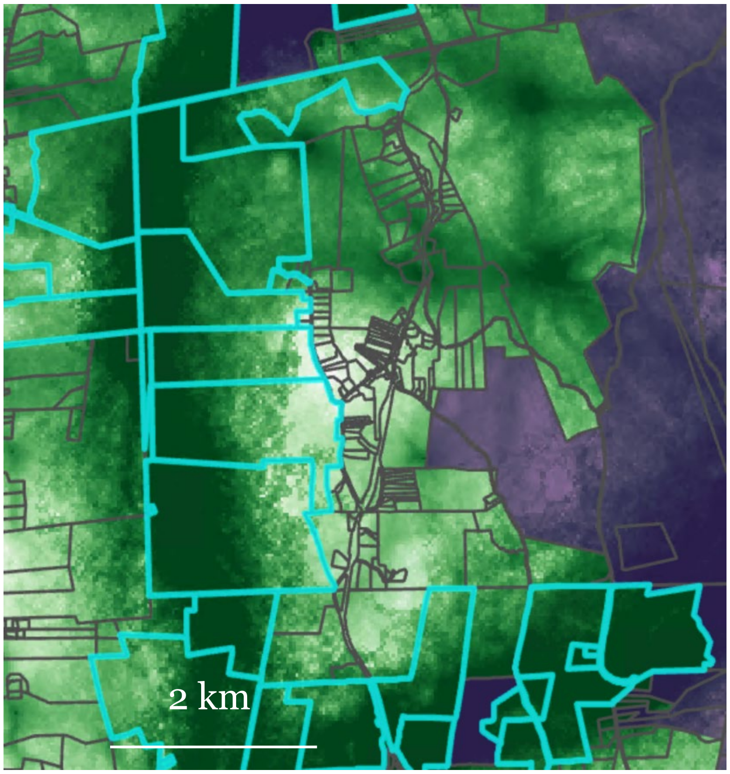
Ecosystem-aware. Rather than simply connecting undeveloped land, connectivity is estimated for forests or wetlands or even finer groups such as ridgetop forests or floodplain forests. Paths are based on ecological similarity to the target systems.



Road-stream crossings. Bridges providing terrestrial passage under highways are accounted for in the model, thus connectivity paths often use bridges to cross under high-traffic roads. Ongoing road-stream assessments through NAACC continue to improve the model.

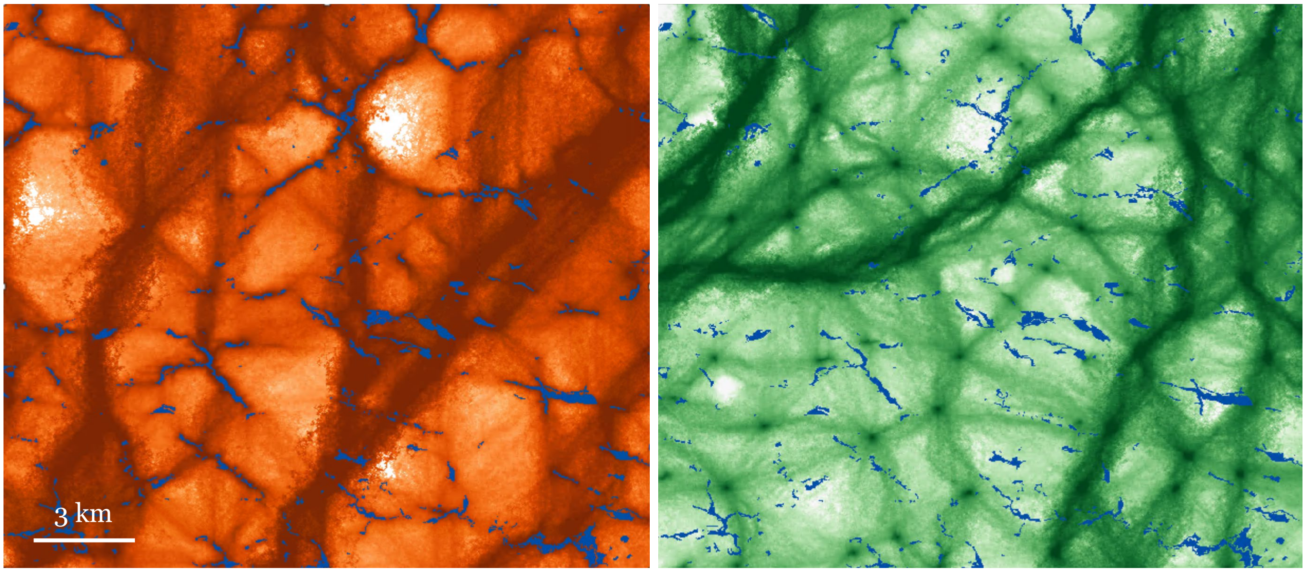


Independent of pre-defined conservation targets. Rather than connecting existing or aspirational conservation cores, all of the landscape is connected, so conservation targets may be brought in later in the planning process or omitted entirely.

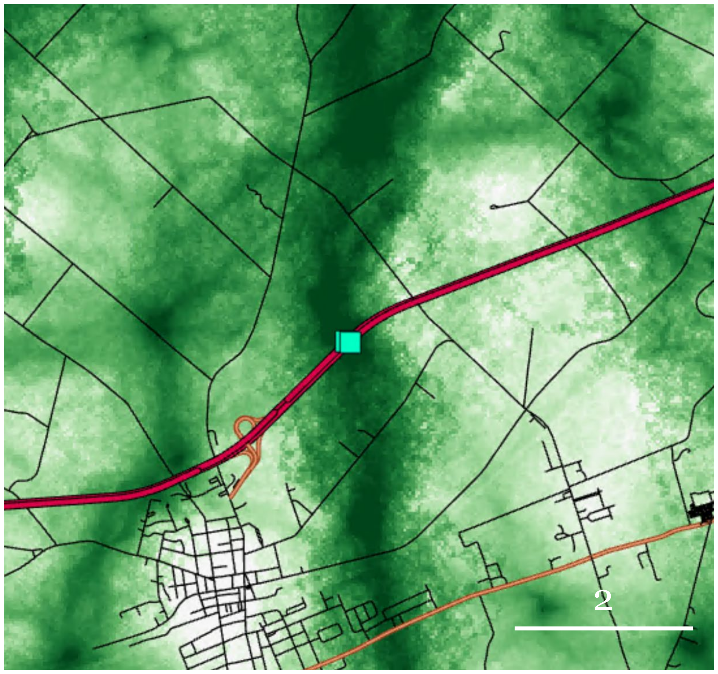


Example 1. ecoConnect for forested ecosystems in northwestern Massachusetts (green), with protected open space (purple) and parcel outlines (gray and cyan).

Parcels highlighted in cyan represent potential targets for conserving regional connectivity in this area.



Example 2. ecoConnect for nonforested wetlands (left), and forests (right) in western Maine, with nonforested wetlands shown in blue. Note that ecoConnect for forests provides very little connectivity for wetlands, illustrating the need for assessing connectivity for each ecosystem of interest separately.



Example 3. ecoConnect for forests in central New York State crossing I-90 at a pair of road-stream crossings. ecoConnect uses data from The North Atlantic Aquatic Connectivity Collaborative (NAACC, https://streamcontinuity.org/naacc) to represent bridges and culverts, and paths often cross major highways at bridges that are expected to have upland passage. An important element of conserving regional connectivity is passability assessments for highway crossings of potential importance for landscape-scale connectivity.

Acknowledgements

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Appendix: Ecological Systems

ecoConnect model results are available for four sets of ecological systems:

1. Forests, including forested wetlands
2. Nonforested wetlands
3. Ridgetop systems
4. Large river floodplain forests

Ecological systems are based on The Nature Conservancy's Terrestrial Habitat Map for the Northeastern U.S. (Ferree & Anderson 2013). Systems may be referred to at two hierarchical levels: system ("ecosystem" in the TNC map) and subsystem ("system" in the TNC map). See https://umassdsl.org/DSLdocs/DSL_documentation_DSLland.pdf for a description of the DSLland landcover data. We may be able to do custom runs for other sets of ecological systems. Contact us to discuss your needs.

ecoConnect model results may be viewed in a web tool, downloaded as geoTIFFs, or accessed as a web service. For links, see https://umassdsl.org/data/regional-ecosystem-based-connectivity.

All forests with forested wetlands (system)

Acadian Low Elevation Spruce-Fir-Hardwood Forest
Acadian Sub-boreal Spruce Flat
Acadian-Appalachian Montane Spruce-Fir-Hardwood Forest
Central and Southern Appalachian Spruce-Fir Forest
Allegheny-Cumberland Dry Oak Forest and Woodland
Appalachian (Hemlock)-Northern Hardwood Forest
Central and Southern Appalachian Montane Oak Forest
Central Appalachian Dry Oak-Pine Forest
Central Appalachian Pine-Oak Rocky Woodland
Central Atlantic Coastal Plain Maritime Forest
Glacial Marine & Lake Mesic Clayplain Forest
Laurentian-Acadian Northern Hardwood Forest
Laurentian-Acadian Northern Pine-(Oak) Forest
Laurentian-Acadian Pine-Hemlock-Hardwood Forest
Laurentian-Acadian Red Oak-Northern Hardwood Forest
North Atlantic Coastal Plain Hardwood Forest
North Atlantic Coastal Plain Maritime Forest
North Atlantic Coastal Plain Pitch Pine Barrens
North-Central Interior Beech-Maple Forest
Northeastern Coastal and Interior Pine-Oak Forest
Northeastern Interior Dry-Mesic Oak Forest
Northeastern Interior Pine Barrens
Piedmont Hardpan Woodland and Forest
Pine plantation / Horticultural pines
South-Central Interior Mesophytic Forest
Southern and Central Appalachian Cove Forest
Southern Appalachian Low Elevation Pine Forest

Southern Appalachian Montane Pine Forest and Woodland
Southern Appalachian Northern Hardwood Forest
Southern Appalachian Oak Forest
Southern Atlantic Coastal Plain Mesic Hardwood Forest
Southern Atlantic Coastal Plain Upland Longleaf Pine Woodland
Southern Piedmont Dry Oak-Pine Forest
Southern Piedmont Mesic Forest
Southern Ridge and Valley / Cumberland Dry Calcareous Forest
Atlantic Coastal Plain Blackwater/Brownwater Stream Floodplain Forest
Central Atlantic Coastal Plain Non-riverine Swamp and Wet Hardwood Forest
Central Interior Highlands and Appalachian Sinkhole and Depression Pond
Glacial Marine & Lake Wet Clayplain Forest
High Allegheny Headwater Wetland
Laurentian-Acadian Alkaline Conifer-Hardwood Swamp
Laurentian-Acadian Large River Floodplain
North Atlantic Coastal Plain Basin Peat Swamp
North Atlantic Coastal Plain Basin Swamp and Wet Hardwood Forest
North Atlantic Coastal Plain Pitch Pine Lowland
North Atlantic Coastal Plain Tidal Swamp
North-Central Appalachian Acidic Swamp
North-Central Appalachian Large River Floodplain
North-Central Interior and Appalachian Rich Swamp
North-Central Interior Wet Flatwoods
Northern Appalachian-Acadian Conifer-Hardwood Acidic Swamp
Piedmont Upland Depression Swamp
Piedmont-Coastal Plain Large River Floodplain
Southern Atlantic Coastal Plain Tidal Wooded Swamp
Southern Piedmont Lake Floodplain Forest
Southern Piedmont Small Floodplain and Riparian Forest

Ridgetop (subsystem)
Central Interior Acidic Cliff and Talus
Cumberland Acidic Cliff and Rockhouse
Laurentian-Acadian Acidic Cliff and Talus
North-Central Appalachian Acidic Cliff and Talus
Southern Appalachian Montane Cliff and Talus
Central Interior Calcareous Cliff and Talus
Laurentian-Acadian Calcareous Cliff and Talus
Southern Interior Calcareous Cliff
North-Central Appalachian Circumneutral Cliff and Talus
Laurentian Acidic Rocky Outcrop
Northern Appalachian-Acadian Rocky Heath Outcrop
Southern Piedmont Granite Flatrock and Outcrop
Laurentian-Acadian Calcareous Rocky Outcrop
Acadian-Appalachian Montane Spr-Fir-Hwd Forest
Central Appalachian Pine-Oak Rocky Woodland

Central and Southern Appalachian Montane Oak Forest
Southern Appalachian Montane Pine Forest and Woodland

Nonforested wetland (system)

Central Appalachian Stream and Riparian
Central Interior Highlands and Appalachian Sinkhole and Depression Pond
High Allegheny Headwater Wetland
Laurentian-Acadian Freshwater Marsh
Laurentian-Acadian Large River Floodplain
Laurentian-Acadian Wet Meadow-Shrub Swamp
North Atlantic Coastal Plain Basin Peat Swamp
North Atlantic Coastal Plain Stream and River
North-Central Appalachian Large River Floodplain
North-Central Interior Large River Floodplain
Piedmont-Coastal Plain Freshwater Marsh
Piedmont-Coastal Plain Large River Floodplain
Piedmont-Coastal Plain Shrub Swamp
Ruderal Shrub Swamp

Large river floodplain forest (subsystem)

North Atlantic Coastal Plain Basin Peat Swamp Larger river floodplain
North Atlantic Coastal Plain Basin Swamp and Wet Hardwood Forest Larger river floodplain
North Atlantic Coastal Plain Pitch Pine Lowland Larger river floodplain
North-Central Interior and Appalachian Rich Swamp Larger river floodplain
Laurentian-Acadian Alkaline Conifer-Hardwood Swamp Larger river floodplain
Laurentian-Acadian Floodplain Forest Larger river floodplain
North-Central Appalachian Acidic Swamp Larger river floodplain
Northern Appalachian-Acadian Conifer-Hardwood Acidic Swamp Larger river floodplain
Atlantic Coastal Plain Small Brownwater River Floodplain Forest Larger river floodplain
Piedmont-Coastal Plain Freshwater Marsh Larger river floodplain
Piedmont-Coastal Plain Large River Floodplain Larger river floodplain
Southern Piedmont Lake Floodplain Forest Lake/pond: any size