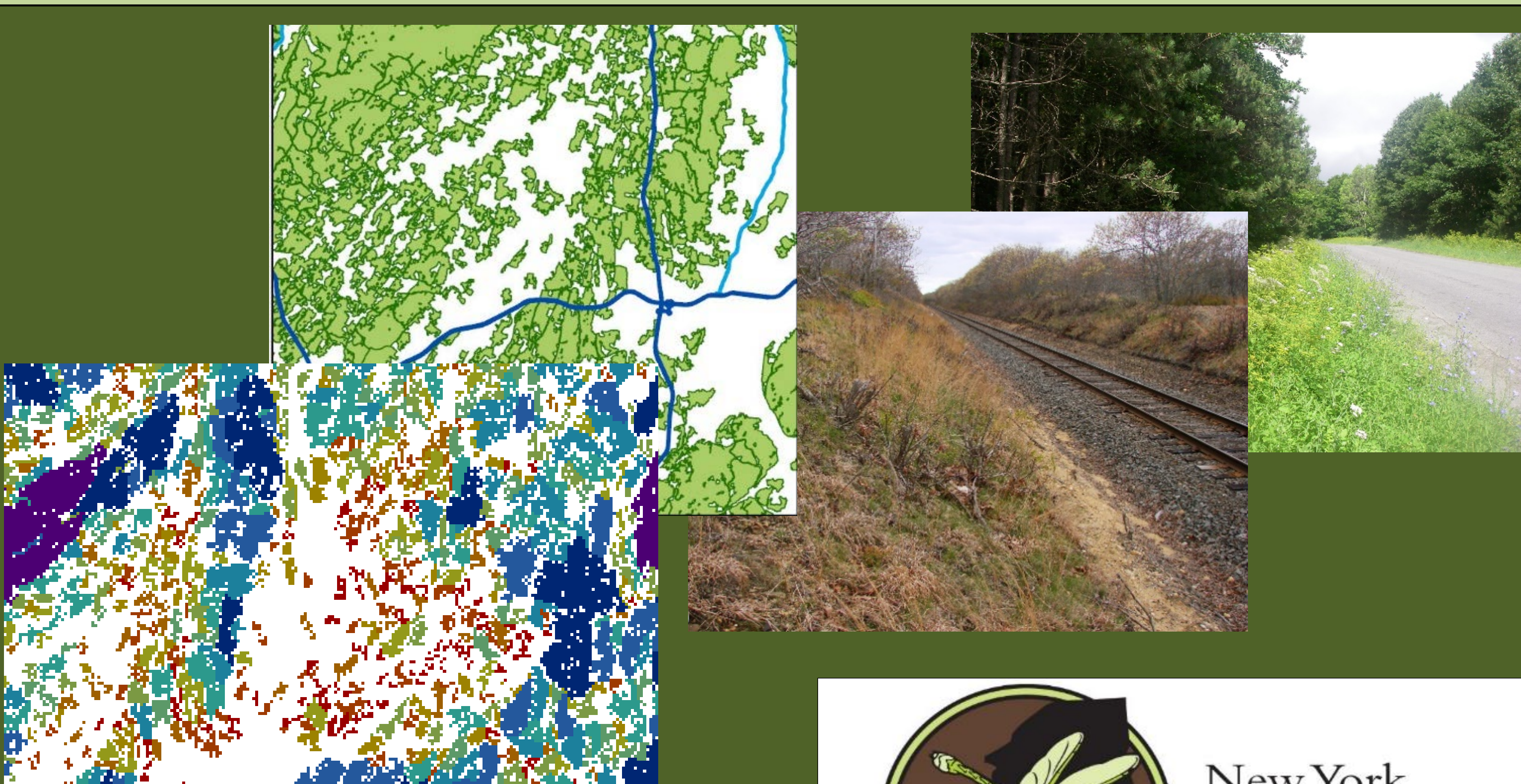
Hudson Valley Forest Patch Update and Assessment

Amy K. Conley, Emily Cheadle, and Timothy G. Howard

December 2019



New York Natural Heritage Program

The New York Natural Heritage Program

The New York Natural Heritage Program (www.nynhp.org) is a program of the State University of New York College of Environmental Science and Forestry that is administered through a partnership between SUNY ESF and the NYS Department of Environmental Conservation. We are a sponsored program within the Research Foundation for State University of New York.

The mission of the New York Natural Heritage Program is to facilitate conservation of rare animals, rare plants, and significant New York ecosystems. We accomplish this mission by combining thorough field inventories, scientific analyses, expert interpretation, and a comprehensive database on New York's distinctive biodiversity to deliver high-quality information for natural resource planning, protection, and management.

Established in 1985, our program is staffed by 27 scientists and specialists with expertise in ecology, zoology, botany, information technology, and geographic information systems. Collectively, the scientists in our program have over 300 years of experience finding, documenting, monitoring, and providing recommendations for the protection of some of the most critical components of biodiversity in New York State. With funding from a number of state and federal agencies and private organizations, we work collaboratively with partners inside and outside New York to support stewardship of New York's rare animals, rare plants, and significant natural communities, and to reduce the threat of invasive species to native ecosystems.

In addition to tracking recorded locations, NY Natural Heritage has developed models of the areas around these locations important for conserving biodiversity, and models of the distribution of suitable habitat for rare species across New York State.

NY Natural Heritage has developed two notable online resources: Conservation Guides include the biology, identification, habitat, and management of many of New York's rare species and natural community types; and NY Nature Explorer lists species and communities in a specified area of interest.

NY Natural Heritage also houses *i*MapInvasives, an online tool for invasive species reporting and data management.

In 1990, NY Natural Heritage published *Ecological Communities of New York State*, an all-inclusive classification of natural and human-influenced communities. From 40,000-acre beech-maple mesic forests to 40-acre maritime beech forests, sea-level salt marshes to alpine meadows, our classification quickly became the primary source for natural community classification in New York and a fundamental reference for natural community classifications in the northeastern United States and southeastern Canada. This classification, which is continually updated as we gather new field data, has also been incorporated into the National Vegetation Classification.

NY Natural Heritage is an active participant in NatureServe (www.natureserve.org), the international network of biodiversity data centers. NatureServe's network of independent data centers collects and analyzes data about the plants, animals, and ecological communities of the Western Hemisphere. The programs in the NatureServe Network, known as natural heritage programs or conservation data centers, operate throughout all of the United States and Canada, and in many countries and territories of Latin America. Network programs work with NatureServe to develop biodiversity data, maintain compatible standards for data management, and provide information about rare species and natural communities that is consistent across many geographic scales.

New York Natural Heritage Program
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Final Report

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Cover photos: (top) J. Jaycox, Putnam County; T. Howard, Sullivan County; T. Howard, Orange County. (bottom) S. Young, Suffolk County; E. White, Montgomery County.

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Introduction

Project Background and Overview

Forests make up the majority of the natural ecosystems and landcover spreading over most of the traditional natural landscape of eastern North America (Braun 1950). Forests provide important habitat for native species, help keep streams cool and clean, and are often included as conservation priorities (e.g. Murdoch et al. 2007; Wiens et al. 2009). Although forests in the Northeastern US had been increasing in their extent since the early 1900s (Flinn and Vellend 2005; Klepeis et al. 2013; Yavuz and Hall 2018), more recently, we are starting to see this trend turn around with development fragmenting and reducing the size of forests on our landscape (see, e.g. https://coast.noaa.gov/digitalcoast/tools/lca.html).

Forests are an important part of the outreach, technical assistance, and conservation work conducted by the Hudson River Estuary Program with municipalities and other partners. The Program frequently uses a data layer that delimits the extant forest patches in the estuary watershed. The most recent version of this forest patch layer is based on land cover data from 2010. Many changes have occurred in our forests since 2010 and updating this information is the first goal of this project.

Not all forests and forest landscapes are equal in their ability to support native species and be resistant and resilient to external stressors. The best way to assess the condition of a forest is to conduct field surveys and quantify the native species, invasive species, structural and habitat heterogeneity, forest health indicators, forest stress indicators, and other measures of forest condition. Lacking the ability to visit every forest patch, however, there are many remote measures that estimate different aspects of forest health that might be used, in concert, to estimate forest condition. This is the second goal of this project: to estimate the condition of each forest patch based on a suite of metrics.

This report is structured around two sections: 1. Delineating forest patches for all of New York State, and 2. Estimating forest patch condition for forest patches in the Hudson Valley.

Study Area

To develop a forest patch layer for the entire state, our goal was to include forest patches within and intersecting the state boundaries for New York State. To ensure we captured the full extent of forest patches intersecting state boundaries, we set our study area for this first section to extend 75 km beyond the state line (Figure 1). Our primary data source was the National Land Cover Dataset (NLCD) that was released in the spring of 2019 for imagery based on 2016 (Yang et al. 2018 and see https://www.mrlc.gov/data/nlcd-2016-land-cover-conus). The NLCD is not available in Canada, so, while we collected other information for Canada, our forest blocks did not cross the international border.

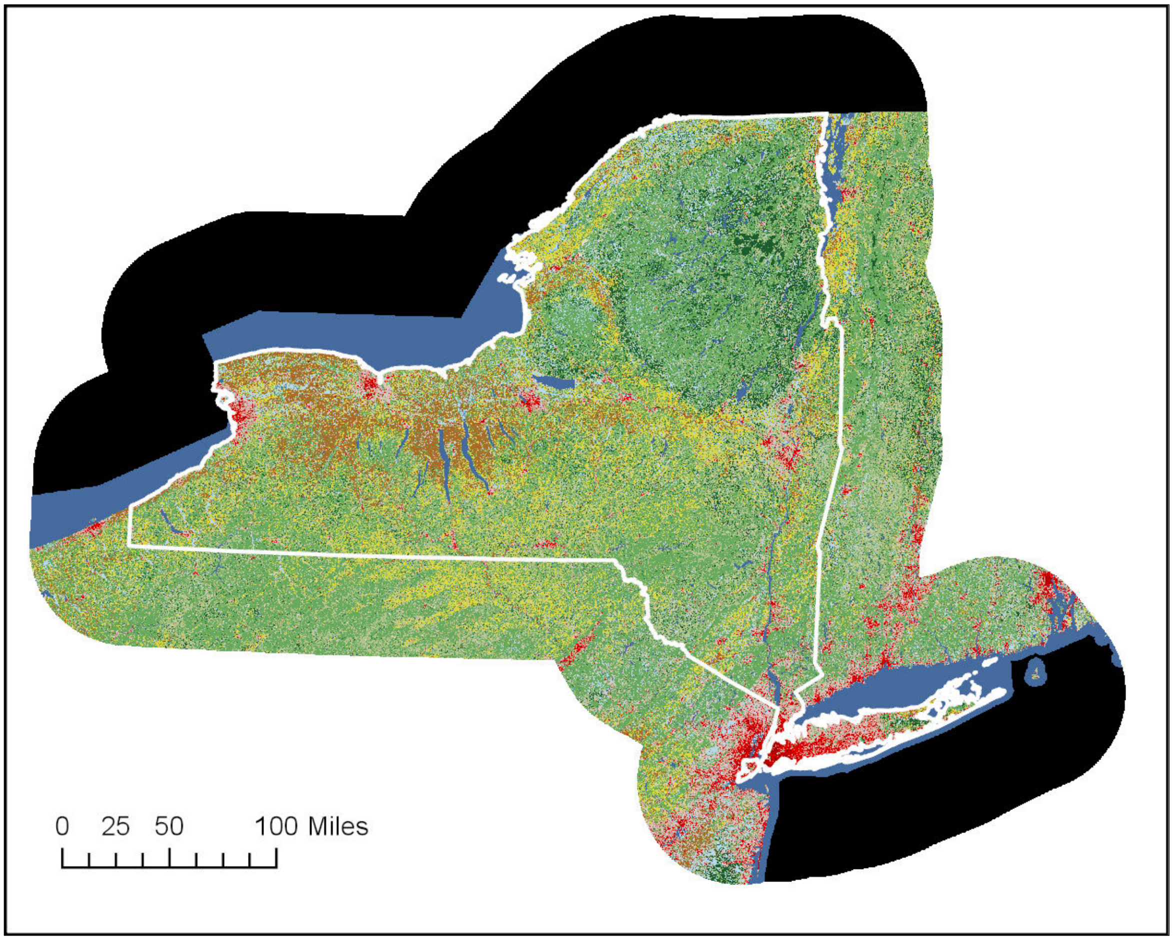

Figure 1. The project study area for creating forest patches was set to 75 km beyond New York State's boundaries. This figure shows this extent, with the 2016 NLCD depicted as the base layer.

The study area for the second portion of this study consisted of the forest patches within the Hudson River Valley. Here, we used the ten counties bordering the Hudson River from the Troy Dam to New York City, with an additional 20 km buffer (Figure 2).

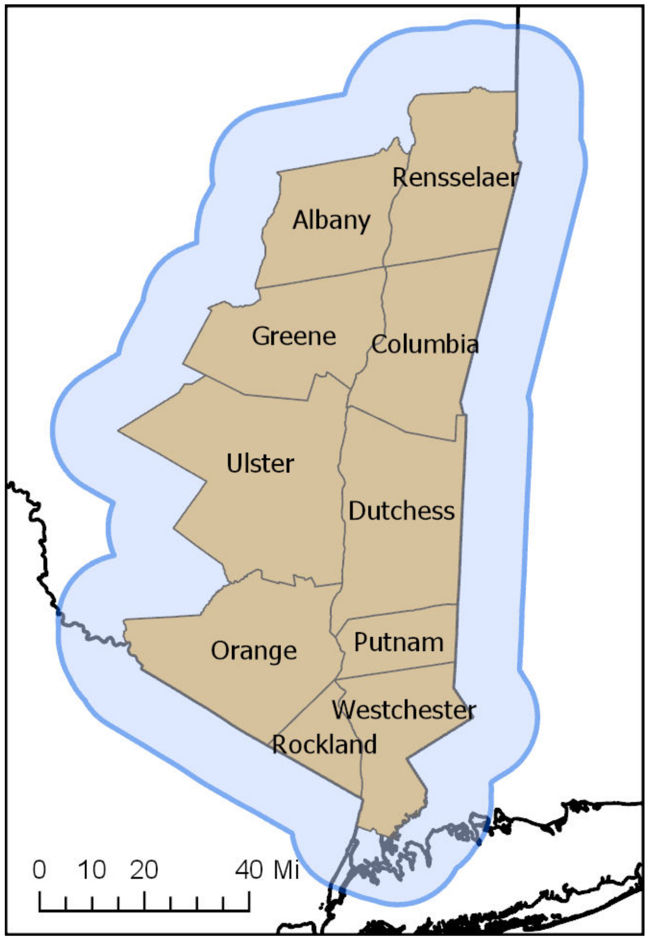

Figure 2. The study area for forest patch assessment encompassed the ten counties of the Hudson River Estuary plus a 20 km buffer.

Project Core Team and Steering Committee

This project benefitted greatly from consideration, discussions, and other input from Laura Heady, Ingrid Haeckel, and Nate Nardi-Cyrus from the Hudson River Estuary Program, who, in addition to the three members from the New York Natural Heritage Program, make up our core team. We also presented on our methods and progress to the much larger Hudson Valley Conservation Partners group. This group effectively worked as our Steering Committee that helped ensure our methods were sound and data sources as complete as possible.

Methods and Results

Developing forest and natural land patches

We used the newly-released NLCD 2016 as our land cover data source (Yang et al. 2018 and see https://www.mrlc.gov/data/nlcd-2016-land-cover-conus). This data set became available on May 10, 2019. Early into the process, and with feedback from the Core Team and Steering Committee, we recognized the benefits of having two different patch data layers for conservation planning: a strictly defined "forest" group and a broader "natural land" group that also includes other natural cover types. The "forest" group includes the Deciduous Forest, Evergreen Forest, Mixed Forest, Shrub/Scrub, and Woody Wetlands classes. The second "natural land" group includes all the forest classes as well as the Barren Land, Herbaceous, and Emergent Herbaceous Wetlands classes (Table 1). We extracted these groups of land cover classes into separate raster data sets. These two rasters (forests and natural lands) represented the landscape we divided further into patches using fragmenting barriers. At this step we also removed clusters of pixels less than 100 acres (450 30x30 m pixels) for increased efficiency as these small patches would also be removed later.

Table 1. Land use classes (defined and raster values) from the NLCD and the two groupings extracted for this project. We created one set of patches by extracting only forest and woody wetlands types (checked in "Forest" column) and a second set by extracting all of the natural cover types ("Natural Land").

NLCD Class	Class values	Forest	Natural Land
Open Water	11		
Developed, Open Space	21		
Developed, Low Intensity	22		
Developed, Medium Intensity	23		
Developed, High Intensity	24		
Barren Land	31		X
Deciduous Forest	41	X	X
Evergreen Forest	42	X	X
Mixed Forest	43	X	X
Shrub/Scrub	52	X	X
Herbaceous	71		X
Hay/Pasture	81		
Cultivated Crops	82		
Woody Wetlands	90	X	X
Emergent Herbaceous Wetlands	95		X

We used roads and railroads as features to divide the forest and natural lands into patches. Because of our goal to create and include forest patches that intersected with but extended beyond New York's state boundary, we needed a representation of each data set (roads and railroads) that extended beyond state lines. For roads, we considered products produced by each state (such as ALIS in NY) but quickly realized the effort required to join road lines at state boundaries would be prohibitive. We explored two different national representations: the TIGER dataset from the US Census Bureau (*https://www.census.gov/geographies/mapping-files/time-series/geo/tiger-line-file.html*) and the North American Detailed Streets layer from ESRI (*https://www.arcgis.com/home/item.html?id=f38b87cc295541fb88513d1ed7cec9fd*). We found enough inaccuracies in the TIGER dataset, such as roads going into natural lands where we knew none currently existed, that we opted for the ESRI product.

After downloading and clipping the roads dataset by our study area (75 km buffer of NYS), we extracted and applied buffers by Arterial Classification Code (ACC), defined in Tables 2 and 3.

Table 2. Arterial Classification Codes (ACC) and their definitions.
Sources: https://library.duke.edu/data/files/esri/esridm/2010/streetmap_na/streets.html and https://gis.ny.gov/gisdata/supportfiles/Streets-Data-Dictionary.pdf

ACC code	Geographic Significance	Routing Importance
1	North America/Continental and Inter-State (and Province)	Largest/Longest Highways, Connect Major/Largest Cities, "Coast-to-Coast" Origin to Destination, Inter-State (and Province) Commerce/Travel, and Intra-State (and Province) Commerce/Travel.
2	Inter-Metropolitan Area	Long/Large Highways, Beltways/Secondary Freeways, and Connect Major Cities.
3	Intra-State (and Province), Intra-Metropolitan Area, and Inter-Metropolitan Area	Medium Highways, U.S./State Highway Network, Connect Minor Cities, Intra-State (and Province) Commerce, and Recreational Travel.
4	City/County/Local	Local Arteries, Retail Commerce, Recreational Activities, and Initial Route Origin/Final Destination.
5	Neighborhood	Neighborhood/Community Access, Initial Route Origin/Final Destination, and all other streets.

The U.S Census Bureau's Feature Classification Code (FCC) has finer divisions of road types. We used these codes to remove trails and very small roads from the ACC level 5 roads extracted above. Specifically, we removed all roads in the ACC = 5 class that also had FCC classifications of A50, A51, A70, A72, A73, and A74. These are 'Vehicular trails' (A50, A51), 'Other thoroughfare' (A70), 'Walkway' (A71), 'Stairway' (A72), 'Alley' (A73), and 'Driveway' (A74). The source of these definitions is here: https://support.esri.com/en/technical-article/000001496 and here https://gis.ny.gov/gisdata/supportfiles/Streets-Data-Dictionary.pdf.

We buffered roads based on their ACC attribution. We used a sampling of measured centerline-to-forest-edge distances throughout the state to help guide the width of the buffers for each class. The final buffer distances ranged from 30 meters for highways, to 7 meters for the smallest roads (Table 3).

Table 3. The buffer distance applied to each road class. Each distance (in meters) was applied from the center line outward in both directions so the final width of the polygon representing the road is twice the buffer applied.

ACC code	Buffer distance (m)
1	30
2	30
3	11
4	11
5	7

We obtained railroad information from each state and province. Most data sets had an attribute about whether the line was in active use as a railroad (e.g. whether it is a rail trail or abandoned) and these inactive rail lines were removed (Table 4). After extracting the appropriate rail lines from each dataset, we buffered each by 11 meters, merged, and then dissolved the dataset to get a single representation of railroads within the study area.

Table 4. Our sources for railroad GIS data. For each state and province, this table lists the online source of the dataset and then the select query used to remove inactive rail lines.

State	Item	details
NY	source	http://gis.ny.gov/gisdata/inventories/details.cfm?DSID=904
	query	"GDB_SUBTYP" NOT IN (4, 5, 6, 7)
PA	source	https://www.pasda.psu.edu/uci/DataSummary.aspx?dataset=48
	query	"STATUS" NOT IN (\'Abandoned\', \'Abandoned and Removed\')
MA	source	https://docs.digital.mass.gov/dataset/massgis-data-trains
	query	"DATE_ABAND" = 0'
VT	source	http://geodata.vermont.gov/datasets/d7b0137115f84c18ae1b1f8a6cf6dc0c_12
	query	"RailTrail" = \'N\'
CT	source	http://cteco.uconn.edu/metadata/dep/document/Railroad_FGDC_Plus.htm
	query	"AV_LEGEND" <> \'ABANDONED\"
NJ	source	https://njogis-newjersey.opendata.arcgis.com/datasets/passenger-railroad-lines-in-new-jersey
	query	None available, assume all active
QC	source	https://www.donneesquebec.ca/recherche/fr/dataset/reseau-ferroviaire
	query	"etat" <> \'Abandonné\'

Finally, we merged the roads and railroads datasets. The large number and total length of the finest-scale roads (ACC=5) created computational problems and so all processes using the barriers were handled in batches with all larger roads and railroads used first and then the small roads applied in groups. These final data sets are depicted in Figure 3.

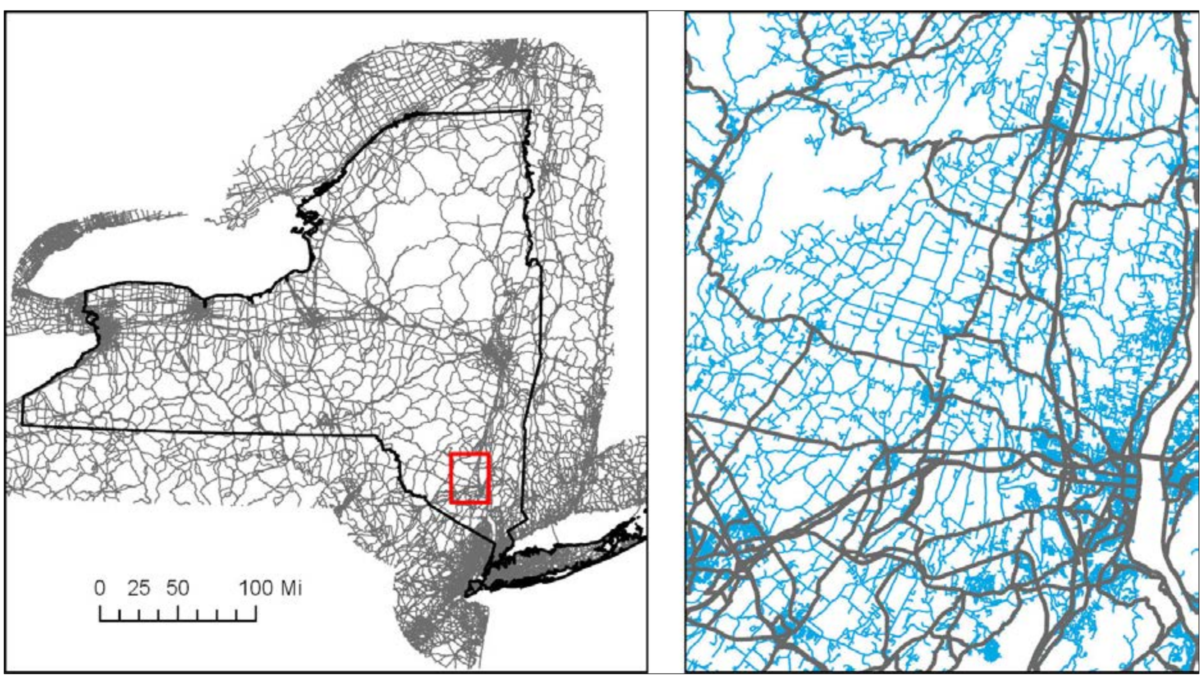

Figure 3. Our final barriers dataset; roads and railroads buffered and merged. The left panel shows roads with ACC values of 1, 2, 3, or 4 and all railroads. The red rectangle in the left panel indicates the extent of

the right panel, which shows the same barriers as the left panel in grey plus the roads with an ACC value of 5 in blue.

Finally, we used the barriers dataset (roads and railroads) to cut ("Erase" tool in ArcGIS) the polygon representations of the forest and natural lands layers. We removed all polygons less than 100 acres to create our final patches dataset. The final forest and natural land patches are depicted in Figure 4. These layers are available as spatial (GIS) datasets from NYNHP.

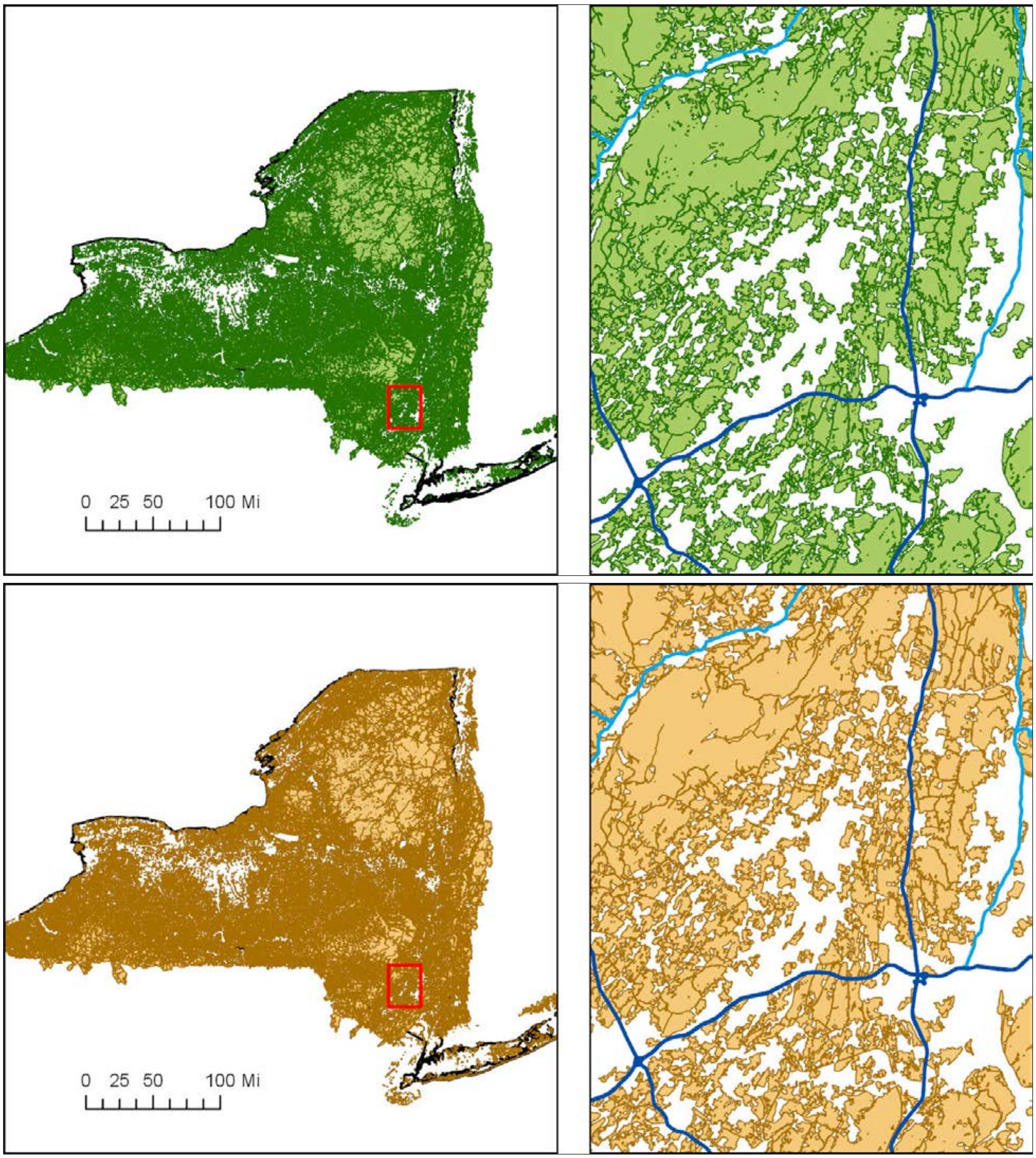

Figure 4. The final set of forest patches (top panels) and natural land patches (bottom panels) developed for this project.

Assessing condition of forest patches in the Hudson Valley

Creating additional units for analysis

For the forest patches within the Hudson River Estuary Watershed, we assessed patch condition and value. Our forest patches are designed to represent roadless blocks of forest; however, nearby features like roads and impervious surfaces impact forest health, and non-forest habitat within a patch, like wetlands, benefit from the services the surrounding forest provides, so it was necessary to create a modified form of the forest patch in order to assess the impact of these features on forest quality and value. To do this, we created a second representation of the forest patches that included all landcover classes within the boundaries of the forest. We created these "analysis patches" by buffering each of our forest patches out by 30 meters, and then buffering the result inward 30 meters. The result of the two buffer steps is an analysis patch that follows the exterior boundary of the original forest patch but encompasses all interior holes and fills in small pockets in the exterior border. An example of the difference in area of the two patches can be seen in Figure 5. The analysis patch was used to assess components of the index that measure the impact of non-forest features. In all descriptions and calculations discussed below, we consistently use the terms "original forest patch" and "analysis patch" to make it clear which patch is being used.

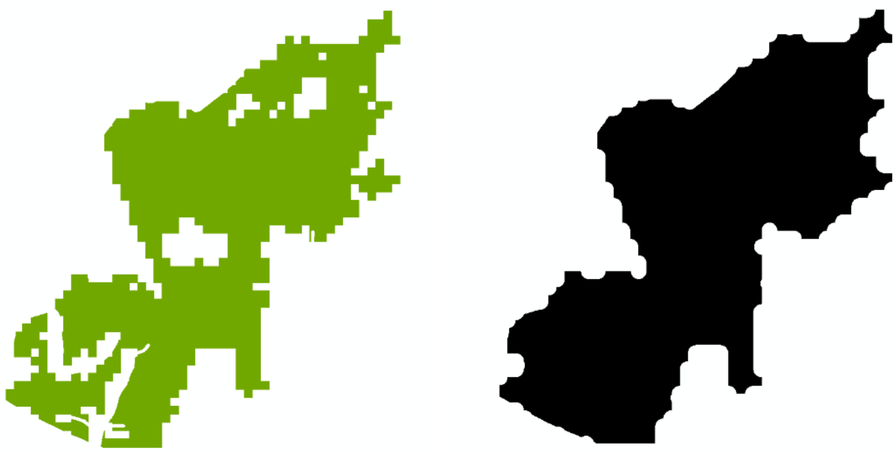

Figure 5 Comparison of an original forest patch (green) and the corresponding analysis patch (black).

Index Components

This section itemizes all the measures that we calculated and used as contributors to the final condition index. Components are grouped below by process or type of effect they have on the forest patch.

SIZE:

Patch size. The area of the original forest patch in acres.

FRAGMENTATION:

We quantified patch fragmentation using the UCONN Landscape Fragmentation Tool v 2.0 (available at http://clear.uconn.edu/tools/lft/lft2/index.htm), which classifies landcover based on pixel-level patterns of forest position relative to non-forest fragmenting habitat. This classification procedure is based on those developed in Vogt. *et al* (2007) and adapted for use in the ArcGIS environment. To prepare our data for use in the tool, we converted the forest patch polygon layer to a 10 meter raster representation, assigned a value of 2 to all pixels in a forest patch and a value of 1 to all non-forest habitat. We used an edge width of 100 meters; the edge width describes the distance over which the non-forest landcover is capable of degrading forest land cover. While the effects of edge width can vary by species and the nature of the fragmenting landcover, an edge width of 100 meters is considered suitable for general purposes (Parent and Hurd 2008 and see clear.uconn.edu/tools/lft/lft2/method.htm). The analysis classified pixels that were farther than 100 meters from non-forest habitat as forest core, pixels within 100 meters of non-forest as forest edge, pixels within 100 meters of an interior gap in the forest as perforated, and pixels in a patch of forest with no core forest as part of a fragment. For our analysis, both perforated and core area pixels are classified as core forest.

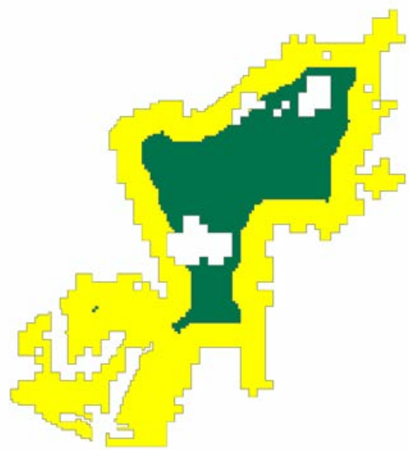

Figure 6. Forest patch after classification of fragmentation using the UCONN Landscape Fragmentation Tool v 2.0. Green areas represent core forest, yellow areas represent forest edges.

We used the output of the fragmentation analysis to describe the forest patches in two metrics:
Core Area Index: The ratio of the total core area to patch area
Edge Density: ratio of edge area to patch area

FOREST CONNECTIVITY

Distance to a large patch: We created a "large patch layer" by selecting forest patches that had total core areas of 500 acres or more according to our fragmentation analysis. We used a near analysis to calculate the distance between each forest patch and the closest "large patch" in meters.

Local connectedness: Connectivity within and among forests depends on more than just the straight line distances between them, the permeability of the habitat determines the ease with which species can move. We used a measure of landscape permeability based on the distribution of natural cover and human-created barriers like major roads, development, and agricultural land (Anderson, Barnett, Clark, Ferree, et al. 2016). For each cell, its connectivity outward, to a maximum distance of 3 kilometers, is calculated based on the resistance of the surrounding landscape, with natural areas facilitating movement and human barriers increasing resistance. The values were normalized based on setting and ecoregion. We calculated the average value within each original forest patch.

Forested landscape: The degree to which the landscape surrounding a patch is forested has important consequences for the species in the forest core. We buffered the analysis patches by 1.5 miles and calculated the proportion of that area that was forested according to the 2016 National Land Cover Dataset. For this component, forest habitat was any area classified by the NCLD as mixed forest, deciduous forest, coniferous forest, scrub/shrub, or forested wetland.

Landscape context (Regional Flow): Forest patches can play an important role in regional patterns of connectivity. We used a regional flow analysis by The Nature Conservancy, which uses circuit theory to model the movement of plants and animals across a landscape like current flowing through a circuit, and is based on the resistance of the landscape to movement and human-made barriers (Anderson, Barnett, Clark, Prince, et al. 2016). These data "highlight locally and regionally significant places where species range shifts may be impeded or concentrated by anthropogenic or ecological resistance." We calculated the maximum regional flow value per original forest patch.

STRESSORS

Landscape Condition Assessment: The extent, quality, and distribution of alterations to the landscape surrounding a forest can impact the health of the habitat. The Landscape Condition Assessment (LCA) incorporates a suite of landscape stressors which describe the distribution and abundance of transportation, urban, industrial, and agricultural land use within New York state (Feldmann and Howard 2013). The 13 input stressors include five categories of roads from ALIS, active rail lines, three categories of development intensity and one representation of open spaces from CCAP, electric and natural gas corridors, and cropland from CropScape (https://nassgeodata.gmu.edu/CropScape/). A sigmoid decay function was applied to each stressor to model the attenuation of ecological effects away from its footprint. We calculated the average score per original forest patch.

Road density: Habitat quality within a forest can be impacted by activities in the surrounding landscape. We calculated road density within a 1.5 mile buffer of the analysis patch. We used the same set of roads described above for creating the forest patches, dividing the total length of roads within the 1.5 mile buffer by the buffer area in acres to create a density measure.

Impervious surface: We based our measure of impervious surface on the 2016 NLCD Urban Imperviousness data set (Yang et al. 2018), which represents impervious surface as a percentage of developed surface for each 30 meter pixel. This measure provides continuous value of the percent of ground covered by impervious surfaces. We calculated the average percent impervious surface for each analysis patch.

Building density: Built structures, and the increased human activity associated with them, can have impacts on forest health. We used building footprint polygons for New York, Pennsylvania, Massachusetts, Connecticut, and New Jersey, created by Microsoft from aerial imagery and available to download from https://github.com/microsoft/USBuildingFootprints. We divided the total building area in square feet in each analysis patch by the analysis patch area in acres to create a measure of building density.

Forest Damage: A forest that has sustained significant damage, even from natural processes, can be less resilient to future disturbances. We used data on known instances of forest damage and their suspected causes from the DEC Forest Aerial Survey Program. The data covered years 2007-2019. We removed damage occurrences that were ambiguous or attributed to natural processes like fire, flood, frost, ice, beaver, and wind. From the remaining subset of damage occurrences, we scored a patch as having damage present if two or more classes of damage were recorded in that analysis patch.

HABITAT AND ECOSYSTEM VALUE

Older Forest: We used data from the U.S. Conterminous Wall-to-Wall Anthropogenic Land Use Trends (NWALT), 1974-2012 (Falcone 2015). This national, 60 meter dataset maps anthropogenic land uses for five time periods, 1974, 1982, 1992, 2002, and 2012, and was derived using a modified version of methods used for the NLCD 2011 then mapped backwards in time. The six product classes were Water (1), Developed (2), Semi-Developed (3), Production (4), Low Use (5), and Very Low Use, Conservation (6). For our estimate of older forest, we selected all pixels that were classified as "Low Use" or "Very Low Use, Conservation" in the 1974 data set, following the assumption that these classes represented natural areas. We created a binary raster of just these areas and then calculated the proportion of our forest patches that were also classified as "Low Use" or "Very Low Use, Conservation" in 1974. This assumes that areas which were not under any kind of anthropogenic use in 1974 and were also classified as forest in 2016 did not change land use status in the intervening 42 years.

Landform diversity: Forests with higher landform diversity provide a greater chance for plant and animal species to find conditions that meet their requirements locally in the face of climate change. We used an existing data set that estimates the variety of microclimates and climatic gradients available within 100 acres of a cell (Anderson, Barnett, Clark, Ferree, et al. 2016). The metric considers landform variety, elevation, wetlands, and soil diversity. The metric also normalizes values based on setting and ecoregion. We calculated the average value for each original forest patch.

Community diversity: Forest patches may contain a mosaic of forest and non-forest natural communities. We used vegetation data based on the Landfire Existing Vegetation Type from Landfire version 1.4.0 (LANDFIRE 2014). Because this was a wall to wall classification, some of its classes describe developed or agricultural habitats that were not the focus of our analysis. We created a subset of the data that excluded any vegetation types classified as 'Developed,' 'Agricultural,' or 'Quarries-Strip Mines- Gravel Pits.' We counted the total number of unique community classes within each analysis patch.

Migratory fish: Forests that encompass habitat for fish species of concern can buffer those communities from disturbance. We used data on the distribution of migratory fish species from the New York Natural Heritage Program's Freshwater Blueprint (White et al. 2011). The Blueprint data predicts suitable habitat for Alewife, American Eel, American Shad, Atlantic Salmon, Atlantic Sturgeon, Atlantic Tomcod, Blueback Herring, Brook Trout, Chinook Salmon, Coho Salmon, Rainbow Smelt, Sea Lamprey, Striped Bass, and Shortnose Sturgeon throughout New York State. We considered migratory fish present in a forest if the analysis patch intersected streams positive for migratory fish presence.

Brook Trout: We used verified patches from the Eastern Brook Trout Joint Venture and New York Natural Heritage Program Important Areas for Wild Brook Trout to create a set of polygons identifying known Brook Trout habitat. We considered Brook Trout to be present in a patch if the analysis patch intersected a brook trout polygon.

Rare species and significant natural communities: Forest patches can contain vital habitats for rare species and exemplary natural communities. We used data from the New York Natural Heritage Program on known occurrences of rare plants and animals and significant natural communities in the state of New York. Each individual occurrence was assigned a value based on its age, quality, and rarity. A continuous statewide raster of total rare species value was created by stacking the occurrences and assigning each 30 meter pixel the cumulative values of all overlapping occurrences. We calculated the average value of this layer within each analysis patch.

Stream condition: The Biological Assessment Profile is an evaluation of stream and river water quality based on macroinvertebrate community data from the DEC's Stream Biomonitoring Unit. Diverse and healthy communities reflect very good water quality. We used data from New York Natural Heritage Program's Fresh Water Blueprint (White et al. 2011), which developed a predictive model of BAP scores for streams statewide. We calculated the average score per analysis patch.

Riparian habitat: Forests which contain riparian areas provide important buffering systems to the stream community and protect the riparian zone from erosion. We used riparian buffers created by the New York Natural Heritage Program for New York State streams delineated in the NHD High Resolution dataset (available at https://www.nynhp.org/treesfortribsny) and FEMA Significant Flood Hazard Areas for the 10 counties in the Hudson River Estuary Watershed (available at https://msc.fema.gov) to represent the extent of the riparian zone. We merged and dissolved the two datasets and calculated the proportion of the analysis patch that intersected the combined riparian habitat.

Wetlands: Forests which contain wetlands provide important ecosystem services to these habitats. We used data on wetland distribution from the National Wetland Inventory (U.S. Fish and Wildlife Service 2014). We calculate the proportion of the analysis patch area that was comprised of wetlands.

CARBON SEQUESTRATION

Carbon sequestration: Forests patches provide an essential service by sequestering carbon. Our carbon sequestration data was based on the Forest Carbon Stocks of the contiguous United States 2000-2009 dataset created by the US Forest Service (Wilson, Woodall, and Griffith 2013). The original data was based on a nearest neighbor imputation method using FIA forest inventory data, MODIS satellite imagery, and other spatial data. The Trust for Public Land modified the units from MgC/Ha to metric tons/pixel and we used this version of the data to calculate the average carbon sequestration per pixel of the original forest patch.

Combining Scores to Create an Index

For each index component, we sorted the 3783 forest patches by their values, from lowest to highest, and each patch was awarded a number of points based on its rank. The maximum number of points which could be earned for each component reflected how much we felt it should contribute to the overall forest index. We set lower maximum point values to components with a narrow focus, such as those that described the presence of a single species or one just type of habitat, and larger maximum point values to components that reflected broader or more comprehensive measures of forest health. When assigning points to a patch, we designed the point system so that a higher point score always reflected a healthier forest (Table 5).

Table 5. Components of the forest index and their weightings. An asterisk ("*") indicates components for which lower raw values indicate better quality habitat. The calculation of the raw value is also provided ("Prop" = proportion), along with the maximum points that could be assigned to each component. The category field indicates which sub-indexes the component is a part of (HEV = Habitat and Ecosystem Value).

Component Name	What the raw value represents:	Max Points	Category
Patch Size	Area in acres	24	Size
Core Area Index	Prop. area core	6	Fragmentation
Edge density*	Prop. area edge	6	Fragmentation
Distance to nearest large patch*	Distance in km	12	Connectivity
Local connectedness	Mean value	12	Connectivity
Forested landscape	Prop. 1.5 mi buffer forested	12	Connectivity
Landscape context (Regional Flow)	Maximum value	12	Connectivity
Landscape Condition Assessment*	Mean value	24	Stressor
Road Density*	km / acre	12	Stressor
Building Density*	Square feet / acre	12	Stressor
Impervious surfaces*	Mean value	12	Stressor
Forest Damage*	Present/Absent	0 or 2	Stressor
Older Forest	Prop. undeveloped in 1974	12	HEV
Landform diversity	Mean Value	12	HEV
Brook Trout	Absent/Present	0 or 2	HEV
Migratory fish	Absent/Present	0 or 2	HEV
Rare species and significant natural communities	Mean Value	12	HEV
Stream condition (BAP)	Mean Value	6	HEV
Riparian habitat	Prop. area riparian	6	HEV
Wetlands (NWI)	Prop. area wetland	6	HEV
Community diversity (Landfire)	Count unique habitats	12	HEV
Carbon sequestration	Mean	12	Carbon Sequestration

We assigned points to each patch based on how the component was weighted (the maximum point value; Table 5) and the percentile of the forest patch (Table 6). Percentile was determined by the patch's rank after sorting patches in order from lowest to highest value for each component. We divided patches into bins by deciles, with each patch in the bin receiving the same number of points. For example, for the component "Patch Size," the 3783 patches were sorted from lowest to highest by their area in acres. The smaller the patch, the lower their rank, and smallest, lowest ranked 378 patches would fall in the 0-10th percentile bin (the lowest scoring 10% of the 3783 patches) and all patches in that bin would receive the same score; for this group it would be the lowest possible point value, 2 points (Table 6). The next lowest ranked 378 patches fall in the second lowest bin, the 10-20th percentile bin, and they would all be assigned 4 points, and so forth. Then, to gain better resolution among the highest scoring forest patches, the 378 patches in the 90th – 100th percentile bin were further subdivided into a 95-99 percentile bin and a 99-100 percentile bin, so only the highest 1% of the patches received the maximum number of points. For some components, like stressors, for which a smaller raw value indicates a healthier forest, we reversed scoring so that instead of the top 1 percentile receiving the maximum point value, the bottom 1 percentile received the maximum point value. For components where the patches were scored as either present or absent, we assigned a patch 2 points or 0, and percentiles were not used.

Table 6. Point assignments for calculating forest index based on three different weighting options (maximum point values of 6, 12, and 24). The first column indicates how percentiles are translated into points for most index components. The second column indicates the percentile assignments for those components where a smaller raw value indicates a healthier habitat (see those marked with an "*" in Table 5). The point system is designed so a higher point value always indicates a healthier forest, regardless of the nature of the original data.

Percentile Value of Raw Score	Percentile Value of Raw Score*	Point Value Max = 6	Point Value Max = 12	Point Value Max = 24
0	100	0	0	0
0 to 10	100 to 90	0.5	1	2
10 to 20	90 to 80	1	2	4
20 to 30	80 to 70	1.5	3	6
30 to 40	70 to 60	2	4	8
40 to 50	60 to 50	2.5	5	10
50 to 60	50 to 40	3	6	12
60 to 70	40 to 30	3.5	7	14
70 to 80	30 to 20	4	8	16
80 to 90	20 to 10	4.5	9	18
90 to 95	10 to 5	5	10	20
95 to 99	5 to 1	5.5	11	22
99 to 100	1 to 0	6	12	24
100	0	6	12	24

We summed the point values for all components to create the forest index. To provide additional context for users, we grouped subsets of the components together to create sub-indexes that describe how a patch scored in the areas of fragmentation, connectivity, stressors, and habitat and ecosystem value.

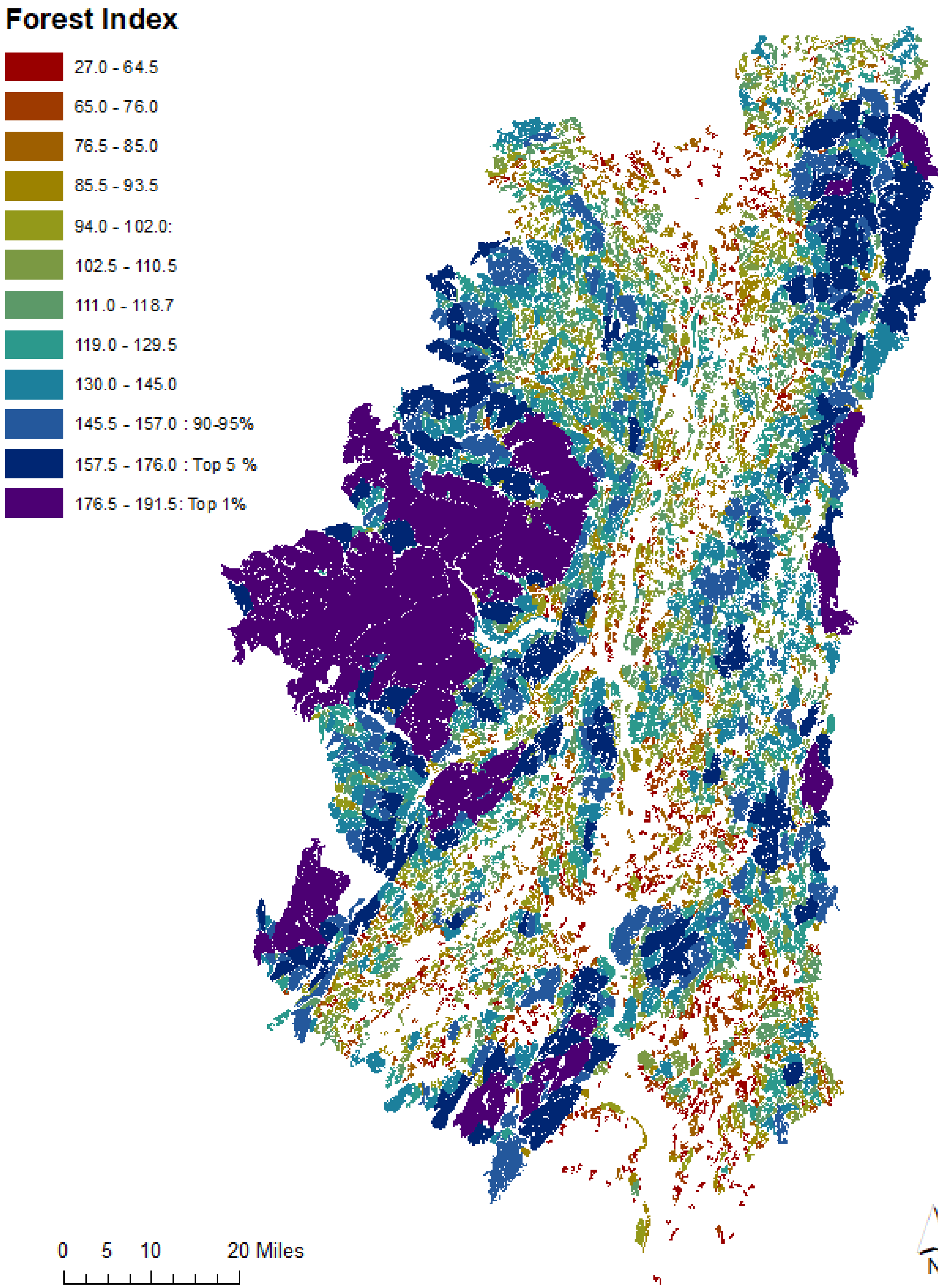

Figure 7. Forest Index for forest patches of 100 acres or more in the Hudson River Estuary Watershed and counties. Colors are associated with 10th percentile bins, with the 90th percentile bin further divided into separate bins for the 95-99 percentile and 99-100 percentile to highlight the highest scoring patches in the area.

Discussion

The forest patch and natural lands patch datasets were developed with a consistent, transparent, and repeatable methodology. This ensures that equivalent patches could be created for future releases of the NLCD in order to track future changes in patch size and configuration. Similarly, this consistent method could be applied to earlier versions of the NLCD to evaluate historical changes. One difficulty in backcasting, however, is that it may be difficult to acquire time-appropriate road and railroad datasets.

The forest index is based on 22 different measures of each forest patch. These measures assess patch size, fragmentation, connectivity, stressors, habitat and ecosystem value, and carbon sequestration. The goal, overall, was to acquire a diverse representation of measures that incorporated as many measures related to forest condition as possible, while also minimizing redundancy. To assess the potential redundancy, we compared the correlations among all 22 variables (Figure 8)

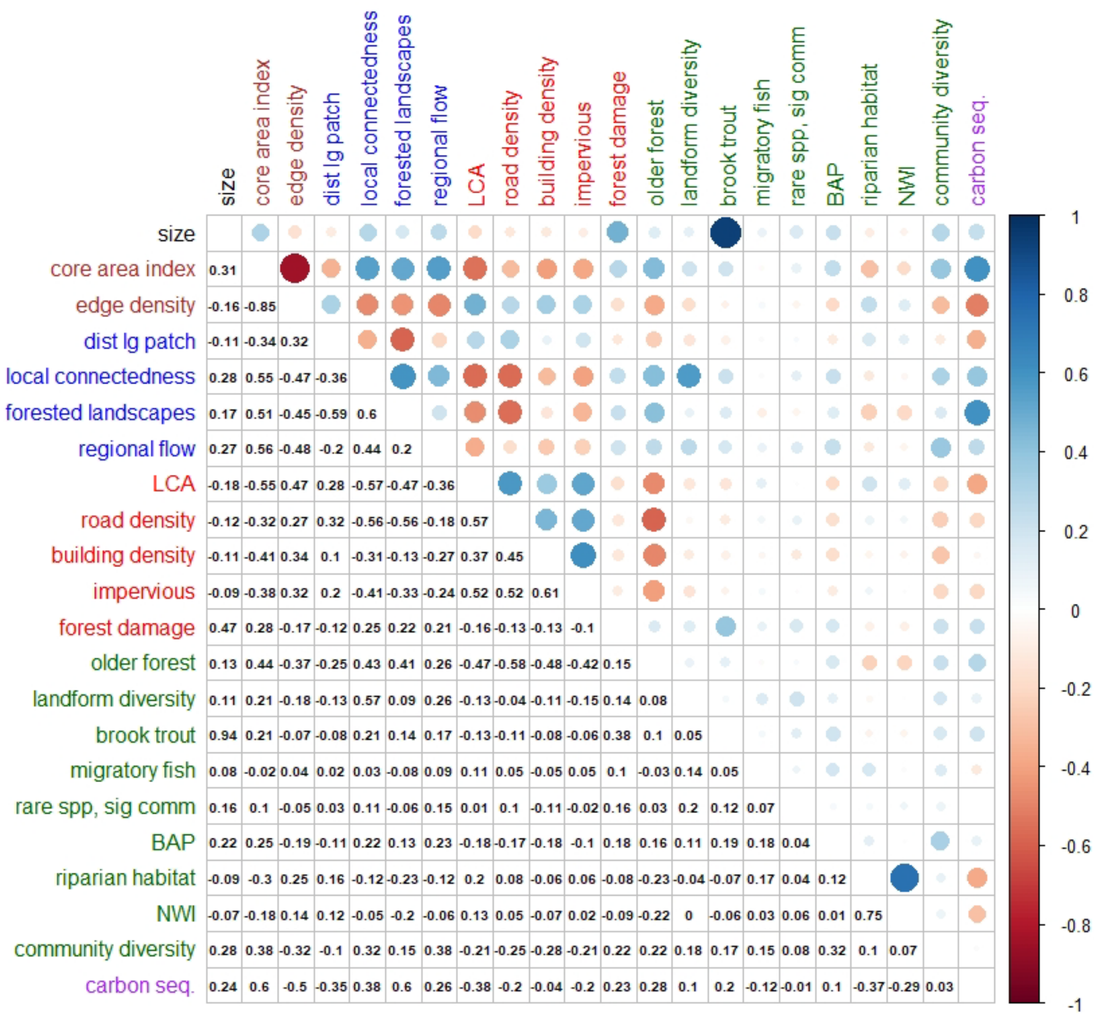

Figure 8. Correlation matrix on the raw values of all 22 forest patch condition metrics. In the upper triangle, dot size represents the strength of the correlation and color the direction of the correlation (blue = positive, brown = negative). Correlation values are provided in the lower triangle. Labels are grouped by their category (Table 5).

The highest correlations are between patch size and brook trout (0.94), edge density and core area index (-0.85), and wetlands and riparian habitat (0.75). These are the only variables with correlations above 0.7. In this correlation assessment, brook trout is an unstandardized measure of the total area of brook trout habitat within the forest patch, clearly resulting in the largest brook trout habitat areas occurring within the larger forest patches. We eliminated this correlation by defining our final metric for brook trout as simply presence or absence of brook trout habitat within the forest patch.

Similarly, we expected edge density and core area index to be a close inverse of each other, as they effectively represent inverse areas of each patch. To address this, we included both metrics but weighted each at 6 points, half of the typical 12 point weighting (Table 5). Finally, it also makes sense that the amount of riparian habitat, as defined by flood zones, would be strongly correlated with National Wetlands Inventory (NWI) wetlands, as large areas of lowlands near a lake or stream would likely have large areas of wetlands. These measures were also weighted at 6 points to minimize this redundancy.

While there are no other highly correlated variables, we provide this correlation matrix as well as individual scorings in the spatial dataset so that other users might create their own combinations informed by this information.

The highest possible forest index score for a forest patch, that is, if a forest patch received top marks in all 22 measures, is 228 points. Our highest scoring patch is 191.5 points, emphasizing there was no patch or group of patches that got all the points and that top scores were distributed among patches in the Hudson Valley.

Overall, the forest index, by considering not just the size of a forest patch, but its shape, landscape context, condition, connectivity, history, habitat, and species communities, will provide municipalities and conservation managers with much needed context when making management decisions.

Future Considerations

Even with the excellent data sets available to use in GIS format, there are still forest health indicators that are difficult to ascertain or even estimate remotely. Perhaps the top two are the presence and prevalence of invasive species and the intensity of deer herbivory and consequential lack of forest regeneration. We are getting closer and closer to remote estimates for each of these. The iMapInvasives database (https://www.nyimapinvasives.org/data-and-maps) becomes more complete each year and adding information related to invasive species to the forest index is something we should be able to do in the future.

Similarly, attempts have been made at estimating forest regeneration and an updated version to Shirer and Zimmerman (2010) is in the works. We hope that more information on deer herbivory and regeneration continues to become available and at high enough resolutions to be effective at the scales we are interested in.

In addition to striving for better and more complete estimates of forest patch condition, we are also interested in landscape-level analyses that can support this type of assessment but could not be included at this time. Regional connectivity among forest patches, for example, plays an important role in gene flow and maintaining population viability. Regional patch connectivity assessments would help us understand the contribution of individual patches to the greater landscape. There are other landscape features related to forests, such as the amount of forest lands within large watersheds, that contribute to ecosystem health. We look forward to finding ways to increasing the breadth of metrics and improving the utility of this dataset overall.

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Appendix A. Field Names, field aliases, and descriptions for fields in the forest_index_patches feature class.

The feature class attribute table includes the raw values, percentile values, and point scores for each individual component of the index, the final forest index, sub-indices that describe similar groups of features, and some intermediate values used to create some components that may be of interest to the user. Fields are listed in the order in which they appear in the forest_index_patches feature class. The forest_index_patches.lyr file contains field aliases and has fewer fields visible. Fields are identified as intermediate ("Interm"), raw value index component ("Comp"), percentile ("Pctle"), and point score ("Score"), and grouped scores ("Group") are identified in the Index field. Fields that represent the raw, percentile, or point score of a component of the forest index have the component name in bold and capitalized.

Field Name	Alias (in forest_index_patches.lyr)	Type	Description
OBJECTID			ArcGIS assigned Unique ID
acres	Area in acres	Comp	**SIZE.** Raw Value. Area of original forest patch in acres
FB_ID	Unique Forest Patch ID	Interm	Unique Forest PatchID
Core_area_MAX	Largest Core Area (acres)	Interm	Area in acres of the largest core area in a patch. In patches with only a single core area, this will be the same as the total core area.
Core_area_SUM	Total Core Area (acres)	Interm	Total core area in acres of all core areas in patch
DistToBigPatch_m	Distance to Nearest Large Patch (m)	Comp	**DISTANCE TO NEAREST LARGE PATCH.** Raw Value. Distance in meters to the nearest patch with a core area of 500 acres or more
BigPatchFBID	Forest Patch ID of Nearest Large Patch	Interm	Identity of the nearest large patch
Edge_area_SUM	Total Edge Area (acres)	Interm	Edge area of the patch in acres based on raster output of UCONN Landscape Fragmentation tool
Total_area_raster	Total Patch Area for Fragmentation Analysis	Interm	Area of the 10 meter rasterized version of the patch used in the UCONN Landscape Fragmentation tool
Edge_Area_Ratio	Edge density	Comp	**EDGE DENSITY.** Raw Value. The proportion of the patch area that is composed of edge.
Carbon_mean	Mean Carbon Sequestration	Comp	**CARBON SEQUESTRATION.** Raw Value. Average value of carbon sequestration in the patch (metric tons/pixel)
OldForest_prop	Proportion of Patch Undeveloped in 1974	Comp	**OLDER FOREST**. Raw Value. Proportion of the original forest patch classified as undeveloped in 1974.
LSC_LocalCon_Mean	Average Local Connectedness	Comp	**LOCAL CONNECTEDNESS.** Raw Value. Average value of TNC Local Connectedness in original forest patch.
LSC_LandDiv_Mean	Average Landform Diversity	Comp	**LANDFORM DIVERSITY.** Raw Value. Average value of TNC Landscape Diversity in original forest patch.

Field Name	Alias (in forest_index_patches.lyr)	Type	Description
LSC_RegFlow_max	Maximum Regional Flow	Comp	**LANDSCAPE CONTEXT (REGIONAL FLOW).** Raw Value. Maximum value of the TNC Regional Flow in the analysis patch.
LCA_mean	Average LCA (manmade stressors)	Comp	**LCA.** Raw Value. Average value of the Landscape Condition Assessment in the original forest patch.
Roads_SUM	Sum of all roads	Interm	Sum of the total length of roads in a 1.5 mile buffer of the analysis patch.
Roads_by_acre	Road density (km/acre)	Comp	**ROAD DENSITY.** Raw Value. Sum of roads in km divided by area of 1.5 mile buffer in acres.
Buildings_count	Count of buildings	Interm	Count of buildings within the analysis patch.
Buildings_SqFeet	Total area of buildings	Interm	Total area of buildings in the analysis patch.
Impervious_mean	Average Impervious Surface	Comp	**IMPERVIOUS SURFACE.** Raw Value. Average percent cover of impervious surface in the analysis patch.
ForestDamage_count	Forest Damage Present	Comp	**FOREST DAMAGE.** Raw Value. Count of the unique classes of forest damage observed in the analysis patch. A value of 2 or more indicates presence.
EO_mean	Average Rare Species Score	Comp	**RARE SPECIES AND SIGNIFICANT NATURAL COMMUNITIES.** Raw Value. Average score of weighted EOs in the analysis patch.
Landfire_SUM	Count of unique habitats (Landfire)	Comp	**COMMUNITY DIVERSITY (LANDFIRE)**. Raw Value. Count of the unique classes in the LANDFIRE Existing Vegetation Type layer in the analysis patch.
Brooktrout_present	Brook Trout present	Comp	**BROOK TROUT.** Raw Value. Area of the brook trout patches that intersect the analysis patch. A nonzero value indicates presence.
Diad_fish_pres	Migratory Fish Present	Comp	**MIGRATORY FISH.** Raw Value. Count of the number of species predicted present in the NYNHP Freshwater Blueprint. A nonzero value indicates presence.
Riparian_prop	Proportion of Patch in Riparian Zone	Comp	**RIPARIAN HABITAT.** Raw Value. Proportion of the analysis patch area that intersects the riparian zone, defined by NYNHP stream buffers and FEMA SFHA.
BAP_mean	Average Stream Health	Comp	**STREAM QUALITY.** Raw Value. Average predicted BAP score from the NYNHP Freshwater Blueprint in the analysis patch.
NWI_prop	Proportion Patch in Wetlands	Comp	**WETLANDS.** Raw Value. Proportion of the analysis patch that intersects NWI wetlands.
Core_Area_Index	Core Area Index	Comp	**CORE AREA INDEX.** Raw Value. Proportion of forest patch composed of core forest.
Build_sqft_ratio	Building Density (sq. ft/acre)	Comp	**BUILDING DENSITY:** Ratio of the total area of buildings in square feet per acre of the analysis patch.
P_acres	SIZE. Percentile Value.	Pctle	**SIZE.** Percentile Value.
P_Core_Area_Index	CORE AREA INDEX. Percentile Value.	Pctle	**CORE AREA INDEX.** Percentile Value.

Field Name	Alias (in forest_index_patches.lyr)	Type	Description
P_Edge_Area_Ratio	EDGE DENSITY. Percentile Value.	Pctle	**EDGE DENSITY.** Percentile Value.
P_OldForest_prop	OLDER FOREST. Percentile Value.	Pctle	**OLDER FOREST.** Percentile Value.
P_LSC_LocalCon_Mean	LOCAL CONNECTEDNESS. Percentile Value.	Pctle	**LOCAL CONNECTEDNESS.** Percentile Value.
P_LSC_LandDiv_Mean	LANDFORM DIVERSITY. Percentile Value	Pctle	**LANDFORM DIVERSITY.** Percentile Value
P_DistToBigPatch_m	DISTANCE TO NEAREST LARGE PATCH. Percentile Value.	Pctle	**DISTANCE TO NEAREST LARGE PATCH**. Percentile Value.
P_LCA_mean	LCA. Percentile Value.	Pctle	**LCA.** Percentile Value.
P_Roads_by_acre	ROAD DENSITY. Percentile Value.	Pctle	**ROAD DENSITY**. Percentile Value.
P_Build_sqft_ratio	BUILDING DENSITY. Percentile Value.	Pctle	**BUILDING DENSITY**. Percentile Value.
P_Impervious_mean	IMPERVIOUS SURFACE. Percentile Value.	Pctle	**IMPERVIOUS SURFACE.** Percentile Value.
P_Carbon_mean	CARBON SEQUESTRATION. Percentile Value.	Pctle	**CARBON SEQUESTRATION.** Percentile Value.
P_LSC_RegFlow_max	LANDSCAPE CONTEXT (REGIONAL FLOW). Percentile Value.	Pctle	**LANDSCAPE CONTEXT (REGIONAL FLOW)**. Percentile Value.
P_EO_mean	RARE SPECIES AND SIGNIFICANT NATURAL COMMUNITIES. Percentile Value.	Pctle	**RARE SPECIES AND SIGNIFICANT NATURAL COMMUNITIES**. Percentile Value.
P_Landfire_SUM	COMMUNITY DIVERSITY (LANDFIRE). Percentile Value.	Pctle	**COMMUNITY DIVERSITY (LANDFIRE)**. Percentile Value.
P_Riparian_prop	RIPARIAN HABITAT. Percentile Value.	Pctle	**RIPARIAN HABITAT.** Percentile Value.
P_BAP_mean	STREAM QUALITY. Percentile Value.	Pctle	**STREAM QUALITY.** Percentile Value.
P_NWI_prop	WETLANDS. Percentile Value.	Pctle	**WETLANDS**. Percentile Value.
forest_in_buffer_acres	Area forested (acres) in 1.5 mile buffer	Interm	Area in a 1.5 mile buffer of the analysis patch classified in the NLCD as Deciduous Forest, Coniferous Forest, Mixed Forest, or Woody Wetlands.
Prop_buffer_forested	Proportion of 1.5 mile buffer forested	Comp	**FORESTED LANDSCAPE.** Raw Value. Proportion of the area in a 1.5 mile buffer of the analysis patch classified in the NLCD as Deciduous Forest, Coniferous Forest, Mixed Forest, or Woody Wetlands.
Area_big_buffer	Area of 1.5 mile buffer (acres)	Interm	Area of the 1.5 mile buffer in acres.
P_Prop_buffer_forested	FORESTED LANDSCAPE. Percentile Value.	Pctle	**FORESTED LANDSCAPE.** Percentile Value.

Field Name	Alias (in forest_index_patches.lyr)	Type	Description
SS_Core_Area_Index	CORE AREA INDEX. Score (Max 6 points)	Score	**CORE AREA INDEX**. Score (Max 6 points)
SS_OldForest_prop	OLDER FOREST. Score (Max 12 points)	Score	**OLDER FOREST.** Score (Max 12 points)
SS_LSC_LocalCon_Mean	LOCAL CONNECTEDNESS. Score (Max 12 points)	Score	**LOCAL CONNECTEDNESS.** Score (Max 12 points)
SS_LSC_LandDiv_Mean	LANDFORM DIVERSITY. Score. (Max 12 points)	Score	**LANDFORM DIVERSITY**. Score. (Max 12 points)
SS_Prop_buffer_forested	FORESTED LANDSCAPE. Score. (Max 12 points)	Score	**FORESTED LANDSCAPE**. Score. (Max 12 points)
SS_acres	SIZE. Score. (Max 24 points)	Score	**SIZE**. Score. (Max 24 points)
SS_Edge_Area_Ratio	EDGE DENSITY. Score. (Max 12 points)	Score	**EDGE DENSITY.** Score. (Max 12 points)
SS_DistToBigPatch_m	DISTANCE TO NEAREST LARGE PATCH. Score. (Max 12 points)	Score	**DISTANCE TO NEAREST LARGE PATCH**. Score. (Max 12 points)
SS_Roads_by_acre	ROAD DENSITY. Score. (Max 12 points)	Score	**ROAD DENSITY.** Score. (Max 12 points)
SS_Build_sqft_ratio	BUILDING DENSITY. Sore. (Max 12 points)	Score	**BUILDING DENSITY.** Sore. (Max 12 points)
SS_Impervious_mean	IMPERVIOUS SURFACE. Score. (Max 12 points)	Score	**IMPERVIOUS SURFACE.** Score. (Max 12 points)
SS_LCA_mean	LCA. Score. (Max 24 points)	Score	**LCA.** Score. (Max 24 points)
SS_Carbon_mean	CARBON SEQUESTRATION. Score. (Max 12 points)	Score	**CARBON SEQUESTRATION**. Score. (Max 12 points)
SS_EO_mean	RARE SPECIES AND SIGNIFICANT NATURAL COMMUNITIES. Score. (Max 12 points)	Score	**RARE SPECIES AND SIGNIFICANT NATURAL COMMUNITIES.** Score. (Max 12 points)
SS_Landfire_SUM	COMMUNITY DIVERSITY (LANDFIRE). Score. (Max 12 points)	Score	**COMMUNITY DIVERSITY (LANDFIRE).** Score. (Max 12 points)
SS_LSC_RegFlow_max	LANDSCAPE CONTEXT (REGIONAL FLOW). Score. (Max 12 points)	Score	**LANDSCAPE CONTEXT (REGIONAL FLOW).** Score. (Max 12 points)
SS_BAP_mean	STREAM QUALITY. Score. (Max 6 points)	Score	**STREAM QUALITY.** Score. (Max 6 points)
SS_NWI_prop	WETLANDS. Score. (Max 6 points)	Score	**WETLANDS**. Score. (Max 6 points)
SS_Riparian_prop	RIPARIAN HABITAT. Score. (Max 6 points)	Score	**RIPARIAN HABITAT.** Score. (Max 6 points)
SS_Brooktrout_present	BROOKTROUT HABITAT. Score. (0 or 2 points)	Score	**BROOKTROUT HABITAT.** Score. (0 or 2 points)

Field Name	Alias (in forest_index_patches.lyr)	Type	Description
SS_Diad_fish_pres	MIGRATORY FISH. Score. (0 or 2 points)	Score	**MIGRATORY FISH.** Score. (0 or 2 points)
SS_ForestDamage_count	FOREST DAMAGE. Score. (2 or 0 points)	Score	**FOREST DAMAGE**. Score. (2 or 0 points)
S_INDEX2	Stress Sub-Index (Max 62 pts)	Group	**STRESS SUB-INDEX.** Sum of scores for LCA, Road Density, Building Density, Impervious Surface, and Forest Damage. Max possible = 62
F_INDEX2	Forest Index	Group	**FOREST INDEX.** Sum of all scores. Max possible = 228
P_F_INDEX2	FOREST INDEX. Percentile.	Pctle	**FOREST INDEX.** Percentile.
Superlatives			List of any components for which the patch's score is in the top 1% or 5% of scores in the area.
FRAG_INDEX	Fragmentation Sub-Index (Max 12 pts)	Group	**FRAGMENTATION SUB-INDEX.** Sum of scores for Core Area Index and Edge Density. Max possible= 12 points.
CONN_INDEX	Connectivity Sub-Index (Max 40 pts)	Group	**CONNECTIVITY SUB-INDEX.** Sum of scores for Distance to nearest large patch, Local Connectedness, Forested Landscape, and Landscape Context (Regional Flow). Max possible = 48 points.
HABITAT_INDEX	Habitat and Ecosystem Value Sub-Index (Max 70 pts)	Group	**HABITAT AND ECOSYSTEM VALUE SUB-INDEX**. Sun of scores for Older Forest, Landform Diversity, Brook Trout, Migratory Fish, Rare species and significant natural communities, Stream Condition, Riparian Habitat, Wetlands, and Community Diversity. Max possible = 70
Shape_Length			ArcGIS feature class mandatory field.
Shape_Area			ArcGIS feature class mandatory field.