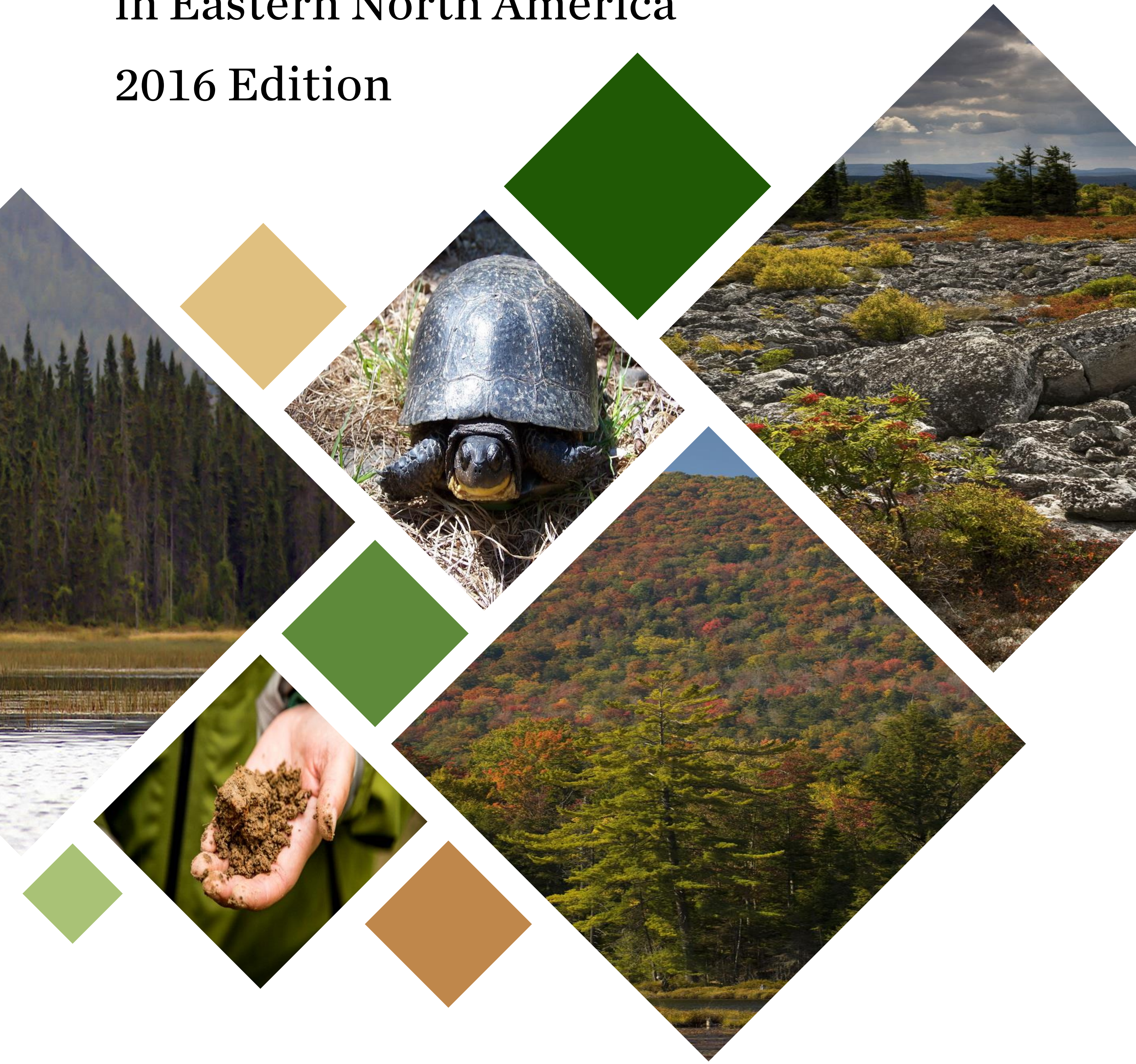
Resilient Sites for Terrestrial Conservation in Eastern North America

2016 Edition



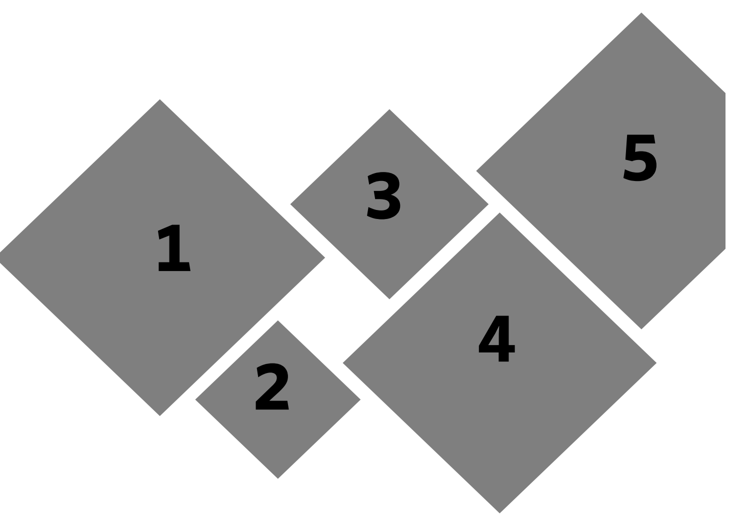
The Nature Conservancy, Eastern Conservation Science

Mark G. Anderson, Analie Barnett, Melissa Clark, Charles Ferree, Arlene Olivero Sheldon, and John Prince

Mark G. Anderson, Analie Barnett, Melissa Clark, Arlene Olivero Sheldon, and John Prince and. 2016. Resilient Sites for Terrestrial Conservation in Eastern North America 2016 Edition. (June 30, 2016 version)
The Nature Conservancy, Eastern Conservation Science
Eastern Regional Office
99 Bedford St, 5th Floor
Boston, MA 02111

Please cite as: Anderson, M.G., A. Barnett, M. Clark, C. Ferree, A. Olivero Sheldon, J. Prince. 2016. Resilient Sites for Terrestrial Conservation in Eastern North America. The Nature Conservancy, Eastern Conservation Science.

This project was supported by grants from the Doris Duke Charitable Foundation and from the U.S. Department of the Interior, Fish and Wildlife Service.



About the Cover:

1. ©Eric Aldrich/TNC. A common loon at East Inlet, in New Hampshire's northernmost town of Pittsburg. The area is part of 25,000 acres The Nature Conservancy helped protect in 2002.

2. © The Nature Conservancy (Devan King). Soil sampling a wetland in First State National Park, DE.

3. Hinman Pond, NH

4. ©Mark Godfrey/TNC. Fall color at Pickwacket Pond in New York's Adirondack mountains. Pickwacket Pond lies within the 161,000 acres of land purchased by The Nature Conservancy from Finch, Pruyn and Company in 2007.

5. © Kent Mason. Dolly Sods Scenic Area Fall landscape on the allegheny front. This scenic area is located in the Monongahela National Forest in Pendleton County. West Virginia.

Acknowledgements

This project was guided by a steering committee of conservationists from the eastern states, and without their engagement, feedback, critique, and review this work would not have come to fruition. We would like to thank members from the state chapters of The Nature Conservancy including: Adam Whelchel (CT), Andy Finton (MA), Alex Wyss (TN), Allison Vogt (MD), Barbara Vickery (ME) Bob Allen (NJ), Chris Bruce (VA), Colette Degarady (SC), Dan Coker (ME), David Patrick (NH), Dirk Bryant (NY), Donnelle Keech (MD), Doria Gordon (FL), Elizabeth Kalies (NC), Eric Krueger (SC), Gwynn Crichton (VA), Jeff Sole (KY), Jessica Dyson (MA), Jodie LaPoint (NC), Joshua Royte (ME), Judy Dunscomb (VA), Kathleen Freeman (FL), Kevin Ruddock (RI), Kristina Serbesoff-King (FL), Lauren Alleman (NY), Malcolm Hodges (GA), Marci Bortman (NY), Margaret Fields (NC), Maria Whitehead (SC), Mary Kate Brown (AL), Megan Sutton (NC), Michele DePhilip (PA), Michelle Canick (MD), Nancy Sferra (ME), Paul Freeman (AL), Peter Steckler (NH), Philip Huffman (VT), Rebecca Benner (NY), Rebecca Shirer (NY), Richard Hilsenbeck (FL), Rose Paul (VT), Sally Palmer (TN), Sara Gottlieb (GA), Scott Bearer (PA) and Thomas Minney (WV).

We would also like to thank our conservation colleagues from other organizations and agencies who provided helpful insights and often much needed perspectives on the issue of climate resilience: Abby Weinberg (Open Space Institute), Amy Keister (South Atlantic Landscape Conservation Cooperative), David Ray (Open Space Institute), Eric Sorenson (VT Natural Heritage Program), Elizabeth Thomson (Vermont Land Trust), Gary Knight (FL Natural Areas Inventory), Jon Ambrose (GA Dept. of Natural Resources), Ron Sutherland (Wildlands Institute), Rua Mordecai (South Atlantic Landscape Conservation Cooperative), and Steve Fuller (North Atlantic Landscape Conservation Cooperative). The connectedness metrics would not have been possible without the help of Brad McRae of The Nature Conservancy and Brad Compton of University of Massachusetts both whom continue to refine the powerful tools they have developed for measuring permeability. We are deeply grateful to NatureServe, the Atlantic Conservation Data Centre, and to the state Natural Heritage Programs across 20 states from ME to AL who openly shared their invaluable data on the locations of species and natural communities.

We gratefully acknowledge and thank Andrew Bowman and Sacha Spector of the Doris Duke Charitable Foundation for support of this work, and for their perceptive feedback and guidance. We thank Peter Howell, Jennifer Melville, Abby Weinberg, and David Ray for launching the Open Space Resilient Landscape Initiative and for all the incredible conservation work that has come out of it. Finally, we would like to thank Michael Lipford, Rodney Bartgis, and Lise Hanners for posing tough questions about land conservation and climate change that gave rise to this work.

Resilient Sites for Terrestrial Conservation in Eastern North America

2016 Version

This is a revised and expanded version of two previous reports: Resilient sites for Terrestrial Conservation reports in the Northeast (Anderson et al. 2012 and 2014) and Resilient Sites for Terrestrial Conservation in the Southeast (Anderson et al 2014)

This 2016 version combines the Northeast and Southeast into one contiguous region with fine scale resolution (30 m) for the whole area. It also expands the boundary to encompass 20 ecoregions which is equivalent to 22 states: ME, NH, VT, MA, RI, CT, NY, PA, NJ, DE, MD, WV, VA, KY, TN, NC, SC, GA, FL, AL, TN, MS; three Canadian Provinces: NS, NB, and PEI; and portions of OH, IN, IL, LA and QC. Scientists and conservation planners from those states and provinces helped develop the methods, the evaluation of datasets, and review of the results.

All results are presented within a framework of ecological regions or "ecoregions" as defined by The Nature Conservancy (TNC) based on the subsections delineated by the US Forest Service and Canadian Provinces. Each region represents an area of similar physiography and landscape features, and are thus appropriate natural units for evaluating geophysical representation and to comparing sites.

Many improvements were made to the datasets and analytical methods from the 2014 published version in response to the wealth of constructive feedback we received from users who were applying the results to places on the ground. The basics are summarized here and details on each improvement are given in the body of the report.

Geophysical Settings: Bedrock and parent material was revised using the most recent national and state data. Surficial soils texture class information was incorporated from SSURGO for the whole region.

Landscape Diversity: Elevation range metrics were improved by accounting for changes in elevation that were uncorrelated from changes in the number of landforms. Wetland metrics were revised to include wetland patch density so we could separate areas with many individual wetlands from one huge wetland when they had the same density. A fine-scale metric of soil variety for the Northeast and Southeast Coastal Plain was added based on 10 m SSURGO data.

Local Connectedness: The US Land cover data was revised to the most recent 2011 National Land Cover Database (NLCD) which we improved by removing the older roads data and replaced it with more recent and more accurate data. We separated natural barrens (beaches, pavements) from anthropogenic barrens (well heads, bombing ranges). We incorporated data on ownership, land securement, and industrial forest management practices into the analysis.

Other: We applied an ecologically appropriate smoothing between ecoregions so that the boundaries between ecoregions were evaluated with respect to both ecoregions in proportion to the area in each.

Web Tool: We created a web-based mapping tool that allows users to explore the data and overlay sites. Try it at http://maps.tnc.org/resilientland/

Citations:

Anderson, M.G., M. Clark, and A. Olivero Sheldon. 2014. Estimating Climate Resilience for Conservation across Geophysical Settings. Conservation Biology 28 (4) 1523-1739. http://dx.doi.org/10.1111/cobi.12272

Anderson, M.G., A. Barnett, M. Clark, C. Ferree, A. Olivero Sheldon, and J. Prince. 2014. Resilient Sites for Terrestrial Conservation in the Southeast Region. The Nature Conservancy, Eastern Conservation Science. 127 pp.

Anderson, M.G., M. Clark, and A. Olivero Sheldon. 2012 Resilient Sites for Terrestrial Conservation in the Northeast and Mid-Atlantic Region. The Nature Conservancy, Eastern Conservation Science. 168pp.

All reports and datasets can be found at

http://nature.org/TNCResilience

Table of Contents

Table of Figures

INTRODUCTION

CHAPTER 1

Climate change is altering species distributions in unpredictable ways (IPPC 2007, Van der Putten et al. 2010) and conservationists require a way to prioritize strategic land conservation that will conserve the maximum amount of biological diversity despite changing distribution patterns. Conservation approaches based on species locations or on predicted species' responses to climate are necessary, but hampered by uncertainty. Here we offer a complementary approach, one that aims to identify key areas for conservation based on land characteristics that increase diversity and resilience.

A climate-resilient conservation portfolio includes sites representative of all geophysical settings selected for their microclimatic variation and relative naturalness. We developed methods to identify such a portfolio. First, we mapped geophysical settings across the entire study area including all physical environments that had a distinct biotic expression (e.g. limestone valley, shale slope, coarse sand plain, fine silt floodplain, granite summit). Second, within each geophysical setting we located sites with relatively more microclimates and that were highly connected by natural cover. We did this using GIS metrics based on the site's landscape diversity and local connectedness. Using information on conservation lands we noted geophysical settings that were underrepresented in current conservation and identified the most resilient places for each setting that could serve as strongholds for diversity both now and into the future.

Our approach to developing a network of resilient sites for Eastern North America is based on several key observations. The first is that species diversity is highly correlated with geophysical diversity (Anderson and Ferree 2010, Lawler et al. 2015). Second, under a changing climate, species take advantage of local microclimates in order to persist in the landscape (Weiss et al. 1988, Suggitt et al 2011, Roth et al 2014, Albano 2015). Third, species populations can use microclimates and adjust to change only if the area is permeable and well connected (Heller and Zavalata 2009). The characteristics of geophysical setting, microclimate, and landscape permeability are primary concepts in this research. The application of the approach individually to each type of geophysical setting, including flat sandplains and gentle limestone valleys, is essential to ensure that the results are not biased towards mountainous terrain (Tingley et al. 2013) but instead cover the full spectrum of diversity in the region.

We use the term **site resilience** to refer to the capacity of a site to adapt to climate change while maintaining diversity and ecological function (modified from Gunderson 2000). We assume that if conservation succeeds, each geophysical setting will support species that thrive in the conditions defined by the physical properties of the setting, although the site may contain different species in the future than are present now. For example, low elevation limestone valleys of the Cumberland region will support species that benefit from calcium-rich soils, alkaline waters, and cave or karst features, while acidic outwash sands of the Coastal Plain will support a distinctly different set of more drought-tolerant and fire-adapted species. **Geophysical setting** is thus broadly defined to refer to the variety of upland and wetland habitats that occur in a similar geologic environment and elevation zone. A low elevation limestone setting, for example, may contain fens, marshes, and riverine wetlands, as well as forests, grasslands, and barrens on dry terrain.

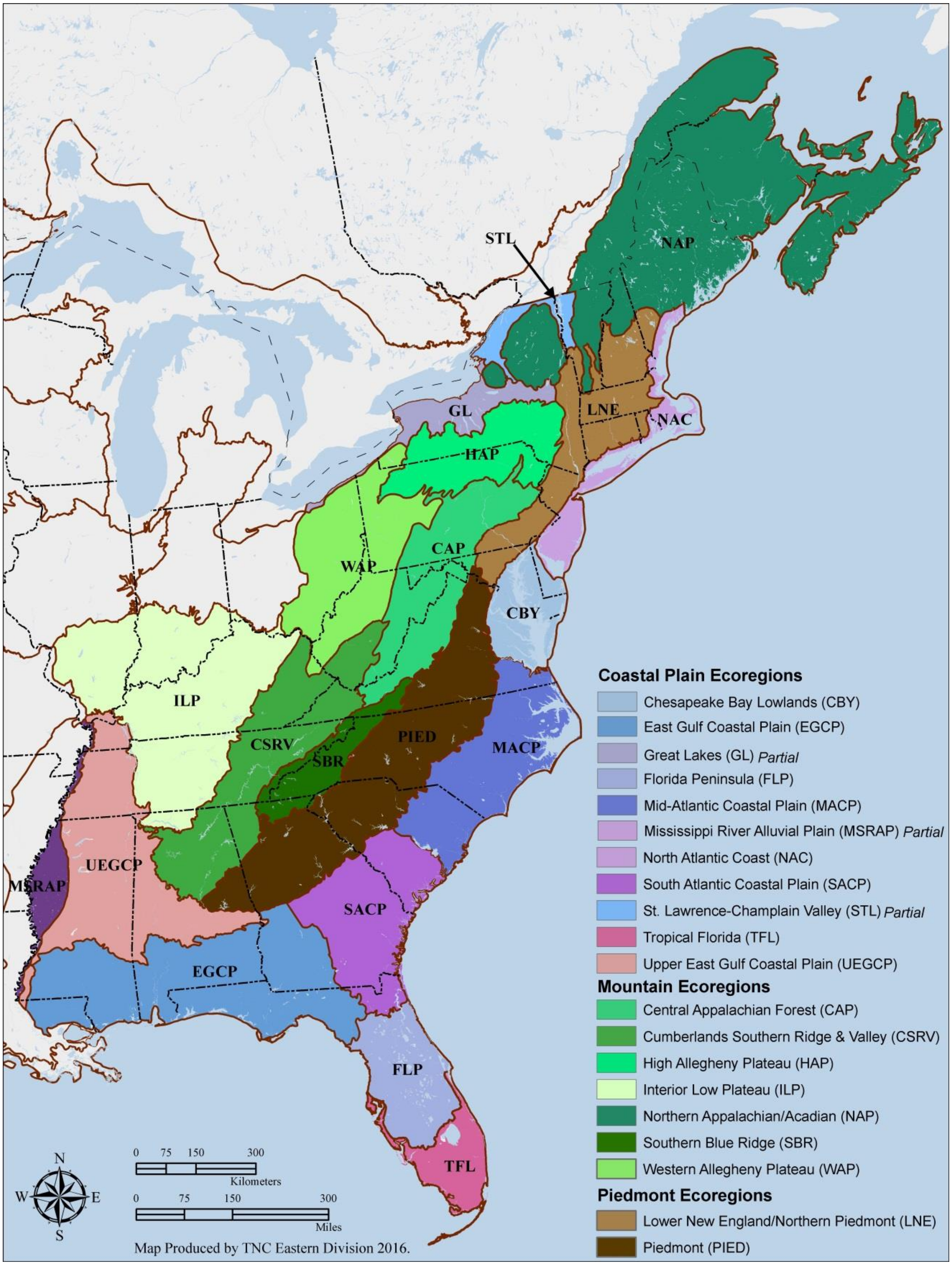
This report is a revision and integration of two previous studies on identifying resilient sites for terrestrial conservation, one in the Northeast (Anderson et al. 2012) and one in Southeast (Anderson et al. 2014). It is organized into three basic parts: In Chapter 2, we use mapping and classification to identify all the distinct geophysical settings in the region. In Chapter 3, we develop and apply methods to identify sites that have a wide variety of microclimates based on their landscape diversity, and intact natural covers based on their local connectedness. These two factors increase a site's resilience by creating locally available climatic options that allow species to persist. Finally, in Chapters 4 and 5 we identify networks of resilient sites representing all the geophysical settings within 20 ecoregions and the region as a whole. The methods introduced in Chapter 3 are designed to quantify the physical and structural aspects of the landscape and they include models that measure a site's physical complexity (landform variety, elevation range, wetland score, and soil diversity).

The value of conserving a spectrum of physical settings is based on empirical evidence (Anderson and Ferree 2010), but there are many choices to make as to how this is accomplished. For example, out of all the possible limestone valleys that could be conserved, which one is the most likely to remain functional and sustain its biological diversity? We address this question in Chapter 3 which focuses specifically on prioritizing among examples of the same setting using physical characteristics that increase resilience. These characteristics fall into two categories. The first, **landscape diversity**, is a method of estimating the number of microclimates and climatic gradients available within a given area. It is measured by counting the variety of landforms, the elevation range, the diversity of soil types, and the density and configuration of wetlands present in a small area (100 acres / 40.4 hectares). Because microclimate diversity buffers against climatic effects, the persistence of most species within a given area increases in landscapes with high landscape diversity relative to other examples of the same setting (Weiss et al. 1988). **Local connectedness**, the second factor, is defined as the number of barriers and the degree of fragmentation within the same area. A highly permeable landscape promotes resilience by facilitating population movements and the reorganization of communities. Roads, development, dams, and other structures create resistance that interrupts or redirects movement and, therefore, lowers the permeability. Maintaining a connected landscape is the most widely cited strategy in the scientific literature for building resilience (Heller and Zavaleta 2009) and has been suggested as an explanation for why there were few extinctions during the last period of comparable rapid climate change (Botkin et al. 2007).

This report is the companion piece to **Resilient and Connected Landscapes for Terrestrial Conservation in Eastern North America** (Anderson et al. 2016b), which focuses on identifying a connected network of resilient sites with confirmed biodiversity values. The latter report focuses on identifying flow conduits, pinch points, and riparian corridors that link the resilient sites into a network that will facilitate range shifts for species adjusting to a changing climate. All results in this report are presented at the scale of **30 meter cells**, within a framework of **ecological regions** or "ecoregions" as defined by The Nature Conservancy (TNC) based on the subsections delineated by the US Forest Service (USDA FS 2007) and Canadian Provinces (Anderson 1999). Because each region represents an area of similar physiography and landscape features, it is an appropriate natural unit in which to evaluate geophysical representation and to compare and contrast sites.

The study area includes the twenty two states of ME, NH, VT, MA, RI, CT, NY, PA, NJ, DE, MD, WV, VA, KY, TN, NC, SC, GA, FL, AL, TN, and MS in their entirety, as well as portions of OH, IN, IL and LA. Also included are three Canadian Provinces of NS, NB, and PEI as well as portions of QC (Figure 1.1). Scientists and conservation planners from those states helped with the development of these methods, the evaluation of datasets, and review of the results. Please see the acknowledgements for a list of all contributors. More background on the approach and detail on how the results relate to current biodiversity patterns can be found in Anderson and Ferree (2010) and Anderson et al. (2014).

Figure 1.1: Study Area. This map shows the 20 Nature Conservancy Ecoregions comprising the study area as well as the 30 States and Provinces fully or partially included.



DEFINING THE GEOPHYSICAL SETTINGS

CHAPTER 2

This chapter describes the process of characterizing and classifying the study region into distinct geophysical settings based on physical properties – geology, soil, and elevation - that correspond to differences in their associated flora and fauna. The geophysical settings also differ in ecological character, in their value for agriculture or mining, and how they have been developed by people. For example, the region's high granite environments are both largely intact and topographically complex, whereas the low sandplains are both more fragmented and relatively flat. The classification enabled us to compare resilience characteristics among sites that represent similar geophysical settings in order to identify the most examples of each setting with the most microclimatic variety and natural cover.

Ecoregions

We assessed the geophysical settings within the larger context of natural ecoregions. Ecoregions are large units of land with similar environmental conditions, especially landforms, geology, and soils, which share a distinct assemblage of natural communities and species. The term "ecoregion" was coined by J.M. Crowley (1967) and later popularized by Robert Bailey of the US Forest Service (USFS). In recent decades, ecoregions have become a defining construct of larger conservation efforts because they provide a needed ecological context for understanding conservation activities by enabling the evaluation of properties considered critical to conserving biodiversity (e.g. representation, redundancy, ecological function, linkages, and endemism).

The ecoregions we used for this analysis were developed by TNC in conjunction with the USFS (with a slight modification to one boundary in Florida - See Appendix). The TNC ecoregions are a modification of Bailey (1995) that puts more emphasis on physical characteristics and natural communities and less on climatic patterns. The analysis fully covered 17 entire ecoregions and parts of three others (Figure 1.1): Central Appalachian Forest, Chesapeake Bay Lowlands, Cumberlands and Southern Ridge and Valley, East Gulf Coastal Plain, Florida Peninsula, High Allegheny Plateau, Interior Low Plateau, Lower New England/Northern Piedmont, Mid-Atlantic Coastal

Plain, North Atlantic Coast, Northern Appalachian/Acadian, Piedmont, South Atlantic Coastal Plain, Southern Blue Ridge, Tropical Florida, Upper East Gulf Coastal Plain, and Western Allegheny Plateau. The two ecoregions that are partially covered because they occur with the boundary of TNC Eastern Division are the Great Lakes, the St. Lawrence/Champlain Valley. Part of the Mississippi River Alluvial Plain is included to complete the state coverage. Work is underway to complete the Great Lakes and its adjacent ecoregions including the Central Tallgrass Prairie, Gulf Coast Prairies and Marshes, North Central Tillplain, and Ozarks, and the Mississippi River Alluvial Plain. By and large, forest is the dominant vegetation in the included ecoregions although they differ widely in the degree of development, agriculture, and wetland present (Figure 2.1)

Geophysical Settings

We defined geophysical setting as the combination of an elevation zone and a geology class, the latter being either a bedrock type or surficial substrate depending on the depth of the overlying sediment. The elevation zones and geology classes were developed to correspond with recognizable changes in species and communities. Below we describe the thresholds and definitions of each class and provide maps to help users understand how the characteristics arrange on the landscape. Further explanation of the landform model is given in Chapter 4 and in Appendix II.

Elevation zones and bedrock geology classes follow those described in Anderson and Ferree (2010), with further divisions of the surficial substrate classes as described below. We compiled spatially explicit digital information on the physical characteristics of the regions from the following primary sources:

- **Bedrock geology**: from state and national digital geology maps (see Appendix I)
- **Soils:** county-level USDA soil surveys from the Soil Survey Geographic (SSURGO, NRCS 2014) database.
- **Elevation**: from a 30 m digital elevation model (DEM, Gesch 2007)
- **Landforms**: derived from the 30 m DEM (see Appendix II)

Specific definitions and thresholds are defined below.

Elevation Zones (Figure 2.2)

These zones correspond to major changes in vegetation and community patterns in eastern North America (Schafale and Weakley 1990, Anderson 1999, Williams 2010). The following six elevation zones were used in defining the geophysical settings (Figures 2.2, 2.3). The elevation breaks for High and Very High elevation classes differed for the northeast vs. southeast ecoregions.

Figure 2.1. Landuse map. The dominant vegetation in Eastern North America is forests, but the area has many major cities, and productive agriculture.

Figure 2.2. Elevation zones. The five elevation zones combined with geologic substrate data create the geophysical settings in this study**.**

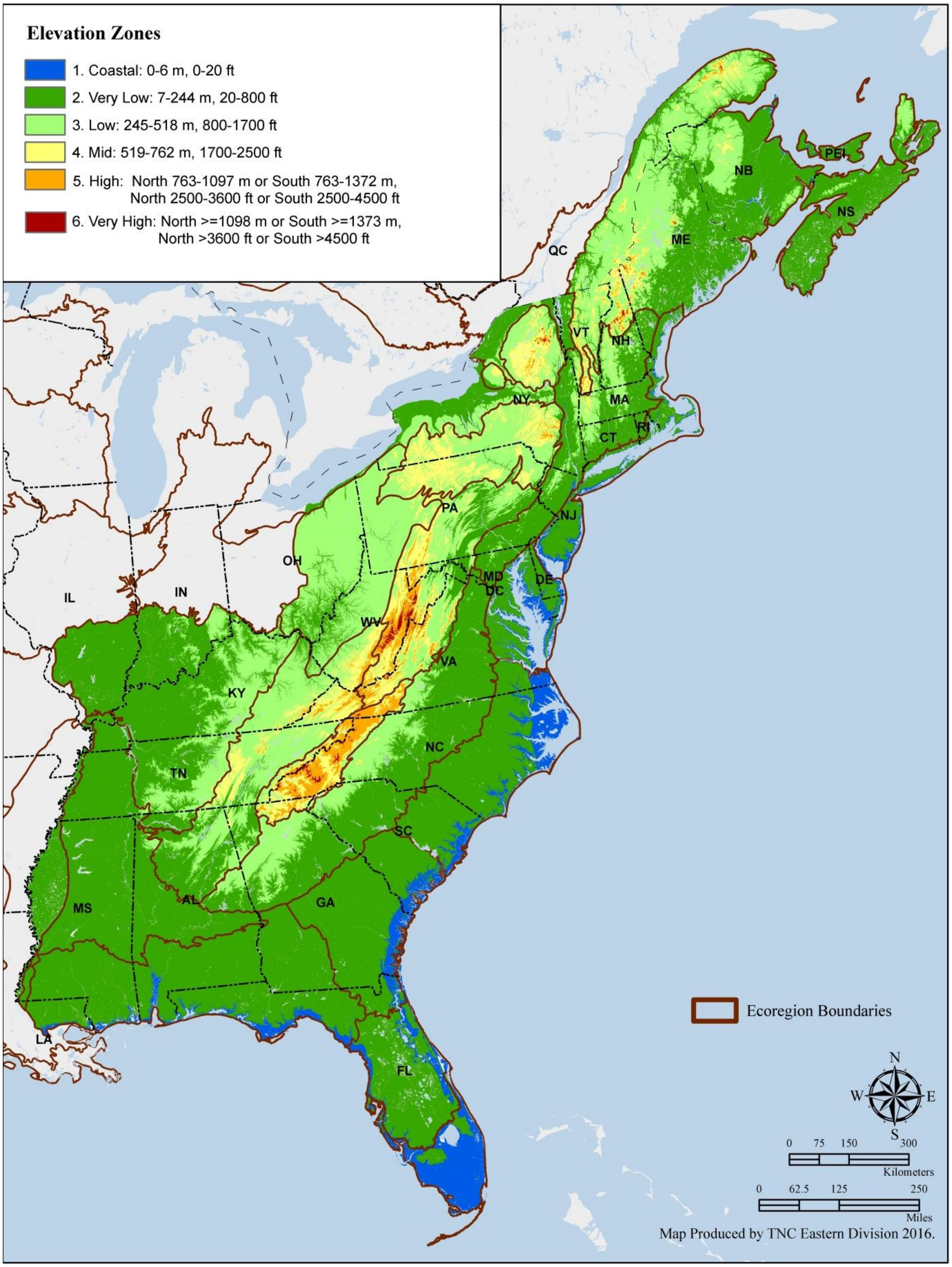


Figure 2.3. Table of the the elevation zone.

Elevation Zones	Northeast	Southeast	Attributes
Coastal	0-20 ft (0-6 m)	Same	Maritime influence, beaches, dunes and estuaries.
Very low	20-800 ft (6-244 m)	Same	Coastal plain, Piedmont, Lower New England. Large floodplains. Oak, Pine-oak
Low	800-1700 ft. (244-518 m)	Same	Appalachian foothills and low mountains, Hemlock-Northern hardwoods, Pine-Northern hardwoods, Lowland spruce
Mid	1700-2500 ft (518-762 m)	Same	Appalachian Mountains Northern hardwoods, Southern Hardwood
High	2500-3600 ft (762-1097 m)	2500-4500 ft (762-1372 m)	High mountains in Central and Southern Appalachians and isolated regions of the Northern Appalachians: Spruce-fir and Spruce-hardwood
Very High	>3600 ft (>1097 m)	>4500 ft. (>1372 m)	Alpine, Montane fir, Krummholz

Northeast ecoregions included the following: Central Appalachian Forest, Chesapeake Bay Lowlands, High Allegheny Plateau, Lower New England / Northern Piedmont, North Atlantic Coast, Northern Appalachian/Acadian, Western Allegheny Plateau, and part of the Great Lakes and St. Lawrence Ecoregion.

Southeast ecoregions included the following: Cumberlands and Southern Ridge and Valley, East Gulf Coastal Plain, Florida Peninsula, Interior Low Plateau, Mid-Atlantic Coastal Plain, Piedmont, South Atlantic Coastal Plain, Southern Blue Ridge, Tropical Florida, Upper East Gulf Coastal Plain and part of the Mississippi River Alluvial Plain.

Geology Classes (Figure 2.4)

We created a regional map of bedrock geology by compiling individual state geological maps and the newly published national dataset of state geology cross walked to a national taxonomy by the US Geologic Society (USGS) (http://mrdata.usgs.gov/geology/state/), and further simplified into one of seven major classes based on the chemical and physical properties of the soils derived from them (Anderson and Ferree 2010). We carefully reviewed each taxonomic type, based on the description, national crosswalk, and our crosswalk in previous reports. Apparent discrepancies between crosswalks were resolved by overlaying Natural Heritage Program rare species and natural community locations to see if they indicated a particularly geology class. For instance, if a polygon was called sandstone by the national taxonomy but limestone by the state taxonomy, and the community overlays indicated it supported limestone outcrop communities, we assumed limestone (i.e. Calcareous) was the correct class. Details and data sources are listed in Appendix I.

Acidic Sedimentary: Fine to coarse-grained, acidic sedimentary or meta-sedimentary rock, this group included: mudstone, claystone, siltstone, non-fissile shale, sandstone, conglomerate, breccia, greywacke, and arenites. Metamorphic equivalents: slates, phyllites, pelites, schists, pelitic schists, granofels.

Acidic Shale: Fine-grained loosely compacted acidic fissile shale.

Calcareous: Alkaline, soft, sedimentary or metasedimentary rock with high calcium content, this group included: limestone, dolomite, dolostone, marble, other carbonate-rich clastic rocks.

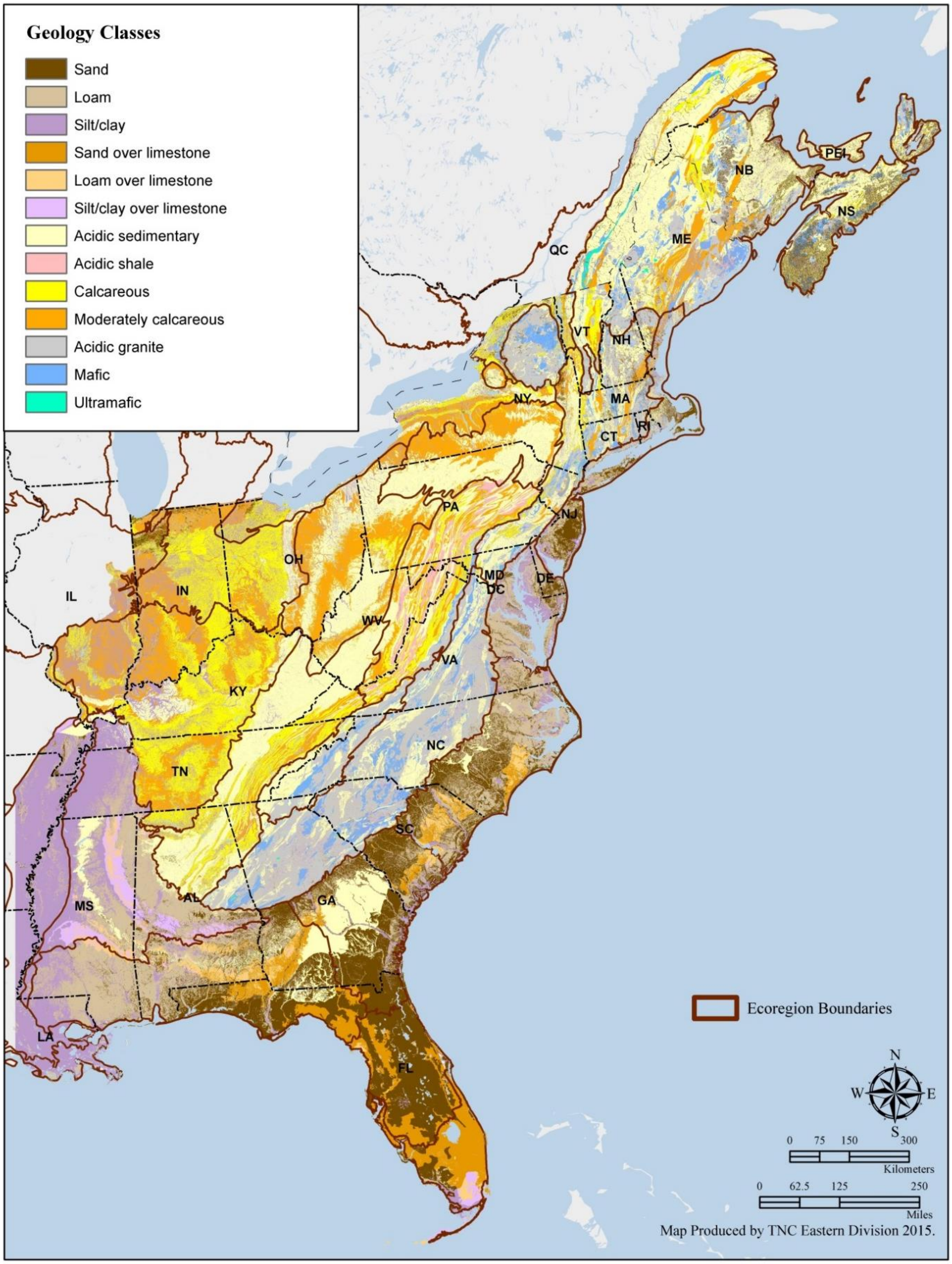
Moderately Calcareous: Neutral to alkaline, moderately soft sedimentary or meta-sedimentary rock with some calcium but less so than the calcareous rocks, this group included: calcareous shales, pelites and siltstones, calcareous sandstones, lightly metamorphosed calcareous pelites, quartzites, schists and phyllites, calc-silicate granofels. This category also includes mixed sedimentary rocks with a substantial calcareous component.

Acidic Granite: Quartz-rich, resistant acidic igneous and high grade meta-sedimentary rock, this group includes: granite, granodiorite, rhyolite, felsite, pegmatite, granitic gneiss, charnockites, migmatites, quartzose gneiss, quartzite, quartz granofel.

Mafic: Quartz-poor alkaline to slightly acidic rock, this group includes: (ultrabas ic) anorthosite (basic), gabbro, diabase, basalt (intermediate), quartz-poor: diorite/ andesite, syenite/ trachyte, greenstone, amphibolite, epidiorite, granulite, bostonite, essexite.

Ultramafic: Magnesium-rich alkaline rock, this group includes: serpentine, soapstone, pyroxenites, dunites, peridotites, talc schist.

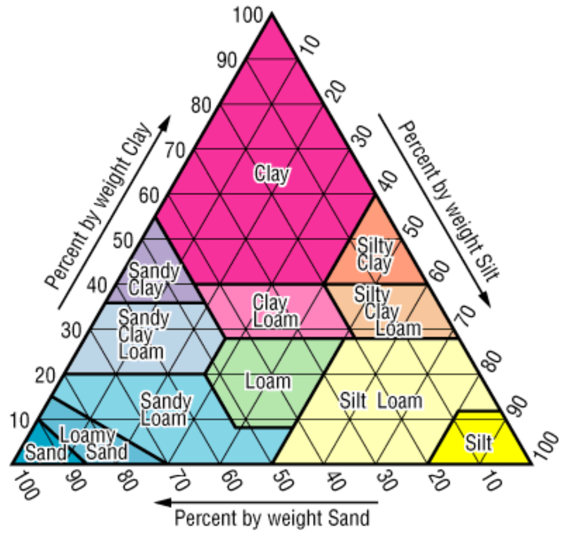
Figure 2.4. Geology classes. The 13 geology classes used with elevation zones to develop the geophysical settings. Seven were bedrock-based and six were based on surficial substrates.



Soil Classes

We created a regional map of surficial mineral sediments by compiling the SSURGO soil units and grouping them by soil texture. Each SSURGO map unit was placed into one of 12 groups shown on the USDA soil texture triangle (Figure 2.5) based on the percent of sand, silt, or clay in the unit. When SSURGO map units were not available, the coarser STATSGO soil map unit information was substituted. The 12 soil type map was then grouped into the following three major classes.

Figure 2.5: Soil triangle.



<u>Sand:</u> Sand, Loamy Sand

<u>Loam:</u> Loam, Sandy Loam, Sandy Clay Loam

<u>Silt/Clay</u>: Silt, Silt Loam, Silty Clay Loam, Clay Loam, Sandy Clay, Silty Clay, Clay

Integrating Bedrock Geology and Soil Texture

We integrated the bedrock geology and soil texture data into a single dataset. The integrated map was based on the bedrock but allowed soil texture to override bedrock in areas of deep surficial deposits such as the coastal plain, or along major rivers. Consequently, different rules for integrating bedrock and soil texture were used depending on whether the ecoregion was part of the coastal plain where surficial soils are the dominant influence, or part of the mountainous or upland regions which bedrock geology is the dominant ecological influence. In both areas, we also made use of the landform models described below to separate flat low position landforms and areas of deeper soils, where soil texture was deemed more influential, from sloping, higher elevation, and shallower soil areas, where bedrock was deemed more influential.

We used the contiguous coastal plain ecoregions included Chesapeake Bay Lowlands, East Gulf Coastal Plain, Florida Peninsula, Gulf Coast Prairies and Marshes, Mid-Atlantic Coastal Plain, Mississippi River Alluvial Plain, South Atlantic Coastal Plain, Tropical Florida, Upper East Gulf Coastal Plain, and the surficial dominated portion of the North Atlantic Coast from Cape Cod south. In these areas, we mapped the three surficial texture classes in all areas ignoring the bedrock unless it was limestone. In the limestone areas, the calcareous influence of the limestone on the soils and erodibility of the soil was maintained by naming the unit sand over limestone, loam over limestone, or silt/clay over limestone. The exception to this rule was where bedrock outcrops were mapped in the state geology dataset. This included the Altamaha Grit area of Georgia where a subterranean band of sandstone reaches the surface under Broxton Rocks creating pavements and outcrops. This area of exposed or slightly buried rock was coded as acidic sedimentary bedrock. For the North Atlantic Coastal ecoregion north of Cape Cod where bedrock was mapped in state geology datasets, we allowed this bedrock to override the surficial data except in extremely flat areas where we assume soils have accumulated. On these flat areas, we instead mapped the setting using the three surficial textures as in other parts of the coastal plain.

The upland ecoregions included Central Appalachian Forest, Cumberlands and Southern Ridge and Valley, High Allegheny Plateau, Interior Low Plateau, Lower New England/Northern Piedmont, Northern Appalachian/Acadian, Piedmont, Southern Blue Ridge, St. Lawrence - Champlain Valley, and Western Allegheny Plateau. In these ecoregions we mapped bedrock geology for most of the area except in extremely flat sections of very deep soils where we let the surficial data override the bedrock. We identified these places using the landform models and soil depth data. Our criteria were:

- landforms with slopes less than 2^0 (i.e. dry flat, moist flat, wet flat, valley/toeslope, or flat at bottom of steep slope), AND
- soil depth greater than or equal to 120 cm root zone depth (SSURGO) or soil rock depth (STATSGO).

The results of this criteria map surficial soils primarily in river channels, valley bottoms, floodplains, wet basins, and morainal deposits. These features were pervasive and common throughout the study area, and were loam soil texture, however, clay and sand texture soils were themselves much more restricted in the region and were further restricted by this method.

For the Canadian portion of the upland ecoregions, the rules used to determine whether to show bedrock or soils in the settings were slightly modified given the available sources of soils data. We allowed sand and silt/clay to be mapped on all flat landforms less than 2^0 slope (dry flats, wet flats, valley/toeslopes, moist flats, and flats at bottom of steep slope). For loam, we only allowed it to be mapped on a more restricted set of flat landforms (moist flats, wet flats, and flats at bottom of steep slope) and where elevation was less than 800 ft. We did not have soil depth information, but found the 800 ft elevation break to generally correspond to where soils began to deepen in the US.

In total, the 13 final types of bedrock (7) and surficial (6) geological classes were mapped for the analysis (Figure 2.5).

Soil Based	**Bedrock Based**
Sand	Acidic Sedimentary
Loam	Acidic Shale
Silt/Clay	Calcareous
Sand over Limestone	Moderately Calcareous
Loam over Limestone	Acidic Granite
Silt/Clay over Limestone	Mafic
	Ultramafic

Integrating Elevation with Geology and Soils (Figure 2.6)

Combining the six elevation zones and 13 geological settings yield 78 possible and 61 actual geophysical settings across the entire study area. The difference reflects the fact that not all combination occur, and that we aggregated six combinations that were too small in acreage (>1000 acres) to have much ecological relevance. These were merged with their most similar geophysical settings. For example, the extremely rare ultramafic bedrock (e.g. serpentine) was found in small amounts at mid, high, and very high elevations and these were combined into one ecological setting reflecting their rarity and the overwhelming importance of the bedrock.

For analysis, the 61 geophysical setings were further stratified by ecoregion resulting in the a final count of 485 unique geophysical setting by ecoregion. We cleaned up this dataset by removing 22 combinations that were too small to be meaningful, such as when a geolgoy type just barely crosses an ecoregion boundary, or just crossed an elevation zone. For example, less than 1 acre of High Elevation Mafic was combined with Mid Elevation Mafic in the Piedmont region.

Landform Types (Figure 2.7)

We created a fifteen-unit landform model that corresponded with topographic micro-climates found in the Mountains, Piedmont, and Coastal Plain subregions (Figure 1.1). The landform modeling is described in Chapter 4.

.

1) Cliff
2) Steepslope warm aspect
3) Steepslope cool aspect
4) Summit/ridgetop
5) Sideslope warm aspect
6) Sideslope cool aspect
7) Cove
8) Slope bottom flat
9) Low hill
10) Low hilltop flat
11) Valley/toeslope
12) Dry flat
13) Moist flat
14) Wet flat
15) Water (includes lakes, ponds,rivers)

Figure 2.6a. Geophysical settings used in this analysis. The 61 geophysical settings were created by combining an elevation zone and a geology class (see legend next page).

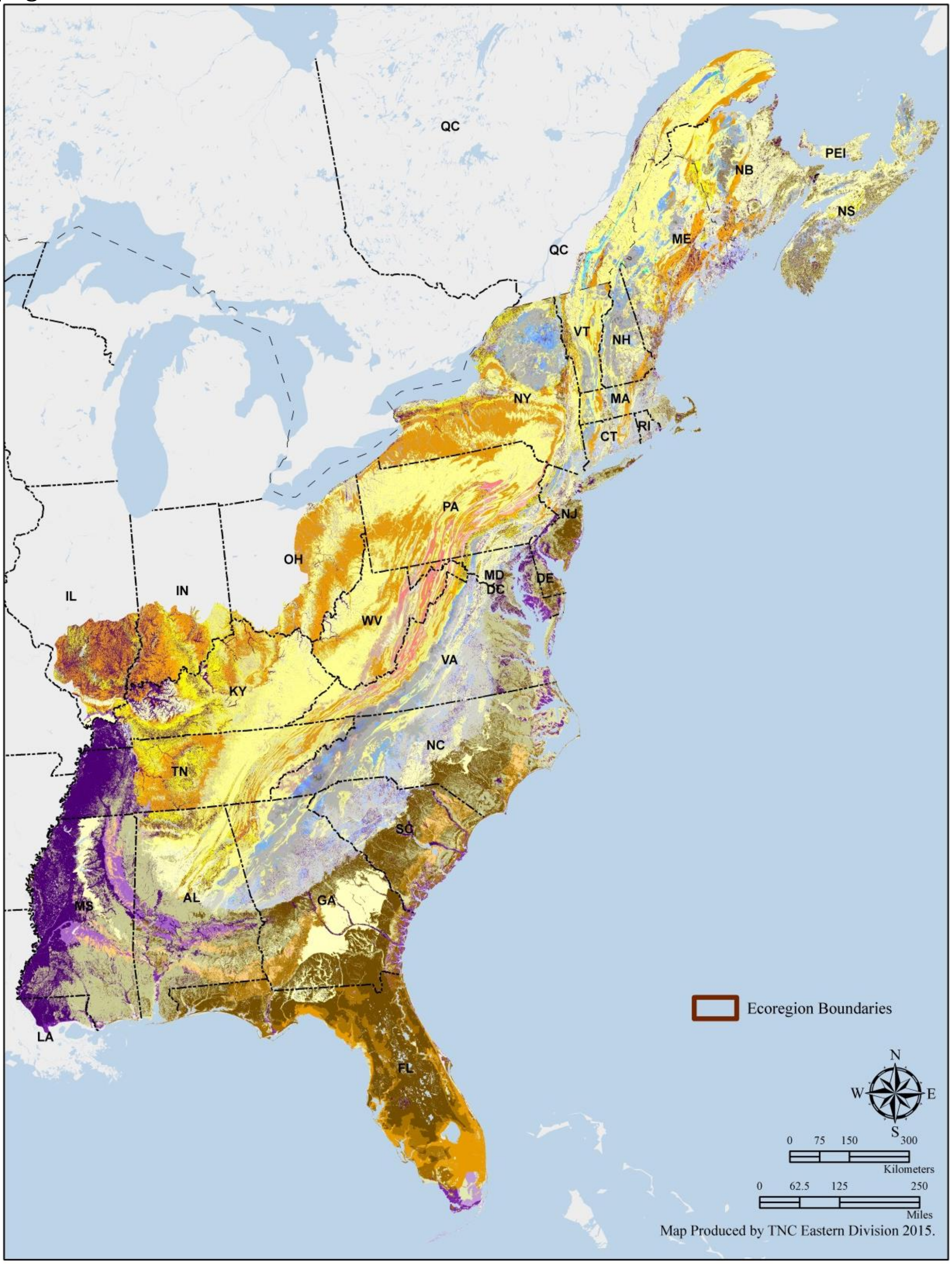


Figure 2.6b. Legend for Figure 2.6a

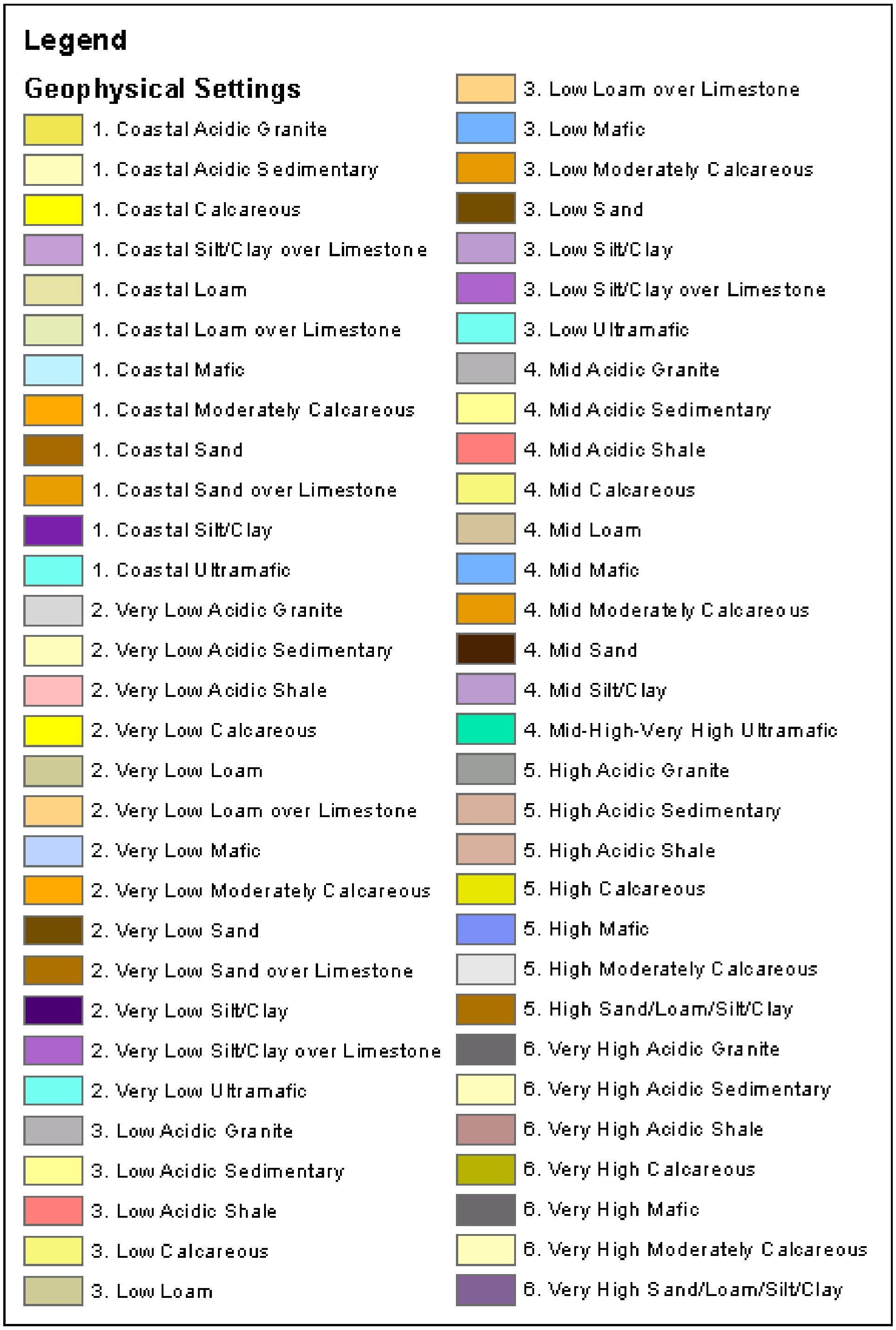


Figure 2.7. Landform types. This map shows the 16 landforms used to characterize the region's topography and to calculate the landform variety metric.

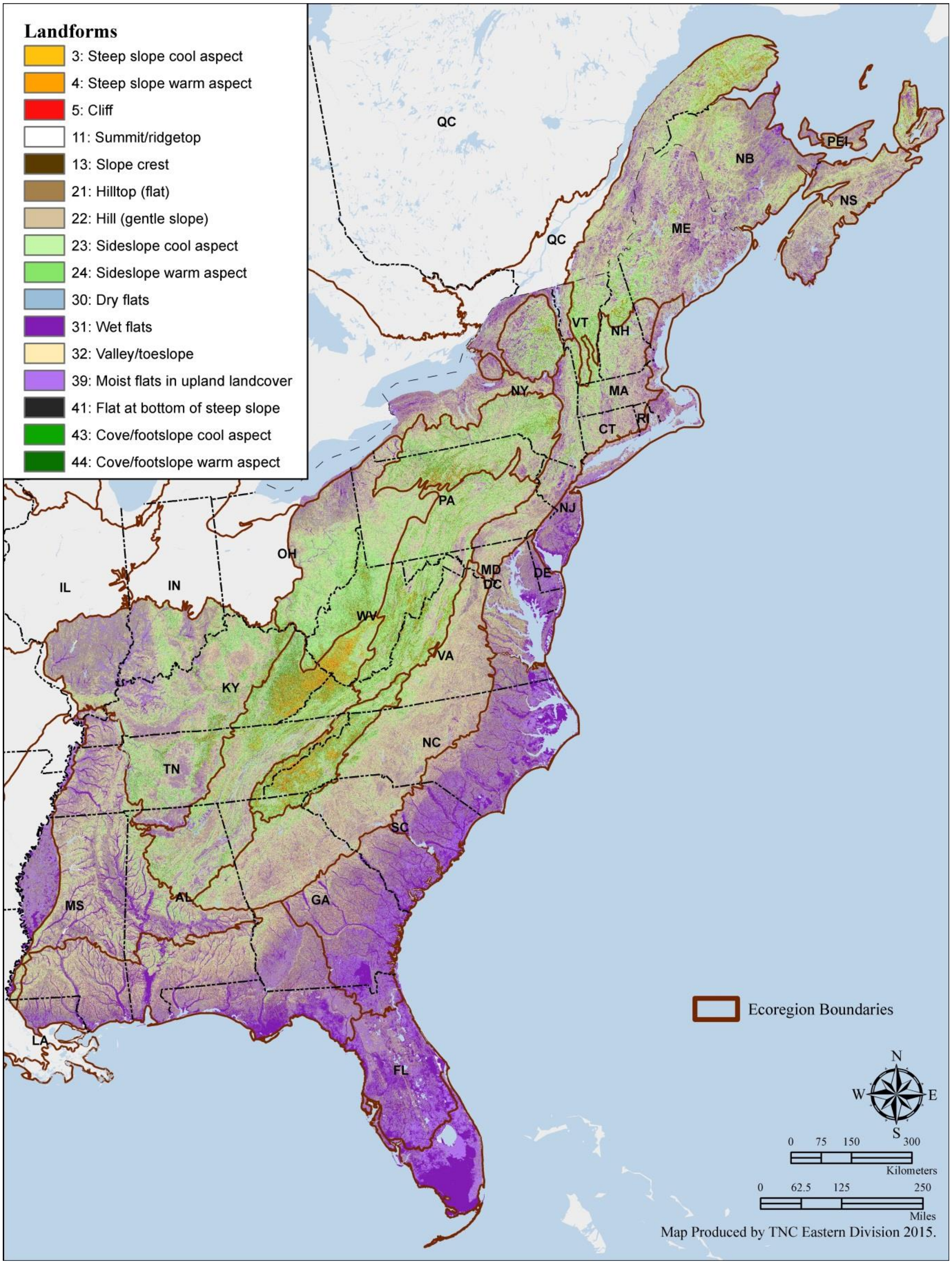


Figure 2.8. Geological settings: Examples of eight bedrock or surficial settings.

Coarse sand: Longleaf pine in Weymouth Woods SP, © Albert Herring.

Sedimentary: Sandstone at the Altamaha Rocks, © Alan Cressler.

Granite: Pisgah State Forest, © Jeff Gunn

Coastal Sand: Cape Hatteras lighthouse, NC, © U.S. Military.

Mafic: Amphibolite mountains, © Jenny Bennet.

Fine silt/organic: Okefenokee Swamp, © Ryan Hagerty.

Limestone: Lost Spring TNC Preserve, © TN TNC.

Moderately calcareous: Crockford-Pigeon Mountain, GA, © Mark Alan Robison.

Characterizing the Geophysical Settings

We defined 61 geophysical settings with each being a combination of a geologic substrate and an elevation zone, which together with latitude represent the strongest physical drivers of biodiversity patterns in the Eastern North America (Anderson and Ferree 2010, Figure 2.6). Latitude is addressed later in this report when the geophysical settings are stratified by ecoregion. The following descriptions of the geophysical settings are arranged by elevation zone and highlight the key characteristics of each setting.

Subregions: Coastal Plain, Piedmont, and Mountains

For several analyses we grouped the ecoregions into three subregions that differ distinctly in their elevation ranges and landforms (Figures 1.1, 2.1, and 2.3). The Coastal Plain subregion is entirely under 800 ft.in elevation and the vast majority is less than 460 ft., with the major elevational split being the coastal zone (0-20′) which is ecologically distinct from the remaining very low elevation zone (20-800′). The Piedmont is almost entirely in the very low (20-800′) and low (800-1700′) elevation zones with a few small mid-elevation areas just over 1700 ft., most notably in the northern piedmont region of lower New England. The majority of the Mountain subregion falls within the low (800-1700′) and mid (1700-2500′) elevation classes where widespread hardwood or mixed hemlock/pine/hardwood forests dominate. The region also contains large sections of high (2500 – 3600/4500′) elevations characterized by spruce fir, and at the highest points (>3600′ in the north, and >4500′ in the south) distinct high-elevation or alpine systems with unique flora and fauna.

Species and Community Information

The elevation zone, geologic substrate, and variety of landforms that comprise a site's physical template often influence the diversity of ecological communities' and species' habitats. The species and communities listed for the geophysical settings are based on Natural Heritage Element Occurrences and represent species of concern or characteristic communities. This information is provided to give users an indication of the type of biodiversity that each setting favors. We expect the future species composition to be of a similar ecological character (e.g., cave-adapted and alkaline-tolerant species in limestone, sand-adapted and fire-tolerant species in coarse sand), but perhaps not the same taxa. Many of the ecosystem and community types will likely be present in some future form but their exact composition and structure may vary widely from their current expression.

Coastal Settings (<20')

Although we present the information on the coastal zone for completeness, the methods and data we used to measure resilience have numerous problems in the coastal zone. On our final maps we "gray out" the 0-1 meter elevation zone because sea level rise is *expected to inundate this zone over the next century and we did not assess changes in coastal processes in this study.*

Coastal Settings (<20′)

Communities: Beach dune, Tidal marsh, Salt Marsh, Brackish Marsh, Maritime Hammock, Rockland Hammock, Maritime Live Oak Hammock, Coastal grassland, Coastal swale Wet flatwoods, Coastal strand, Salt Shrub Thicket, Coastal Plain Pond, and Oyster reef.

Northeast Rare Species found in this zone include**:** Plants: Seabeach knotweed, Delmarva Beggar-ticks, Mudwort, Seabeach amaranth, Heartleaf Plantain, Bushy Rockrose, Long's Bitter Cress, Estuary Beggarticks, Estuary Hatpins, River-arrowhead, Marsh Straw Sedge, Swamp Pink. Herptiles: Loggerhead, Leatherback, Timber Rattlesnake - Coastal Plain Population, Kemp's Ridley. Birds: Piping plover, Roseate Tern, Least Tern, Red Knot, Saltmarsh Sharp-tailed Sparrow, Seaside Sparrow, King Rail, Black rail.

Southeast rare species found in this zone include**:** Plants: Large-leaved Jointweed, Joewood, Godfrey's Goldenaster, Seabeach Amaranth, Climbing Buckthorn, Coastal Vervain, Christmas Bery, Gulf Coast Lupine, Thick-leaved Water-willow, Corkwood, Pineland Jaquemontia, Godfrey Blazing Star. Herptiles: Gopher Tortoise, Eastern Indigo Snake, Eastern Diamondback Rattlesnake, Loggerhead, Diamondback Terrapin, Carolina Watersnake, Green Sea Turtle, Gulf Salt Marsh Snake, Alabama Red-bellied Turtle, Alligator Snapping Turtle. Mammals: Florida Black Bear, Key Largo Woodrat, Florida Manatee, Key West Raccoon, Lower Keys Rabbit. Birds Least Tern, Wood Stork, Brown Pelican, Piping Plover, Florida Scrub-Jay, White-crowned Pigeon, Florida Burrowing Owl, Reddish Egret, Snowy Plover, Black Rail

Surficial Settings

Coastal Sand: Maritime settings under 20′ elevation on coarse sand. Beaches, dunes, swales and sandplains

Coastal Loam: Maritime settings under 20′ elevation on loam and sandy loam. Maritime forests and grasslands

Coastal Fine Silt and Clay: Maritime settings under 20′ elevation on fine silts and mud. Coastal tidal marshes, salt marsh, river mouths, and swamps

Coastal Sand over Limestone: Maritime settings under 20′ elevation on coarse sand over limestone bedrock. Seeps, springs, sinkholes, swales and sandplains

Coastal Loam over Limestone: Maritime settings under 20′ elevation on loam and sandy loam over limestone bedrock. Springs, sinkholes, forests and grasslands

Coastal Fine Sediment over Limestone: Maritime settings under 20’ elevation on fine silts and mud over limestone bedrock. Springs, flushes, swamps, floodplain and marshes

Bedrock Settings
Coastal Acidic Granite: Rocky bedrock-based acidic granite setting with hilltop woodlands.

Coastal Acidic Sedimentary: Coastal plain settings on sandstone, siltstone, and conglomerate may show bedrock outcrops overlain with sandy surficial soils.

Coastal Calcareous: Fertile agricultural and timber lands on limestone and dolomite that support an array of distinctive communities and rare species.

Coastal Mafic: Setting on volcanic basalts, or other mafic rocks such as trap rock ridges or old ring dikes; often with a richer flora and fauna than the more acidic settings.

Coastal Moderately Calcareous: Fertile settings similar to calcareous but less distinctive and slightly more common. Bedrock is a mixture of acidic and calcareous rock.

Coastal Ultramafic: Settings on toxic soils high in nickel and chromium supporting stunted trees and a unique flora.

Very Low Elevation (20' to 800')

Very Low Elevation (20′ to 800′)

Communities in this elevation zone include: floodplains, flatwoods and bottomlands, sandhills, pine savannah, levee forest, scrub and hammock, bogs and fens, Carolina bays, brownwater swamp, depression forest, prairies, dolomite woodland, sinkhole ponds, marl outcrops, sandstone glade, diabase glade, dome swamp, basin marsh.

Northeast Rare Species found in this zone include: Plants: Plymouth Gentian, Rose coreopsis, Featherfoil, Hyssop-leaved Hedge-nettle, Sandplain Flax, Golden Seal, Great St. John's-wort, Serpentine Aster, Longleaf Bluet, Limestone Petunia, Small whorled pogonia, Climbing Fern. Herptiles: Pine Barrens Treefrog, Wood Turtle, Blanding's Turtle, Bog turtle, Mammals: New England Cottontail. Birds: Black Tern:

Southeast rare species: Plants: Ciliate-leaf Tickseed, Lanceleaf Seedbox, Chapman's Butterwort, Roughleaf Dogwood, Chalky Indian-plantain, Riverbank Grape, Cherokee Sedge, Social Sedge, Baldwin's Spikerush, Broomsedge, Long-horn Orchid, Walter's Iris, Tall Beakrush, Longleaf Wedgescale, Carolina Bog Laurel. Herptiles: Hills Salamander, Sand Skink, Florida Pine Snake, Northern Pine Snake. Mammals: Gray Myotis. Birds: Red-cockaded Woodpecker, Bachman's Sparrow

Geophysical Settings in the Very Low Elevation Group

Non-coastal settings that occur above 20′ and below 800′, these are the most abundant and widespread environments in the region.

Surficial Settings

Very Low Elevation Fine Sediment: Fertile silt or clay setting in stream beds, floodplains, clay plains, and tidal marshes.

Very Low Elevation Fine Sediment over Limestone: Fine silts and clay over limestone bedrock. This setting is associated with springs, seeps, deep cut rivers, and sinkholes. The surface communities are silty floodplains, old lake beds and other fine grained settings.

Very Low Elevation Loam: Deep loams, sandy loams, and sandy clay loam supporting acidic forests and marshes.

Very Low Elevation Loam over Limestone: Deep loams, sandy loams, and sandy clay loam over limestone bedrock. This setting is associated with springs, seeps, deep cut rivers, and sinkholes. The surface communities resemble loam types.

Very Low Elevation Sand: Pure sand settings of the coastal plain supporting sandhill communities, pine forests and barrens, fluctuating ponds, and fire-driven communities like longleaf pine. Many rare species.

Very Low Elevation Sand over Limestone: Coarse sand over limestone bedrock. Surface communities are similar to sand but associated with springs, seeps, deep cut rivers, and sinkholes.

Bedrock Settings

Acidic sedimentary settings occur in both the Coastal Plain and Mountains and Piedmont, but because they support a relatively distinct flora and fauna in those subregions we separated them as follows:

Very Low Elevation Acidic Sedimentary: Widespread settings on sandstone, siltstone, and conglomerate, usually overlain with shallow till and supporting many common acidic forests types. Coastal plain settings on sandstone, siltstone, and conglomerate may show bedrock outcrops overlain with sandy surficial soils.

Very Low Elevation Acidic Shale: Settings on unstable shale slopes often supporting a unique flora, and sedimentary-like shale lowlands.

Very Low Elevation Acidic Granite: Rocky bedrock-based acidic granite setting with hilltop woodlands.

Very Low Elevation Calcareous: Fertile agricultural and timber lands on limestone and dolomite that support an array of distinctive communities and rare species.

Very Low Elevation Mafic: Setting on volcanic basalts, or other mafic rocks such as trap rock ridges or old ring dikes; often with a richer flora and fauna than the more acidic settings.

Very Low Elevation Moderately Calcareous: Fertile settings similar to calcareous but less distinctive and slightly more common. Bedrock is a mixture of acidic and calcareous rock.

Very Low Elevation Ultramafic: Settings on toxic soils high in nickel and chromium supporting stunted trees and a unique flora.

Low Elevation (800' to 1700')

Low Elevation (800′ to 1700′)

Communities in this elevation zone include: floodplains, flatwoods and bottomlands, sandhills, pine savannah, levee forest, scrub and hammock, bogs and fens, Carolina bays, brownwater swamp, depression forest, prairies, dolomite woodland, sinkhole ponds, marl outcrops, sandstone glade, diabase glade, dome swamp, basin marsh.

Northeast Rare Species found in this zone include: Plants: American Ginseng, Autumn Willow, Kate's Mountain Clover, Alleghany Plum, Small Anthered-bittercress, American Gromwell, Swamp Fly-honeysuckle, Queen-of-the-prairie, Appalachian Sandwort, Pale Vetchling, Eastern Featherbells, Showy Lady's-slipper, Goldie's Fern, Blunt-lobe Grape Fern. Herptiles: Jefferson Salamander, Timber Rattlesnake, Eastern Massasauga. Mammals: Allegheny Woodrat, Birds: Cerulean Warbler, American bittern, Golden-winged Warbler, Rusty Blackbird

Southeast Rare Species found in this zone include: Plants: Bighorn Hornwort, Climbing Fumitory, French Broad Heartleaf, Sweet Pinesap, Ash-leaf Bush-pea, Large-flowered Skullcap, Large Witch-alder, Allegheny Mountain golden banner, Piratebush, Mountain Camellia, Monkeyface Orchid, Small Whorled Pogonia, Reflexed Blue-eyed Grass, Coville's Rush, Sweet White Trillium. Herptiles: Green Salamander, Hellbender, Black Mountain Salamander, Shovelnose Salamander. Mammals: Allegheny Woodrat, Indiana Myotis, Rafinesque's Big-eared Bat. Birds: Swainson's Warbler

Geophysical Settings in the Low Elevation Group

Non-coastal settings that occur above 20′ and below 800′, these are the most abundant and widespread environments in the region.

Surficial Settings

Low Elevation Fine Sediment: Fertile silt or clay setting in stream beds, floodplains, clay plains, and tidal marshes.

Low Elevation Fine Sediment over Limestone: Fine silts and clay over limestone bedrock. This setting is associated with springs, seeps, deep cut rivers, and sinkholes. The surface communities are silty floodplains, old lake beds and other fine grained settings.

Low Elevation Loam: Deep loams, sandy loams, and sandy clay loam supporting acidic forests and marshes.

Low Elevation Loam over Limestone: Deep loams, sandy loams, and sandy clay loam over limestone bedrock. This setting is associated with springs, seeps, deep cut rivers, and sinkholes. The surface communities resemble loam types.

Low Elevation Sand: Pure sand settings of the coastal plain supporting sandhill communities, pine forests and barrens, fluctuating ponds, and fire-driven communities like longleaf pine. Many rare species.

Low Elevation Sand over Limestone: Coarse sand over limestone bedrock. Surface communities are similar to sand but associated with springs, seeps, deep cut rivers, and sinkholes.

Bedrock Settings

Low Elevation Acidic Sedimentary: Widespread settings on sandstone, siltstone, and conglomerate, usually overlain with shallow till and supporting many common acidic forests types.

Low Elevation Acidic Granite: Rocky bedrock-based acidic granite setting with hilltop woodlands.

Low Elevation Acidic Shale: Settings on unstable shale slopes often supporting a unique flora, and sedimentary-like shale lowlands.

Low Elevation Calcareous: Fertile agricultural and timber lands on limestone and dolomite that support an array of distinctive communities and rare species.

Low Elevation Mafic: Setting on volcanic basalts, or other mafic rocks such as trap rock ridges or old ring dikes; often with a richer flora and fauna than the more acidic settings.

Low Elevation Moderately Calcareous: Fertile settings similar to calcareous but less distinctive and slightly more common. Bedrock is a mixture of acidic and calcareous rock.

Low Elevation Ultramafic: Settings on toxic soils high in nickel and chromium supporting stunted trees and a unique flora.

Mid Elevation (1700' to 2500')

Mid Elevation (1700′ to 2500′)

Communities in this elevation zone include low mountain and foothill types such as: foothill cove forest, forested seep, granitic dome, montane alluvial forest, low mountain pine forest, ultramafic outcrop barren, shale slope woodland, southern mountain pine--oak forest, calcareous oak-walnut forest, french broad valley bog, low montane oak--hickory forest, low elevation rocky summit, chestnut oak forest, montane oak--hickory forest, appalachian seep/bog, pine-oak heath forest, hemlock forest, sandstone outcrop.

Northeast Rare Species found in this zone include: Plants: Bog Jacob's-ladder, Appalachian Blue Violet, Mountain Bugbane, Shale Barren Rockcress, Canby's Mountain-lover, Swordleaf Phlox, Mountain Parsley, Smooth Coneflower, Bog Goldenrod, Box huckleberry, Lillydale Onion, Case's Ladies'-tresses, Algae-like Pondweed. Herptiles: Green Salamander, Hellbender. Mammals: Northern Myotis, Eastern Small-footed Myotis, Indiana Bat

Southeast Rare Species found in this zone include: Plants: Bighorn Hornwort, Climbing Fumitory, Sweet Pinesap, Ash-leaf Bush-pea, Large-flowered Skullcap, Large Witch-alder, Allegheny Mountain golden banner, Piratebush, Mountain Camellia, Monkeyface Orchid, Small Whorled Pogonia, Reflexed Blue-eyed Grass, Coville's Rush, Sweet White Trillium. Herptiles: Green Salamander, Hellbender, Black Mountain Salamander, Shovelnose Salamander. Mammals: Allegheny Woodrat, Indiana Myotis, Rafinesque's Big-eared Bat. Birds: Swainson's Warbler

Geophysical Settings in the Mid Elevation Group

These are settings that occur above 1700′ and below 2500′ elevation and all are in the Mountain or Piedmont subregions.

Mid Elevation Fine Sediment: Fertile silt or clay setting in stream beds, floodplains, clay plains, and tidal marshes.

Mid Elevation Loam: Deep loams, sandy loams, and sandy clay loam supporting acidic forests and marshes.

Mid Elevation Sand: Pure sand settings of the coastal plain supporting sandhill communities, pine forests and barrens, fluctuating ponds, and fire-driven communities like longleaf pine. Many rare species.

Bedrock Settings

Mid Elevation Acidic Sedimentary: Foothills, ridges and plateaus composed of sandstone, siltstone, or conglomerates. This abundant setting supports many common acidic forests types.

Mid Elevation Acidic Shale: Settings on unstable shale slopes often supporting a unique flora, and sedimentary-like shale lowlands.

Mid Elevation Calcareous: Fertile rolling settings on limestone and dolomite that support an array of distinctive communities including caves, alkaline wetlands and limestone barrens.

Mid Elevation Granite: Foothill settings supporting natural communities typical of acid, nutrient-poor and shallow-soil environments.

Mid Elevation Mafic: Foothill settings often intermixed with granite, but derived from volcanic basalts or intrusive igneous rocks, and supporting a richer flora and fauna.

Mid Elevation Moderately Calcareous: Fertile settings similar to calcareous, but less distinctive and slightly more common. Bedrock is a mixture of acidic and calcareous rock.

Mid Elevation Ultramafic: Very rare settings on toxic serpentine soils high in nickel and chromium supporting stunted trees and a unique flora. Moderate, high and very high elevation occurrences were grouped together as there were only a few acres total of this habitat and the unique soils tend to influence the vegetation more than elevation.

High Elevation (2500' to 360' in the Northeast and 2500' to 4500' in the Southeast)

High Elevation (2500′ to 360′ in the Northeast and 2500′ to 4500′ in the Southeast)

Communities in the elevation zone include: acidic cove forest, boulderfield forest, Canada hemlock forest, cumberland highlands forest, heath bald, high elevation granitic dome, high elevation mafic glade, high elevation red oak forest, high elevation rocky summit, high elevation white oak forest, montane alluvial forest, montane seep, montane cliff, montane oak-hickory forest, montane red cedar-hardwood woodland, mountain bog forest, mountain herb bog, mountain shrub bog, outcrop community, northern hardwood forest, rich cove forest, rich montane seep, and Southern Appalachian bog.

Northeast Rare Species found in this zone include: Plants: Running Buffalo Clover, White Monkshood, Large Cranberry, Darlington's Glade Spurge, Northern Mountain-ash, Silverling, Roan Mountain Goldenrod, Gray's Lily, Kidneyleaf Twayblade, Spreading Pogonia, Summer Sedge, Appalachian Fir-clubmoss, Bog Fern. Mammals: Appalachian Cottontail, Long-tailed Or Rock

Southeast Rare Species found in this zone include: Plants: American Ginseng, Appalachian Gentian, Mountain Catchfly, Rock Skullcap, Trailing Wolfsbane, Fraser Loosestrife, Cuthbert's Turtlehead, Cranberry, Mountain Watercress, Divided-leaf Ragwort, Roan Mountain Sedge, Gray's Lily, Manhart's Sedge, Pretty Sedge, Ruth's Sedge, Bog Oatgrass, Rock Clubmoss, Gorge Filmy Fern, Lobed Spleenwort. Herptiles: Seepage Salamander, Weller's Salamander, Red-legged Salamander, Bog Turtle, Timber Rattlesnake. Mammals: Southern Water Shrew Birds: Cerulean Warbler, Golden-winged Warbler, Appalachian Bewick's

These settings occur from 2500′ to 4500′ elevation and all are in the high mountains.

High Elevation Acidic Granite: Mountainous granitic settings supporting natural communities typical of acid, nutrient-poor and shallow-soil environments.

High Elevation Acidic Sedimentary: Bedrock mountains, resistant ridges and high plateaus composed of sandstone, siltstone, conglomerates and minor amounts of acidic shale. This abundant setting supports many common acidic forests types.

High Elevation Acidic Shale: Bedrock hills, bluffs and mountains composed of fissile shale. This uncommon setting supports common acidic forests types.

High Elevation Calcareous: Mountainous landscapes of rich limestone or dolomite.

High Elevation Moderately Calcareous: high elevation landscape of calcareous shales and sandstone-limestone mixtures. .

High Elevation Mafic: Mountainous settings often intermixed with granite, but derived from volcanic basalts or intrusive igneous rocks, and supporting a richer flora and fauna.

Ultramafic: Note: the few cells of very high ultramafic that exist were combined with the high and medium ultramafic.

Very High Elevation (over 3600' in Northeast and 4500' in Southeast)

Very High Elevation (over 3600′ in Northeast and 4500′ in Southeast)

Communities in this elevation zone include: fraser fir forest, heath bald, high elevation birch boulderfield forest, high elevation boggy seep, high elevation red oak forest, high elevation rocky summit, northern hardwood forest, red spruce - fraser fir forest, Southern Appalachian grass and shrub bald, swamp forest--bog complex.

Northeast Rare Species found in this zone include: Plants: Alpine Blueberry, Dwarf White Birch, Mountain Avens, Cutler's Alpine Goldenrod, Boott's Rattlesnake Root, White Alumroot, Long-stalk Holly, Wavy Bluegrass. Herptiles: Cheat Mountain Salamander, Cow Knob Salamander. Birds: Bicknell's Thrush.

Southeast Rare Species found in this zone include: Plants: Small Mountain Bittercress, Spreading Avens, Roan Mountain Bluet, Rugel's Ragwort, Bent Avens, Clingman's Hedge-nettle, Blue Ridge Goldenrod, Heller's Blazing-star, Fraser Fir, Rock Gnome Lichen, Smoky Mountain Mannagrass, Herptiles: Pygmy Salamander. Mammals: Carolina Northern Flying Squirrel, Long-tailed or Rock Shrew, Southern Rock Vole, Appalachian Cottontail. Birds: Southern Appalachian Northern Saw-whet Owl, Southern Appalachian Black-capped Chickadee

These distinct settings are all above 3600′ in the Northeast Appalachians and 4500′ elevation in the highest mountains of the Southern Appalachians. Several geologic types are lumped together because at this elevation, high elevation processes like wind shear and desiccation predominate over some soil distinctions.

Very High Elevation Granite: Bedrock mountain setting of intrusive granitic rock with minor plutons of mafic rock or volcanic basalts.

Very High Acidic Sedimentary: Bedrock mountain setting of sandstone, quartzite, conglomerate and minor inclusions of moderately calcareous sedimentary rocks.

Very High Elevation Acidic Shale: Bedrock hills, bluffs and mountains composed of fissile shale.

Very High Elevation Calcareous: Mountainous landscapes of rich limestone or dolomite.

Very High Elevation Moderately Calcareous: Very High elevation landscape of calcareous shales and sandstone-limestone mixtures.

Very High Elevation Mafic: Mountainous settings often intermixed with granite, but derived from volcanic basalts or intrusive igneous rocks.

Ultramafic Note: the few cells of very high ultramafic that exist were combined with the high and medium ultramafic.

Summary of Geophysical Settings (See figure 2.6)

Coastal (0-20'): 12 settings

- Coastal Acidic Granite
- Coastal Acidic Sedimentary
- Coastal Calcareous
- Coastal Loam
- Coastal Loam over Limestone
- Coastal Mafic
- Coastal Moderately Calcareous
- Coastal Sand
- Coastal Sand over Limestone
- Coastal Silt/Clay
- Coastal Silt/Clay over Limestone
- Coastal Ultramafic

Very Low Elevation (20-800'): 13 settings

- Very Low Elevation Acidic Granite
- Very Low Elevation Acidic Sedimentary
- Very Low Elevation Acidic Shale
- Very Low Elevation Calcareous
- Very Low Elevation Loam
- Very Low Elevation Loam over Limestone
- Very Low Elevation Mafic
- Very Low Elevation Moderately Calcareous
- Very Low Elevation Sand
- Very Low Elevation Sand over Limestone
- Very Low Elevation Silt/Clay
- Very Low Elevation Silt/Clay over Limestone
- Very Low Elevation Ultramafic

Low Elevation (800 – 1700'): 15 settings

- Low Elevation Acidic Granite
- Low Elevation Acidic Sedimentary
- Low Elevation Acidic Shale
- Low Elevation Calcareous
- Low Elevation Loam
- Low Elevation Loam over Limestone
- Low Elevation Mafic
- Low Elevation Moderately Calcareous
- Low Elevation Sand
- Low Elevation Sand over Limestone
- Low Elevation Silt/Clay
- Low Elevation Silt/Clay over Limestone
- Low Elevation Ultramafic

Mid Elevation (1700-2500'): 10 settings

- Mid Elevation Acidic Granite
- Mid Elevation Acidic Sedimentary
- Mid Elevation Acidic Shale
- Mid Elevation Calcareous
- Mid Elevation Loam
- Mid Elevation Mafic
- Mid Elevation Moderately Calcareous
- Mid Elevation Sand
- Mid Elevation Silt/ Clay
- Mid-High-Very High Elevation Ultramafic

High Elevation, 7 settings

- High Elevation Acidic Granite
- High Elevation Acidic Sedimentary
- High Elevation Acidic Shale
- High Elevation Calcareous
- High Elevation Mafic
- High Elevation Moderately Calcareous
- High Elevation Sand/Loam/Silt/Clay

Very High Elevation, 7 settings

- Very High Elevation Acidic Granite
- Very High Elevation Acidic Sedimentary
- Very High Elevation Acidic Shale
- Very High Elevation Calcareous
- Very High Elevation Mafic
- Very High Elevation Moderately Calcareous
- Very High Elevation Sand/Loam/Silt/Clay

CHAPTER 3

Estimating Site Resilience

The physical structure of a site - its topography, density and configuration of wetlands, and soil diversity - can buffer resident species from the direct effects of climate change. Most species experience climate at extremely local scales (meters or centimeters) and thus a diverse landscape is experienced as a heterogeneous mix of microclimates which may allow species to persist even where the average background climate appears unsuitable. Sites with a large variety of microclimates that are well connected by natural cover may enable species to persist indefinitely, with individuals and populations shifting around to take advantage of the microclimate variation. These sites are hypothesized to have high **site resilience**. In this section, we describe the concepts, methods, and data used to estimate the relative site resilience of any given place. The two factors important to the estimate - landscape diversity and local connectedness – are discussed separately, because the tools for assessing and measuring them are distinctly different.

Section 1: Landscape Diversity

Landscape-based climatic variation can be substantial, on par with, or greater than, the 1^{0}- 5^{0} C warming expected for extreme future climate change. Surgett et al. (2010) placed climate data loggers across gradients of slope, aspect and elevation in northern England, and found maximum temperature differences over 20^{0} C / 34^{0} F. Dobkin et al. (1987) measured micro-topographic thermal climates in a California serpentine grassland and found up to 20^{0} C differences between slope maximums. Weiss et al. (1988) working in the same landscape later demonstrated that areas of high local landscape diversity were important for long-term population persistence of butterfly species and their host plants under variable climatic conditions. In South Carolina's Blue Ridge Mountains, the temperature on south-facing slopes has been measured at 40^{0} C / 104^{0} F in July, while a few hundred yards away the sheltered ravines were a cool 26^{0} C / 79^{0} F (P. McMillan, personal communication, October 2010). Like temperature, moisture gradients are also correlated with hillslope position and aspect. On Appalachian slopes, Yeakley et al. (1998) found 15%-18% fractional soil moisture differences from upper slope to valley bottom with topography explaining 40%-72% of the moisture variation. Bennie et al. (2008) found that in England's chalk grasslands, aspect created differences in soil moisture content ranging up to 20% of fractional moisture differences.

This "microclimatic buffering" (Willis and Bhagwat 2009) may create suitable combinations of temperature and moisture for species even in areas where coarse-scale climate models suggest unsuitable climate. Topography redistributes temperature and precipitation so completely that in some landscapes no areas actually experience the "average" regional climate: basins are wetter, summits are dryer, south-facing slopes are hotter and north-facing slopes are cooler. The effect is a function of the scale of measurement. For example, Randin et al. (2008) found that coarse-scale models predicting the loss of all suitable habitats for plants in the Swiss Alps conversely predicted the persistence of suitable habitats for all species when they were rerun at local scales that captured topographic diversity.

In actual landscapes (as opposed to coarse-scale climate models) the microclimates created by the topographic structure offer thermal and moisture options to resident species, and in response to climatic changes, species populations shift their locations to take advantage of this variation and stay within their preferred climatic habitats. Thus, the variety of microclimates present in a site - its **landscape diversity -** can be used to estimate the capacity of the site to maintain species diversity and ecological functions. Here we describe our methods to quantify landscape diversity at a relatively fine 30-m scale and to estimate the number of species-relevant microclimates within a site. First, elevation data was used to delineate and assess topographic features across the landscape. Measures of wetland and soil properties were then used to detect subtle gradients in flat landscapes.

Landform Variety

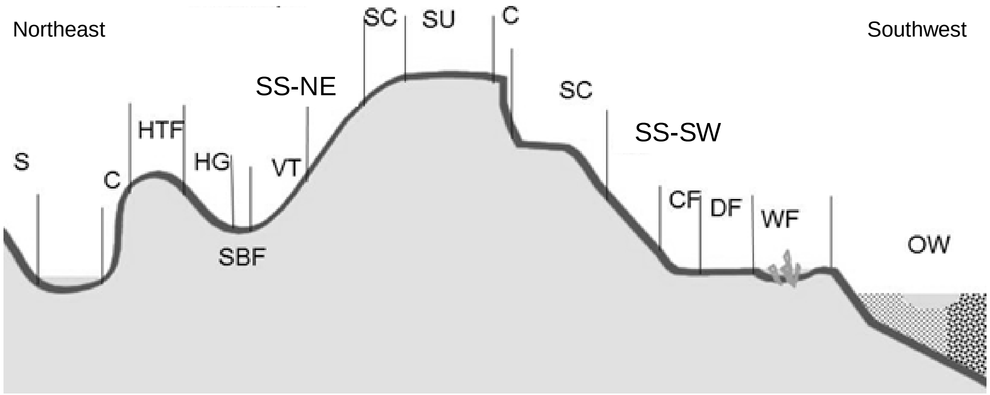
Landforms are natural features of the earth's surface created by topography. Collectively they comprise a region's terrain. Landforms determine local vegetation patterns because they present physically stable combinations of temperature, moisture, exposure, nutrient availability, and soil depth, and they influence individual species distributions through the variation they create in these factors (Forman 1995). Landforms often create distinct ecological habitats that support characteristic communities and species. For example, concave toe slopes where moisture and nutrients accumulate support moist cove forests, while upper slopes support species adapted to thin dry soils and greater exposure. The basic landform unit (aka. elementary landform, land segment, land facet, or relief unit) is the smallest homogeneous division of the land surface at a given scale, and is categorized by characteristic attributes such as elevation, slope, aspect, exposure, and soil depth. In general, moisture regime is most strongly linked with land position, while temperature is highly correlated with aspect and slope, but because each landform represents a local expression of solar radiation and moisture availability, a site with a variety of landforms results in a site with a variety of meso- and microclimates available to species.

To quantify the microclimates created by an area's landforms we developed a model that classifies a surface into one of 17 elementary landforms (figure 2.7). Our methods are described in detail elsewhere (Anderson 1999, Anderson et al. 2012) and are based on those of Fels and Matson (1997). The landform model was built from a 30-m digital elevation model (DEM; Gesch 2007, Canada Digital Elevation Data 2011), and used topographically derived variables such as slope, aspect, land position, and moisture accumulation, to map recognizable landforms that could be verified in the field (Figures 3.1 and 3.2). Major divisions in the model were based on relative land position and slope, with slopes further subdivided by aspect, and flats further subdivided by moisture accumulation (Figures 3.1-3.3).

To create the landform model, the following initial datasets were generated as grids from the 30 m DEM: topographic position, slope, aspect, and degree of moisture accumulation. Briefly, to derive the relative topographic position we evaluated the elevation differences between any cell and the surrounding cells within a specified search radius and scored it using a relative topographic position index (TPI). For example, if the model cell was, on average, higher than the surrounding cells, then it was considered to be closer to the ridge top (a more positive position value), and conversely, if the model cell was, on average, lower than the surrounding cells, then it was considered closer to the slope bottom (a more negative position value). Degree of slope was calculated as the difference in elevation between two neighboring cells, expressed in degrees. Aspect was calculated using the GIS Aspect tool which fits a plane to the z-values of a 3 x 3 cell neighborhood around a center cell. The direction the plane faces is the aspect for the center cell. A moisture index was calculated using a flow accumulation model which maps variation in moisture accumulation and soil residence time using the equation: Moist_index = ln [(flow_accumulation + 1) /(slope + 1)]. We used National Wetlands Inventory datasets to calibrate the moisture index and set a wet/dry threshold. The individual grids were then combined in a structured way corresponding to driving processes to create the landforms (Figure 3.2). For example, a south-facing side-slope was defined by land position, slope and aspect, whereas a wet flat was defined by land position, slope and moisture accumulation.

The landform model can distinguish any number of units, but we used a 17-unit model that captures the major differences in temperature and moisture as reflected in the current distribution of the biota (Figure 3.3). To calculate the variety of landforms surrounding a given cell (Figure 3.4), we tabulated the number of landforms within a 404-ha (100-acre) circle around every 30 m cell using a focal variety analysis. All landforms that occurred on pixels classified as developed in the 2011 National Land Cover Dataset (NLCD; Fry et al.2011) and the Canadian Land Cover datasets (Ministère des Ressources naturelles 2014, New Brunswick Forest Inventory Database 2012, New Brunswick Wetlands Inventory 2006, Prince Edward Island Corporate Land Use Inventory 2010) were removed from the analysis. The search area was based on a radius that provided the best discrepancy between cells (highest between-cell variance). Our assumption was that most species populations could access this relatively small neighborhood to locate suitable microclimates.

Figure 3.1: Distribution and definitions of landforms.



C - Cliff: a high, steep or overhanging face of rock or earth. Cliffs provide nesting places for birds and crevice-rooting ferns.

S - Steep slope (SW and NE aspects): a steeply sloping escarpment, headwall, ledge, or bluff, less vertical than a cliff. The accumulation of rock fragments at the base creates talus slopes.

SU -Summit/ridgetop: the topographically highest position of a hillslope profile with a nearly level surface. Typically summits have thin soils and extreme winds.

SC -Slope crest: a slope crest or shoulder is the hillslope position that forms the convex, erosional surface near the top of a hillslope, transitioning from summit to sideslope.

SS – Sideslope (SW and NE aspects): the hillslope profile position that forms the moderately steep middle portion of the hill or mountain. Bounded by convex shoulder and concave footslope.

CF - Cove/footslope (SW and NE aspects): refers to the hillslope profile position that forms the concave surface at the base of a hillslope. A moist, nutrient-rich, depositional setting.

VT - Valley/toeslope: the hillslope position that forms the gently inclined surface at the base of a hillslope. Toeslopes in profile are commonly gentle and linear, forming depositional environments.

SBF - Slopebottom flat: the flat channel in a narrow steep-sided ravine, commonly V-shaped in cross section. Slopebottom flats usually contain streams.

HF - Hilltop flat: the level top of a low hill with low local relief, rising slightly above surrounding lowlands.

HG - Hill gentle slope: the sloping sides of a hill or rounded land surface with low local relief, rising slightly above surrounding lowlands.

DF - Dry flat: a level plain or flat land surface in a low landscape position that does not accumulate water.

MF - Moist flat: a level plain or flat land surface in a low landscape position that accumulates some water.

WF - Wet flat: the nearly level to gently concave bottom surface of a flat basin that accumulates substantial water. Most wetland habitats are found in wet flats.

OW - Water/lake/river: open waterbodies, often in the center of a wet flat and large river segments.

Figure 3.2: The underlying slope and land position model used to map the landforms. Adapted from Fels and Matson 1997.

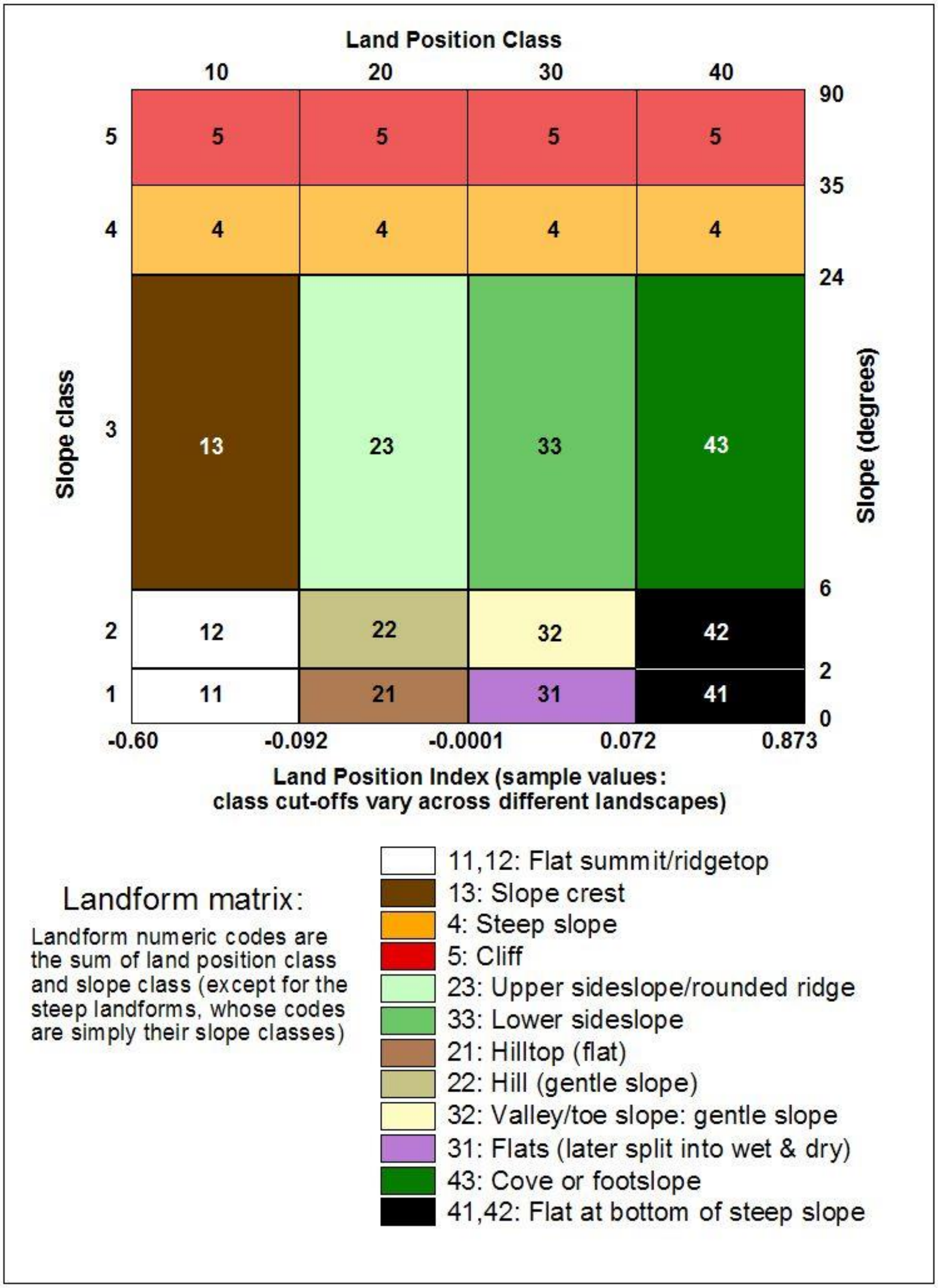


Figure 3.3: The 17-unit landform model. These images show how the landform model partitions the landscape based on slope, aspect, land position, and moisture accumulation. **A)** The area in shaded relief, **B)** with an overlay of the landforms. **C)** The dashed oval indicates the region with the highest number of landform units encompassing wet flats to summits and upper slope crests. Mount Mansfield VT.

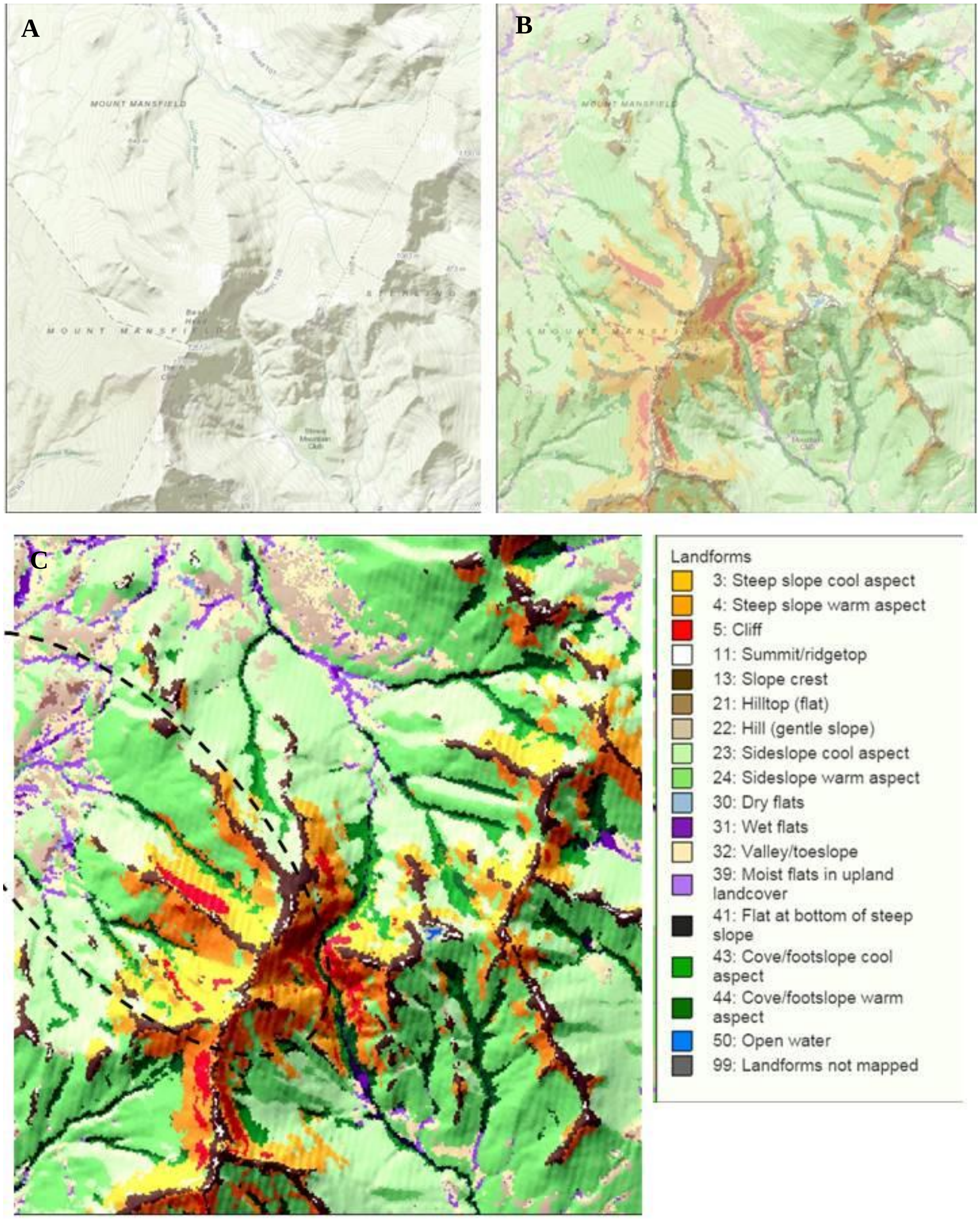
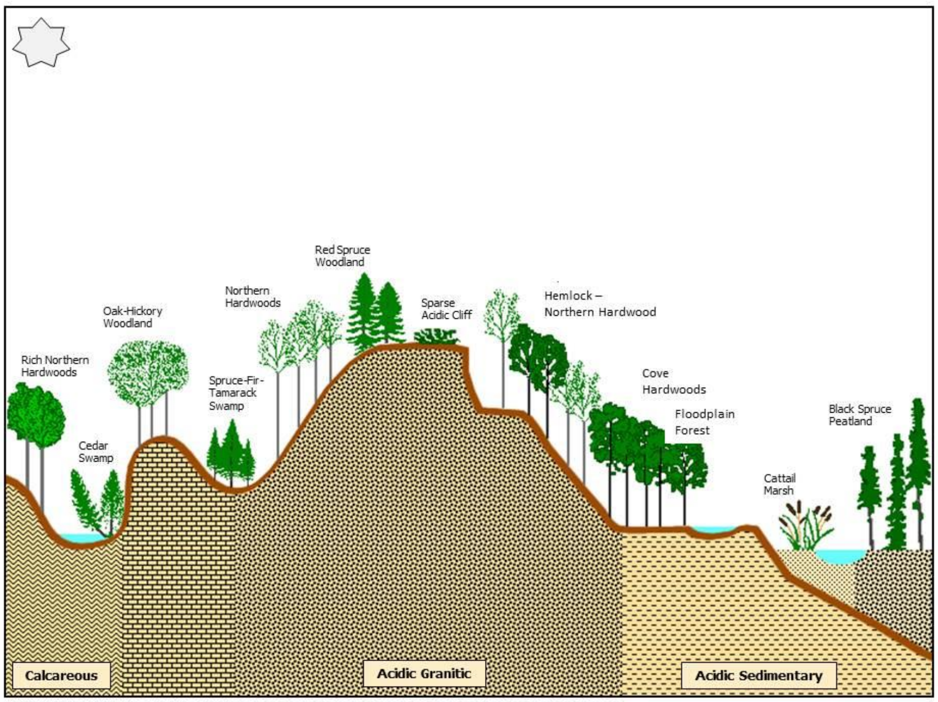


Figure 3.4. Landform variety. This map counts the number of landforms (17 possible) in a 100-acre circle around a central cell, and compares it to the regional average.

Landform and Species Relationships

The thresholds delineating one landform from another were based on observable relationships between topography, plant communities, and rare species (Figure 3.4). For example, concave toe slopes where moisture and nutrients accumulate tend to support nutrient-demanding rich cove forests, while sideslopes, which transport nutrients and moisture along their slopes, tend to support less demanding matrix-forming forest types. The point on a slope where transport ends and accumulation begins forms the split between sideslope and cove landforms, delineating two distinct thermal-moisture environments.

Figure 3.5: Generalized distribution of Northeastern US natural communities across landforms.



We were interested in how the individual components of the land's topography (position, moisture, slope, and aspect) combine to create relatively discrete environments that could be verified in the field and tested for evidence of distinct species compositions. To examine the latter, we overlaid over 200,000 locations of 4252 rare species found in the region, and calculated the importance value of each landform to each species (Importance Value = the % of the known locations that occur on this landform more than expected by chance multiplied by the number of locations). The Importance Value is a measure of the strength and confidence of the species-landform association. We defined a preferential species as one that occurred more often than expected on the landform of interest compared to any other landform (Importance Value > 1, Anderson et al. 2015), and then examined how they were distributed across landforms (Figures 3.5, 3.6).

For example, south-facing steep slopes had the highest Importance Value for timber rattlesnake as the 178 known locations occurred on this landform 20% more than expected by chance (e.g., the probability that a random point would land on a south-facing steep slope), and this was greater than on any other landform. However, other landforms also had positive but lower probabilities: south-facing sideslopes(17%), south- facing coves (2%), and cliffs (5%), reflecting the snake's predilection for denning and basking in sunny spots. In the future, if the preferred habitat becomes too hot, it is likely the populations will shift to these slightly cooler environments.

We tested the distinctiveness and similarity between a landform's preferential species using a simple Sorenson measure based on the Importance Values of rare species occurring on each landform (Figure 3.7, 3.8). As the climate changes, closely related landform-based habitat might substitute for each other and this will likely become more common as the changes become more substantial.

Figure 3.6: Distribution of selected species across landforms in the Northeastern US. Steep curves indicate greater preference for a single landform type, and rounded curves indicate a species that prefers several related landforms.

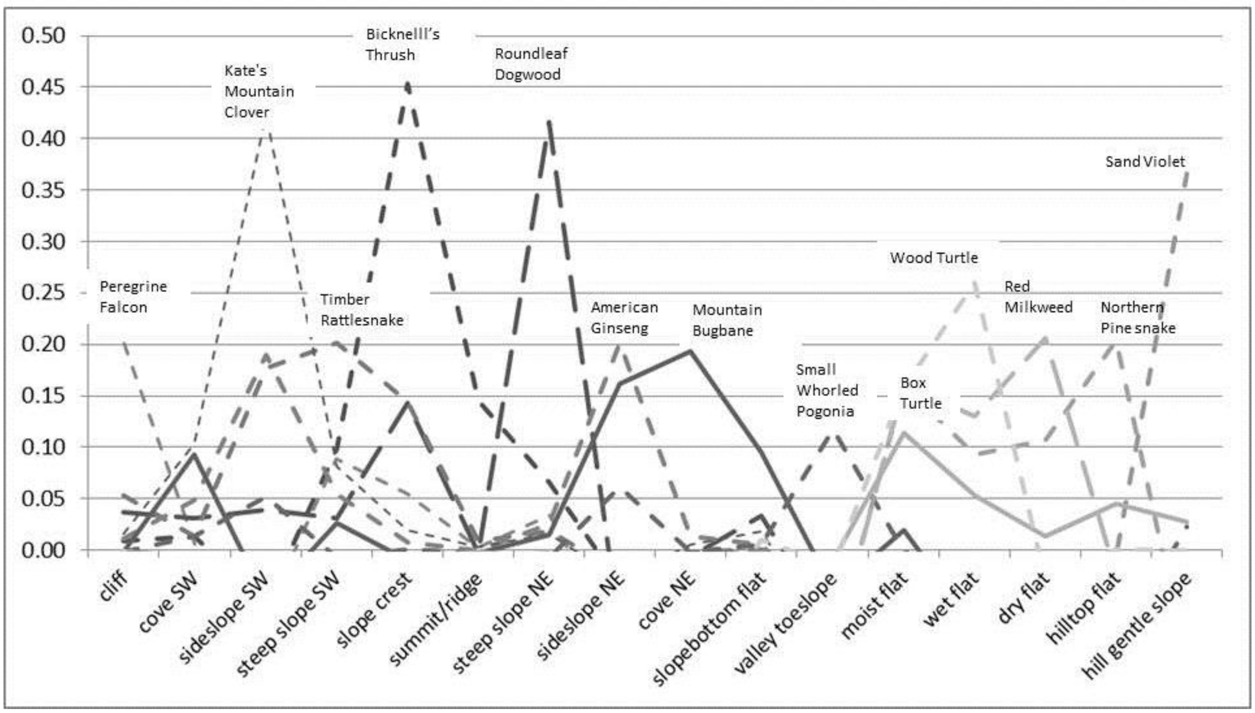


Figure 3.7: Landforms and preferential rare species. The number and examples of preferential rare species (G1-G4), defined as species found more often than expected on this landform compared to any other (Anderson et al. 2015), recorded for each landform in the Northeastern US.

Landform	Characteristics	Restricted Species Examples	G1-4	Total
Slopes			**271**	**1208**
Cliff	Dry, bedrock, crevices	Peregrine Falcon, Golden Eagle, Fragrant Cliff Fern	9	106
Steep slope -NE	Cool, humid, thin soil	Roundleaf Dogwood, American Harebell, Coal Skink	12	55
Steep slope -SW	Hot, dry, thin soil	Timber Rattlesnake, Allegheny Woodrat, Purple Clematis	19	106
Sideslope -NE	Cool, moist, mod. soil	American Ginseng, Northern Myotis, Northern Flying Squirrel	88	296
Sideslope -SW	Warm, mesic mod. soil	Kate's Mountain Clover, Shale Barren Rockcress, Copperhead	127	521
Cove/footslope-NE	Cool, moist, enriched	Mountain Bugbane, Northern Beech Fern, Longtail Salamander	6	60
Cove/footslope-SW	Warm, moist, enriched	Blackbelly Salamander, Clasping Twisted Stalk, Squashberry	10	64
Flat or Gently Sloping			**674**	**3419**
Dry flat	Dry, deep soils	Red Milkweed, Migrant Loggerhead Shrike, Karner Blue	21	169
Moist flat	Moist, deep soils	Eastern Box Turtle, Eastern Silvery Aster, Eastern Spadefoot	136	606
Wet flat	Wet, organic soils	Wood Turtle, Blanding's turtle, American Bittern,	258	1325
Open water	Open water	Common Loon, Yellow Lampmussel, Algae-like Pondweed	155	575
Flat Summit	Dry, exposed, bedrock	Cheat Mt.Salamander, Greater Straw Sedge, Early Hairstreak	4	32
Slope crest	Dry, exposed, thin soil	Bicknell's Thrush, Alpine Blueberry, Bigelow's Sedge	19	138
Valley/Toe slope	Moist, cool, mod. Soils	Small Whorled Pogonia, Marbled and Jefferson Salamander	23	178
Slope bottom flat	Moist to wet, ravines	Ocellated Darner, Northern Water Shrew, Crested Dwarf Iris	10	73
Hilltop flat	Dry, thin to mod. Soils	Northern Pinesnake, Grasshopper Sparrow, Sandplain Gerardia	33	190
Hill/gentle slope	Mesic, moderate sols	Sand Violet, Broom Crowberry, Dickcissel	15	133

Figure 3.8: Similarity among landforms based on their rare species (G1-G4) composition. Similarity is based on the Sorenson index. The most similar landforms are moist and wet flats with 60% shared species.

Similarity in G1-G4 Species based on the Sorenson Similarity Index.	*Steep slope cool*	*Steep slope warm*	*Cliff*	*Summit / ridge*	*Slope crest*	*Side-slope cool*	*Side-slope warm*	*Hilltop flat*	*Hill gentle-slope*	*Cove cool*	*Cove warm*	*Valley / toe-slope*	*Slope-bottom flat*	*Dry flat*	*Moist flat*	*Wet flat*	*Open water*
Steep slope cool	1.00	0.52	0.43	0.32	0.47	0.32	0.35	0.03	0.09	0.37	0.40	0.10	0.30	0.05	0.13	0.09	0.07
Steep slope warm		1.00	0.47	0.34	0.53	0.33	0.45	0.05	0.11	0.36	0.45	0.11	0.30	0.05	0.15	0.11	0.10
Cliff			1.00	0.33	0.43	0.21	0.26	0.03	0.09	0.27	0.33	0.08	0.18	0.04	0.07	0.05	0.05
Summit /ridge				1.00	0.39	0.19	0.24	0.03	0.09	0.20	0.24	0.07	0.16	0.04	0.07	0.06	0.03
Slope crest					1.00	0.36	0.46	0.08	0.17	0.29	0.40	0.14	0.27	0.09	0.16	0.12	0.07
Side-slope cool						1.00	0.50	0.10	0.20	0.31	0.36	0.26	0.28	0.11	0.26	0.18	0.13
Side-slope warm							1.00	0.12	0.23	0.28	0.40	0.27	0.28	0.13	0.27	0.21	0.14
Hilltop flat								1.00	0.22	0.03	0.04	0.17	0.04	0.36	0.29	0.29	0.12
Hill gentle-slope									1.00	0.07	0.11	0.21	0.07	0.16	0.20	0.15	0.07
Cove cool										1.00	0.42	0.15	0.41	0.07	0.22	0.17	0.15
Cove warm											1.00	0.19	0.41	0.09	0.25	0.18	0.14
Valley / toe-slope												1.00	0.15	0.21	0.33	0.28	0.14
Slope-bottom flat													1.00	0.10	0.28	0.22	0.20
Dry flat														1.00	0.32	0.34	0.15
Moist flat															1.00	0.60	0.38
Wet flat																1.00	0.47
Open water																	1.00

Elevation Range (Uncorrelated from Landforms)

Species distributions may increase or decrease in elevation as species seek suitable climate habitat, and in many landscapes the effects of slope may be magnified by elevation. Evidence shows that over the last two decades many species have shifted their geographic distributions toward higher elevations or upslope (Chen et al. 2011, Figure 3.9). Upslope movement has been documented for over 1,000 species and appears to be greatest among plants, herptiles and mammals. With the exception of birds, the evidence for significant upslope movement now seems overwhelming and may range from 6 m to 11 m per decade (Lenoir et al. 2010, Chen et al. 2011). In many places, upslope range shifts are more likely than latitudinal shifts in the short term as elevational temperature gradients are steep and local.

Figure 3.9: Summary of elevational observed range shifts from 30 studies (modified from Chen et al. 2011). ORS = observed range shift, SE = standard error. "Margin" refers to whether the studies focused on changes in the upper leading margin or average distribution. The list of sources for Chen et al. 2011 may be found at http://www.sciencemag.org/content/333/6045/1024/suppl/DC1

Observed Elevational Range Shifts

Taxa group	Species (#)	Margin (Upper / Average)	Duration (yrs.)	Mean ORS (m)	Min ORS (m)	Max ORS (m)	SE of ORS (m)	Temp change (C)	# Studies (#)
Invertebrates	554	U/A	20-42 yrs.	37.7	7.4	108.6	12.3	0.62	5
Herptiles	30	A	10 yrs.	65.3	65.3	65.3	24	0.24	1
Birds	326	A/U	11-25 yrs.	-4.75	-19.3	7.6	9.3	0.795	4
Mammals	37	U/A	25-88 yrs.	50	31	69	71.6	3.05	2
Plants	495	U/A	22-94 yrs.	62.4	21	89	16.2	0.97	7

Initially, we measured local elevation range by compiling a 30 m DEM (Gesch 2007, Canada Digital Elevation Data 2011) for the region and using a focal range analysis to tabulate the range in elevation within a 100-acre circle around each cell. Prior to running the focal range analysis, the DEM was extracted by the modified landform grid so that all null areas (i.e., developed, ocean) were consistent between the two grids. Examination of the results, however, revealed a strong correlation between the elevation range and the landform variety (Pearson R^2 =0.84).

To generate a raster dataset of the elevation range not explained by the variety of landforms – the uncorrelated elevation range - we used a robust regression (Hampel et al. 1986) with log-transformed elevation range as the dependent variable and landform variety as the independent variable. A bivariate regression raster was calculated using a randomized subsample of pixels stratified by the three subregions (Coastal Plain, Piedmont, and Mountains) (Figure 1.1) and fitted using an iterated re-weighted least squares algorithm. The resulting dataset estimated the range of elevation present in a 100-acre circle around each 30 m cell that was not due to the variety of landforms (Figure 3.7). For example, if two cells were both surrounded by south-facing sideslopes and summits, some elevation range would be expected due to the presence of the two landforms; however, the one with the longer slopes would have more elevation range, and that range would be independent of the landform number.

We calculated the standardized normal score for every cell in the study area. In a later step, when we integrated elevation range with the other landscape diversity factors, only positive values were added to cells to identify where the elevation range provided additional climatic options. We did not subtract lower scores from cells where the elevation range was equal to the landform diversity (Figure 3.10).

Figure 3.10: Elevation range (uncorrelated with landform variety). This map measures the elevation range in a 100-acre circle around a central cell that is not correlated with the number of landforms and compares it to the regional average.

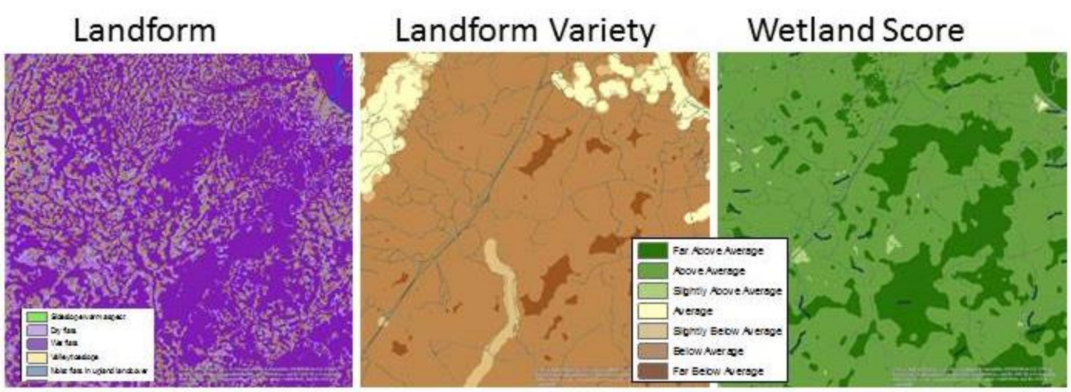
Wetland Score

Much of Eastern North America is flat. In these areas the landform variety and elevation range are inherently low, and micro-topographic variation determines where moisture accumulates and how it is distributed (Figure 3.11). This micro-topographic variation structures wetland communities and creates options for species by producing small-scale hummock and hollow microhabitats favored by different species (Vivian-Smith 1997). A high density of wetlands or wetland patches thus correlates with areas of high flow accumulation and high micro-topography. As the climate changes, these areas will likely become increasingly important because they retain soil moisture longer, dry out unevenly, and preserve a mixture of organic and wetland soils.

There is much evidence that wetlands formed in basins where water collects tend to have high evapotranspiration rates and play a unique role in sustaining the resilience of a landscape. Protecting wetlands and riparian corridors has been suggested as one of the single best actions in promoting resilience and in sustaining biodiversity (Naiman 1993, Fremier 2015). Further and as described above, landscapes with many wetland patches predictably have high moisture and extensive micro-topography which creates options for wetland and upland species. We assumed that areas with a high density of wetlands and a high number of wetland patches had the highest topographic variation, and that small isolated wetlands were more vulnerable to shrinkage and disappearance than wetlands embedded in a landscape crowded with other wetlands.

The landform model includes a unit called "wet flats" which are the moisture-accumulating basins within which virtually all natural wetlands are found. However, there is much variation in how much of a wet flat landform is actually covered by wetlands and this variation is largely a function of the micro-topography which governs the distribution of water within the wet flat. Thus, for the wetland score we directly

Figure 3.11: Landform, landform variety and wetland scores. In a dense wetland landscape where a few landforms repeat over and over, landform variety tends to score low. The wetland score boosts the score in places where there is a high density or patchiness of wetlands. Apalachicola, Florida.



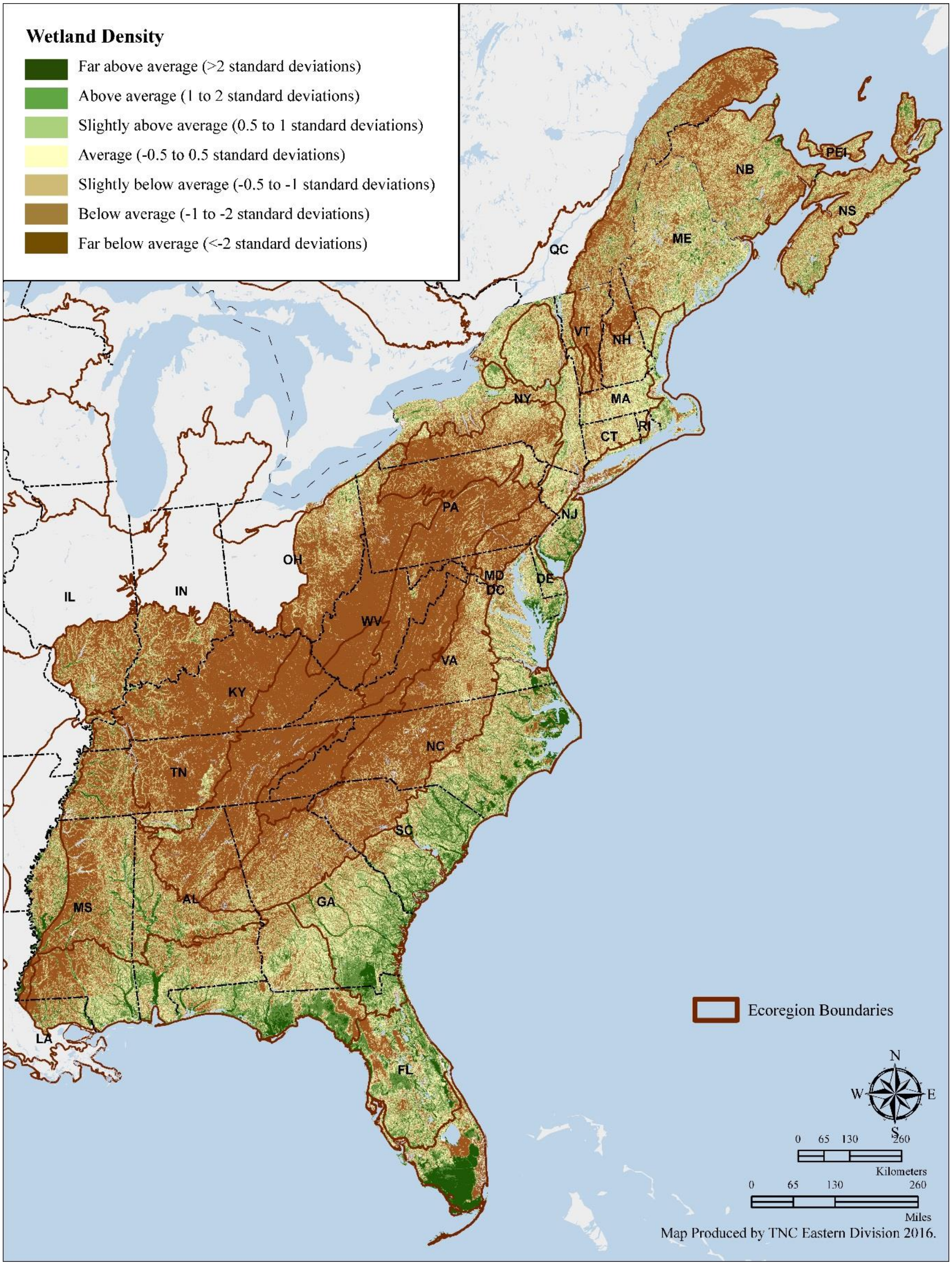
measured wetland density and patchiness based on aerial interpreted photo imagery (National Wetlands Inventory). We came to this decision after experimenting with calculating local rugosity measures which did not perform well in very flat landscapes, and deciding that the interpreted imagery provided the best available gauge of small and micro-scale topographic diversity.

To calculate a wetland score, we compiled National Wetlands Inventory data (NWI 2013) for all states in the study area, except for Florida, where we used a more comprehensive wetlands dataset from Florida Natural Areas Inventory (FNAI 2012) which contained a similar level of detail and aligned well with the NWI wetlands along the state's borders with Georgia and Alabama. Wetland data for the Canadian portion of the project area were compiled from the following provincial sources: the New Brunswick Department of Natural Resources; the Nova Scotia Department of Natural Resources; the Prince Edward Island Department of Agriculture & Forestry; and the Quebec Ministries of Sustainable Development and the Environment, and of Energy and Natural Resources. As with the US wetlands data, datasets for the provinces were combined and gridded to 30 m. From the combined dataset we removed the non-wetland classes (estuarine and marine deepwater, freshwater pond, lake, riverine, unconsolidated shore, other), and then rasterized the polygons to create a single 30-m wetlands grid.

To match the scale of the landform variety and elevation range datasets, we calculated the percent of wetlands within a 100-acre circle for each 30-m cell using a focal mean function in GIS. We based the density calculation on the part of each 100-acre circle that was not open water, so that areas with a high proportion of water would not be penalized. Additionally, to assess the wetland density of the larger landscape, we calculated the percent of wetlands in an area one magnitude larger (1000-acre circle) around each 30-m cell in the region. The two extents had the same mean wetland percentages (9.1) but the 100-acre circle had a slightly higher variance (20.1 vs. 17.2). We log-transformed the values to approximate a normal distribution and calculated a standardized normalized score for each scale. Finally, to calculate the wetland density for each cell, we combined the standardized values from both search distances, weighting the 100-acre wetland density twice as much as the 1000-acre wetland density, and summed the values into an integrated metric (Figure 3.12) using the following formula: *Wetland Density = (2*100-acre wetland density + 1000-acre wetland density) / 3*

Large wetlands translate to high wetland density scores, but a number of smaller wetlands within a given radius, though they may be lower in total density, may offer more habitat options to plants and animals (Figure 3.13). To estimate wetland patchiness, we generated a region-wide grid of the 1.4 million discrete wetlands of any size and then performed a focal variety analysis to calculate the number of wetland

Figure 3.12: Wetland density. This map measures the weighted density of wetlands in a 100- and 1000- acre circle around a central cell and compares it to the regional average.



patches within a 1000-acre window. Values ranged from 0 to 63 wetland patches per 1000 acres, with a mean of 5.6 and a standard deviation of 4.9. We calculated z-scores for this grid using a rank-based method because the values were not normally distributed (Figure 3.14).

The scores for wetland density and wetland patches were combined such that the patchiness score was added only if the mean of the combined score was higher than the wetland density score. This was done to increase the wetland score where there were a lot of wetland patches, but not to penalize the score where there were fewer patches (Figure 3.15). The rules are outlined below.

If wetland patch score < wetland density score, only use the wetland density score:
*Wetland Score = Wetland Density = (2*100-acre wetland density + 1000-acre wetland density) / 3*

If wetland patch score > wetland density, add wetland patch score to the formula:
*Wetland Score = (2*100-acre wetland density + 1000-acre wetland density+ 1000-acre patchiness) / 4*

Figure 3.13: Wetland density, wetland patchiness and wetland scores. This sequence shows an area with a large wetland in the lower right panel (seen in the wetland density map) and an area of many wetland patches in the upper left image (seen in the wetland patchiness map). The integrated wetland score shows how the area receives a boost due to the patchiness but retains the density score. Apalachicola National Forest, Florida.

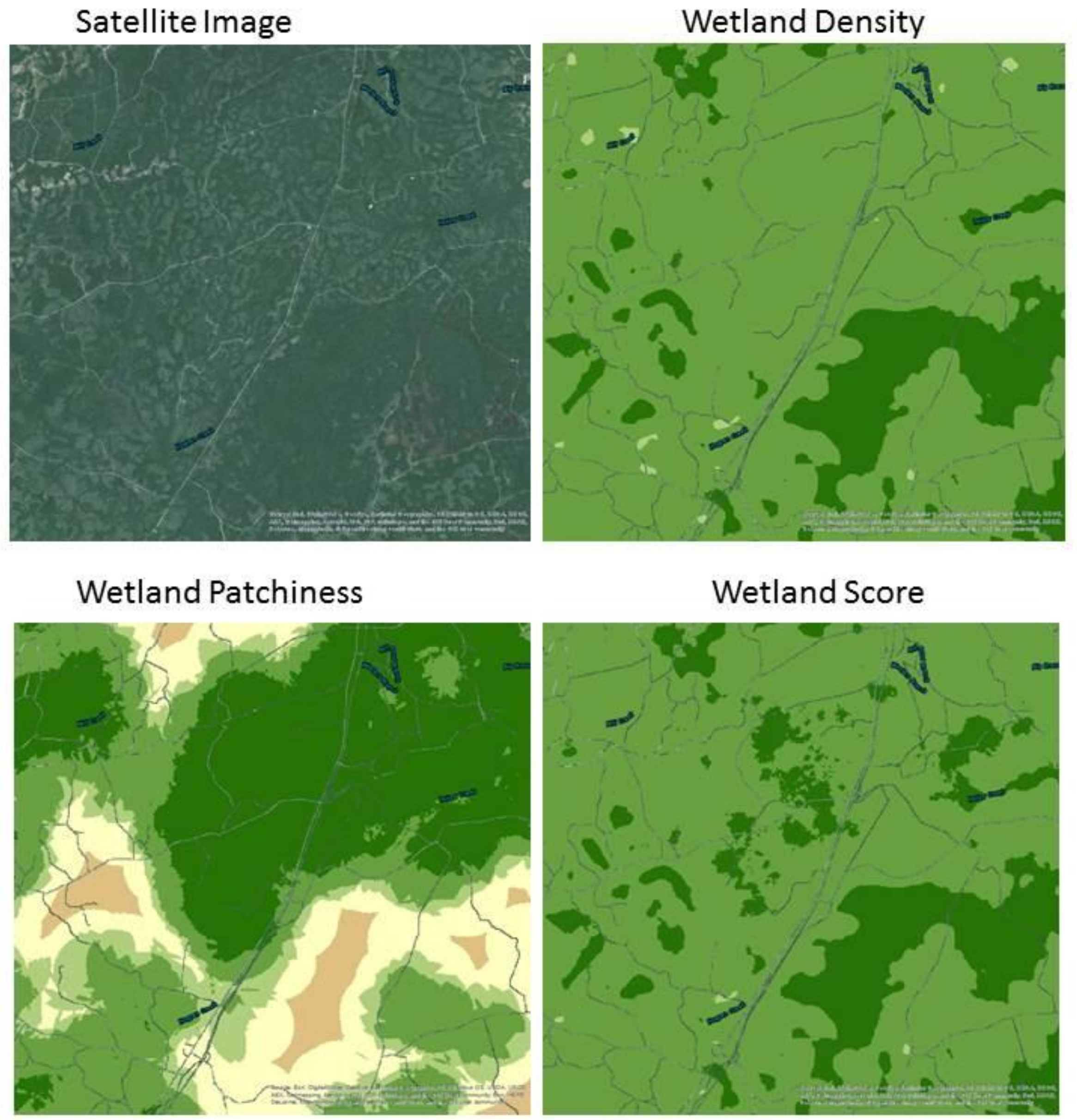
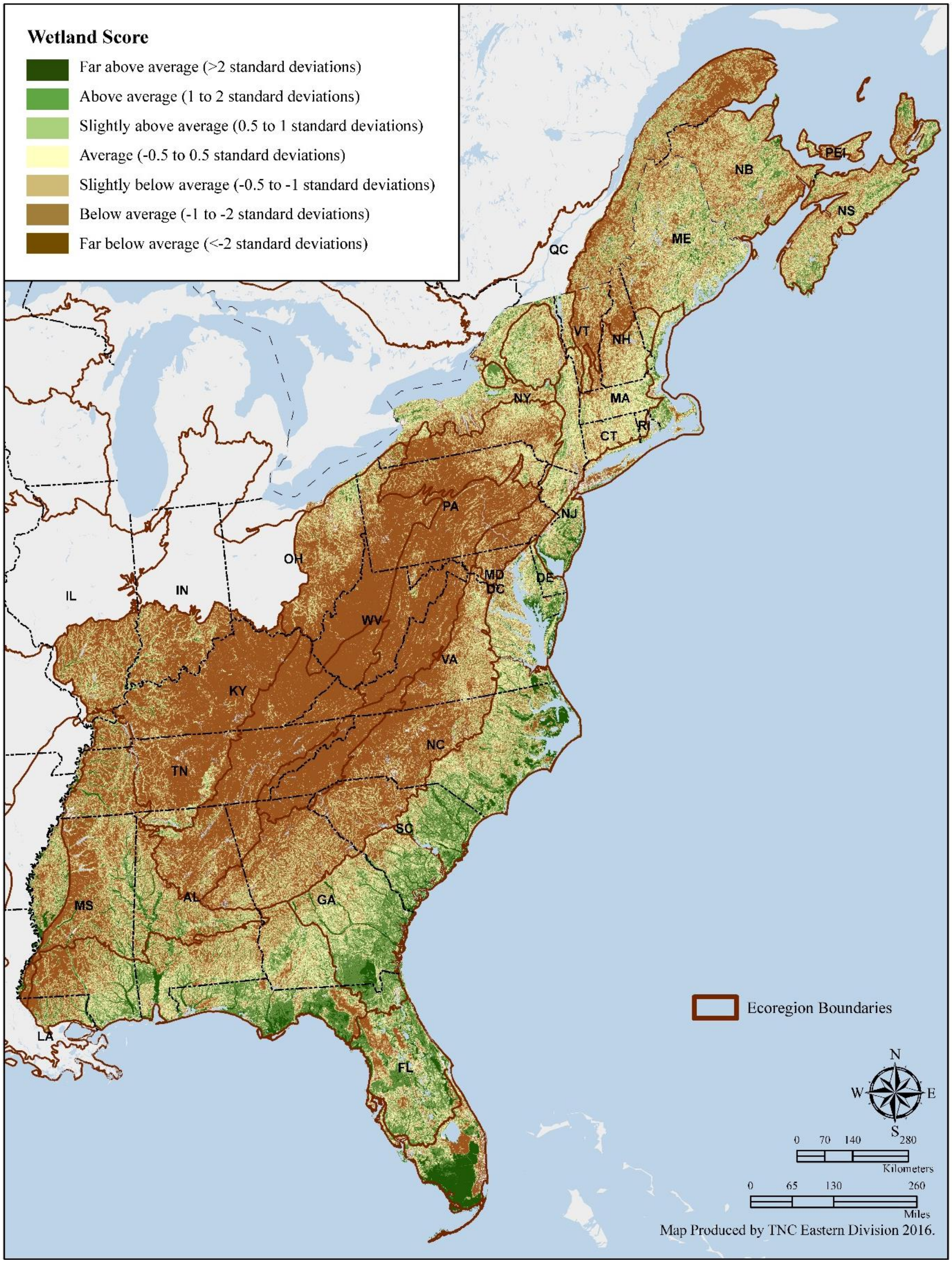


Figure 3.14: Wetland patches. This map measures the patches of wetlands in a 100- and 1000- acre circle around a central cell and compares it to the regional average.

Figure 3.15: Wetland score. This map measures the combines score for wetland density and wetland patches. The patchiness score was only added if its mean was higher than the mean for wetland density.



Soil Diversity

Soils in low-relief landscapes like the Eastern Coastal Plain may contain pockets of high soils diversity that create options for species by offering a range of fine-scale moisture, texture and drainage patterns (Albano 2015). Some of this variation was detected by the landform variety and wetland score metrics but ecologists from the Georgia Department of Resources identified several places where the scale of variation was finer than a 30-m dataset could detect. Through exploration and discussion, we found that these places mostly corresponded to areas with high levels of soil diversity as shown in the 10-m SSURGO soil dataset. To account for this fine scale variation, we added soil diversity to the landscape diversity metric. In more topographically diverse areas the soil patterns were strongly correlated with the landform, elevation and wetland metrics so this metric was only used as a component of the landscape diversity score in flat areas of the conterminous Eastern Coastal Plain.

To identify flat areas with high soil diversity we obtained the newly released (gSSURGO 2014, official release 2015) 10-m gridded SSURGO data for each state in the region. The finest level of classification in this dataset is the "soil series" and soil series is mapped as an individual soil map unit. Each map unit is equal to one named soil type (e.g., Mandarin fine sand, 0-2% slope). Areas with high soil diversity could be identified because they have many soil map units in close proximity (Figures 3.16-3.17). To use the map unit name as an indicator of soil type we first had to clean up the names so they were equivalent across all counties and states. Within each state, we standardized the spelling and removed duplicate soil map unit names from the dataset. We assigned beaches and coastal beaches to a single value, classified all urban soils as a single value, assigned all water classes to one value, and combined eroded/moderately-eroded/severely-eroded into one class. We then reclassified the gridded SSURGO on this simpler set of names and merged together all the state datasets to create soil map unit names that were consistent across the project area. We limited the analysis extent to the Coastal Plain boundary plus a 2-km buffer, and ran a focal variety count of SSURGO map unit names that occurred on flat landforms (landforms flat bottom of steep slope, moist flats, wetflats, dry flats) within 100 acres of each 10-m pixel. We did not include water or urban land in the focal variety analysis.

Our final map shows the relative soil diversity within each county on the Coastal Plain. One of the noticeable problems in the soil map unit data is that it is based on county soil surveys and can be inconsistent across county lines. Initial results for the whole region highlighted inflated soil variety values due to county line issues. To fix this we ran a smoothing algorithm for a zone 380 m on either side of county lines where we took a focal average of the soil variety values within 760 m (2x distance of zone) for each pixel in this zone. This buffer area was chosen as it captured the zone with the greatest deviation in the map unit variety score along the county line. This smoothed out sharp county line discrepancies; however, when we converted the soil variety scores to a Z-score based on the regional mean, the county to county differences were very apparent. Whole counties tended to score high or low relative to other counties and this was likely due to the particular vintage, methods, or creator of a given county soil survey. We decided that for consistency and accuracy, we had to calculate the Z-scores by county, so the final soil diversity values show places within each county that have particularly high soil diversity (Figure 3.18).

Figure 3.16: Landform diversity vs. soil diversity. The map compares the 30-m landform dataset on the left to the 10-m soil map unit diversity on the right for a floodplain region in Telfair County, GA. The area has four formations of loamy sand with different slopes and ponding attributes, plus two flooded associations and Blanton sand. This is one of the higher diversity soil areas.

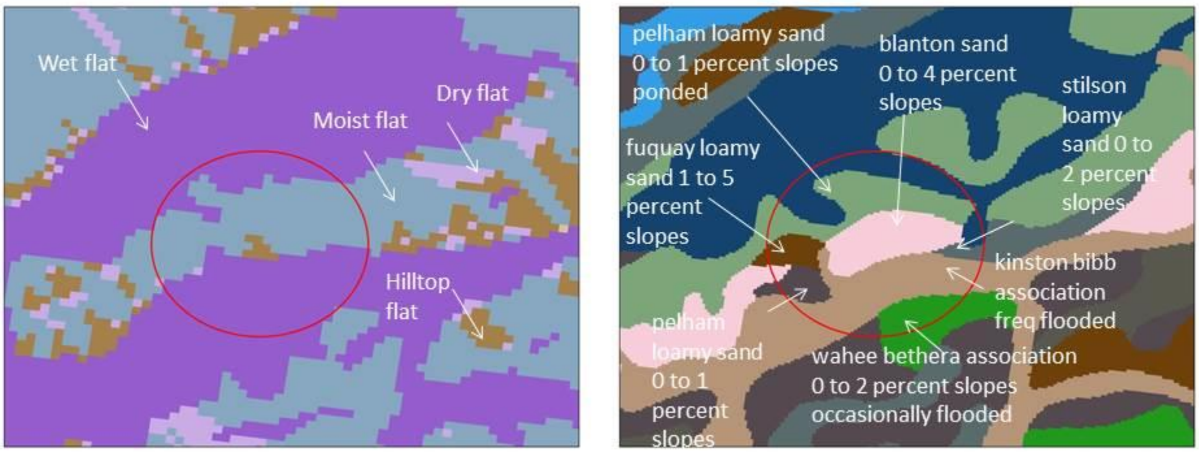


Figure 3.17: Landforms and normalized soil diversity. The map compares the 30-m landform dataset on the left to the normalized soil diversity metric (Z-score) which counts the number of soil types on flats within a 100-acre focal area and compares it to the rest of the county. These results are for Telfair County, GA. Zoom in area of Figure 3.16 shown as a red circle.

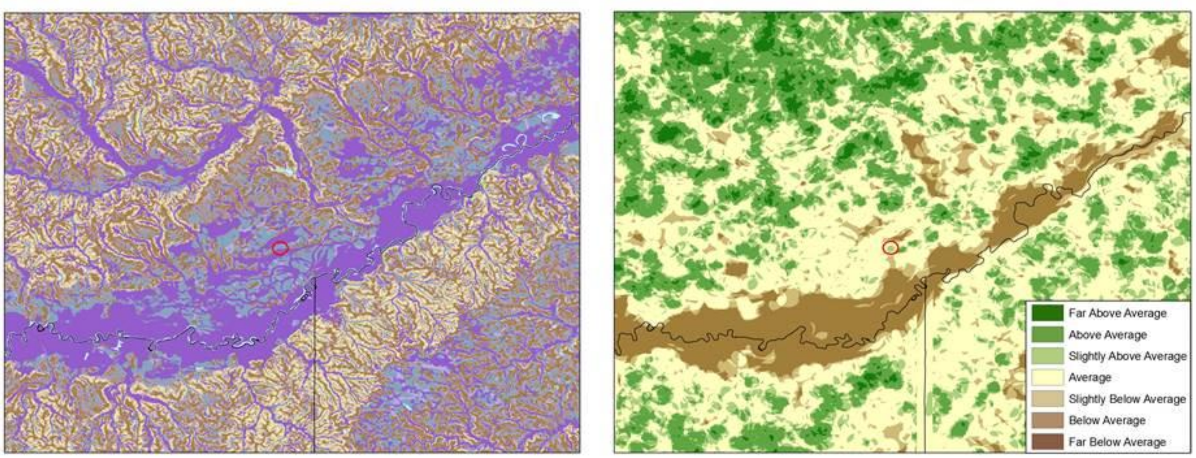


Figure 3.18. Soil diversity. This map shows the relative number of soil types within each county on the coastal plain, based on an analysis of sSURGO soil types within a 100-acre search radius around each 30- m cell.

Landscape Diversity Combined Index

To create a standardized metric of landscape diversity we transformed all three indices (landform variety (LV), elevation range (ER), wetland score (WS), and soil diversity (SD) to standardized normal distributions ("Z-scores" with a mean of 0 and standard deviation of 1) and then combined them into a single index. Before converting each index, we examined the distribution and if necessary transformed the data to approximate a normal distribution. This was usually accomplished via logarithmic transformation but in the case of wetland score we used rank-based z-scores because the distributions were so skewed. Combining the various values was done in a systematic and specific order with landform variety always getting twice the weight of the other variables. Each variable was added only where the combined average Z-score was greater with the variable than without it, ensuring that elevation, wetland density and soil diversity could only enhance the score (Figures 3.19-3.21)

The final map of landscape diversity shows the areas estimated to have the most microclimates based on landform variety, uncorrelated elevation range, wetland density and patchiness, and soil diversity (Figure 3.21). To help users understand which factor into the final score, we created a factor map that shows the contribution to each grid cell (Figure 3.22).

Figure 3.19. Schematic for combining variables into a single landscape diversity metric.

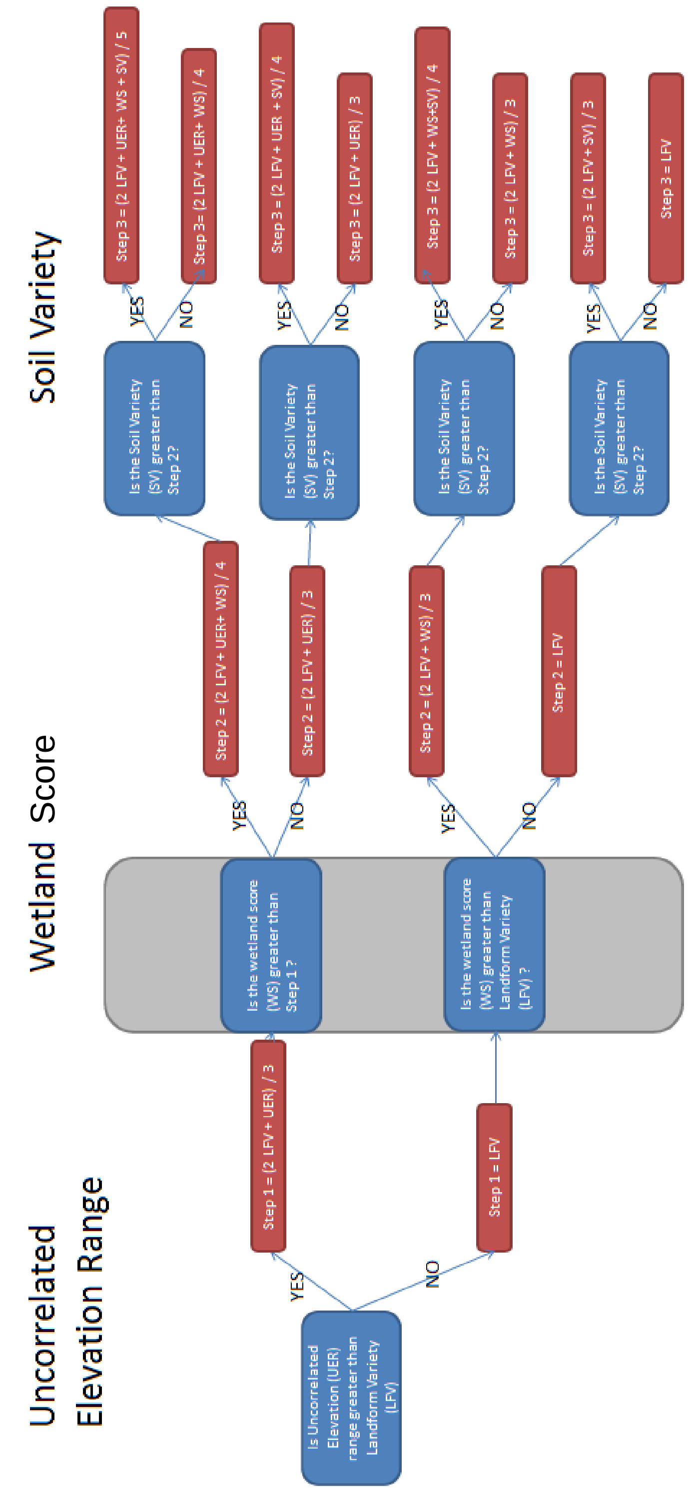


Figure 3.20: A three-dimensional look at the metrics of landscape diversity in southern North Carolina. All metrics are measured in 100-acre circles around every point (30-m cell) on the landscape. **A.** The original landform model. **B**. The Landform Variety metric shows the number of landforms with dark green as high and dark purple as low. **C.** The Elevation Range metric shows the range of elevation with darker greens indicating a wider range. **D.** Wetland Score is shown with purple as high and brown as low.

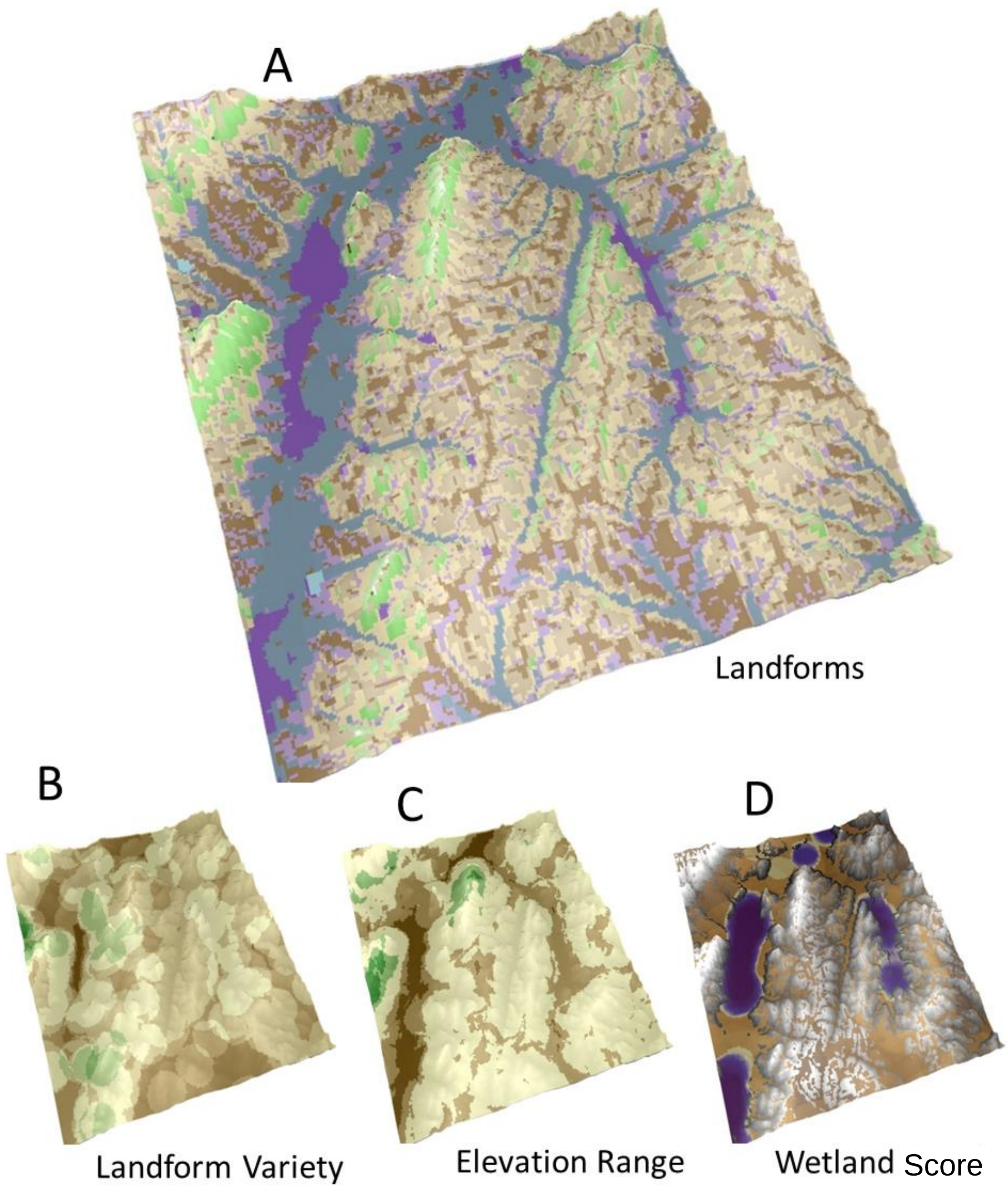
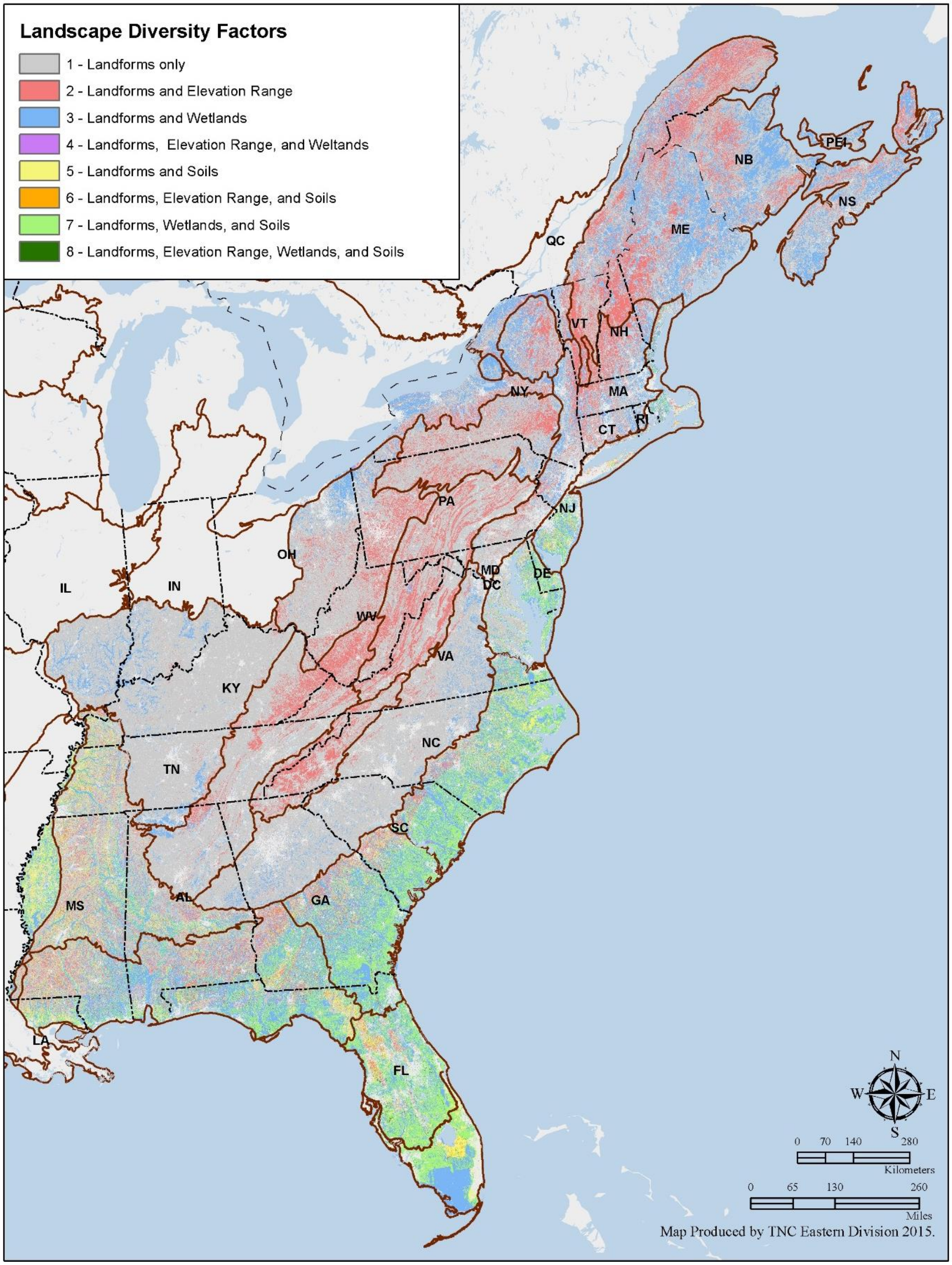


Figure 3.21: Landscape diversity. Landscape diversity of all cells based on the combined values of Landform Variety, Elevation Range, Wetland Score, and Soil Diversity and compares it to the regional average. At this scale the map obscures many of the subtle local changes amplified later in the ecoregion section.

Figure 3.22: Landscape diversity factors. All cells started with the score for Landform Variety. Each other variable was added only where the combined average Z-score was greater with the variable than without it, ensuring that elevation, wetland density and soil diversity could only enhance the score.



Section 2: Landscape Permeability

The natural world constantly rearranges, but climate change is expected to accelerate natural dynamics, shifting seasonal temperature and precipitation patterns and altering disturbance cycles of fire, wind, drought, and flood. Rapid periods of climate change in the Quaternary, when the landscape was comprised of continuous natural cover, saw shifts in species distributions but little extinction (Botkin et al. 2007). Now, pervasive landscape fragmentation disrupts ecological processes and impedes the ability of many species to move or adapt to changes. The concern is that broad-scale ecological degradation will result from the impaired ability of nature to adjust to rapid change, creating a world dominated by depleted environments and weedy generalist species. Fragmentation, in combination with habitat loss, poses one of the greatest challenges to conserving biodiversity in a changing climate. Not surprisingly, the need to maintain **connectivity** has emerged as a point of agreement among scientists (Heller and Zavaleta 2009, Krosby et al. 2010). In theory, maintaining a permeable landscape, when done in conjunction with protecting and restoring sufficient areas of high quality habitat, should facilitate the expected range shifts and community reorganization of species responding to a changing climate.

We use the terms '**permeability**' and **'connectedness'** instead of 'connectivity' because the conservation literature commonly defines 'connectivity' as the capacity of individual species to move between areas of habitat via corridors and linkage zones (Lindenmayer and Fischer 2006). Accordingly, the analysis of landscape connectivity typically entails identifying linkages between specific places, usually patches of good habitat or natural landscape blocks, with respect to a particular species (Beier et al. 2011). In contrast, facilitating the large-scale ecological reorganization expected from climate change - many types of organisms, over many years, in all directions – requires a more comprehensive and continuous analysis, one appropriate to thinking about the transformation of whole landscapes.

Landscape permeability, as used here, is not based on individual species movements, but is a measure of landscape structure: the hardness of barriers, the connectedness of natural cover, and the arrangement of land uses. It is defined as *the degree to which regional landscapes, encompassing a variety of natural, semi-natural and developed land cover types, will sustain ecological processes and are conducive to the movement of many types of organisms* (definition modified from Meiklejohn et al. 2010). To measure landscape permeability, we developed methods that map permeability as a continuous surface, not as a set of discrete cores and linkages typical of connectivity models. In line with our definition, we aimed for an analysis that quantified the physical arrangement of natural and modified habitats, the potential connections between areas of natural habitat within the landscape, and the quality of the converted lands separating these fragments. Our aim was to create a surface that revealed the implications of the landscape structure with respect to the continuous flow of natural processes, including the dispersal and recruitment of plants and animals, and the rearrangement of existing communities. We use the term "ecological flow" to refer to both species movements and ecological processes.

Because permeability is a multidimensional characteristic, we developed two separate analytical models to assess different aspects of its local and regional nature. The first, **local connectedness,** starts with a focal cell and looks at the resistance to flows outward in all directions through the cell's local neighborhood. The second, **regional flow,** examines broad east-west and north-south flow patterns across the entire region and measures how flow patterns become slowed, redirected, or channeled due to the spatial arrangements of cities, towns, farms, roads, and natural land. Only the local connectedness metric was used in estimating the resilience of a site and the descriptions below refer to this metric. The regional flow analysis is described in detail in the accompanying report on identifying resilient networks "Resilient and Connected Landscapes for Conservation Across Eastern North America" (Anderson et al. 2016b).

Local Connectedness

The **local connectedness** metric measures how impaired the structural connections are between natural ecosystems within a local landscape. Roads, development, noise, exposed areas, dams, and other structures all directly alter processes and create resistance to species movement by increasing the risk of harm, or the perceived risk of harm. This metric is an important component of resilience because it indicates whether a process is likely to be disrupted or how much access a species has to the micro-climates within its given neighborhood.

Our basic assumption is that the permeability of two adjacent cells increases with the similarity of those cells and decreases with their contrast. If adjacent landscape elements are identical (e.g., forest to forest), then there is no disruption in permeability. Contrasting elements (e.g., forest to developed land) are presumed less permeable because of differences in structure, surface texture, chemistry or temperature. Organisms and processes can move across different landscape elements, but the sharper the contrast, the more likely the movement will be altered, slowed, restricted or channeled. The degree to which a cell alters the flow arriving from an adjacent cell is referred to as its **resistance**, and in the local connectedness model a cell is assigned a **resistance weight** between 1-20 based on its land cover or land use. The analysis intentionally focused on the connections across natural land and species that thrive on natural lands.

Our analysis began with three basic landscape elements that were then subdivided into finer land cover types using the weighting schemes described below:

Natural lands (resistance weights 1-5): landscape elements where natural processes are unconstrained and unmodified by human intervention such as forest, wetlands, or natural grasslands. Human influences are common, but are mostly indirect, ephemeral, and not the dominant process.

Agricultural or modified lands (resistance weights 5-7): landscape elements where natural processes are modified by direct, sustained, and intentional human intervention. This usually involves constant modifications to both the structure (e.g., clearing and mowing) and ecological processes (e.g., flood and fire suppression, predator regulation, nutrient enrichment).

Developed lands (resistance weights 8-20): landscape elements dominated by the direct conversion of physical habitat to buildings, roads, parking lots, or other infrastructure associated with human habitation and commerce. Natural processes are highly disrupted, channeled or suppressed. Vegetation is highly tended, manicured and controlled.

A variety of methods have been developed for assigning resistance weights to land cover elements. Some have included the identity of the vegetation types (e.g., oak forest to oak forest assumed to be more connected than oak forest to spruce forest) (B. Compton personal communication 2009, Compton et al. 2007). However, our weighting scheme was intentionally more generalized, such that any natural cover adjacent to other natural cover was scored with a low resistance value. We did not differentiate between forest types, wetlands, and upland habitats (Figure 3.23). Our assumption was that the requirements for species movement and the flow of processes through natural landscapes were less specific than the requirements for breeding. In addition, our goal was not to represent a single species but many species by maintaining the natural relationships and connections between all types of natural land (Hunter and Sulzer 2002, Ferrari and Ferrarini 2008, Forman and Godron 1986).

Creating and Conditioning the Resistance Grid

To create the resistance grid, we combined many datasets representing land cover, land use, roads, and railroads. For the US, the source data was the 30-m 2011 NLCD which identifies each grid cell as belonging to one of 16 classes of land cover (Homer et al. 2015). For Canada, we used five provincial land use, forestry, and wetlands datasets (Ministère des Ressources naturelles 2014, New Brunswick Forest Inventory Database 2012, New Brunswick Wetlands Inventory 2006, Prince Edward Island Corporate Land Use Inventory 2010, Nova Scotia Forest Inventory and Wetlands Inventory 2014). Accurate waterbodies were obtained from Canada's National Hydrology Network (Geobase 2004), and were merged on top of the land use data. For the small areas outside of the main study area in Canada, we used the Agriculture and Agri-food

Canada Annual Crop inventory (AAFC 2014, Fisette et al. 2014). This dataset is primarily used for crop identification, but also includes information on water, barrens, shrublands, wetlands, and forests. The 30-m 2013 AAFC was created using satellite interpretation methods similar to how the NLCD was developed.

Each of the Canadian datasets had a different schema and detailed land use categories. We created a look-up table to convert the detailed classifications to our more generalized classification:

- Natural, Water
- Agriculture, Hay/Pasture, Plantation Forest
- Low Density Development, Medium Density Development, High Density Development, Powerline/Pipeline, Railroads, Roads.

Although the 2011 NLCD and the Canadian Provincial datasets are the most current datasets available, we made several adjustments to them that substantially improved their performance as resistance grids. These included: 1) updating the roads and railroads, 2) adding dirt roads, 3) adding transmission line data, 4) reclassifying barrens as natural or developed, 5) adding plantation forests, 6) differentiating between hay/pasture and cropland and 7) reclassifying water polygons.

<u>Roads:</u> All of the NLCD products (2011, 2006, and 2001) have older and inaccurate roads data burned into them from the Bureau of Transportation Statistics. These roads do not align with the more commonly used and more accurate Tiger Road dataset (US Census 2014). To address this issue, we removed the older roads from the 2011 NLCD and replaced them with roads from the newer Tiger 2014 dataset, greatly improving the spatial accuracy of the roads component. First, cells in the 2011 NLCD's "developed open space" class (which contains the roads) were shrunk by one pixel, effectively removing linear road pixels but not the larger actual developed open space areas. Values for these cells were replaced with the majority value of the surrounding pixels. Next, the 2014 Tiger roads were "burned in" on top of the 2011 NLCD to replace the old roads with the more accurate data.

The compiled Canadian land use data did not contain information on roads except for some of the major highways, so we "burned in" road data from the National Road Network (National Road Network 2015). The latter was the most comprehensive information available, but it was uneven in it representation of minor roads across the provinces, being most complete in Nova Scotia and least complete in Quebec. We supplemented the National Road Network data with a detailed provincial roads dataset available for New Brunswick.

<u>Dirt roads:</u> Dirt roads or unpaved forest management roads are unevenly mapped in both the US and Canadian land use datasets, even though they may create substantial

road networks in some parts of the region. To map unpaved roads we used data from OpenStreetMap (2014) which is an open-source global dataset built by a community of mappers that contribute and maintain data about roads and trails. We extracted roads tagged as "track" which includes roads used primarily for agriculture, forest tracks, etc. This class of roads is usually unpaved but may include paved roads suitable for two-track vehicles such as tractors or jeeps. Trails and paths that are not wide enough for a two-track vehicle are excluded from this class. Although the quality and consistency of this dataset is not known, visual inspection suggested that it was more comprehensive than any other available dataset for mapping unpaved roads. In the resistance grid, cells were assigned an additional resistance point if they contained one or more unpaved roads. For example, the resistance of hay/pasture cells with track roads increased from a "3" to a "4."

Transmission Lines: We added in the location of transmission lines to the land use datasets. For this step we obtained access to power industry GIS data (Ventyx 2014), which was used with permission through a TNC agreement. We selected all transmission lines in service by voltage class, and all in-service natural gas pipelines. These were incorporated into the land cover dataset using power industry standard right of way widths: transmission lines less than 230 volts = 30-m width, greater than 230 volts = 180-m width, and all pipelines = 30-m width (Duke Energy 2014). We compared the dataset to aerial photos to confirm that these widths were reasonable and to ensure that we added only features that made a distinguishable footprint on the ground.

Barrens: In the US land cover dataset (Homer et al. 2015), the category "barrens" often included misclassified developed lands such as oil and gas wellheads or airport runways. To distinguish natural barrens (e.g., beaches and summits) from highly developed barrens (e.g., airport runways), we used a spatial analysis of the land cover types in a 100-m buffer surrounding each barren cell to distinguish barrens associated with industry or commercial development from barrens associated with bare rock, exposed beach, lake shorelines, and other natural settings. All barren areas greater than 300 acres were visually inspected to make sure that they were in the correct class. Also, all barrens on military lands (determined from an overlay of a secured lands database) were assumed to be non-natural barrens such as bombing ranges and runways. For Florida, we used the "Extractive" class in the Florida Cooperative Land Cover dataset (FNAI 2015) to identify barren land used for mines, quarries, gas fields, and other industrial activities.

Plantation Forest: In the US, industrial plantation forests dominate much of the Southeast Coastal Plain but they are lumped together with natural forest in the NLCD 2011 land cover dataset. To separate plantation form natural forest. we used information on the locations of plantations from four data sources. The first was the Southeast GAP land use dataset (Southeast GAP Land Cover Dataset 2010) which classified plantation forests from aerial imagery and spatially mapped three classes: deciduous plantation, evergreen plantation, and clear cut. The second data source was a proprietary dataset of land ownership with parcel shapes and ownership information for most of the Southeast (ParcelPoint 2013). We conducted queries on the parcel data to identify and map major industrial forest/timber ownership that occurred on land cover classes compatible with commercial forest operations. The third data source was an Industrial Forest Classification developed by the Open Space Institute (Open Space Institute 2009) using information from landowners and third party sources. The fourth dataset was a Global Forest Change dataset (Hansen et al 2013). From this dataset we compiled both the global forest loss (2000 – 2014) and the global forest gain (2000 – 2012), and we used the dataset only where ParcelPoint (2013) ownership data was not available or where the majority of industrial timber lands were in small holdings and therefore difficult to identify by owner. The latter included all of the Chesapeake Bay ecoregion and the Illinois portion of the Interior Low Plateau ecoregion. We merged the four compiled datasets of plantation / industrial forest with the 2011 NLCD. Where industrial forest cells overlapped with the NLCD cells classified as “forest” or “shrub-scrub” (NLCD classes 40,41,42, and 52) we overrode the cell as “plantation/industrial forest” except in the Western Allegheny Plateau and the Interior Low Plateau where state experts recommended we only use the industrial forest data on conifer forest (NLCD 42), shrub/scrub (NLCD 52), and grassland/ herbaceous (NLCD 71), because pine plantations dominate these ecoregions and there are no known hardwood plantations.

We assigned industrial forests a resistance score of “3” as this land use is subject to frequent cutting, road development and other anthropogenic disturbances, and typically has less groundcover (Figure 3.24). An exception was when the industrial forests were on land that was permanently secured against conversion (GAP Status 1 – 3). Because these lands, by definition, are being managed for natural values we assigned them a lower resistance score of “1.5.”

Industrial forests are well mapped and classified in the Canadian Terrestrial Habitat Map (Ferree and Anderson 2015), which was developed using the provincial forestry datasets. We assigned the classes “plantation forest” and “early seral forest” to the industrial forest class. Because Canadian plantations are cut more lightly and selectively than the Southeast plantations we scored them with a lower resistance value of “1.5.”

Pasture: The differences between pasture/hay and cultivated agriculture were discussed extensively in our advisory committee meetings and it was agreed that cultivated cropland creates more resistance than pasture due to the heavy management and common use of pesticides in the latter. Thus we assigned cropland a resistance value of “7.” The resistance score of pasture varied depending on how much it contrasted with the dominant land cover in each subregion. A resistance value of “3” was assigned to pastureland in the Coastal Plain and Piedmont subregions which are largely comprised of open forest and agricultural land, and a resistance value of "5" was used in the Mountain subregion where the landscape is generally covered by closed canopy forest (Figure 1.1).

Waterbodies: We adjusted the resistance score of waterbodies to reflect their size because very large waterbodies can impede the movement of terrestrial species more so than small streams or ponds. To quantify the effect of waterbody size, we selected all water pixels in the NLCD, converted the pixels to polygons, and buffered them inward 200 and 400 m. We assigned water within 200 m of a shoreline a resistance value of "1" (natural), water between 200 and 400 m of a shoreline received a resistance value of "3", and water greater than 400 m from a shoreline was given a value of "5" because of the barrier it presents to movement (Figure 3.25).

Table 3.23: Land cover classes and the assigned resistance weights.

Land Cover Code in 2011 NLCD*	Land Cover Description	Resistance Score	Source
21	Developed, Open Space	8	NLCD 2011
22	Developed, Low intensity	8	NLCD 2011
23	Developed, Medium Intensity	9	NLCD 2011
24	Developed, High Intensity	20	NLCD 2011
31	Barren Land, non-natural	9	NLCD 2011
32	Barren Land, natural	1	NLCD 2011
41	Deciduous Forest	1	NLCD 2011
42	Evergreen Forest	1	NLCD 2011
43	Mixed Forest	1	NLCD 2011
52	Shrub/Scrub	1	NLCD 2011
71	Herbaceous	1	NLCD 2011
81	Hay/Pasture (Coastal Plain & Piedmont)	3	NLCD 2011
81	Hay/Pasture (Mountains)	5	NLCD 2011
82	Cultivated Crops	7	NLCD 2011
90	Woody Wetlands	1	NLCD 2011
95	Emergent Herbaceous Wetlands	1	NLCD 2011
11	Open Water, Shoreline Distance <200 m	1	NLCD 2011
11	Open Water, Shoreline Distance 200-400m	3	NLCD 2011
11	Open Water, Shoreline Distance >400 meters	5	NLCD 2011
	Major Roads	20	Tiger 2014 (US)& Open Street Map 2014 (CA)
	Minor Roads	10	Tiger 2014 (US)& Open Street Map 2014 (CA)
	Dirt Roads	Resistance +1	Open Street Map 2014
	Transmission Lines	9	Ventex 2014
	Pipelines	9	Ventex 2014
	Railroads	9	CTS 2015
	Unprotected/Private Industrial Forest (US)	3	SEGAP, Parcelpoint, OSI
	Protected Industrial Forest (US)	1.5	SEGAP, Parcelpoint, OSI
	Industrial Forest Canada	1.5	NE Habitat Map (TNC)

***Absence of a code indicates data obtained from a source other than the 2011 NLCD.**

Figure 3.24: Plantation forest. The left panel shows a satellite image of plantation forests ,and the right panel shows the same area with mapped plantations in orange.

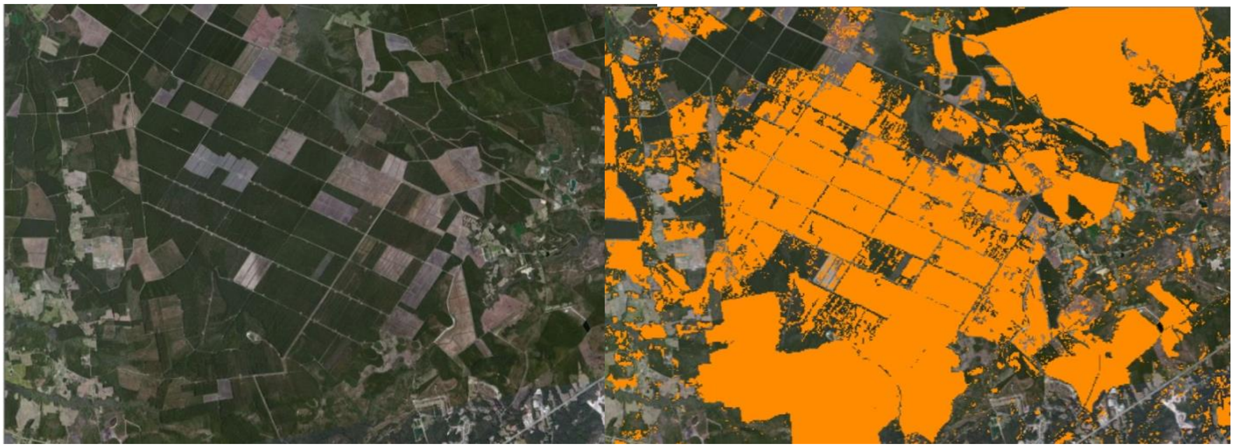
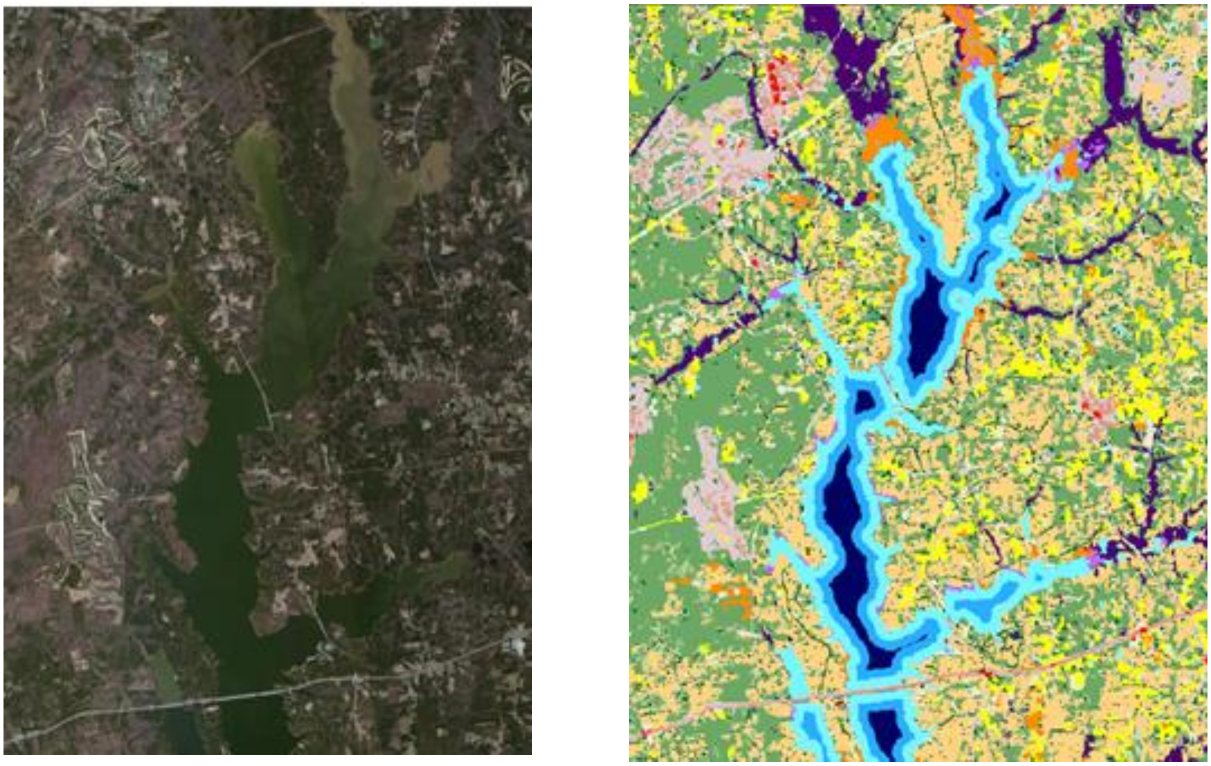


Figure 3:25: Waterbodies and the zones used in the resistance weighting. Waterbodies are shown in blue with darker blues indicating higher resistance values at 0-200, 200-400, and 400+ m.



Mapping Local Connectedness

The method used to map local connectedness was resistant kernel analysis, developed and run by Brad Compton using software developed by the UMASS CAPS program (Compton et al. 2007). Connectedness refers to the connectivity of a focal cell to its ecological neighborhood when it is viewed as a source. In other words, connectedness answers the question: "To what extent are ecological flows outward from that cell impeded or facilitated by the surrounding landscape?" Specifically, each cell of a resistance grid is coded with a resistance weight based on land cover or road class (see Figure 3.23), and the theoretical spread of a species or process outward from a focal cell is a function of the resistance values of the neighboring cells and their distance from a focal cell out to a maximum distance of three kilometers (the recommended distance determined by the software developer).

To run the local connectedness analysis on the resistance surface we increased the grid cell size from 30 m to 90 m. This allowed us to run the analysis with a reasonable processing time (weeks) because the CAPS software program is computationally intensive. We aggregated the 30 m cells to the 90 m cells using the average of the 30 m resistance weights (Table 3.4). The final result was a grid of 90-m cells for the entire region where each cell was scored with a local connectivity value from 0 (least connected) to 100 (most connected). The actual scores had a mean of 41.63 and a standard deviation of 25.21 for the region (Figures 3.27-3.31).

Figure 3.27: Examples of four resistant kernel cells shown with the land cover and roads map. The focal cell is the central point of each kernel and the spread, or size, of the kernel reflects the amount of constraints. The score for the focal cell is based on the area round the cell (i.e., the constraints) and is shown here in a bluish-purple color. Kernel A is the most constrained and has the lowest connectedness score, while D is the least constrained and has the highest connectedness score.

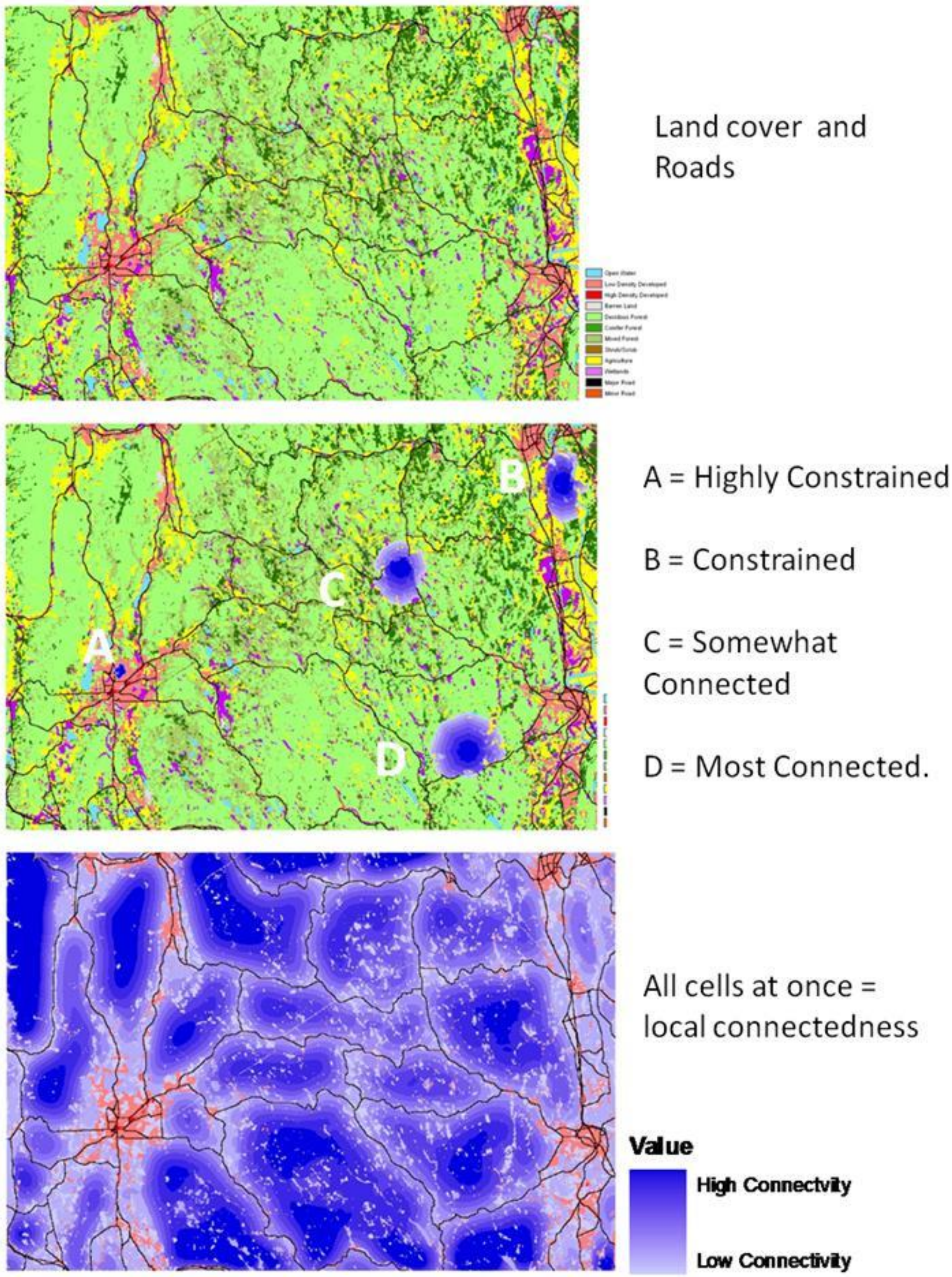


Figure 3.28 Detailed look at Kernel B in Figure 3.13. The top left image shows the topographic map for a location near Deerfield, MA. The top right image shows the land use grid details. The bottom left panel shows the aerial image with the 3-km circular resistant kernel distance outlined in orange. The bottom right box shows the kernel spread. Kernel B is constrained on the west by roads and railroads and on the east by water. The kernel can flow well through the natural landscape in the north and south direction.

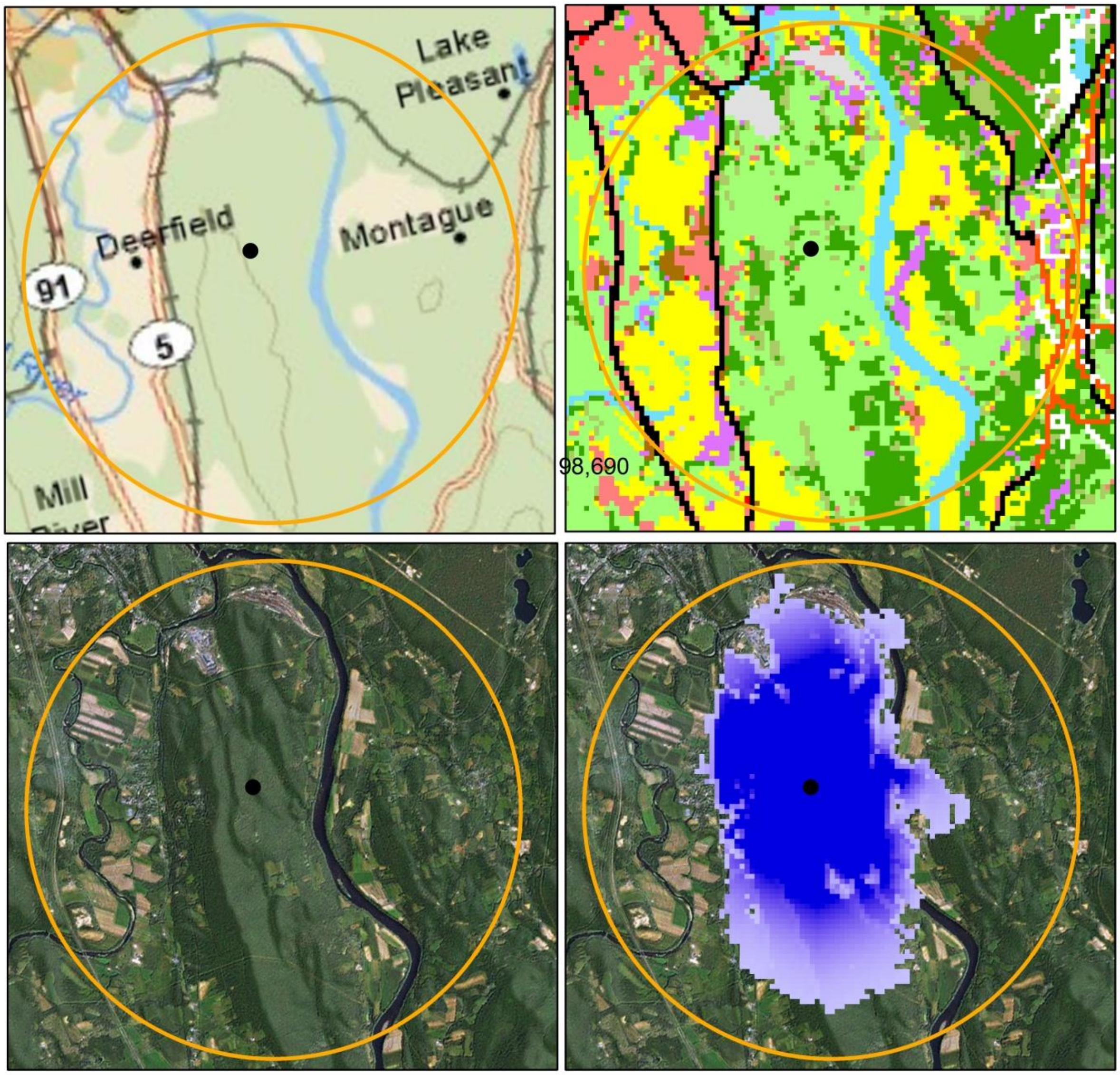


Figure 3.29: Visual comparison of local connectedness grid (top) with aerial photo of site (bottom). These images show a fragmented landscape on Prince Edward Island. The top image is a close up of the local connectedness surface with the site outlined in blue. The bottom image shows a photo of the area with the approximate site circled in blue (mean local connectedness score = 6.0, Z-score = -0.83).

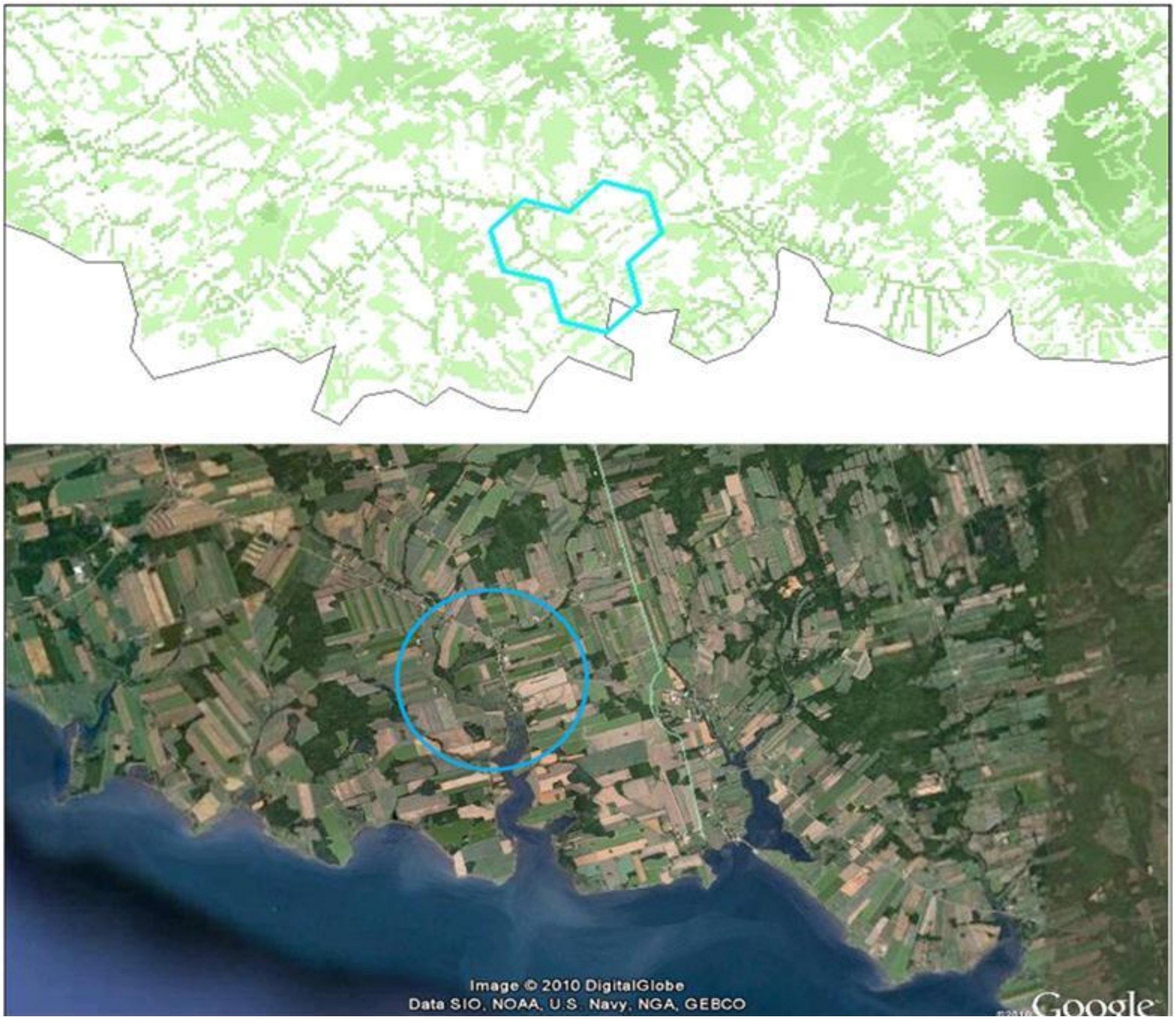


Figure 3.30: A gallery of satellite images and their corresponding local connectedness (lc) scores. The mean scores are based on a roughly circular site positioned at the center of each image (not shown). Z is units of standard deviation from the regional mean.

Local Connectedness = 20
Z-score = -0.83

Local Connectedness = 50
Z-score = 0.55

Local Connectedness = 80
Z-score = 1.974

Local Connectedness = 100
Z-score = 2.9933

Map 3.31: Local connectedness. This map estimates the degree of connectedness of a cell with its surroundings within a three-km radius, and compares it to the regional average.

Section 3: Combined Resilience Factors

We combined the landscape diversity and the local connectivity scores into an integrated resilience score. The integrated score is useful for mapping the areas where those factors combine to create high resilience, but we also encourage users to look closely at the individual factors as they reveal interesting and different information about the landscape.

To ensure that the two factors had equal weight in the integrated score we transformed each metric to standardized normalized scores (z-scores) so that each had a mean of zero and a standard deviation of one (this prevents the factor with a larger mean or variance from having more influence). The formula for calculating the z-scores was:

$$z = \frac{x - \mu}{\sigma}$$

The cell score “x” minus the mean score of all cells “µ” divided by the standard deviation of all cells “σ”

The estimate of resilience for each 30 meter cells was equal to:

Estimated Resilience = (Landscape diversity (z-score) + Local connectedness (z-score) /2

Map 3.32: Unstratified resilience score. This map shows the raw cell scores for estimated resilience (landscape diversity + local connectedness) before we stratified the score by geophysical setting and ecological region.

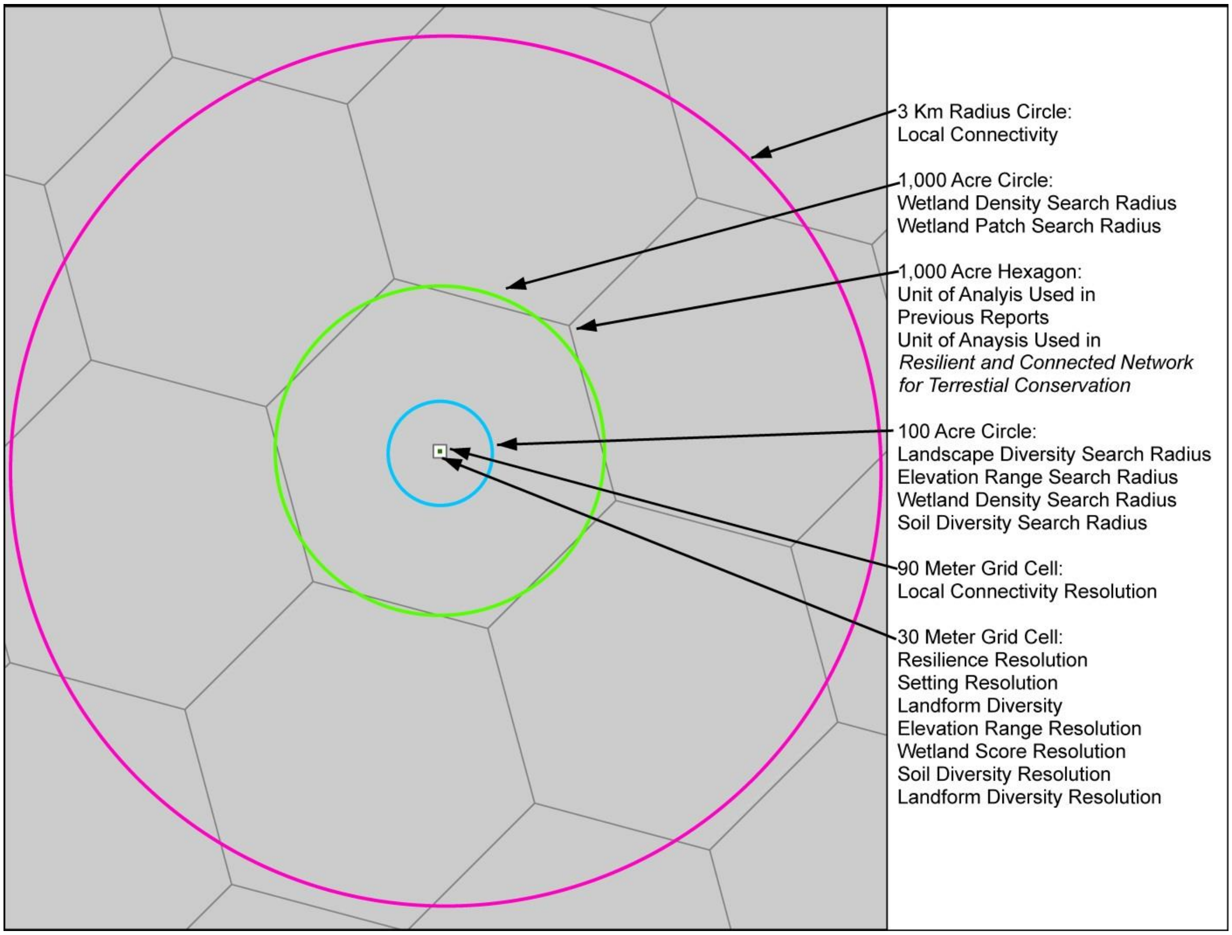
Results: Estimated Site Resilience

CHAPTER 4

In this chapter, we present the results derived by integrating the estimated resilience scores with the geophysical settings within the context of ecoregions (Figure 2.1). The final scores are thus relative to a particular geophysical setting within a particular ecoregion (e.g. low elevation calcareous within the Central Appalachians) and show the places with the highest number of estimated microclimates and highest local connectedness relative to the setting and ecoregion. This stratification was essential, in order to ensure that we identified areas for all types of geophysical settings and thus captured the full spectrum of biodiversity. Additionally, the stratification was necessary because the settings had inherently different amounts degrees of landscape diversity and fragmentation. For example, coarse sand in the Coastal Plain is inherently flatter and more fragmented than resistant granite in the Appalachian Mountains. In this analysis each setting is compared only to itself and not across settings.

We applied the estimates and attributes of resilience to each 30m cell the study area to identify the most resilient areas of each geophysical setting within each ecoregion. Despite the search radius, all information for landscape diversity was summarized at the 30 meter cell. The local connectivity was at 90 meter cell size. When combined we maintained the 30 meter cell size (Figure 4.1). Our goal was to combine the data such that each layer contributed equally to the final scores, unless intentionally weighted.

Figure 4.1: The variety of local neighborhood sizes used in this assessment. The information was all tagged to the 30-meter cell (the smallest center point). Landform diversity, elevation range, and wetland density all used a 100-acre search radius around each 30-meter cell, with the latter also weighted by a 1000 acre search radius. Local connectivity was scored to the 90-meter cell, but evaluated over a search radius covering 3 kilometers (pink circle).



Resilience and Vulnerability

Resilience to climate change and its converse, vulnerability to climate change, are relative concepts for which we currently do not have absolute thresholds. Admittedly, we have a limited understanding of how climate-induced changes will interact, how those interactions will play out on the landscape, and exactly how systems will recover and transform. In this document, a resilient site was defined as one that has characteristics (microclimatic buffering and connectedness) that maintain ecological functions and will likely sustain a diversity of species. We expect that these sites will support an array of specialist and generalist species, even as the composition and ecological processes change. In contrast, a vulnerable site was defined as one where processes are disrupted and fragmented, and where the site is likely to lose diversity. We expect that these sites will increasingly favor opportunistic "weedy" species adapted to high levels of disturbances and anthropogenic degradation. Climate change is expected to greatly exacerbate the degradation of vulnerable sites; however, these sites may still perform many natural services, such as buffering storm effects or filtering water. Thus, vulnerable sites are not without value, but they are places where it will be increasingly difficult to sustain the natural functions and species diversity of whole ecological systems over time (Figure 4.2).

The maps in this chapter illustrate the estimated resilience of sites on a scale that is relative to the setting and ecoregion. To create these maps, we first calculated the average resilience score for the geophysical setting within the ecoregion, and then we then compared the scores of each individual site to the average score. This method identified the sites that scored above or below average in estimated resilience using the -0.5 SD to 0.05 SD of the range of sites as the definition of average. Our standard legend was as follows:

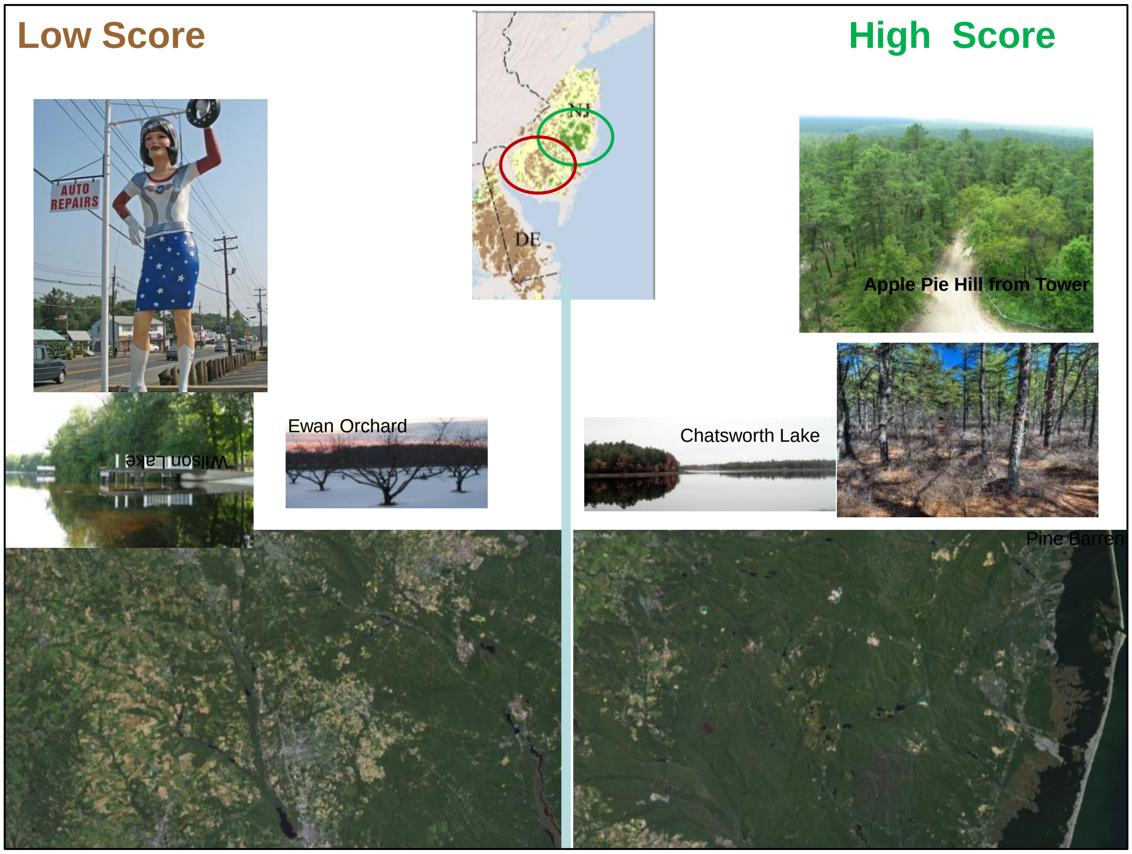
Far below average (<-2 standard deviations)	**Most Vulnerable**
Below average (-1 to -2 standard deviations)	**More Vulnerable**
Slightly below average (-0.5 to -1 standard deviations)	**Somewhat Vulnerable**
Average (-0.5 to 0.5 standard deviations)	**Average**
Slightly above average (0.5 to 1 standard deviations)	**Somewhat Resilient**
Above average (1- 2 standard deviations)	**More Resilient**
Far above average (>2 standard deviations)	**Most Resilient**

Use of this scheme assumed that the scores followed a normal distribution with a mean and standard deviation that accurately summarized the data. To ensure that this was true, we examined the distribution patterns and when necessary log transformed the data; this did not affect the actual relationships.

Resilience and Geophysical Settings

People have been aware of the differences between geophysical settings for centuries, particularly the fertility of the soils, the structural properties of the bedrock, and the hydrologic cycle of the groundwater flow. Not surprisingly, most settlement has occurred in the gentle landscapes with productive soils, while most conservation areas are located on poor soils with steep slopes. As a result, settings like low elevation limestone and coastal sands are not only less complex in structure, but also more fragmented by human use (Figure 4.3).

Figure 4.2. Estimated resilience and vulnerability. This image shows aerial photos for two areas in New Jersey. The one on the left is flat and fragmented, and scores low for resilience while the one on the right has greater landscape diversity and connectedness, and scores higher for resilience.

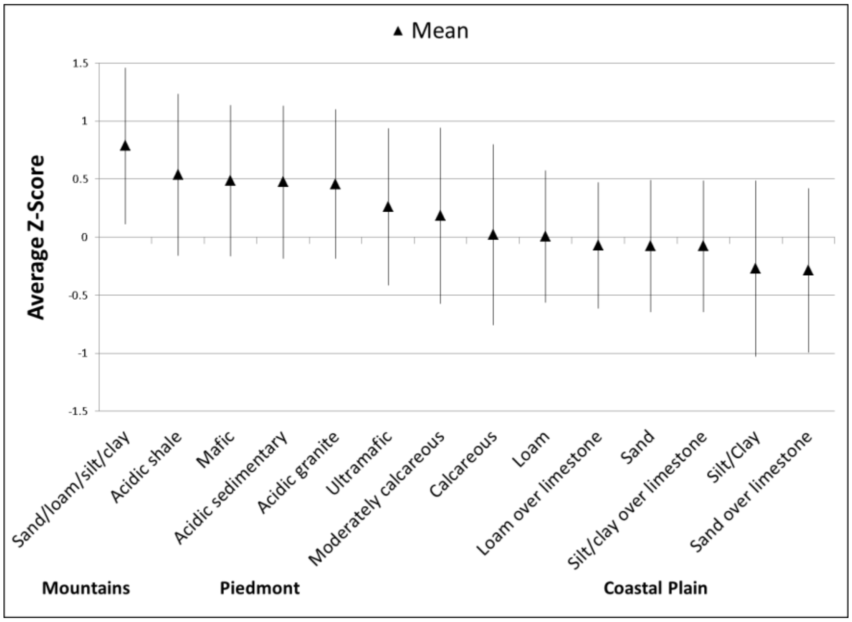


For each geophysical setting we identified the area with the highest resilience scores by calculating the mean estimated resilience score for all cells of each setting, and then identifying those hexagons that scored above the mean or that were above the mean for the entire region. To account for the inherent differences in landscape diversity and local connectedness between settings, each was evaluated individually and the results were combined into a single map that showed the highest scoring areas for each setting (Figure 4.4).

The various geophysical setting also differed dramatically in their conservation securement status, reflecting, to some extent, the degree of utility of the setting for agriculture, settlement or other human uses (Figure 4.5). Like the low scoring settings, the underrepresented settings were predominantly low elevation regions with soils derived from surficial sediments or calcareous bedrock.

Figure 4.3: Average resilience acores of geologic classes and elevation zones. This chart shows the average resilience score for each non-combined geology classes (a) and elevation zone (b) in relation to the mean score of the whole study area. Scores are in standard normal units. For example, the mafic geology class has an average score that is 0.5 SD higher than the average score. Scores for settings in the mountain and piedmont settings are inherently higher than scores for the coastal plain.

(a)



(b)

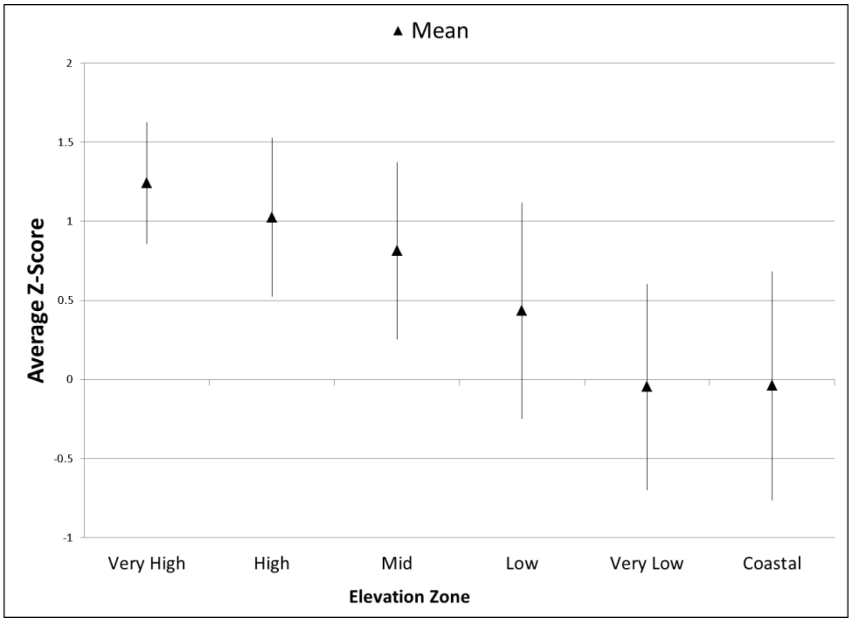
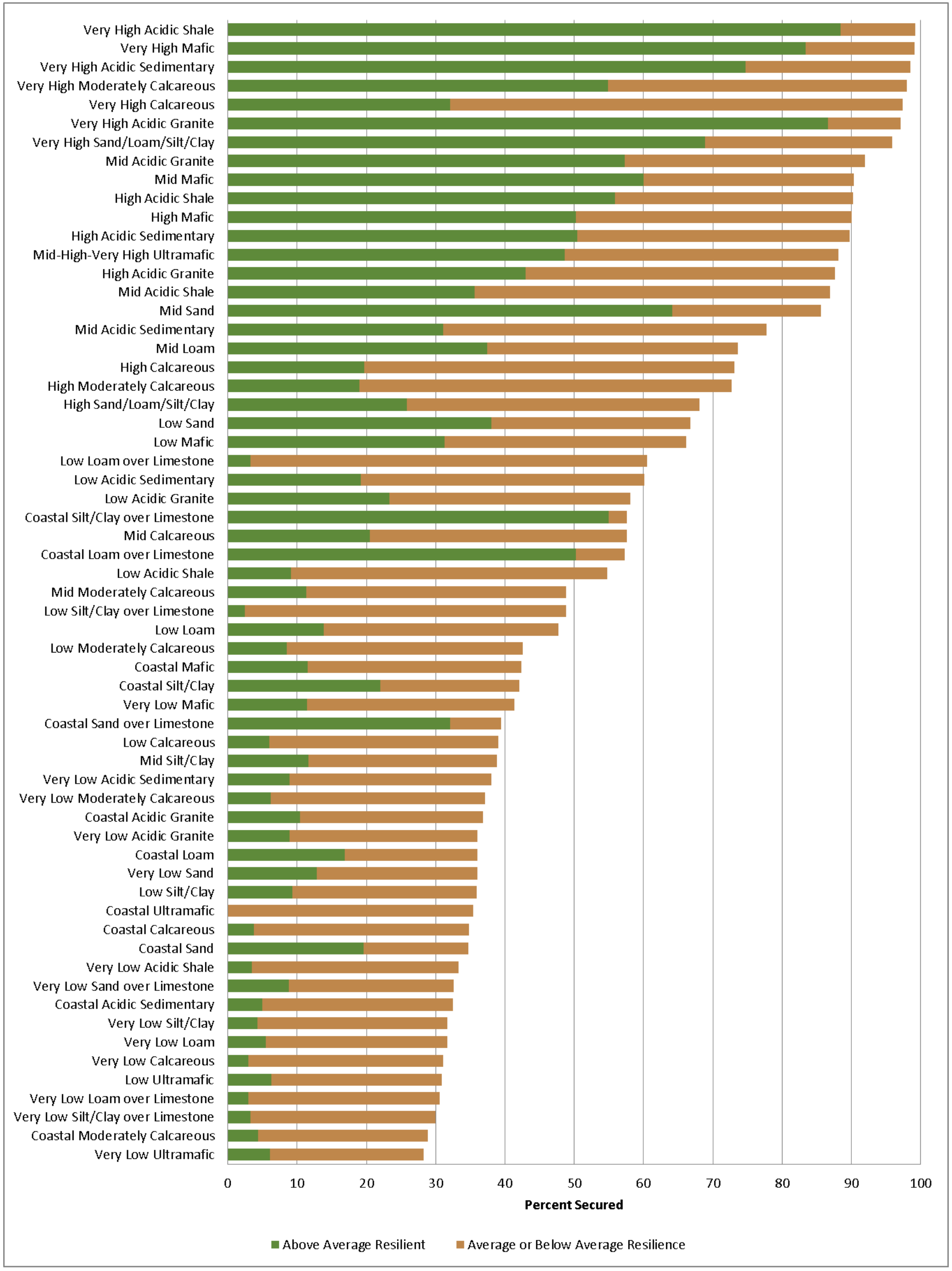
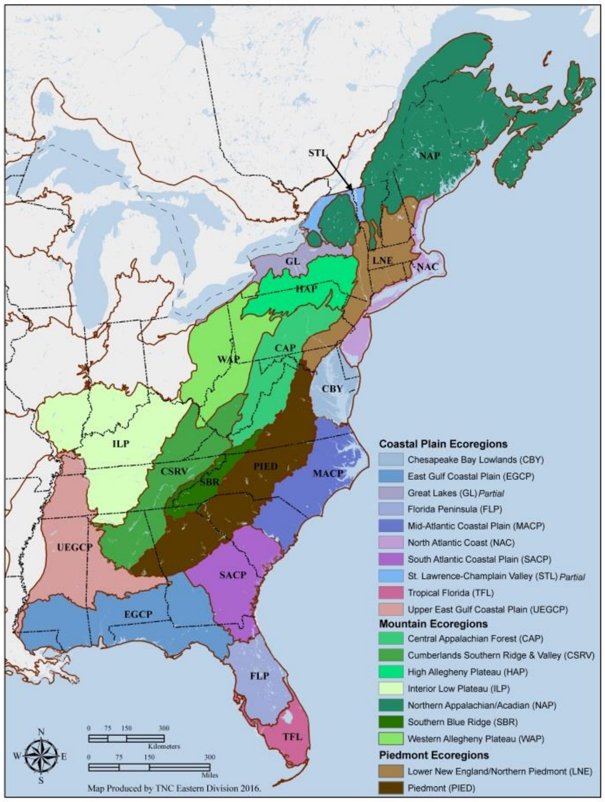

▲ Mean
2
1.5
1
0.5
0
-0.5
-1
Average Z-Score
Very High
High
Mid
Low
Very Low
Coastal
Elevation Zone

Figure 4.4: Resilience score by geophysical setting. This map shows the estimated resilience score stratified by each of the 61 geophysical settings. For each setting we calculated the mean and standard deviation of the scores for the entire setting. The map shows areas that are above (green) or below (brown) the mean.

Figure 4.5: Securement status of the geophysical settings. This chart shows the proportion of total securement for each setting (when the score are stratified by setting ONLY. This does not include the ecoregions or regional override), further divided by whether the site scored above average or below average for resilience. This chart suggests that for most settings at least half of the securement has been in areas with a high potential for adapting to climate change (green). Securement has largely been biased towards high elevations.



Ecological Regions



We performed our evaluation of estimated resilience for each setting within natural ecoregions. Ecoregions are large units of land with similar environmental conditions, especially landforms, geology and soils, which share a distinct assemblage of natural communities and species. The term "ecoregion" was coined by J.M. Crowley (1967) and later popularized by Robert Bailey of the USFS. In recent decades, ecoregions have become a defining construct of larger conservation efforts because they provide a needed ecological context for understanding conservation activities by enabling the evaluation of properties considered critical to conserving biodiversity (e.g. representation, redundancy, ecological function, linkages, and endemism).

A primary reason for using natural ecoregions is that they are relatively homogenous in terms of their geophysical settings and species richness. Species richness has been suggested as a resilience factor because ecosystems comprised of a large number of species may have a high capacity to adapt to novel conditions because the diversity of species ensures that there are more possible combinations of species tolerances and microclimates available. Thus, it is less likely that all species will be effected the same way by a changing climate and more likely that some species will thrive in the new environment (notably, however, some depauperate systems, like acidic bogs in the Northeast, have persisted over thousands of years with a very low diversity of species.) Further, species diversity increases with latitude and latitude has been shown to be a good predictor of the number of species in a state (Anderson and Ferree 2010). By using ecoregion as our primary focus, we could account for the regional changes in species richness and to some extent for latitudinal influences.

The ecoregions we used for this analysis were developed by TNC in conjunction with the USFS. They are a modification of Bailey (1995) that puts more emphasis on natural communities and less on climate (Figure 2.1). We made one modification to the previously published version of this map by adjusting the boundary between the Florida Peninsula and Tropical Florida ecoregions so that it now follows the boundary between nine and ten degrees (the average minimum temperature for January 1981 – 2010, see appendix for details). Seventeen ecoregions were fully contained within the analysis and it is within these that we have high confidence in the results of this analysis. Alphabetically by subregion these were (Figure 1.1):

Coastal Plain Ecoregions

Chesapeake Bay Lowlands (CBY)

Coastal and fluvial plains in DE, MD, and VA.

East Gulf Coastal Plain (EGCP)

Coastal plain of GA, FL, AL, MS, and LA.

Great Lakes(GL) *Partial*

Glaciated lake plain, lowlands, morainal hills and till plains in PA and NY.

Peninsular Florida (FLP)

Coastal plain region on the Florida peninsula.

Mid-Atlantic Coastal Plain (MACP)

An extensive low-relief plain from VA, NC, and SC.

North Atlantic Coastal Plain (NAC)

Glaciated irregular plains composed of sandy till and modified by coastal processes in NJ, DE, NY, RI, CT, MA, NH, and ME.

South Atlantic Coastal Plain (SACP)

An extensive low-relief plain from SC, GA

St. Lawrence-Champlain Valley (STL) *Partial*

A lowland lake plain in NY and VT; includes the St Lawrence River and the Champlain Valley.

Tropical Florida (TFL)

Southern third of Florida peninsula

Upper East Gulf coastal Plain (UEGCP)

Northern part of the gulf coastal plain with more rugged terrain and hilly topography in KY, TN, MS, AL, LA.

Mountain Ecoregions

Central Appalachian Forest (CAP)

Mountainous regions of central PA, WV, VA, and TN.

Cumberland Southern Ridge and Valley (CSRV)

Mountainous regions of WV, KY, TN, AL, GA

High Allegheny Plateau (HAP)

A wide plateau that includes low mountains, high hills, and steep ridges in southern NY, northern PA, and northwest NJ.

Interior Low Plateau (ILP)

Hilly and rolling Plateau in IL, IN, OH, KY, TN, and AL.

Northern Appalachian/Acadain (NAP)

Mountainous regions and boreal hill and lowlands in northern New England and maritime Canada.

Southern Blue Ridge (SBR)

Mountainous regions of VA, NC, SC, GA, TN

Western Allegheny Plateau (WAP)

Mature stream dissected plateau in NY, PA, and WV.

Piedmont Ecoregions

Lower New England/Northern Piedmont (LNE)

An extensive low relief plain with scattered high hills in the east and low mountains in the west that stretches from ME to PA.

Piedmont (PIED)

Flat plateau of MD, VA, NC, SC, GA, AL

Ecoregion Results

For each ecoregion wholly contained in the study area we present the results as five maps:

1) Estimated resilience for all geophysical settings in the ecoregion,
2) Geophysical settings in the ecoregion
3) The most resilient examples of each geophysical setting in the ecoregion,

All results are relative to the geophysical settings within the ecoregion. Explanations, interpretation, and, in some cases, the method of mapping, are described below. Partially included ecoregions are from the Great Lakes and St. Lawrence-Champlain Valley with the Northern Appalachians map series. The partial ecoregion of the Mississippi Alluvial Plain is shown with the Upper East Gulf Coastal Plain. Users should be aware that the results are incomplete in the partial ecoregions.

Estimated Resilience for all Geophysical Settings in the Ecoregion

The maps of each ecoregion show the places that scored above or below the mean for estimated resilience, relative to all possible occurrences of the setting in the ecoregion (i.e. the legend described at the start of this chapter). Green colors indicate areas that scored above average for estimated resilience. These were the places with the highest landscape diversity and local connectedness relative to the geophysical setting within the ecoregion. These maps may be used for an in-depth look at the detailed patterns of resilience and vulnerability in the ecoregion.

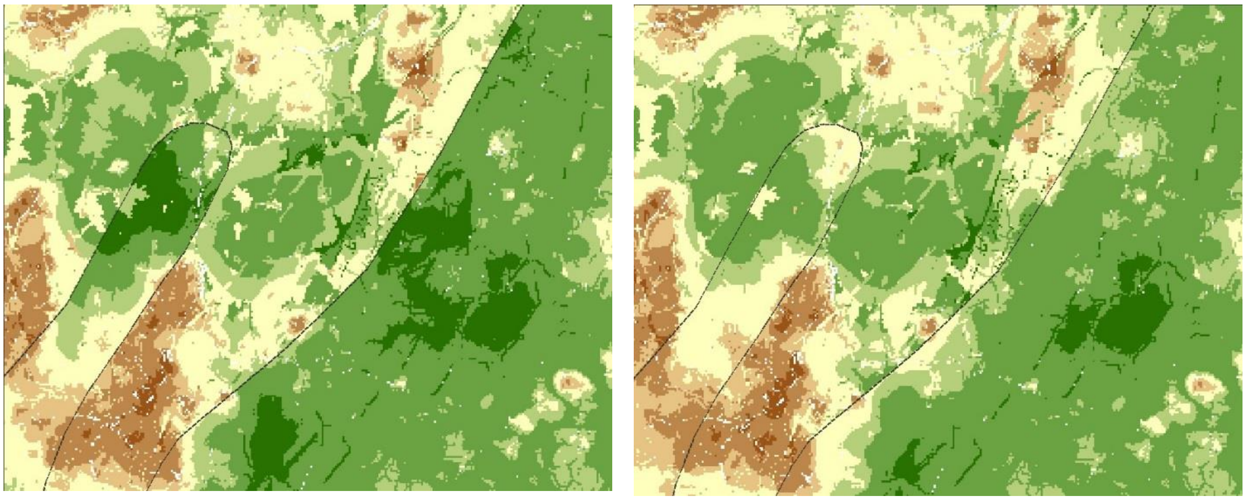
Ecoregional Fade

When stratifying by setting and ecoregion, ecoregions that are less similar have wider differences in their means and standard deviations for individual settings. This means that a setting on one side of an ecoregional boundary can have the same raw resilience score as a grid cell with the same setting on the other side of the ecoregion boundary, but after stratifying by setting and ecoregion the scores can be quite different (See figure 4.6 left). Ecoregional boundaries are gradual in nature, and are not drawn at the scale of a 30 meter grid cell. This radical difference in scores is artificial, and we developed a method to fade or blur the effects of the boundary.

The "ecoregional fade" blurs the ecoregion boundary by distance weighted average of the standardization values for ecoregions with in a 20 km of the ecoregion line. The ecoregional fade is a script we developed that use zonal mean within 20 km of the ecoregion to smooth the mean and standard deviation grids that are used to stratify the results.

For the regional results, we used a buffer distance of 20 km. The sharpness of the contrast for each ecoregion varies, so it did not make sense to look at scientific

Figure 4.6: Ecoregional Fade Example. This example shows how the ecoregion boundary by a distance weighted average of the standard deviation values within 20 km of the ecoregion line. This is the boundary between the Piedmont and the Northern Appalachian Ecoregions in Virginia.



literature for distances. Instead, our team looked at a variety of distances going from 10 km to 40 km. We looked at the amount of smoothing, looking to smooth the area directly around the ecoregion boundary, but not distort settings farther from the ecoregional boundary. We settled on a buffer distance of 20 km. Due to the stratification process, we implemented the ecoregional fade three time, once for landscape diversity, once for local connectivity, and then for the combined landscape diversity/local connectivity map.

Ecoregional Override

A small, but logical, modification to the regional and ecoregional maps was the incorporation of a **regional override**. Essentially, we overrode the ecoregional score in places where the hexagon was one of the highest scoring in the whole region but not in the ecoregion. This was necessary when all the examples of the setting in the ecoregion were high scoring; in these cases our method of calculating the average and showing the examples above and below the mean forced half of these examples to appear below the mean – even if they were among the best in the region. By adding the sites that had scores >0.5 SD for the entire study area and the regional score was greater than the stratified score we corrected for this problem.

Maps by Ecoregion:

Resilient Estimates
Resilience Stratified by setting and ecoregion with the regional override.

Setting Map
A map of the settings for each ecoregion. These settings are decried in detail in Chapter 2.

Resilient Examples of each Geophysical Setting in the Ecoregion
These maps show only the grid cells that scored above the mean (> 0.5 SD) for resilience with their various settings displayed by color. These maps were useful in understanding how the settings influence, and were reflected in, the resilience scores. The maps reveal how the visual patterns of resilience were influenced by the amount of each setting in the ecoregion. They also reveal how the resilient areas are distributed with respect to the clustering or dispersion of the high-scoring settings throughout the ecoregion.

COASTAL PLAIN ECOREGIONS

Chesapeake Bay Lowlands

The Chesapeake Bay Lowlands consist of low coastal and fluvial plains in DE, MD and VA with extensive marine and estuarine habitats. Mosaics of natural communities include salt marsh, beach dune and barrier island systems, fresh and brackish tidal marshes. Forest types include coastal pine-oak forests, oak-beech-holly forest, red maple-sweetgum swamps. (Text adopted from TNC ecoregional plan).

Read more at:
https://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/edc/reportsdata/terrestrial/ecoregional/cby/Pages/default.aspx

Figure 4.6 Chesapeake Bay Lowlands Resilience. Areas in green score above average and are estimated to be more resilient based for their geophysical setting, based on landscape diversity and local connectedness. Areas in yellow are average. Areas in brown are below average and are estimated to be vulnerable to climate change and other factors.

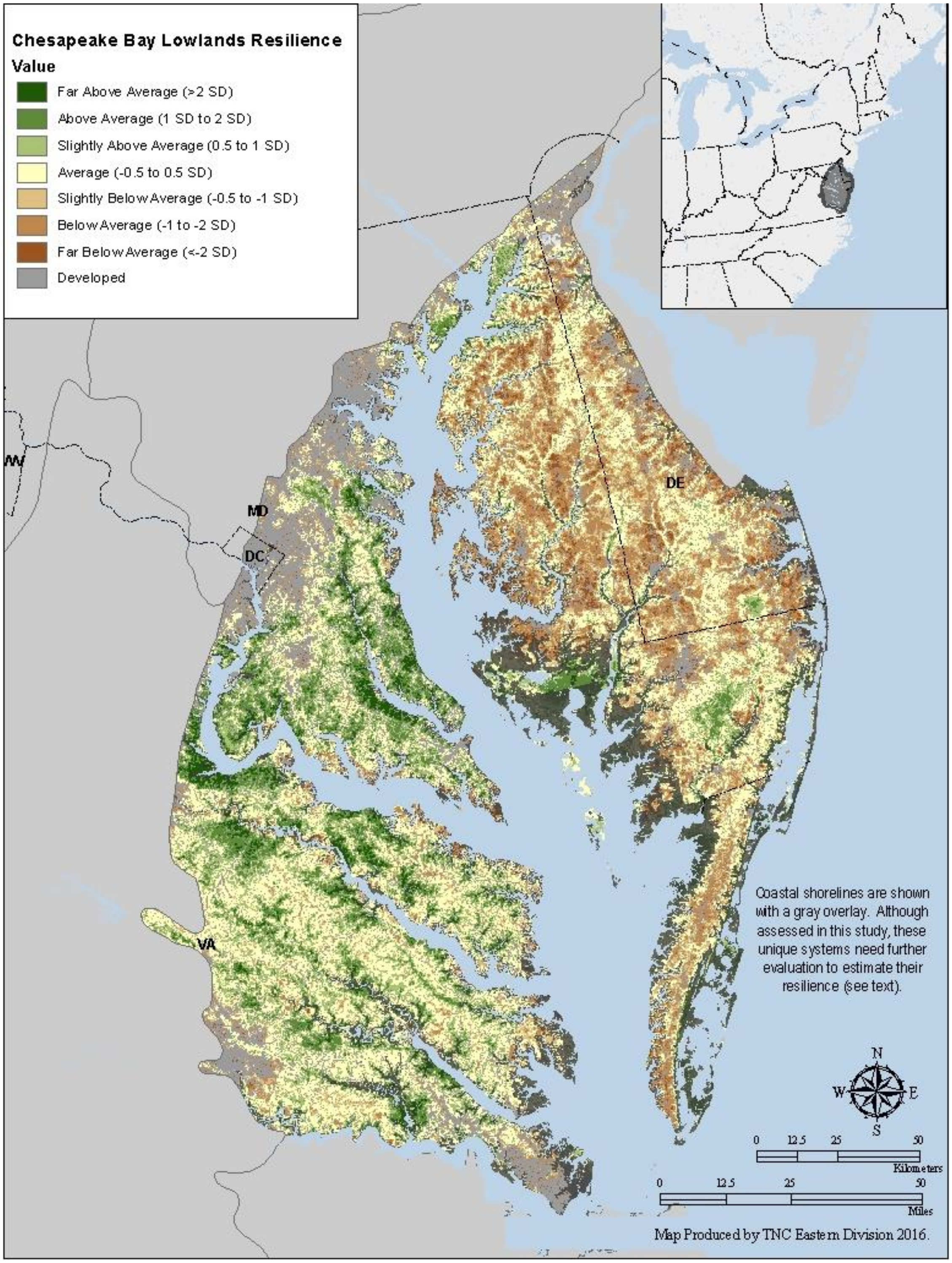


Figure 4.7 Chesapeake Bay Lowlands Settings. The geophysical settings in this ecoregion that were created by combining an elevation zone and a geology class. These are the settings that are used for the stratification by setting for this ecoregion.

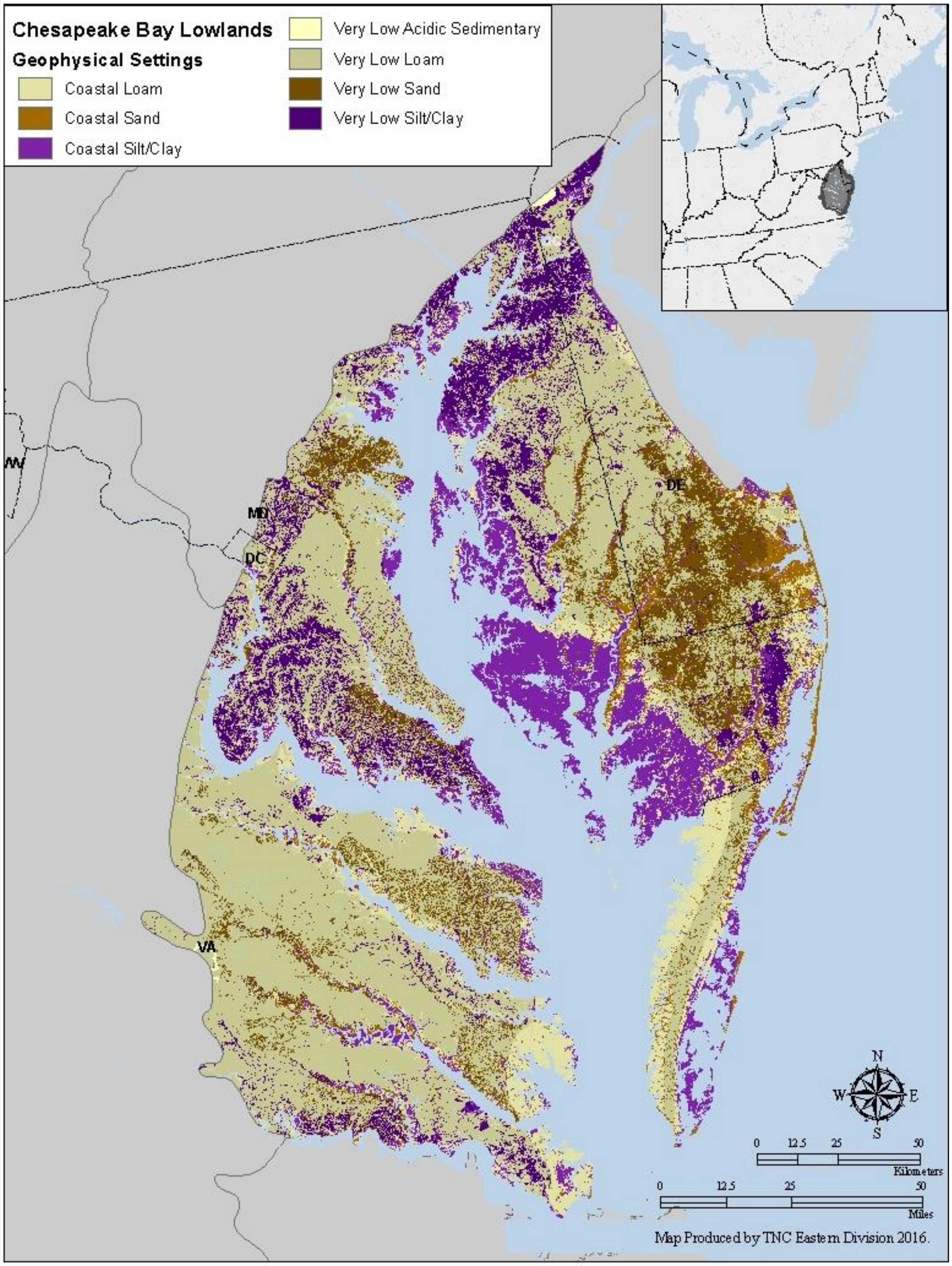
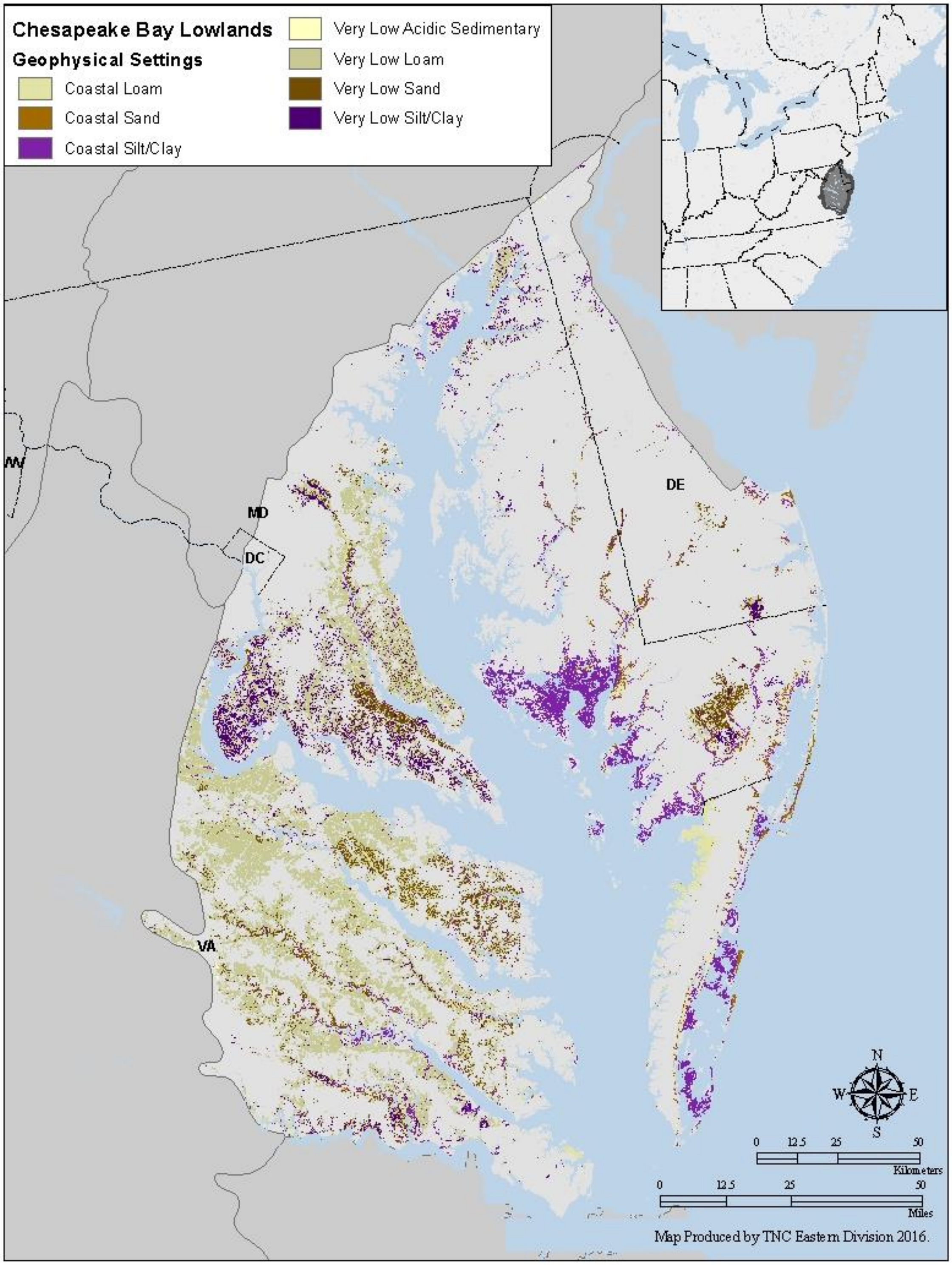


Figure 4.8 Chesapeake Bay Lowlands Settings assessed as most resilient. The map shows only the grid cells that score above the mean for estimated resilience as compared to others in in their ecoregion; each high scoring grid cell is colored based on its corresponding geophysical setting. This map reveals how the settings are reflected in the resilience scores.



East Gulf Coastal Plain

The East Gulf Coastal Plain ecoregion encompasses portions of five states (Georgia, Florida, Alabama, Mississippi, and Louisiana) and over 42 million acres, stretching from the southwestern portion of Georgia across the Florida Panhandle and west to the southeastern portion of Louisiana (Map 2). The ecoregion has a stunning diversity of ecological systems, ranging from sandhills and rolling longleaf pine-dominated uplands to pine flatwoods and savannas, seepage bogs, bottomland hardwood forests, barrier islands and dune systems, and estuaries. In fact, in North America, the East Gulf Coastal Plain ecoregion is one of the true hotspots of biodiversity and endemism. Many species, particularly vascular plants, reptiles, amphibians, and fishes occur only in this ecoregion, and many are even more narrowly limited within the ecoregion. The freshwater aquatic systems of the East Gulf Coastal Plain are among the most significant aquatic biodiversity resources in North America. Many aquatic animals are endemic to the ecoregion, with many species occurring only in a single river system and its tributaries.

Fire-maintained longleaf pine and slash pine woodlands, and their associated seepage bogs and depression wetlands, once dominated a string of five ecoregions from southeastern Virginia to eastern Texas, including the East Gulf Coastal Plain (Map 3). This system has now been reduced to less than five percent of its former range, making it one of the most endangered landscapes in North America (Noss et al, 1995). Not only have these pineland ecosystems in the East Gulf Coastal Plain been directly reduced in extent, but remaining areas are also fragmented and many suffer from the exclusion of fire, a critical ecological process for their maintenance and health. Aquatic systems have been severely affected by hydrologic alterations, pollution, and introduction of non-native species. Most of the hundreds of species endemic to the ecoregion, many of which were never common, have been further imperiled by these changes. (Text adopted from TNC ecoregional plan).

Read more at:
http://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/edc/reportsdata/terrestrial/ecoregional/egcp/Pages/default.aspx

Figure 4.9 East Gulf Coastal Plain Resilience. Areas in green score above average and are estimated to be more resilient based for their geophysical setting, based on landscape diversity and local connectedness. Areas in yellow are average. Areas in brown are below average and are estimated to be vulnerable to climate change and other factors.

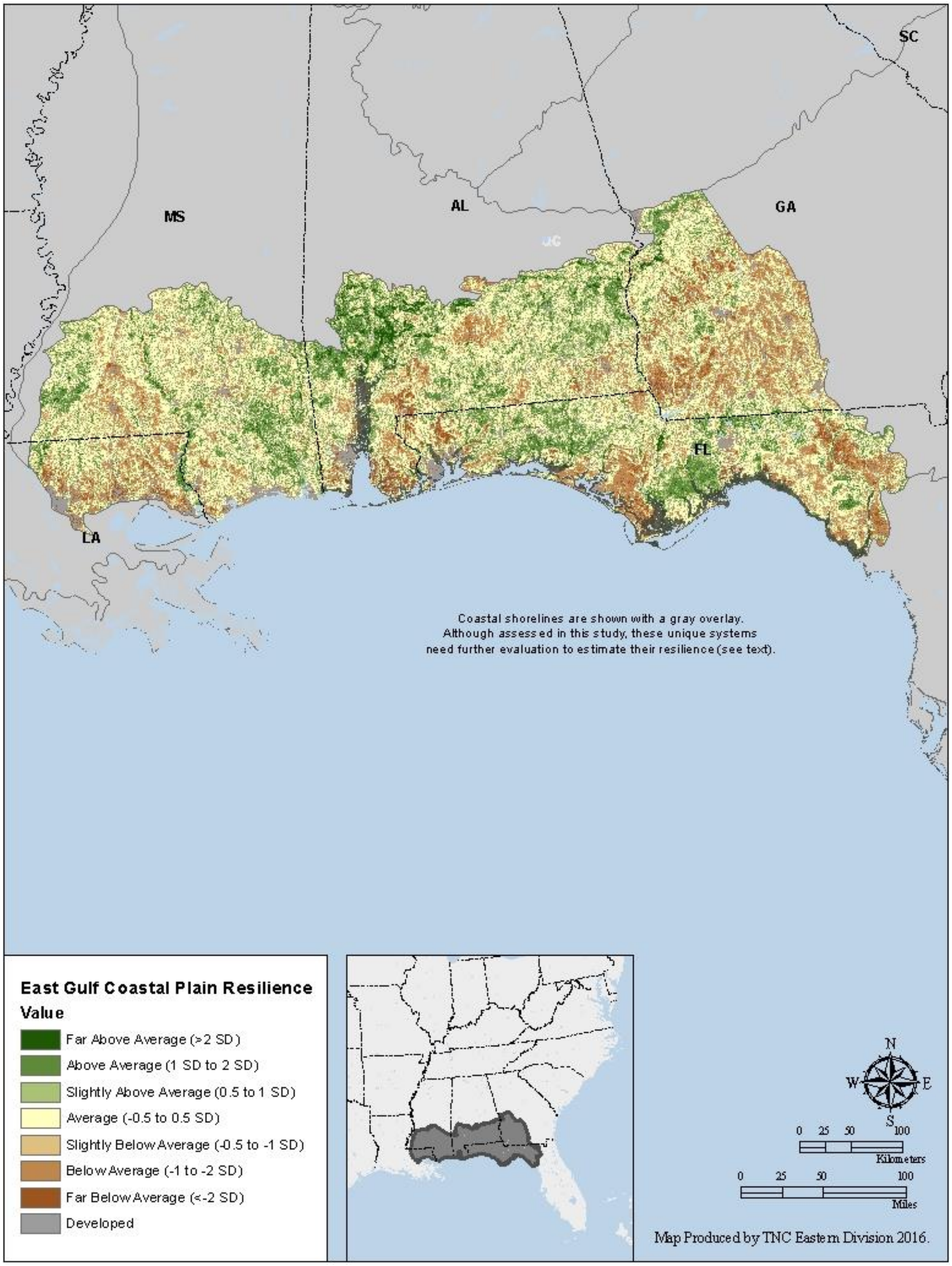


Figure 4.10 East Gulf Coastal Plain Settings. The geophysical settings in this ecoregion that were created by combining an elevation zone and a geology class. These are the settings that are used for the stratification by setting for this ecoregion.

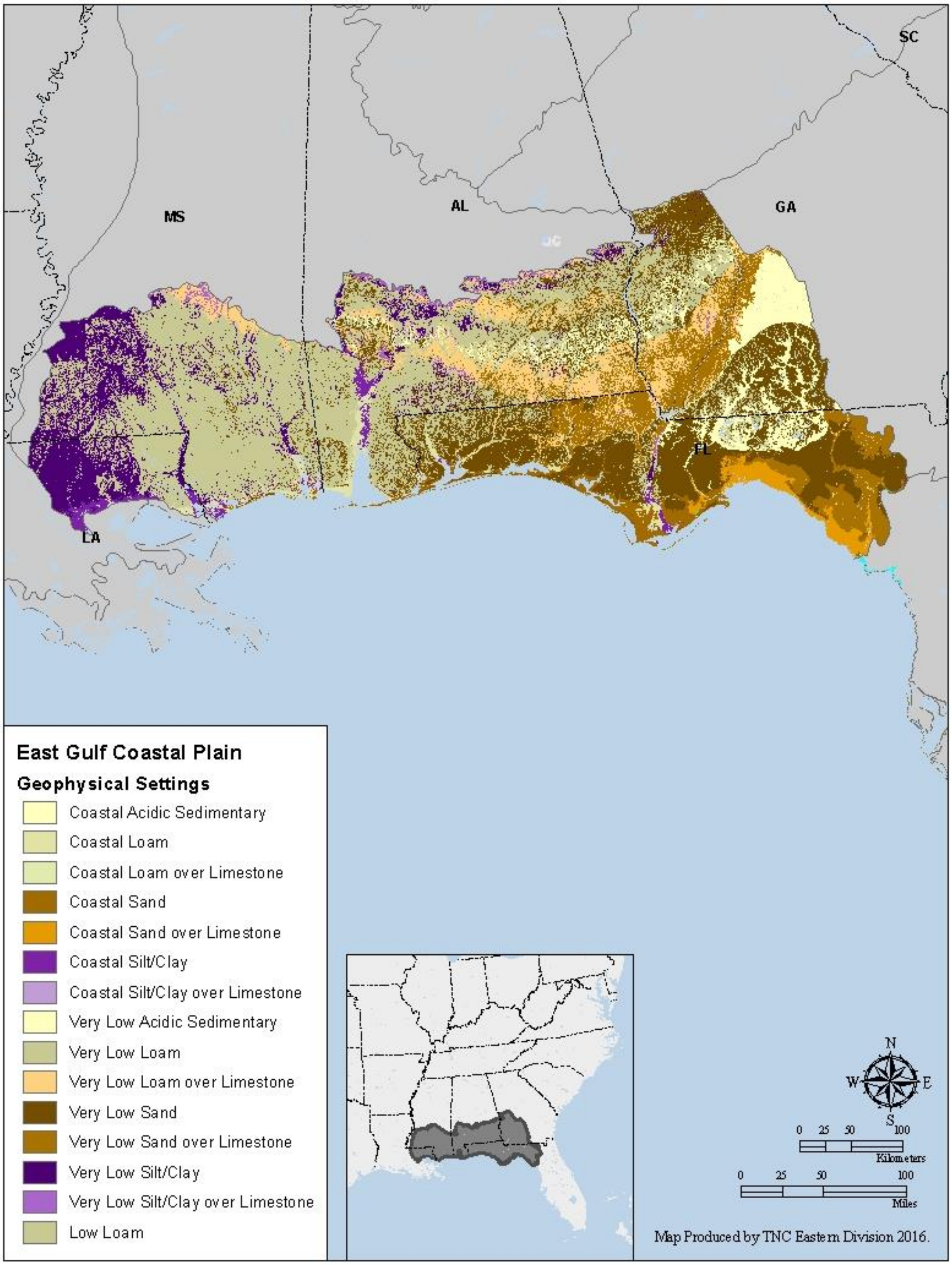
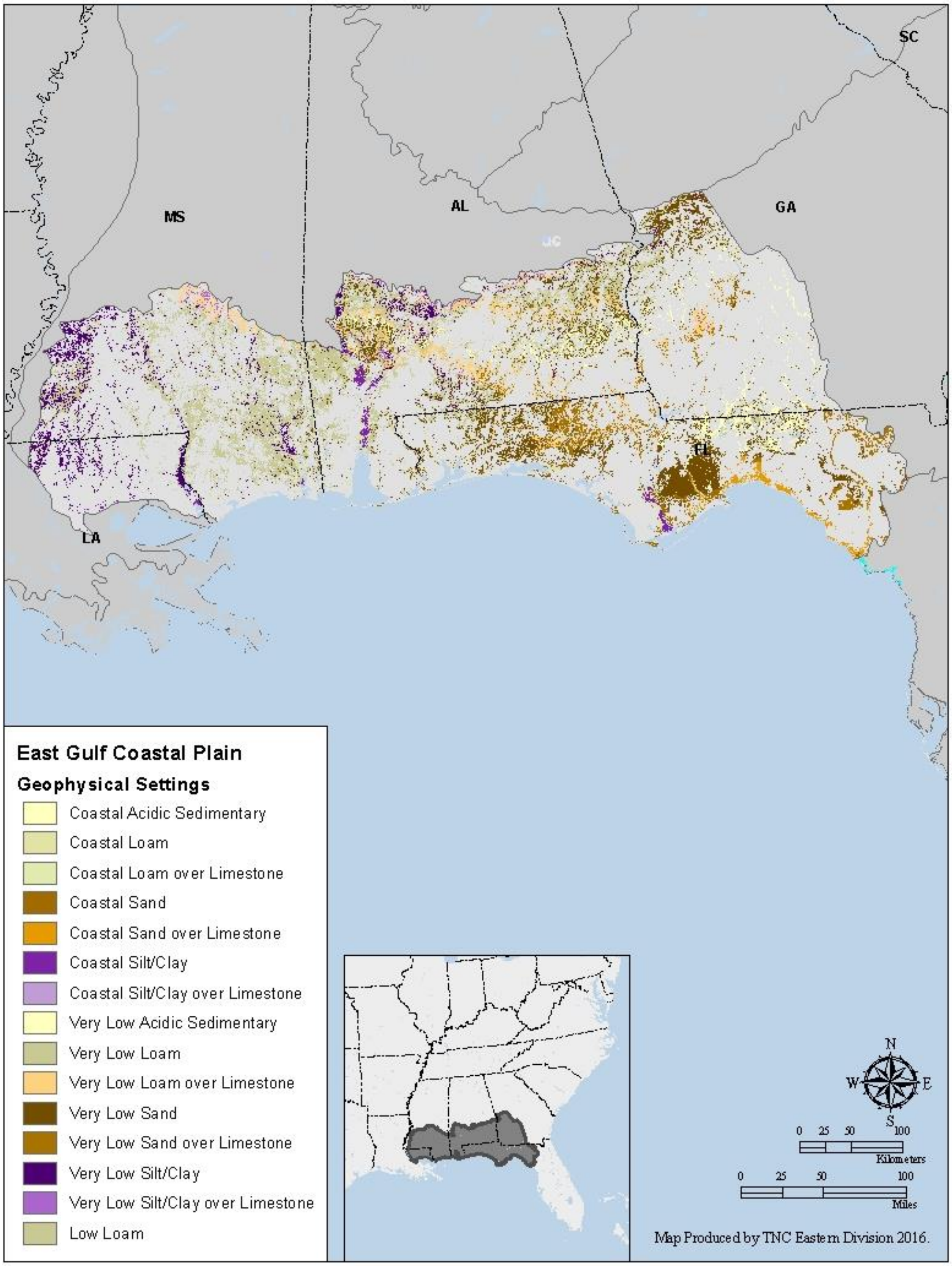


Figure 4.11 East Gulf Coastal Plain settings assessed as resilient. The map shows only the grid cells that score above the mean for estimated resilience as compared to others in in their ecoregion; each high scoring grid cell is colored based on its corresponding geophysical setting. This map reveals how the settings are reflected in the resilience scores.



Florida Peninsula

Covering some three-and-a-half degrees of latitude, the Florida Peninsula Ecoregion includes areas having a temperate flora and fauna characteristic of the Carolinian Biotic Province in its northern reaches, to species and communities with definite tropical affinities of the Caribbean Biotic Province at its southern limit (Myers and Ewel, 1990). Encompassed by the Gulf of Mexico on its west and the Atlantic Ocean (and the Gulf Stream) on its east, the ecoregion includes hundreds of miles of coastline. Two large metropolitan areas, Orlando (including the number one tourist destination in the world, Disney World) and Tampa, are prominent, sprawling features on the landscape. Additionally, three interstate highways fragment the ecoregion. Several large managed areas also occur in the ecoregion and are a basis for natural resource conservation. The five largest managed areas are the Ocala National Forest (383,180 acres), Merritt Island National Wildlife Refuge (138,263 acres), Withlacoochee State Forest (128,750 acres), Green Swamp (119,365 acres) and Avon Park Bombing Range (106,110 acres).

The Florida Peninsula Ecoregion has a mild climate with temperatures in the central portion typically ranging between 23 degrees Fahrenheit and 95 degrees Fahrenheit during an average year. The entire peninsula is characterized by relatively high rainfall, averaging 65 inches per year. The species and communities are shaped by several dominant forces: pronounced wet and dry seasons, once frequent fires that swept unimpeded for miles across the landscape (and other large-scale disturbance factors like hurricanes), a high water table, mucky or peaty soils that have developed in numerous depressional features on a karst, limestone-based substrate, a relatively flat terrain where even slight changes in topography can dramatically influence the kind of community that develops, and generally infertile, moderately to excessively well-drained sandy soils on several prominent ridge systems that run parallel to the coastlines (Myers and Ewel, 1990). (Text adopted from TNC ecoregional plan).

Read more at:
https://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/edc/reportsdata/terrestrial/ecoregional/flp/Pages/default.aspx.

Figure 4.12 Florida Peninsula Resilience Estimates. Areas in green score above average and are estimated to be more resilient based for their geophysical setting, based on landscape diversity and local connectedness. Areas in yellow are average. Areas in brown are below average and are estimated to be vulnerable to climate change and other factors.

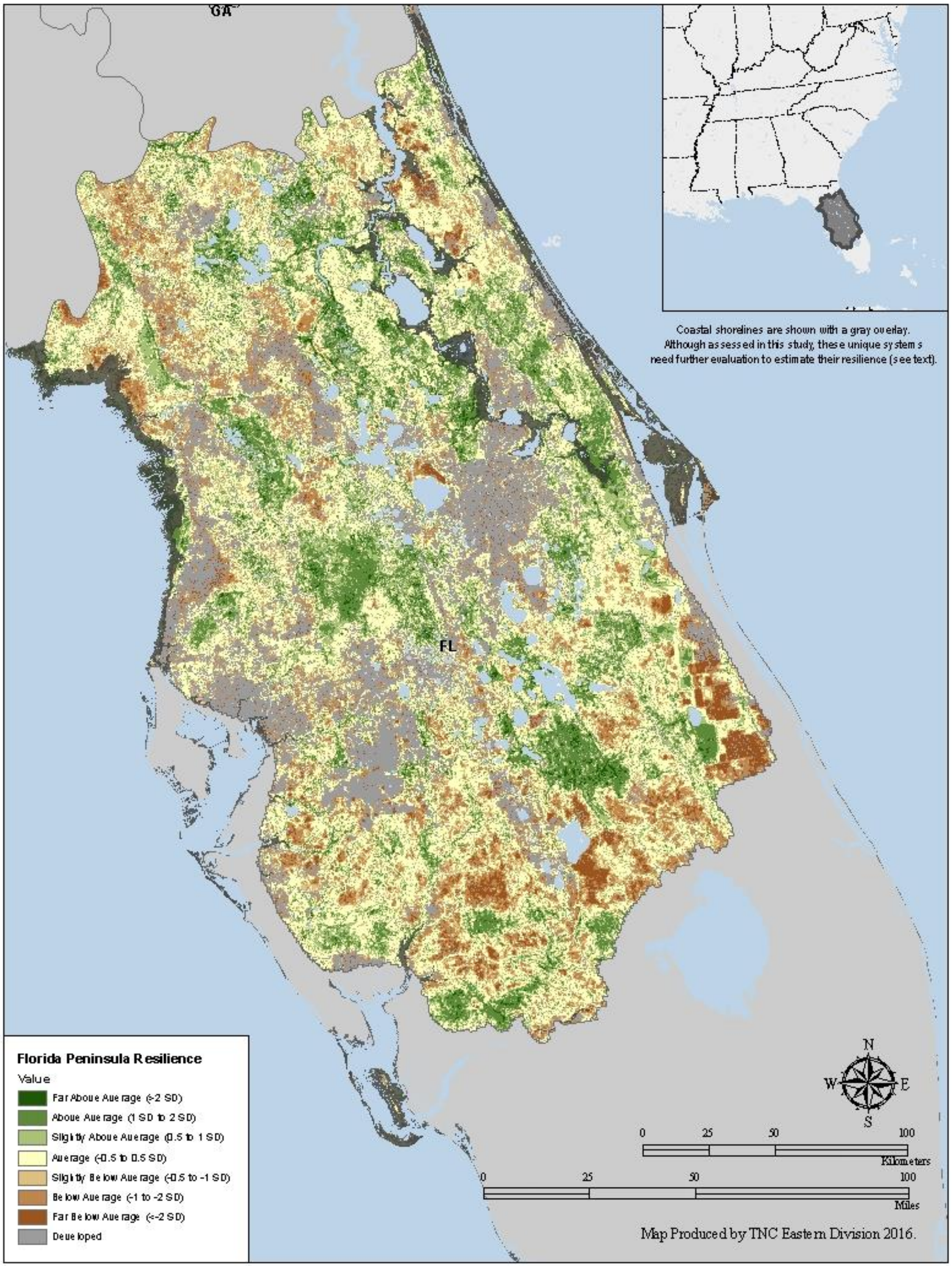


Figure 4.13 Florida Peninsula Settings. The geophysical settings in this ecoregion that were created by combining an elevation zone and a geology class. These are the settings that are used for the stratification by setting for this ecoregion.

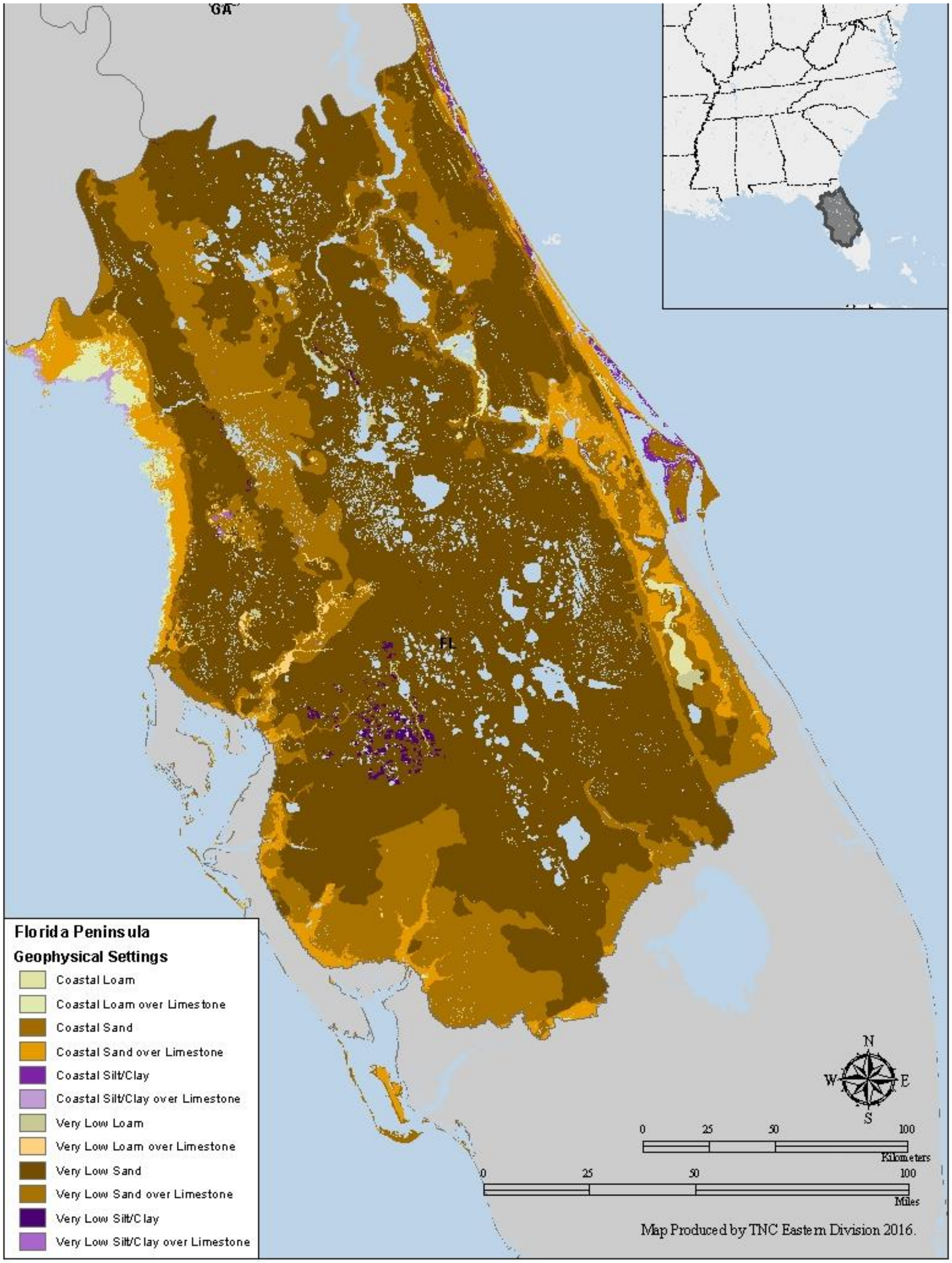
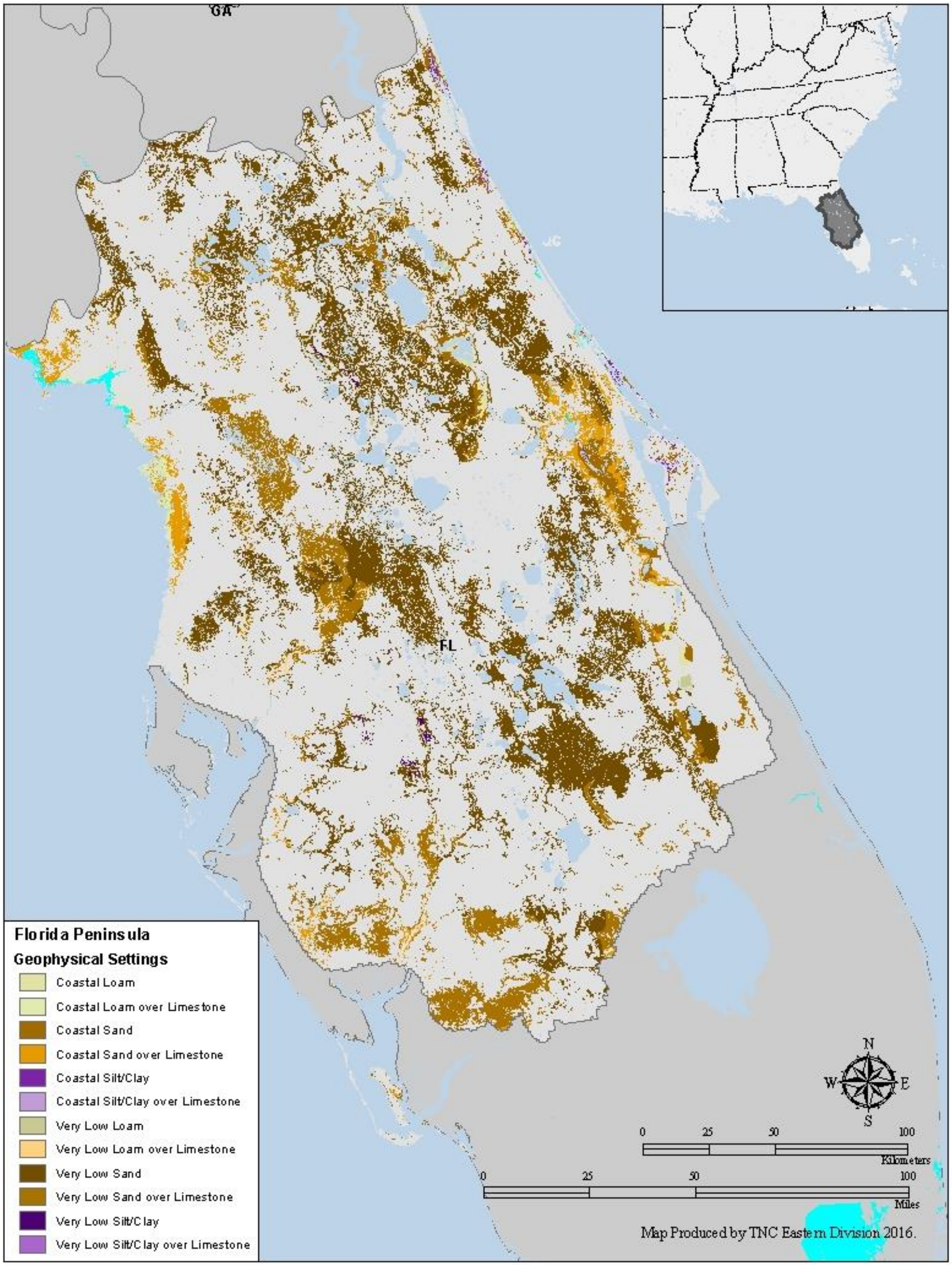


Figure 4.14 Florida Peninsula Settings assessed as most resilient. The map shows only the grid cells that score above the mean for estimated resilience as compared to others in in their ecoregion; each high scoring grid cell is colored based on its corresponding geophysical setting. This map reveals how the settings are reflected in the resilience scores.



Mid-Atlantic Coastal Plain

The Mid-Atlantic Coastal Plain (MACP) occupies 26 million acres east of the fall line between the Piedmont and Atlantic Coastal Plain, south of the James River in Virginia and north of Charleston Harbor in South Carolina. About two thirds of this very rich ecoregion is in North Carolina. This is the land of longleaf pines and bald cypress trees; of bottomland hardwood forests and swamps; of pocosins and palmettos; of Carolina Bays and Carolina Sandhills; of the Outer Banks and some of the world's best and most active coastal dunes, sounds, and estuaries; of red-cockaded woodpeckers and the now-extinct Carolina parakeet; of Venus fly-traps and red wolf. Natural fires, floods, and storms are so dominant in this region that the landscape changes very quickly. Rivers routinely change their courses and emerge from their banks. The Outer Banks have been described as a "river of sand" flowing south along the continental shelf. This is an ecoregion where the xeric environments of sand dunes and ridges share ecotones with the hydric environments of sounds, pocosins, and Carolina Bays. As an ecoregion, occurring at the interfaces between continent and ocean and between tropical and temperate climates, the MACP is as ecologically dynamic as any. Natural communities move around, and new species appear on the biological horizon. The Mid-Atlantic Coastal Plain is almost a factory for the generation of new and novel species, communities, and ecological patterns and processes. (Text adopted from TNC ecoregional plan).

Read more at:
https://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/edc/reportsdata/terrestrial/ecoregional/mac/Pages/default.aspx.

Figure 4.15 Mid-Atlantic Coastal Plain Resilience Estimates. Areas in green score above average and are estimated to be more resilient based for their geophysical setting, based on landscape diversity and local connectedness. Areas in yellow are average. Areas in brown are below average and are estimated to be vulnerable to climate change and other factors.

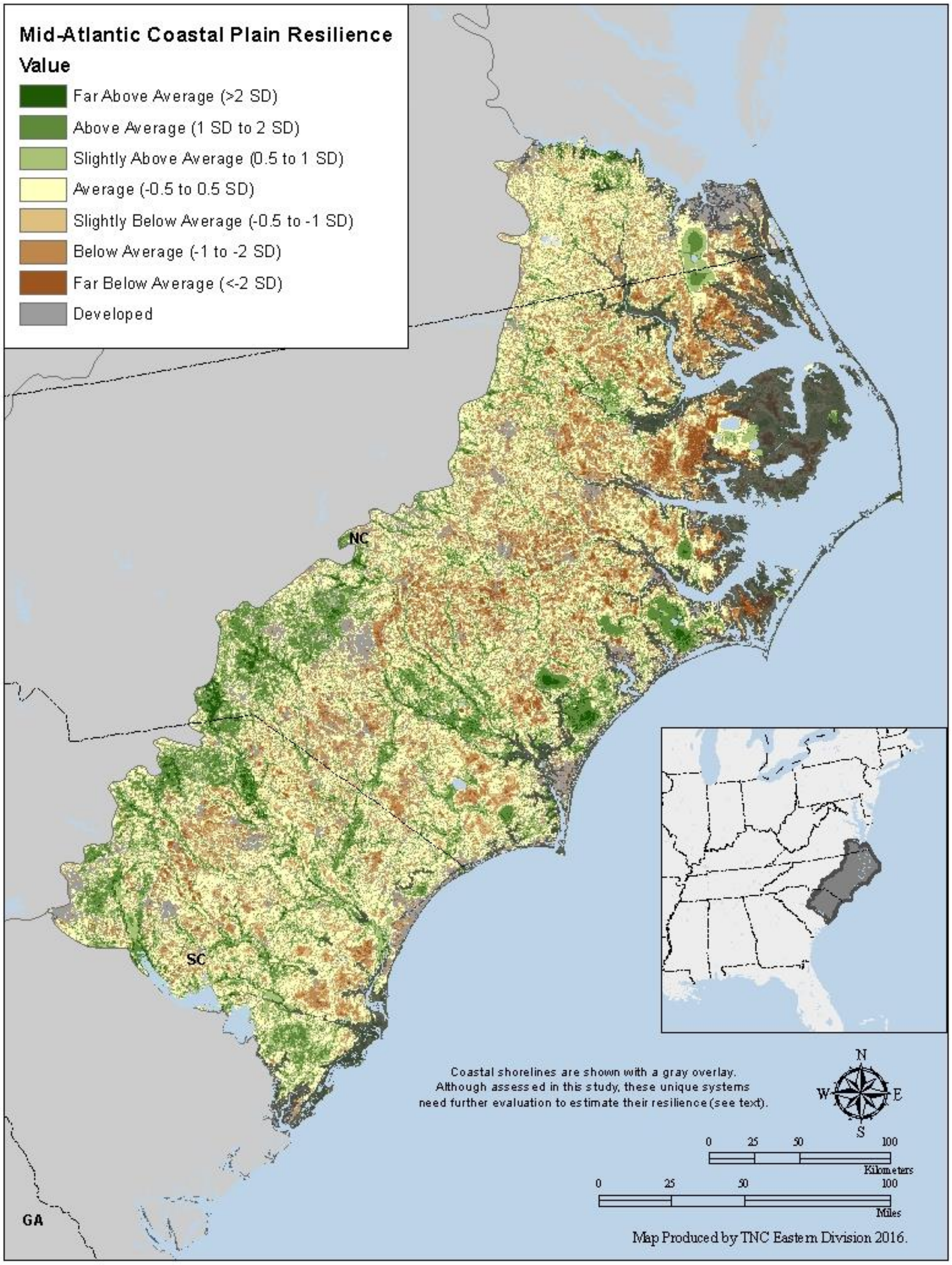


Figure 4.16 Mid-Atlantic Coastal Plain Settings. The geophysical settings in this ecoregion that were created by combining an elevation zone and a geology class. These are the settings that are used for the stratification by setting for this ecoregion.

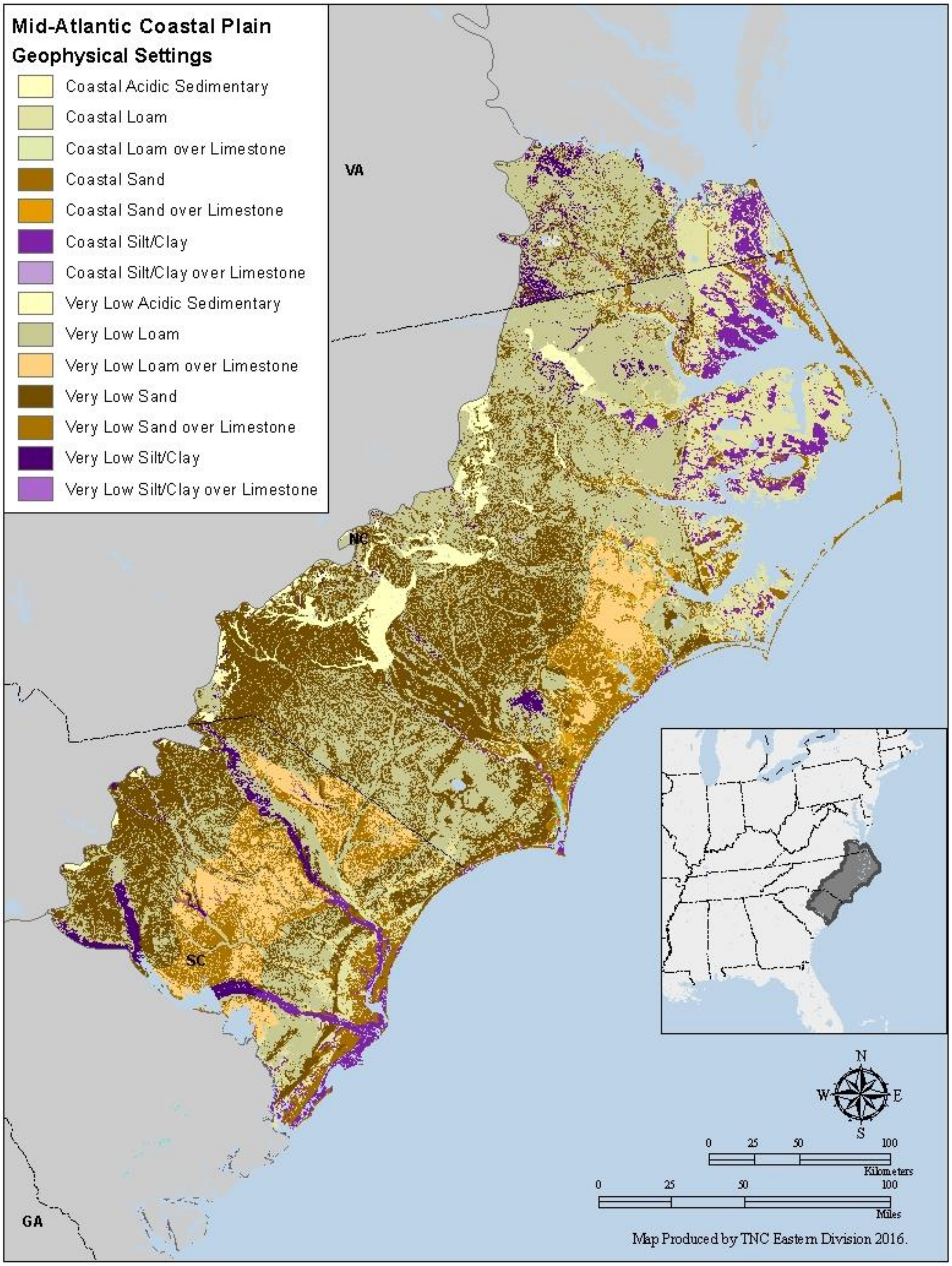
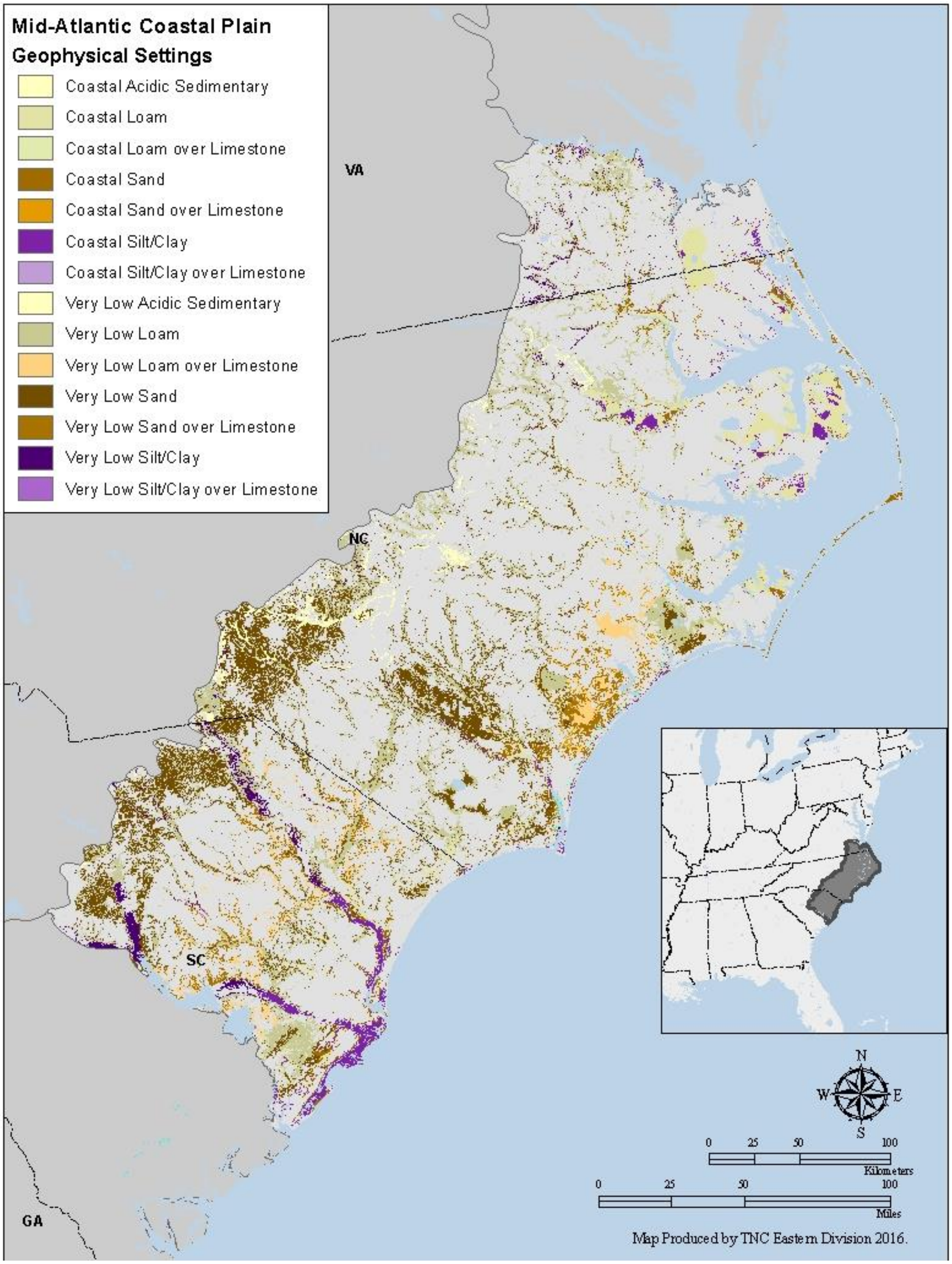


Figure 4.17 Mid-Atlantic Coastal Plain Settings in Areas Assessed as Resilient. The map shows only the grid cells that score above the mean for estimated resilience as compared to others in in their ecoregion; each high scoring grid cell is colored based on its corresponding geophysical setting. This map reveals how the settings are reflected in the resilience scores.



North Atlantic Coast

The North Atlantic Coast is a glaciated irregular plain composed of sandy till and modified by coastal
processes in NJ, DE, NY, RI, CT, MA, NH and ME. Elevation ranges 0 - 600 ft. Kames, kettle holes,
drumlins and reworked terminal moraines are typical features. The region includes extensive marine and
estuarine habitats and a correspondingly high number of rare species.
The region is highly developed and contains several major cities and suburbs, as well as natural areas.
Characteristic natural community mosaics include salt marsh, beach dune and barrier island systems,
fresh and brackish tidal marshes. Forest types include coastal pine-oak forests, oak-beech-holly forest.
Text adopted from TNC ecoregional plan).

Read more at:
https://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/edc/reportsdata/terrestrial/ecoregional/nac/Pages/default.aspx

Figure 4.18 North Atlantic Coast Resilience Estimates. Areas in green score above average and are estimated to be more resilient based for their geophysical setting, based on landscape diversity and local connectedness. Areas in yellow are average. Areas in brown are below average and are estimated to be vulnerable to climate change and other factors.

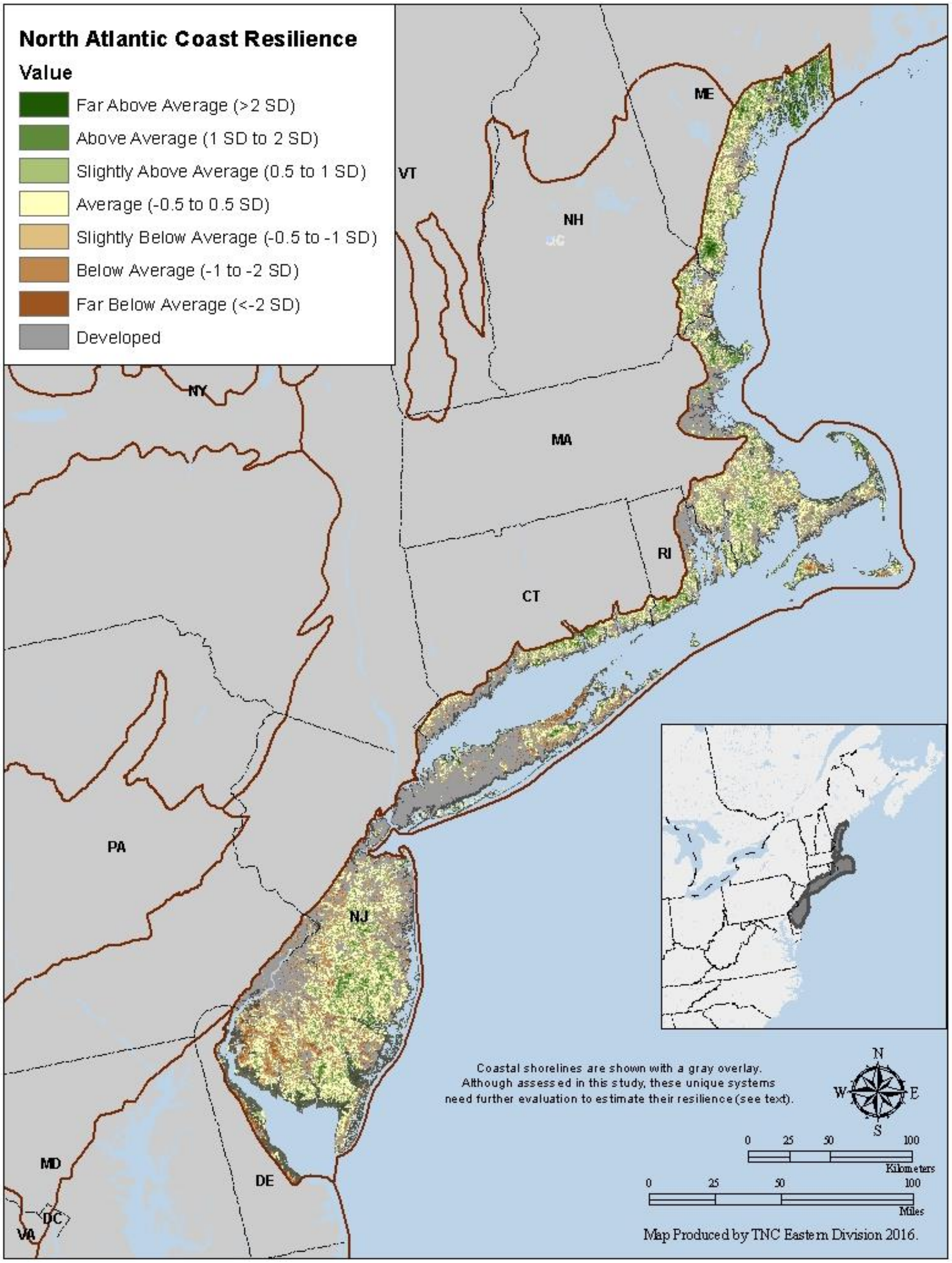


Figure 4.19 North Atlantic Coast Settings. The geophysical settings in this ecoregion that were created by combining an elevation zone and a geology class. These are the settings that are used for the stratification by setting for this ecoregion.

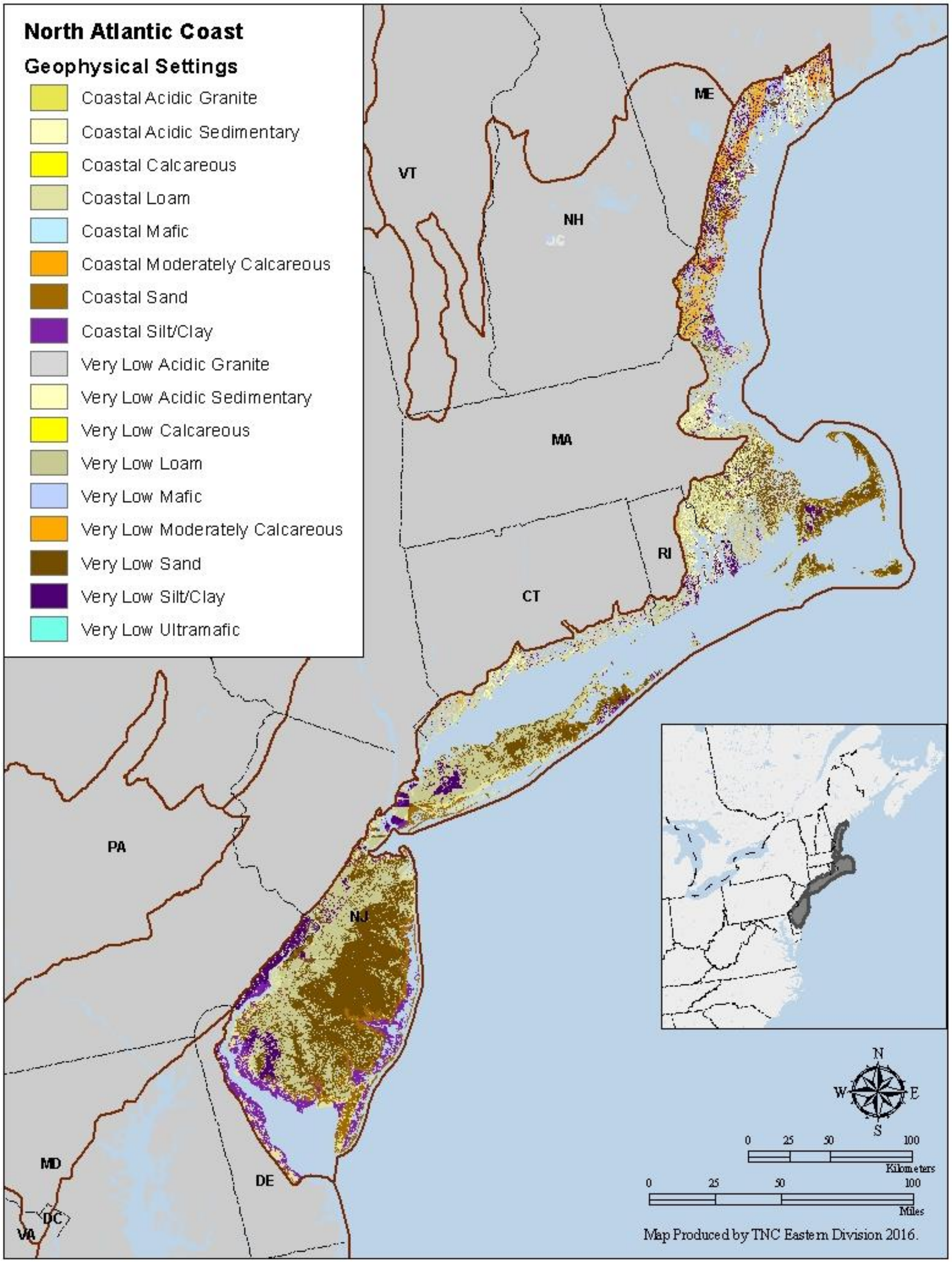
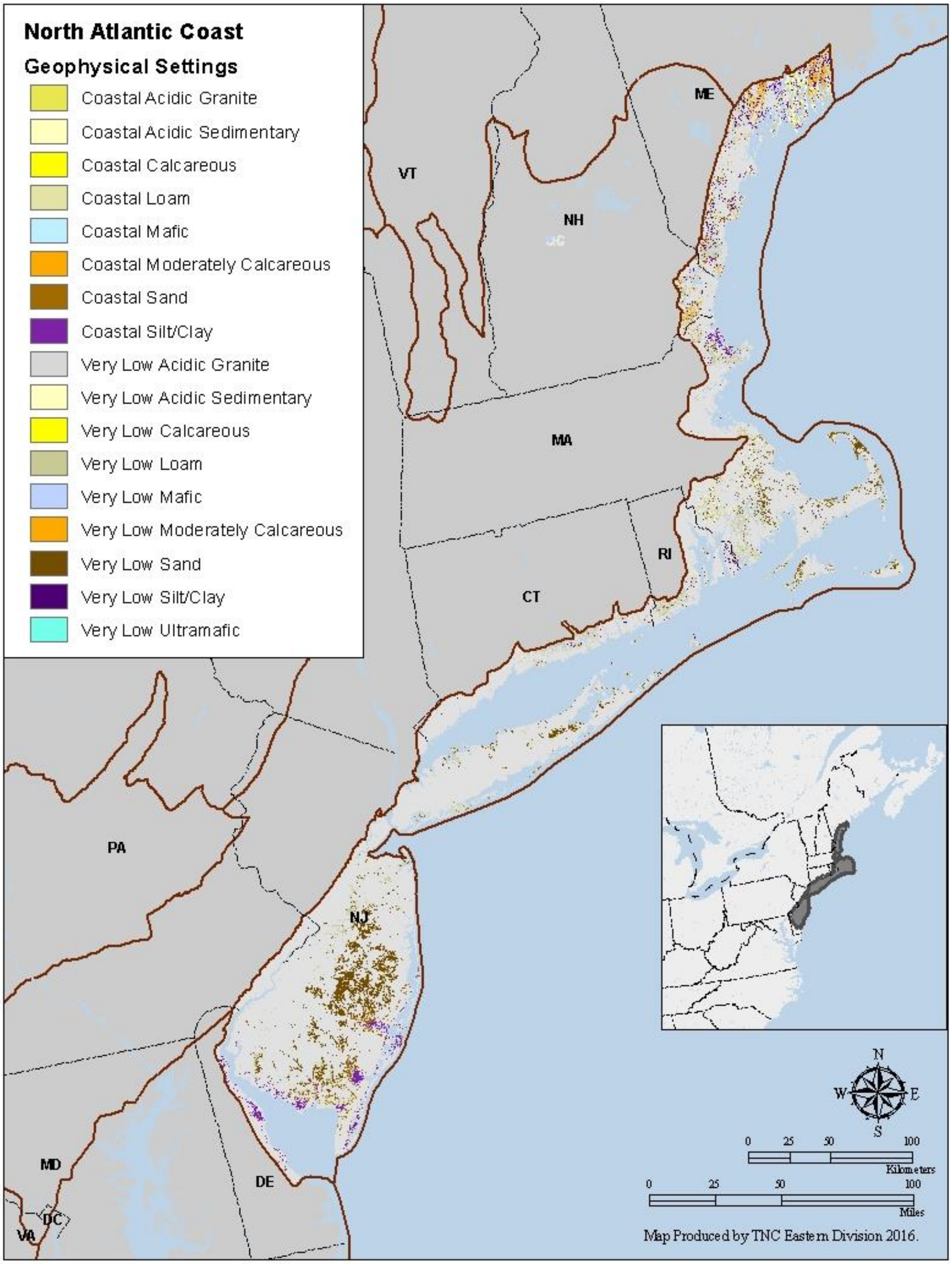


Figure 4.20 North Atlantic Coast Settings in Areas Assessed as assessed as most resilient. The map shows only the grid cells that score above the mean for estimated resilience as compared to others in in their ecoregion; each high scoring grid cell is colored based on its corresponding geophysical setting. This map reveals how the settings are reflected in the resilience scores.



South-Atlantic Coastal Plain

The South Atlantic Coastal Plain ecoregion encompasses more than 23 million acres across three states, including the southern portion of South Carolina, southeastern Georgia and northeastern Florida. The ecoregion is bordered to the east by the Atlantic Ocean, and to the northwest by the Fall Line (a geologically distinct zone corresponding to the interface between the relatively flat coastal plain and the topographically varied Piedmont). It is bordered on the northeast by the Mid-Atlantic Coastal Plain, on the west by the East Gulf Coastal Plain, on the south by the Florida Peninsula and on the north by the Piedmont.

Though changes in topography may be slight, the South Atlantic Coastal Plain is extremely rich in both species diversity and ecological community diversity. The many ecological systems found in the South Atlantic Coastal Plain ecoregion range from fall-line sandhills to rolling longleaf pine uplands to wet pine flatwoods; from small streams to large river systems to rich estuaries; from isolated depression wetlands to Carolina bays to the Okefenokee Swamp. Other ecological systems in the ecoregion include maritime forests on barrier islands, pitcher plant seepage bogs and Altamaha grit (sandstone) outcrops. (Text adopted from TNC ecoregional plan).

Read more at:
https://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/edc/reportsdata/terrestrial/ecoregional/sacp/Pages/default.aspx.

Figure 4.21 South Atlantic Coastal Plain Resilience Estimates. Areas in green score above average and are estimated to be more resilient based for their geophysical setting, based on landscape diversity and local connectedness. Areas in yellow are average. Areas in brown are below average and are estimated to be vulnerable to climate change and other factors.

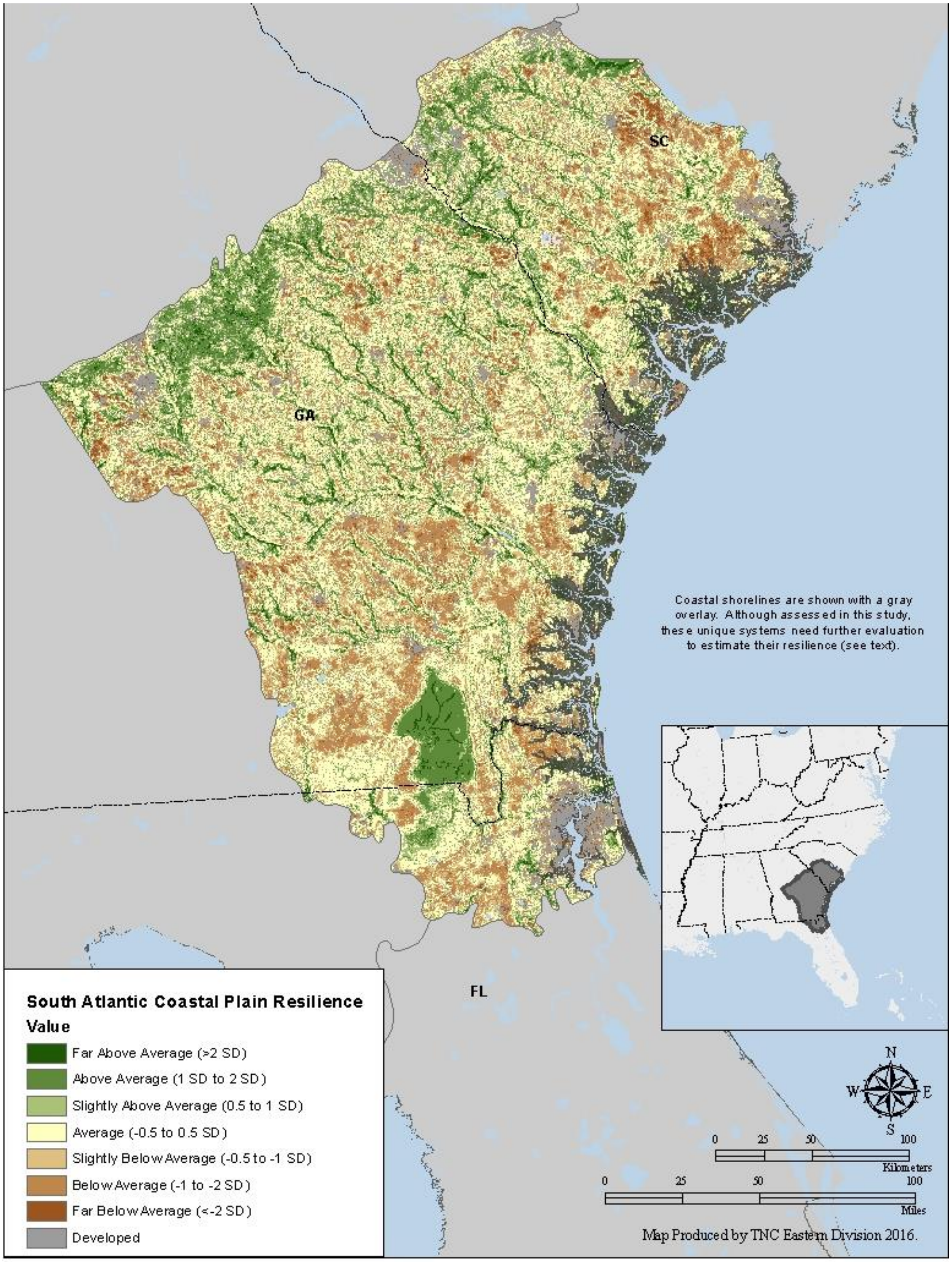


Figure 4.22 South Atlantic Coastal Plain Settings. The geophysical settings in this ecoregion that were created by combining an elevation zone and a geology class. These are the settings that are used for the stratification by setting for this ecoregion.

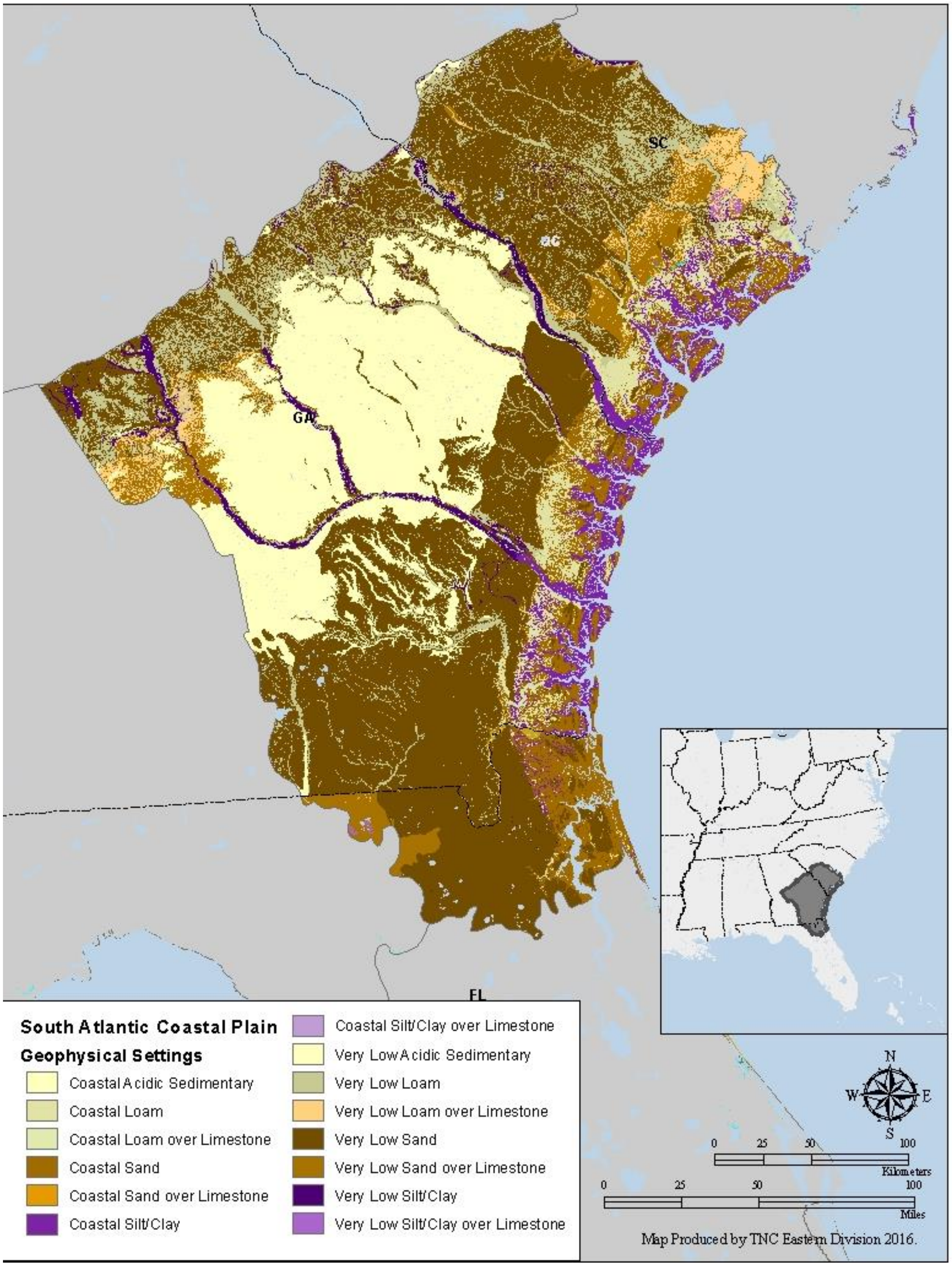
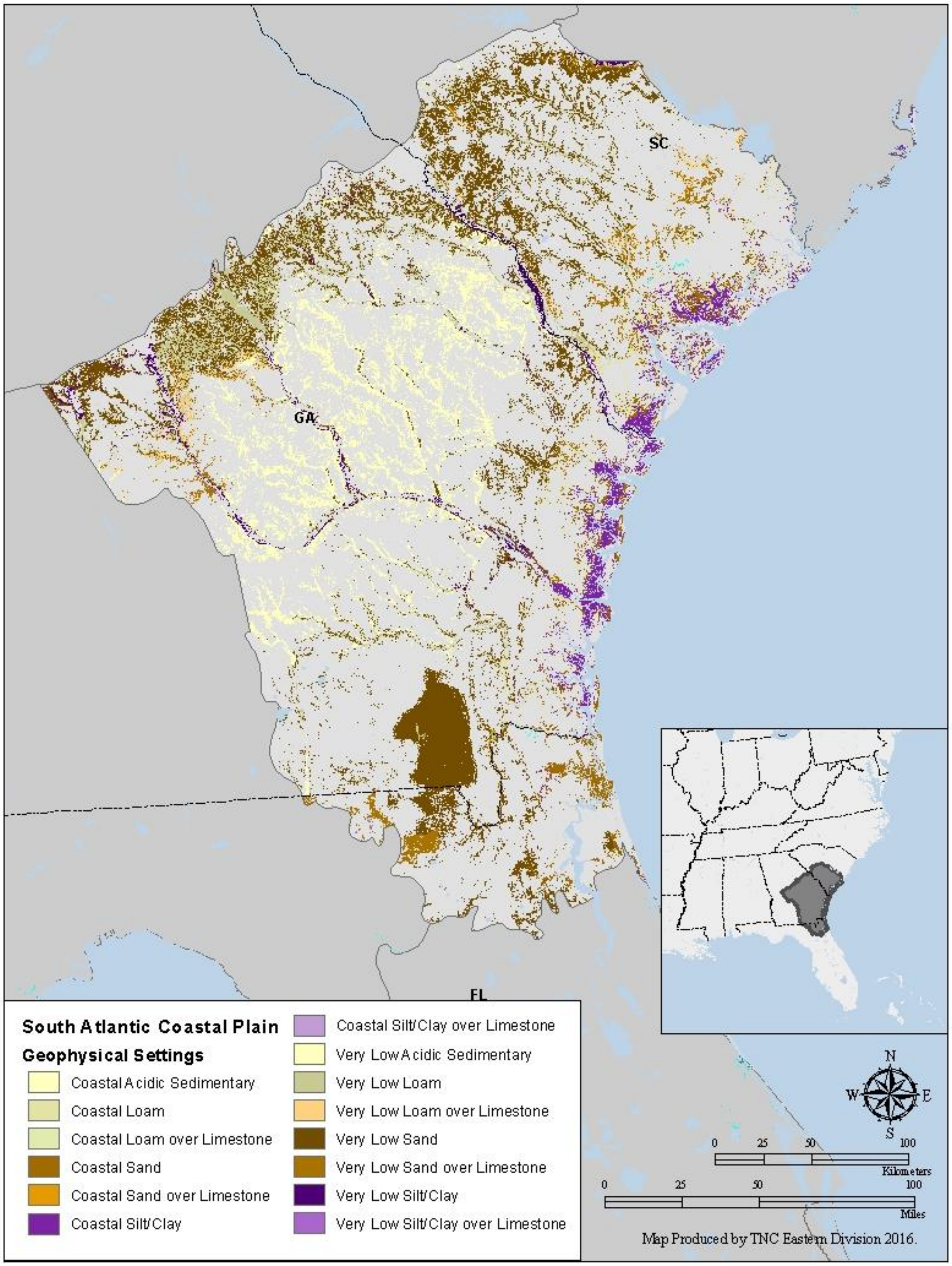


Figure 4.23 South Atlantic Coastal Plain Settings assessed as most resilient. The map shows only the grid cells that score above the mean for estimated resilience as compared to others in in their ecoregion; each high scoring grid cell is colored based on its corresponding geophysical setting. This map reveals how the settings are reflected in the resilience scores.



Tropical Florida

Tropical Florida is a landscape under siege. It is also a landscape of great contrasts between highly fragmented upland terrestrial ecological communities/systems and vast expanses of herbaceous wetlands. The tip of the Florida peninsula that comprises the Tropical Florida Ecoregion is surrounded by the Gulf of Mexico to its west, the Atlantic Ocean (and warm Gulf Stream) to its east and the Florida Straits that divide Florida from the Bahamas and the Caribbean island of Cuba to its south. The Florida Keys – an archipelago of limestone islands clothed in lush vegetation heavily influenced by the adjacent tropics – arc south-southwestward from near the southeastern edge of the peninsula. Biscayne Bay, a once productive estuary that is now enveloped by metropolitan Miami, lies along the southeastern coast of the ecoregion, while dense forests of mangroves dominate the Ten Thousand Islands area along a still nearly inaccessible portion of the southwestern coastline. Florida Bay, a productive fishing ground for pink shrimp, stone crab, and a variety of sportfish lies between (and is partially encompassed by) Everglades National Park and the Florida Keys.

The Tropical Florida Ecoregion has a mild climate with temperatures typically ranging between 47 degrees Fahrenheit and 90 degrees Fahrenheit during an "average" year. The entire ecoregion is characterized by relatively high rainfall averaging 60 inches per year (although it is somewhat less in the Florida Keys). The species and communities are shaped by several dominant forces: pronounced wet and dry seasons, once frequent fires that swept unimpeded for miles across the landscape, a high water table, mucky or peaty soils that have developed in numerous depressional features in a limestone-based substrate, a relatively flat terrain where even slight changes in topography can dramatically influence the kind of community that develops, the recent geology of the region, the proximity to the tropics and Gulf Stream, and catastrophic large-scale disturbance events in the form of hurricanes (Myers and Ewel, 1990). (Text adopted from TNC ecoregional plan).

Read more at:
https://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/edc/reportsdata/terrestrial/ecoregional/tfl/Pages/default.aspx.

Figure 4.24 Tropical Florida Resilience Estimates. Areas in green score above average and are estimated to be more resilient based for their geophysical setting, based on landscape diversity and local connectedness. Areas in yellow are average. Areas in brown are below average and are estimated to be vulnerable to climate change and other factors.

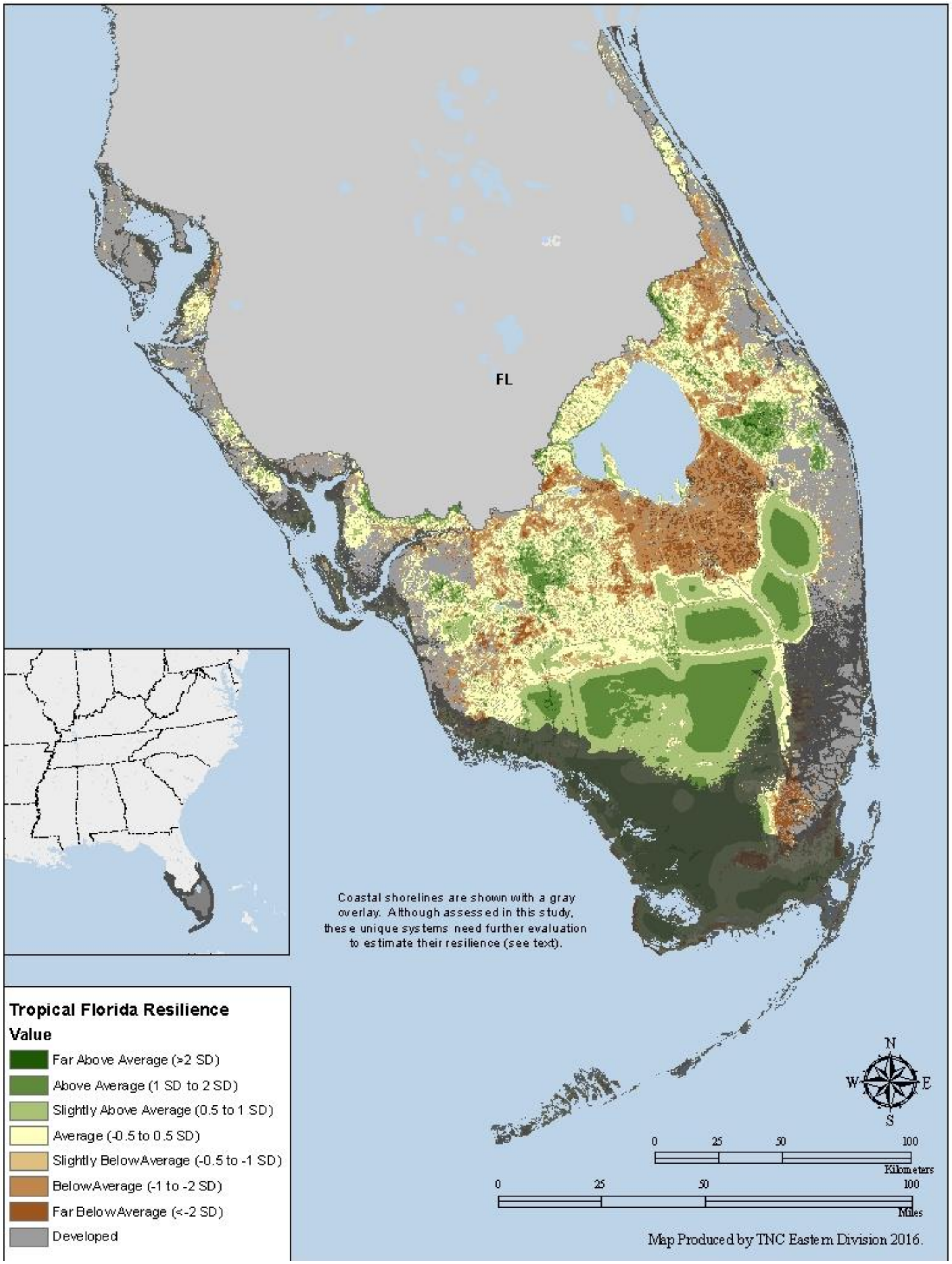


Figure 4.25 Tropical Florida Settings. The geophysical settings in this ecoregion that were created by combining an elevation zone and a geology class. These are the settings that are used for the stratification by setting for this ecoregion.

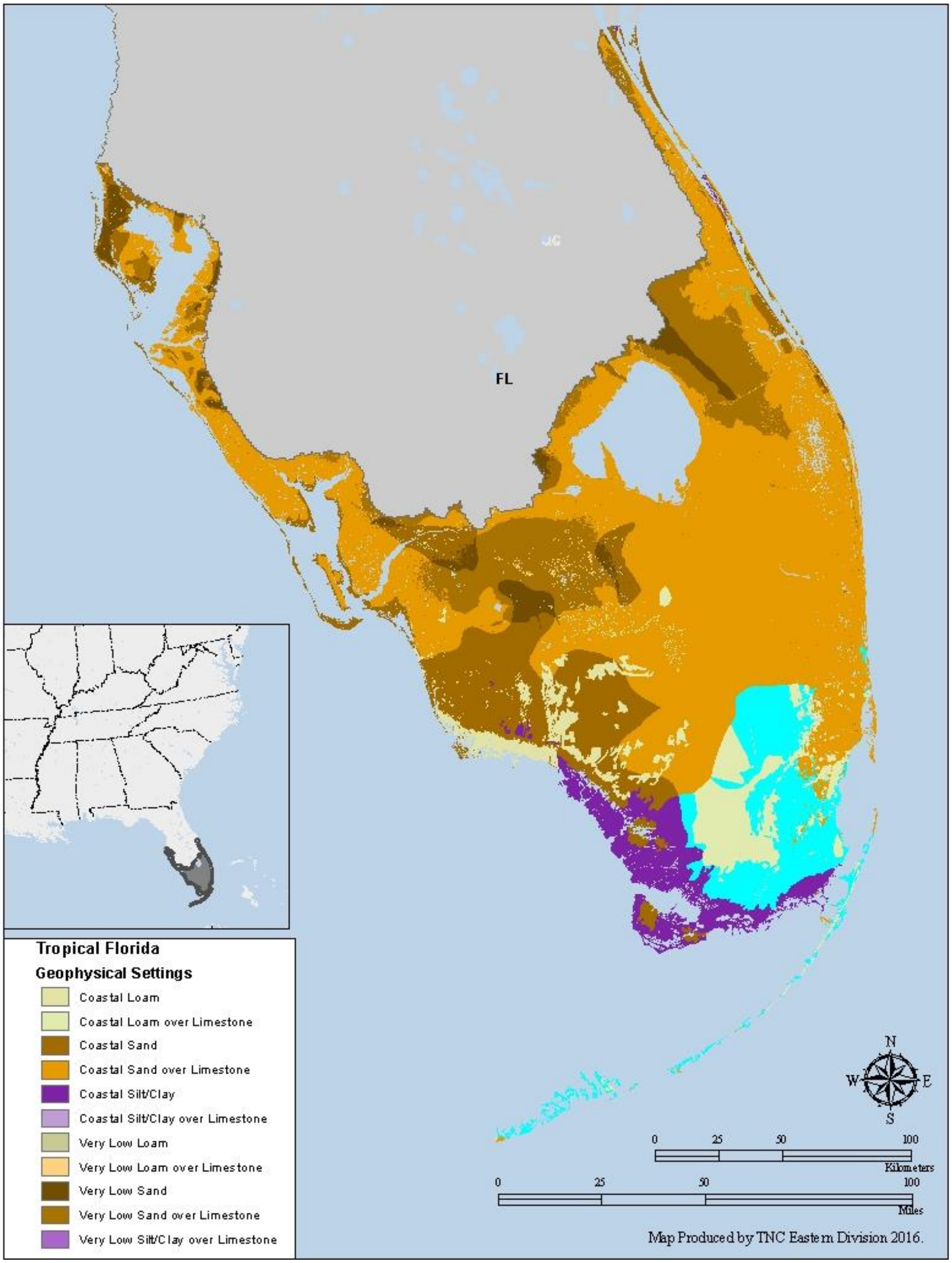
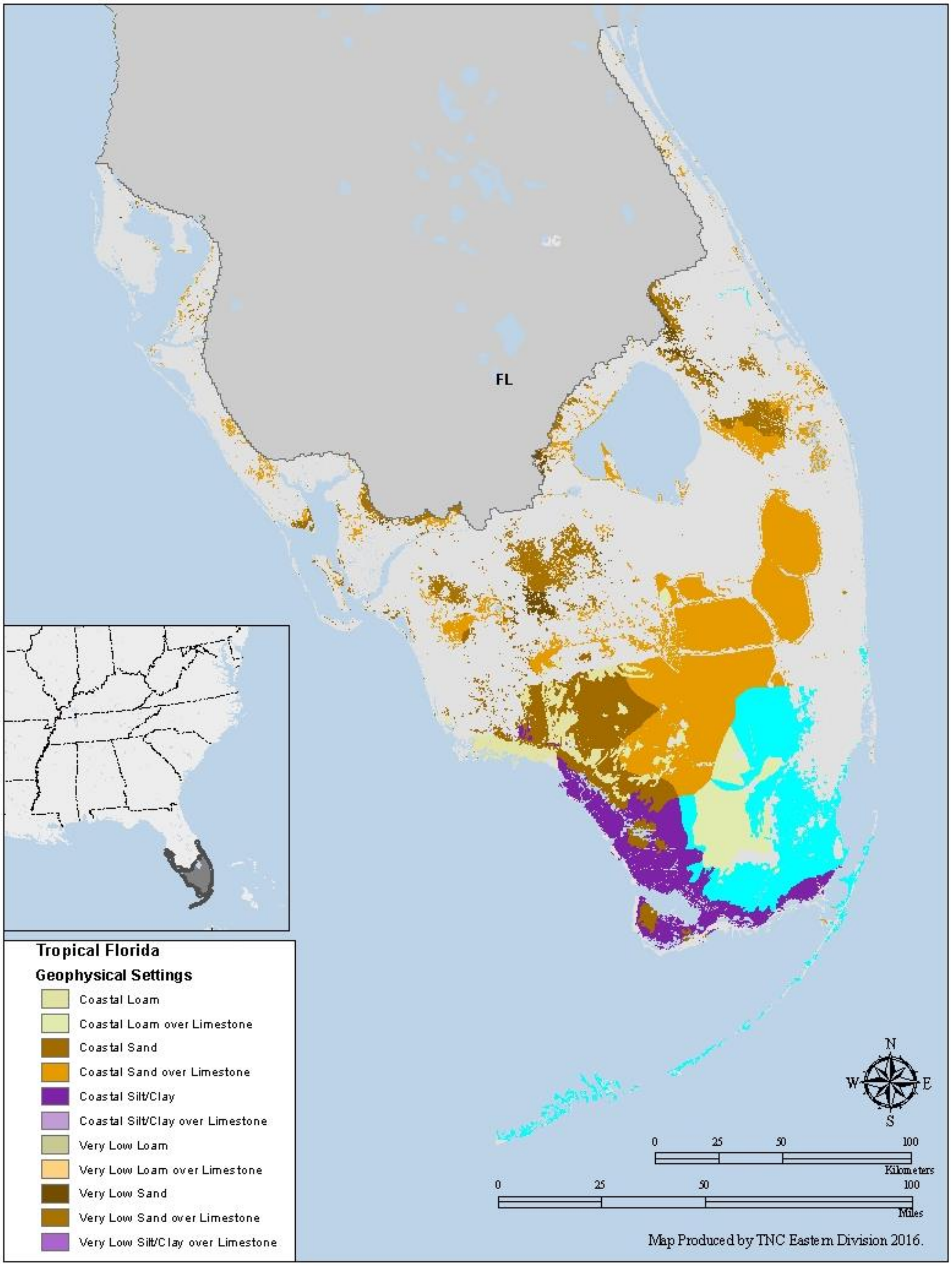


Figure 4.26 Tropical Florida Settings in Areas assessed as most resilient. The map shows only the grid cells that score above the mean for estimated resilience as compared to others in in their ecoregion; each high scoring grid cell is colored based on its corresponding geophysical setting. This map reveals how the settings are reflected in the resilience scores.



Upper East Gulf Coastal Plain

The Upper East Gulf Coastal Plain ecoregion encompasses 33,861,051 acres or 52,908 square miles. The region ranges from southern Illinois, western Kentucky and Tennessee, throughout much of Mississippi, east to Alabama and a limited area of Georgia, and southeastern Louisiana. The region is bounded on the west by the Mississippi River Alluvial Plain and on the north by the Ohio River, and Tennessee River (now Kentucky Lake). The eastern margin occurs at the contact point with older rocks of the Piedmont and Southern Ridge and Valley. The southern margin of the region is perhaps the least obvious on the ground, but represents the boundary between the middle and outer coastal plain of Keys et al. (1995). In contrast to the outer coastal plain, this region has more rugged terrain and hilly topography (McWilliams 1992, Keys et al. 1995). In addition, the southern boundary approximates the range limits of major potential natural vegetation types of Küchler (1964), oak-hickory-pine to the north, and southern mixed hardwood forests to the south. (Text adopted from TNC ecoregional plan).

Read more at:

http://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/edc/reportsdata/terrestrial/ecoregional/uegcp/Pages/default.aspx

Figure 4.27 Upper East Gulf Coastal Plain Resilience Estimates. Areas in green score above average and are estimated to be more resilient based for their geophysical setting, based on landscape diversity and local connectedness. Areas in yellow are average. Areas in brown are below average and are estimated to be vulnerable to climate change and other factors.

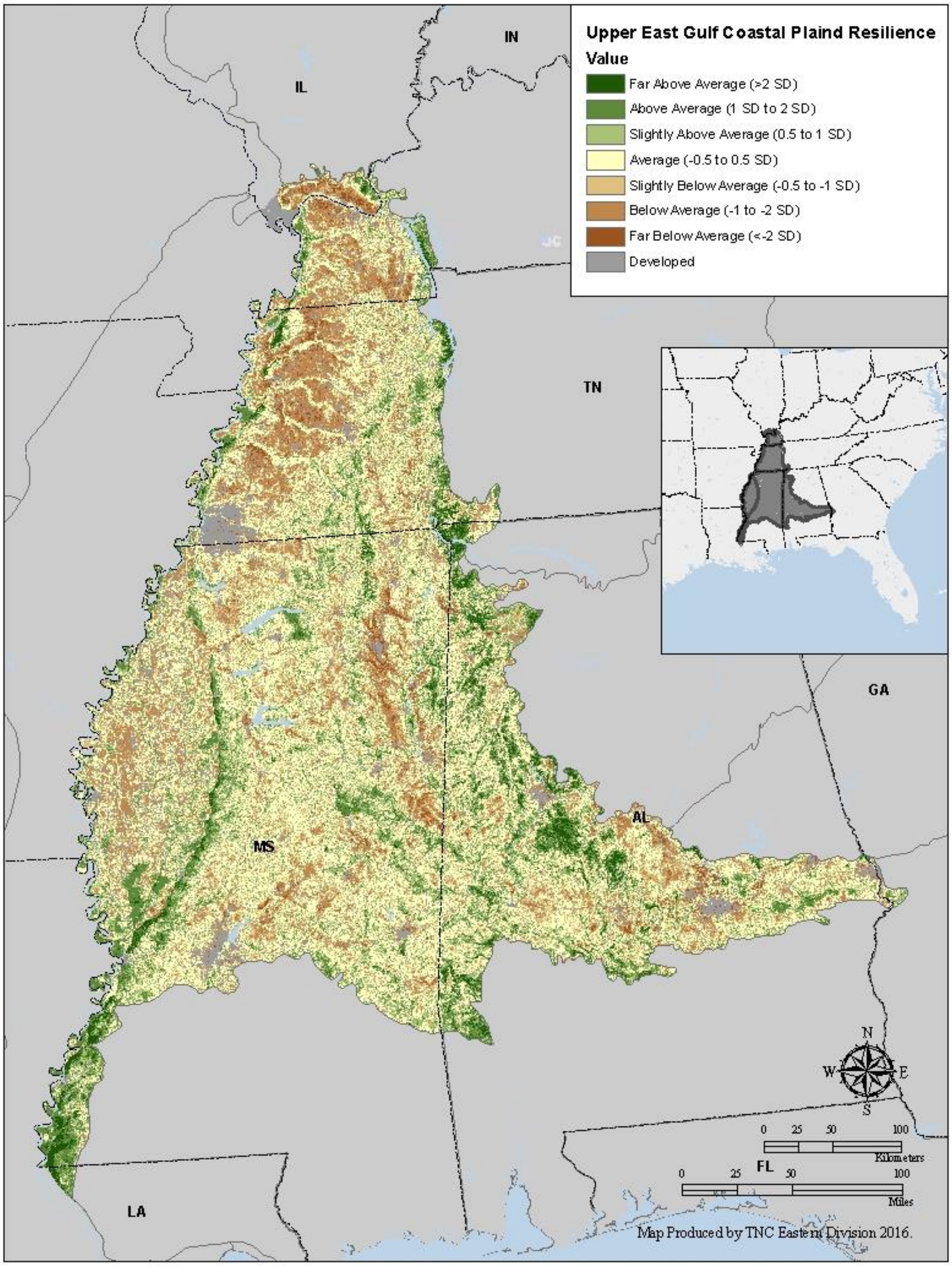


Figure 4.28 Upper East Gulf Coastal Plain Settings. The geophysical settings in this ecoregion that were created by combining an elevation zone and a geology class. These are the settings that are used for the stratification by setting for this ecoregion.

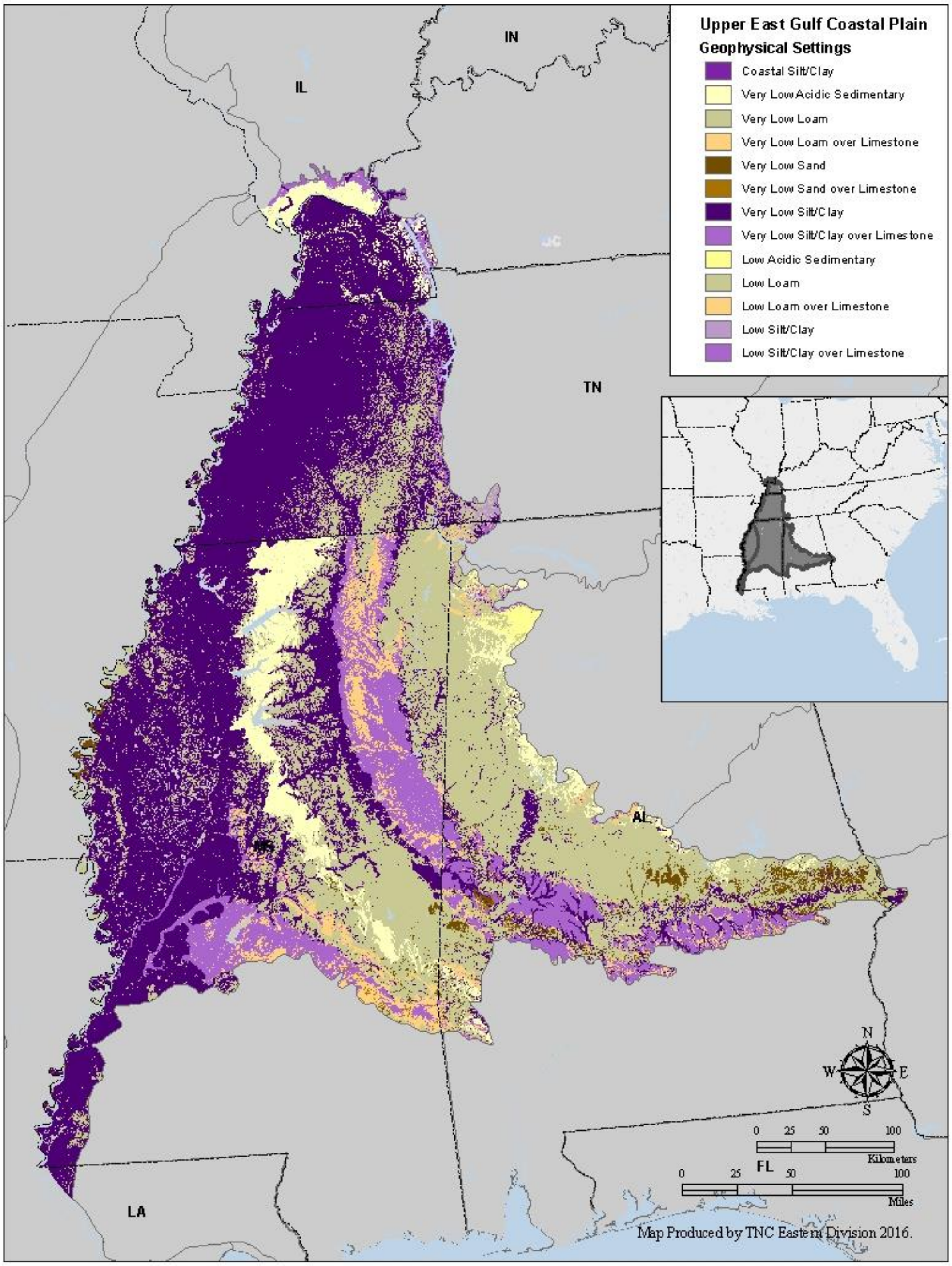
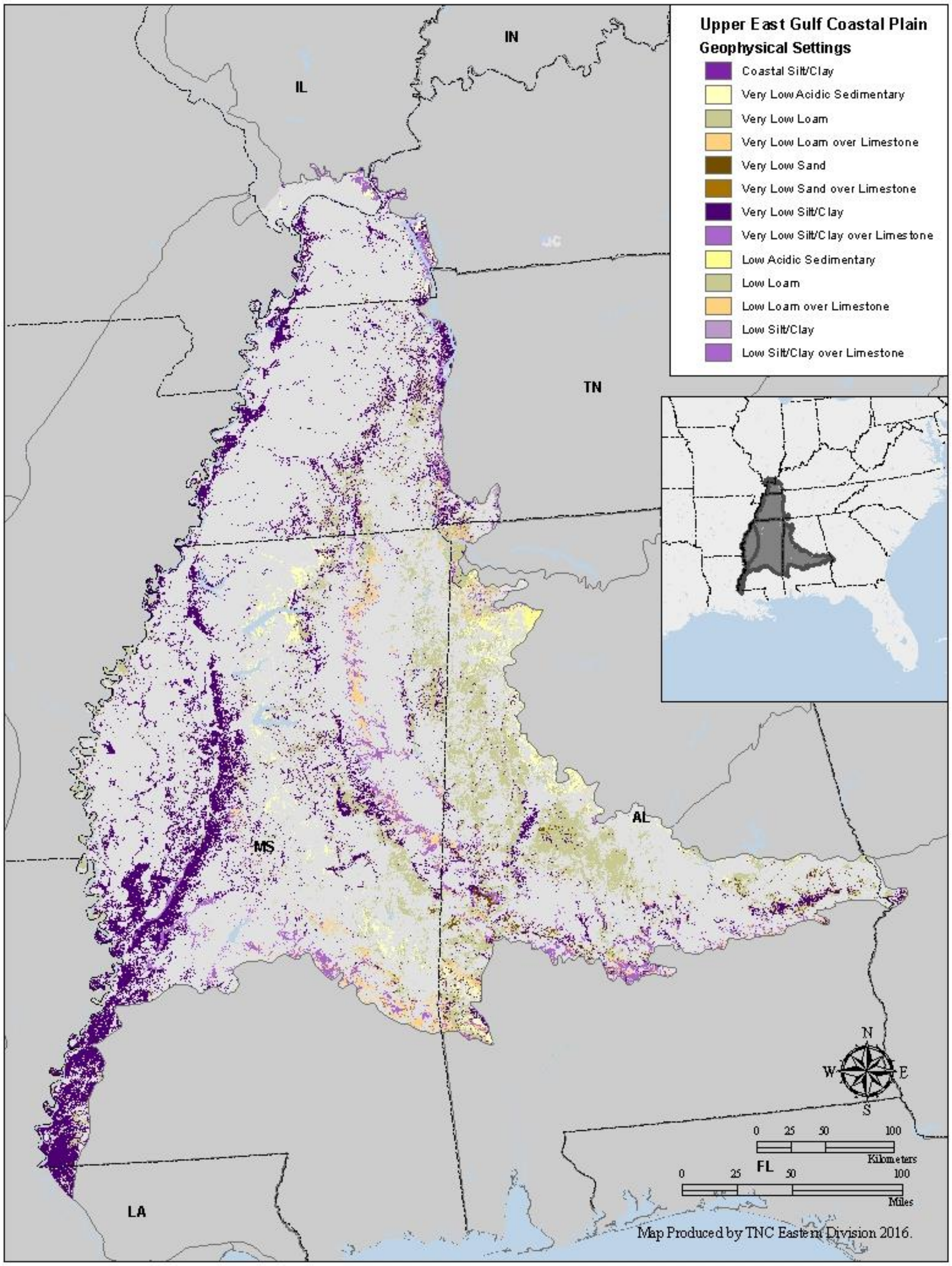


Figure 4.29 Upper East Gulf Coastal Plain Settings assessed as most resilient. The map shows only the grid cells that score above the mean for estimated resilience as compared to others in in their ecoregion; each high scoring grid cell is colored based on its corresponding geophysical setting. This map reveals how the settings are reflected in the resilience scores.



MOUNTAIN ECOREGIONS

Central Appalachian Forest

The Central Appalachian ecoregion is a mountainous region running south from central PA, across MD and WV, and ending in VA. The region forms a critical connecting link between the Northern and Southern Appalachians, and it is a global center of endemism in its own right. Of all the ecoregions in the Northeast and Mid-Atlantic, the Central Appalachians support the highest diversity of species; an estimated 7,452 plants and animals (not counting microscopic species). The rich diversity is directly associated with the diversity of geophysical settings found in the region, including all nine geology classes and elevation up to 4861 feet. The geophysical diversity is arranged in complex formations that include high plateaus in the Allegheny Mountains, folded and faulted parallel ridges, a large belt of folded limestone (the Great Valley) and uplifted plutonic mountains in the northern Blue Ridge. This region is primarily forested with oak-heath forest, mixed mesophytic forest and oak-hickory-ash forest forming the dominant matrix. High elevation areas contain red spruce rocky summits and swamps, talus slope woodlands, shale barrens, ridge top pitch pine barrens, and dwarf red oak communities. Lowlands contain a variety of floodplain forests, river-shore grasslands, and forested coves. Limestone areas support calcareous seepage fens, unique open glades and woodlands, and a wealth of caves. (Text adopted from TNC ecoregional plan).

Read more at:
https://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/edc/reportsdata/terrestrial/ecoregional/cap/Pages/default.aspx

Figure 4.30 Central Appalachian Forest Resilience Estimates. Areas in green score above average and are estimated to be more resilient based for their geophysical setting, based on landscape diversity and local connectedness. Areas in yellow are average. Areas in brown are below average and are estimated to be vulnerable to climate change and other factors.

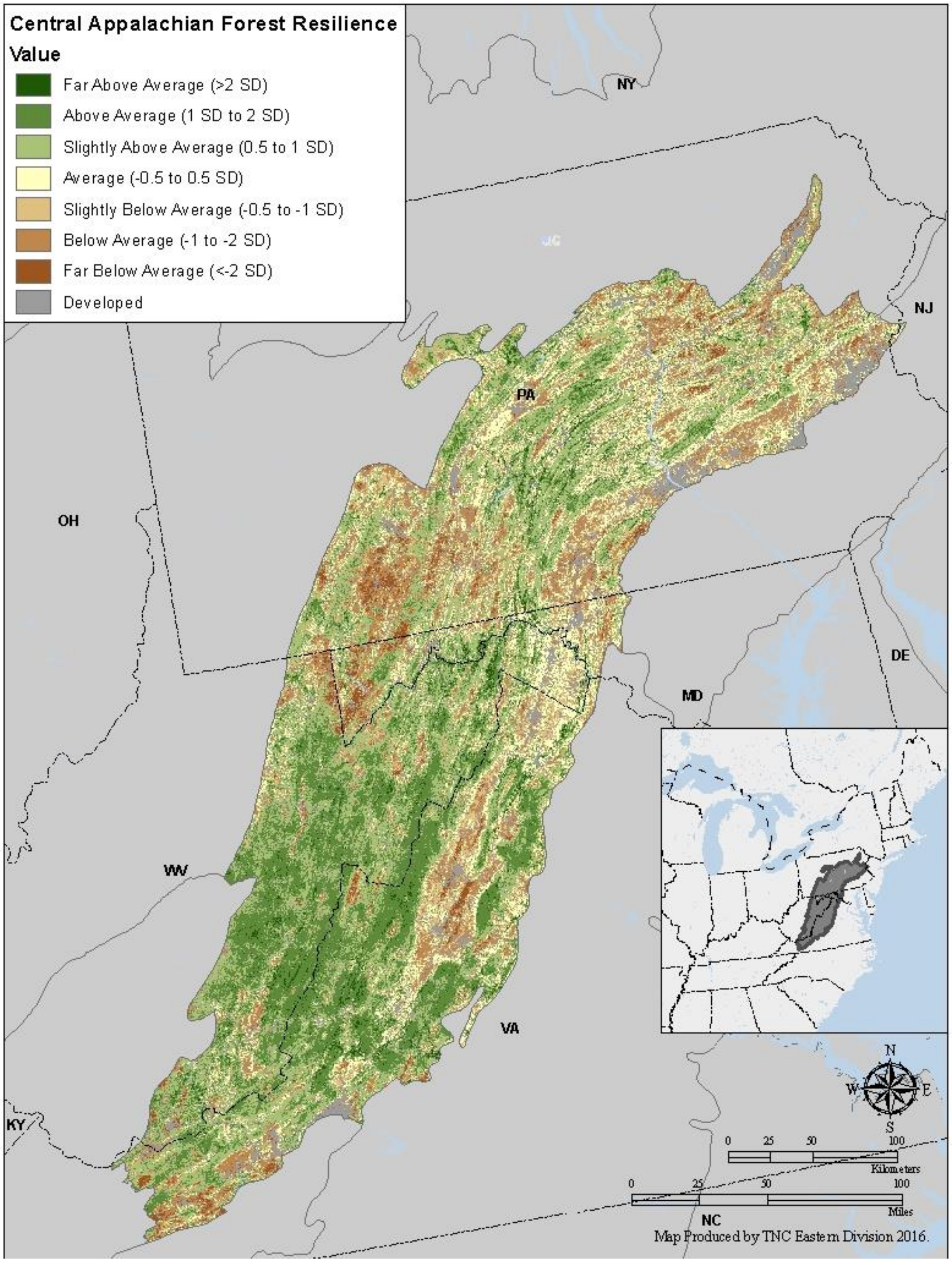


Figure 4.31 Central Appalachian Forest Settings. The geophysical settings in this ecoregion that were created by combining an elevation zone and a geology class. These are the settings that are used for the stratification by setting for this ecoregion.

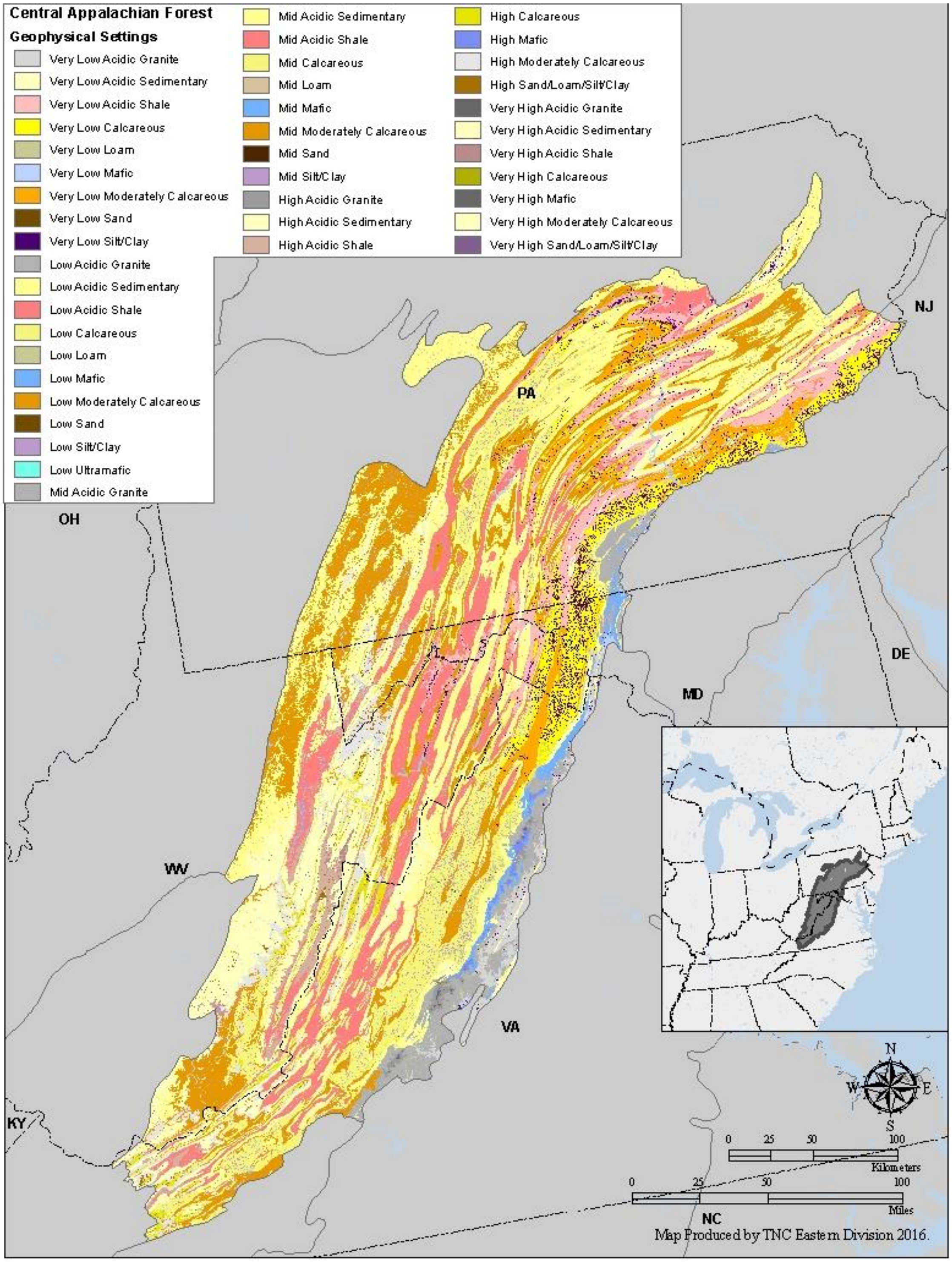
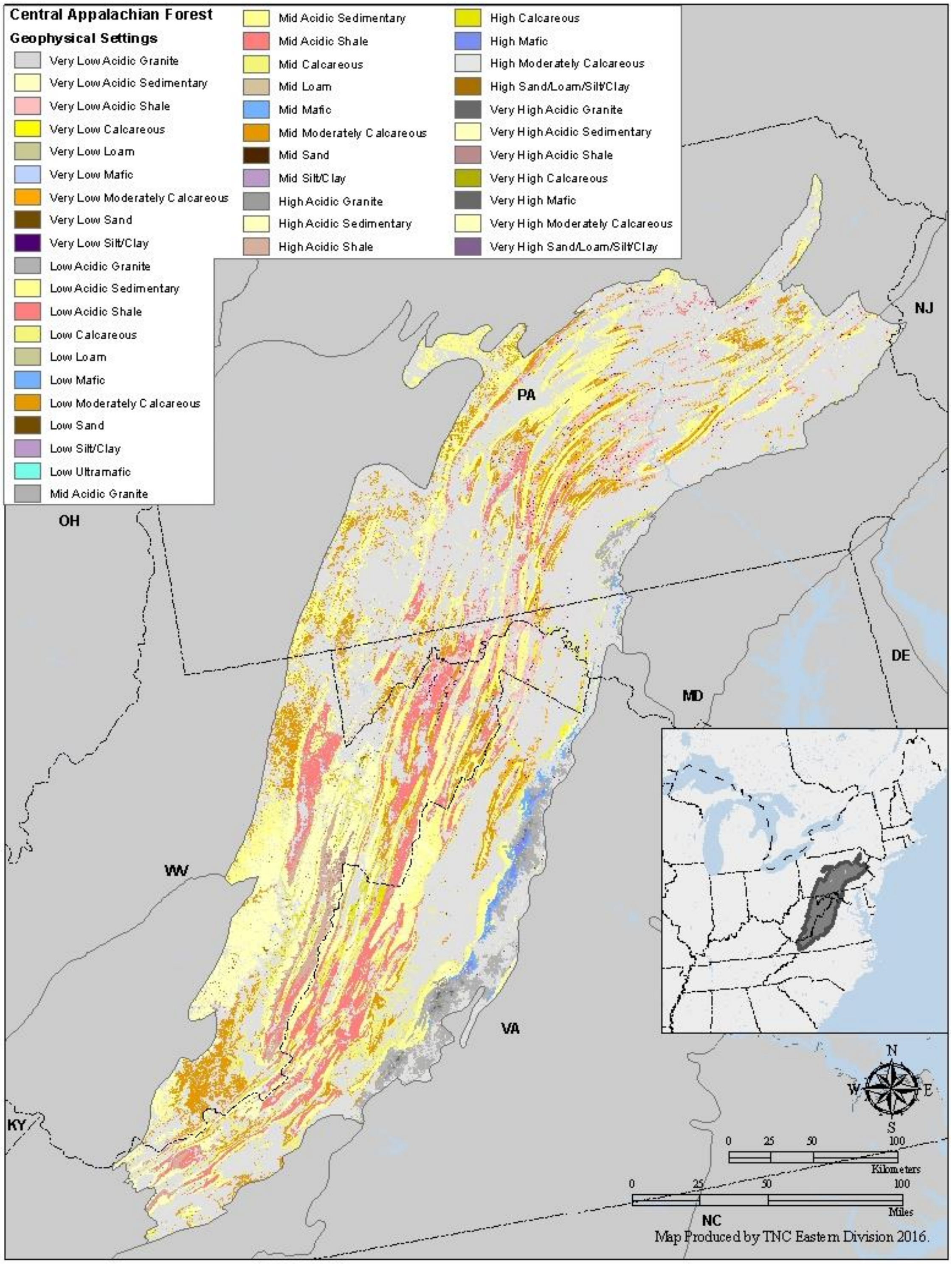


Figure 4.32 Central Appalachian Forest Settings assessed as most resilient. The map shows only the grid cells that score above the mean for estimated resilience as compared to others in in their ecoregion; each high scoring grid cell is colored based on its corresponding geophysical setting. This map reveals how the settings are reflected in the resilience scores.



Cumberlands and Southern Ridge & Valley

The Cumberlands and Southern Ridge & Valley Ecoregion is a highly variable landscape with a complex geologic history. Stretching over 500 miles from northern Alabama to southern West Virginia, the ecoregion encompasses approximately 37 million acres in portions of six states. Overall, the CSRV is bordered by six other ecoregions: the Interior Low Plateau, the Western Allegheny Plateau, the Central Appalachian Forest, the Southern Blue Ridge, the Piedmont, and the Upper East Gulf Coastal Plain.

An extreme physiographic divide exists between the Cumberlands and the Southern Ridge & Valley portions of the ecoregion. The Cumberlands section is composed of a high plateau and low mountains, which represent the western-most extension of the Southern Appalachian mountain chain. In contrast, the Southern Ridge & Valley is characterized by a series of narrow valleys bounded by high ridges. Primarily, the topography of the Southern Ridge & Valley separates the Cumberlands from the higher elevations of the Southern Blue Ridge Ecoregion to the east.

Read more at:
https://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/edc/reportsdata/terrestrial/ecoregional/cp/Pages/default.aspx

Figure 4.33 Cumberlands and Southern Ridge & Valley Resilience Estimates. Areas in green score above average and are estimated to be more resilient based for their geophysical setting, based on landscape diversity and local connectedness. Areas in yellow are average. Areas in brown are below average and are estimated to be vulnerable to climate change and other factors.

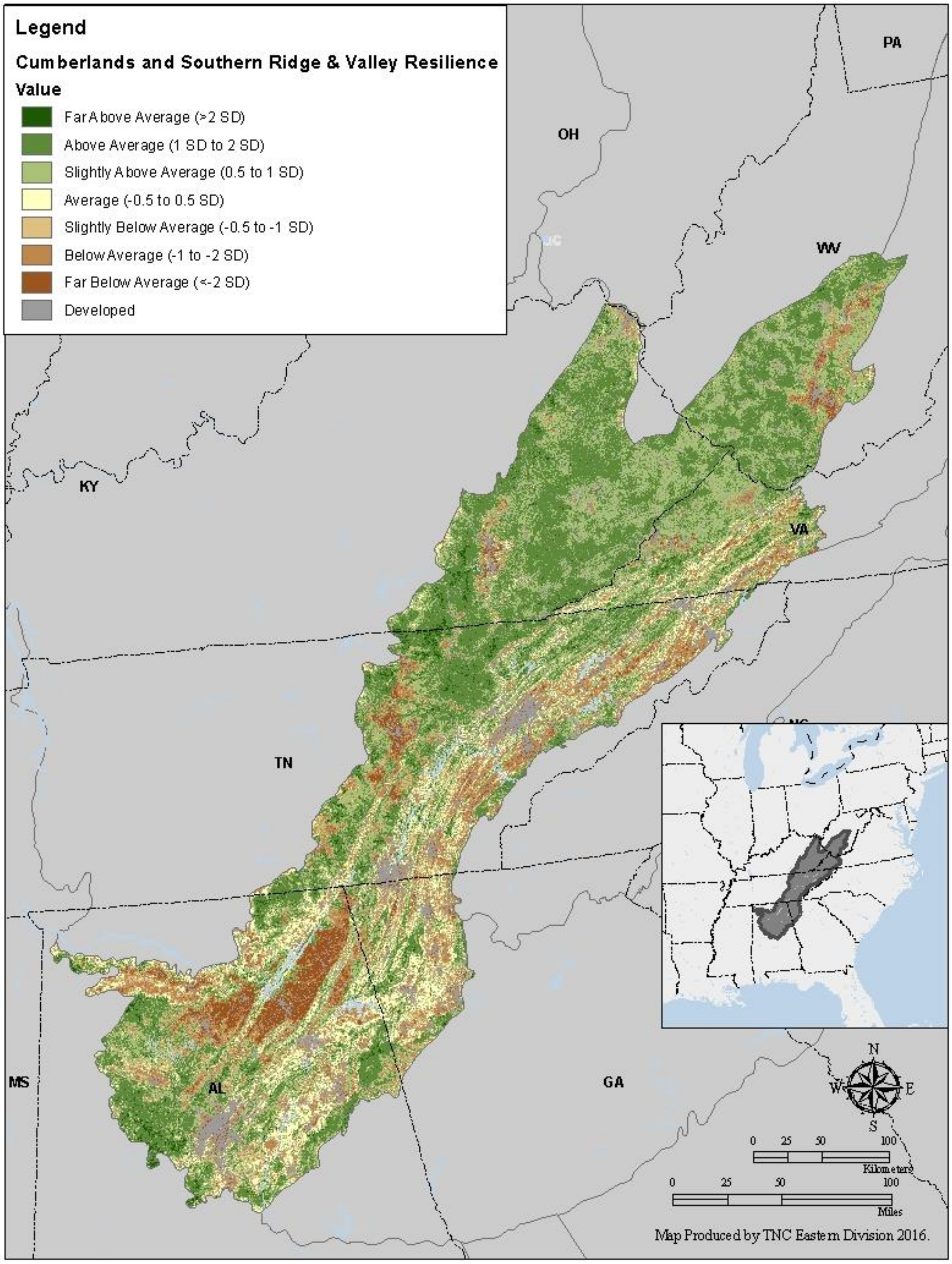


Figure 4.34 Cumberlands and Southern Ridge & Valley Settings. The geophysical settings in this ecoregion that were created by combining an elevation zone and a geology class. These are the settings that are used for the stratification by setting for this ecoregion.

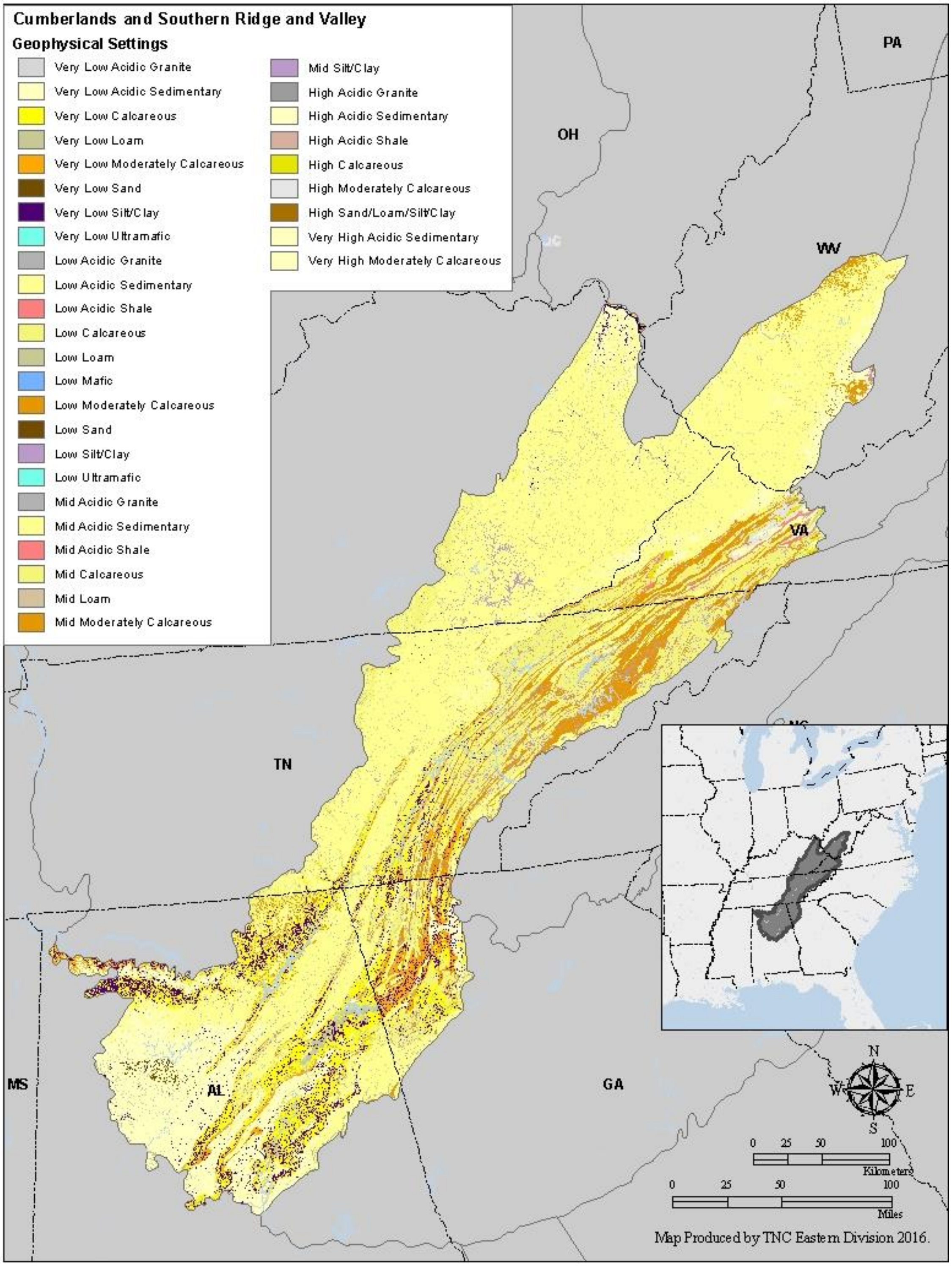
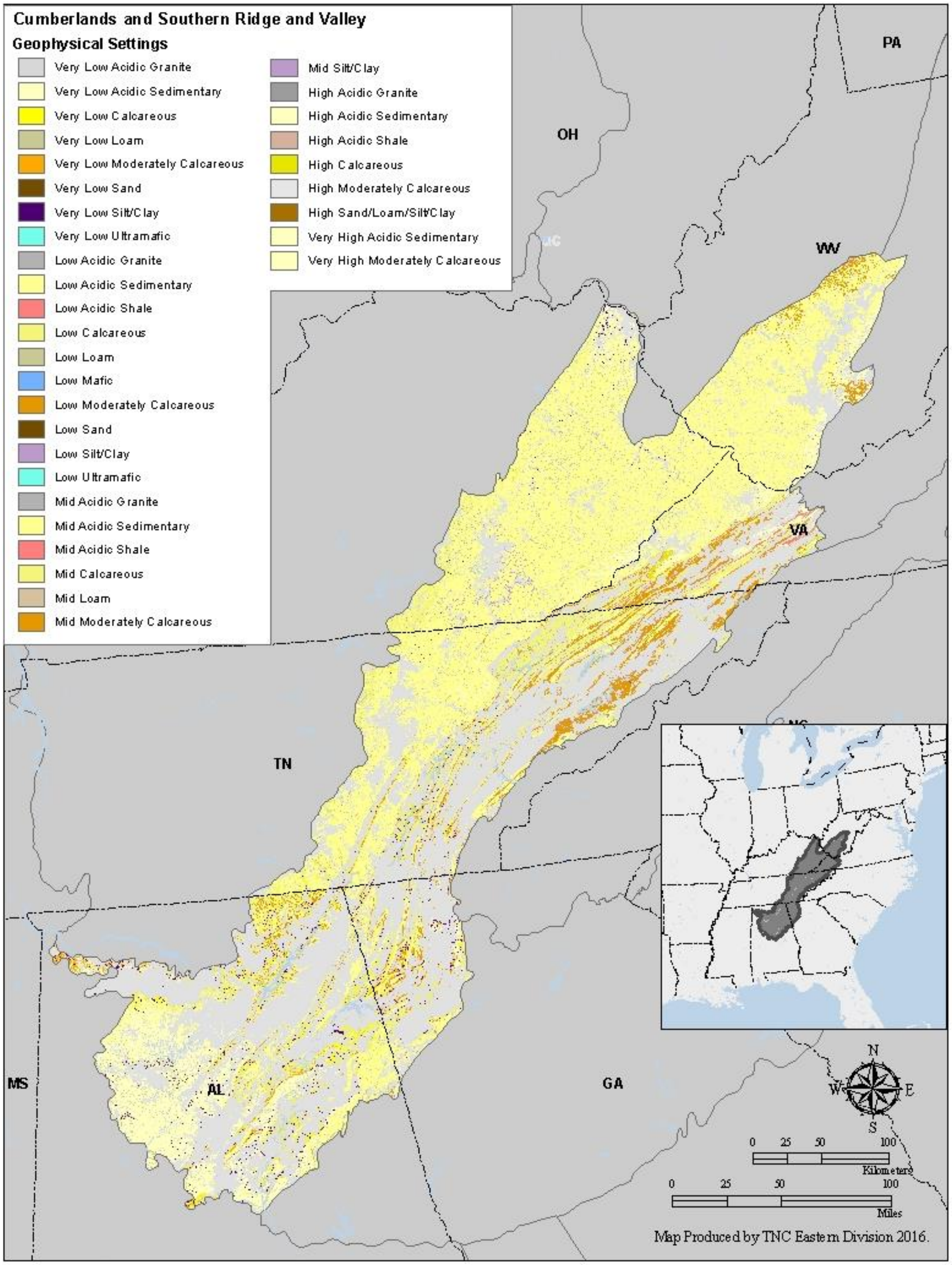


Figure 4.35 Cumberlands and Southern Ridge & Valley Settings assessed as most resilient. The map shows only the grid cells that score above the mean for estimated resilience as compared to others in in their ecoregion; each high scoring grid cell is colored based on its corresponding geophysical setting. This map reveals how the settings are reflected in the resilience scores.



High Allegheny Plateau

The High Allegheny Plateau is a wide upland plateau that includes low mountains (Catskills), high hills (Allegheny Plateau) and steep ridges (Kittatinny and Shawangunks) in southern NY, northern PA, and northwest NJ. Glaciated sections primarily consist of till soils while the un-glaciated regions are mostly sandy clays. The region is fairly simple in underlying geology, composed largely of shale and other sedimentary rocks, and it has a correspondingly low diversity of species (estimated 3196 plants and animals). However, it has large intact forest areas with some of the highest and most concentrated EastWest flow patterns in the region.

This ecoregion is primarily forested with oak-heath forests, maple-beech-birch northern hardwoods, hemlock-white pine and oak-hickory-ash forest forming the dominant matrix type. Other typical communities include hemlock swamps, leather leaf bogs and blueberry bogs. (Text adopted from TNC ecoregional plan).

Read more at:
https://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/edc/reportsdata/terrestrial/ecoregional/hap/Pages/default.aspx

Figure 4.36 High Allegheny Plateau Resilience Estimates. Areas in green score above average and are estimated to be more resilient based for their geophysical setting, based on landscape diversity and local connectedness. Areas in yellow are average. Areas in brown are below average and are estimated to be vulnerable to climate change and other factors.

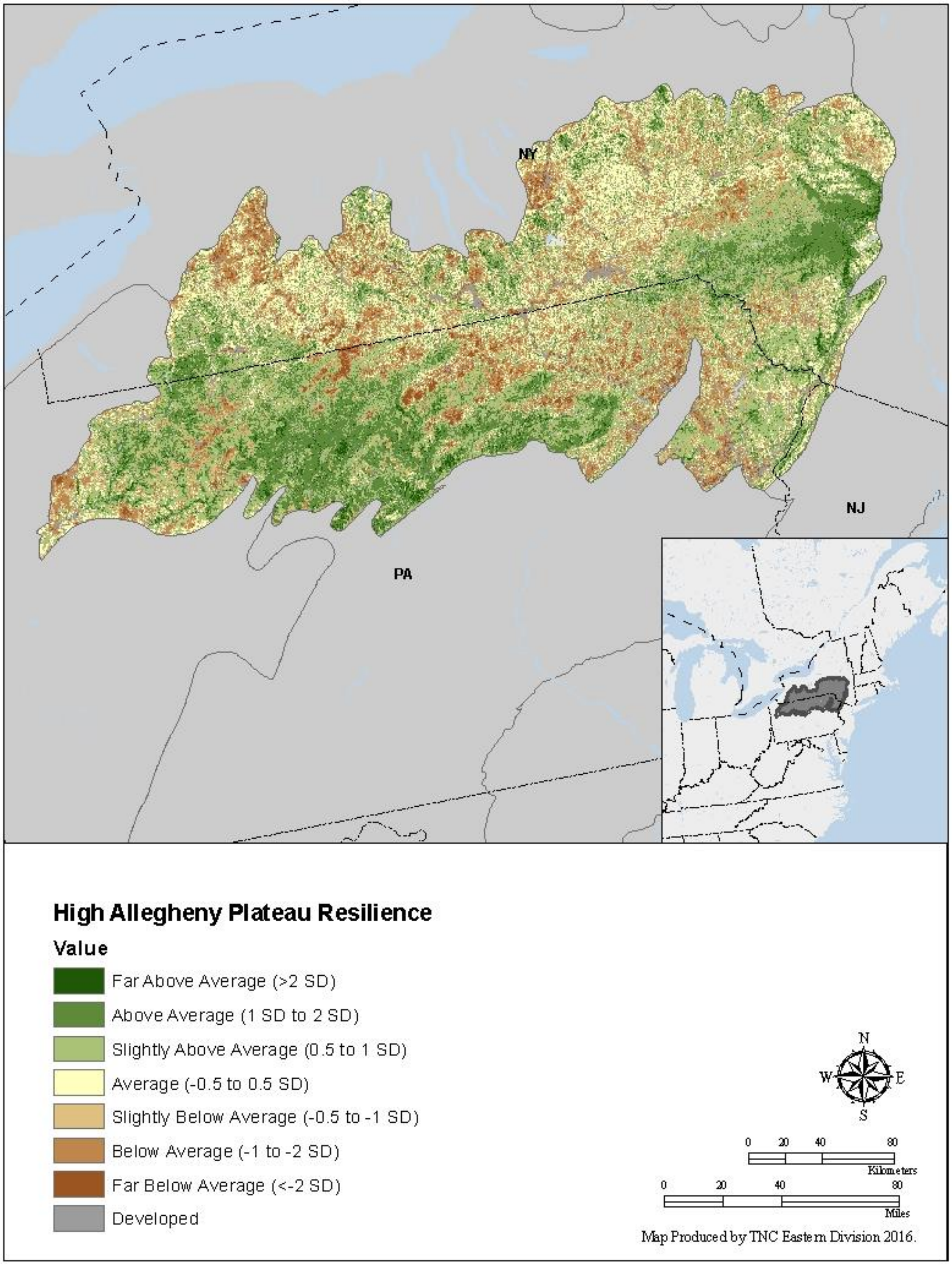


Figure 4.37 High Allegheny Plateau Settings. The geophysical settings in this ecoregion that were created by combining an elevation zone and a geology class. These are the settings that are used for the stratification by setting for this ecoregion.

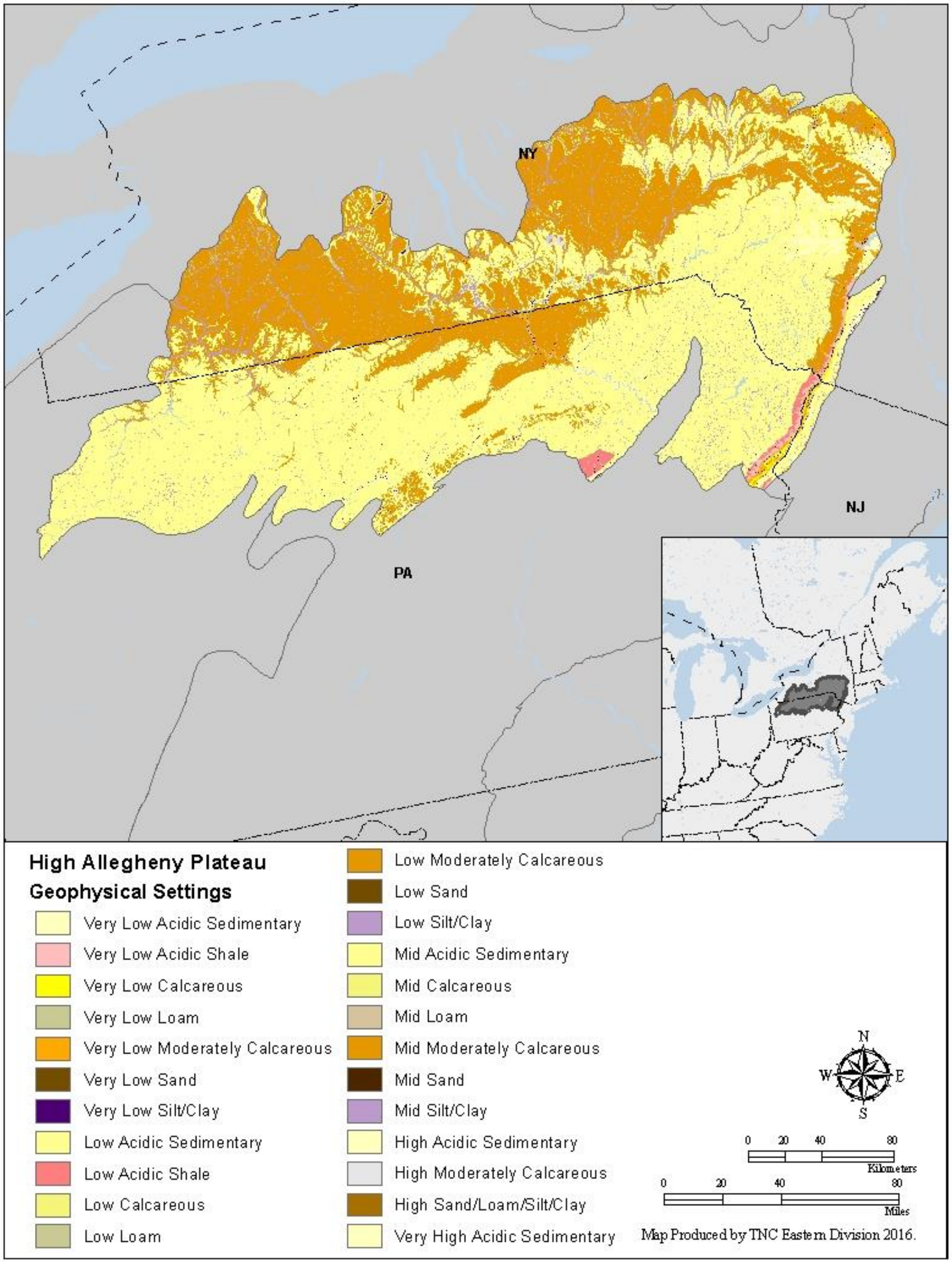
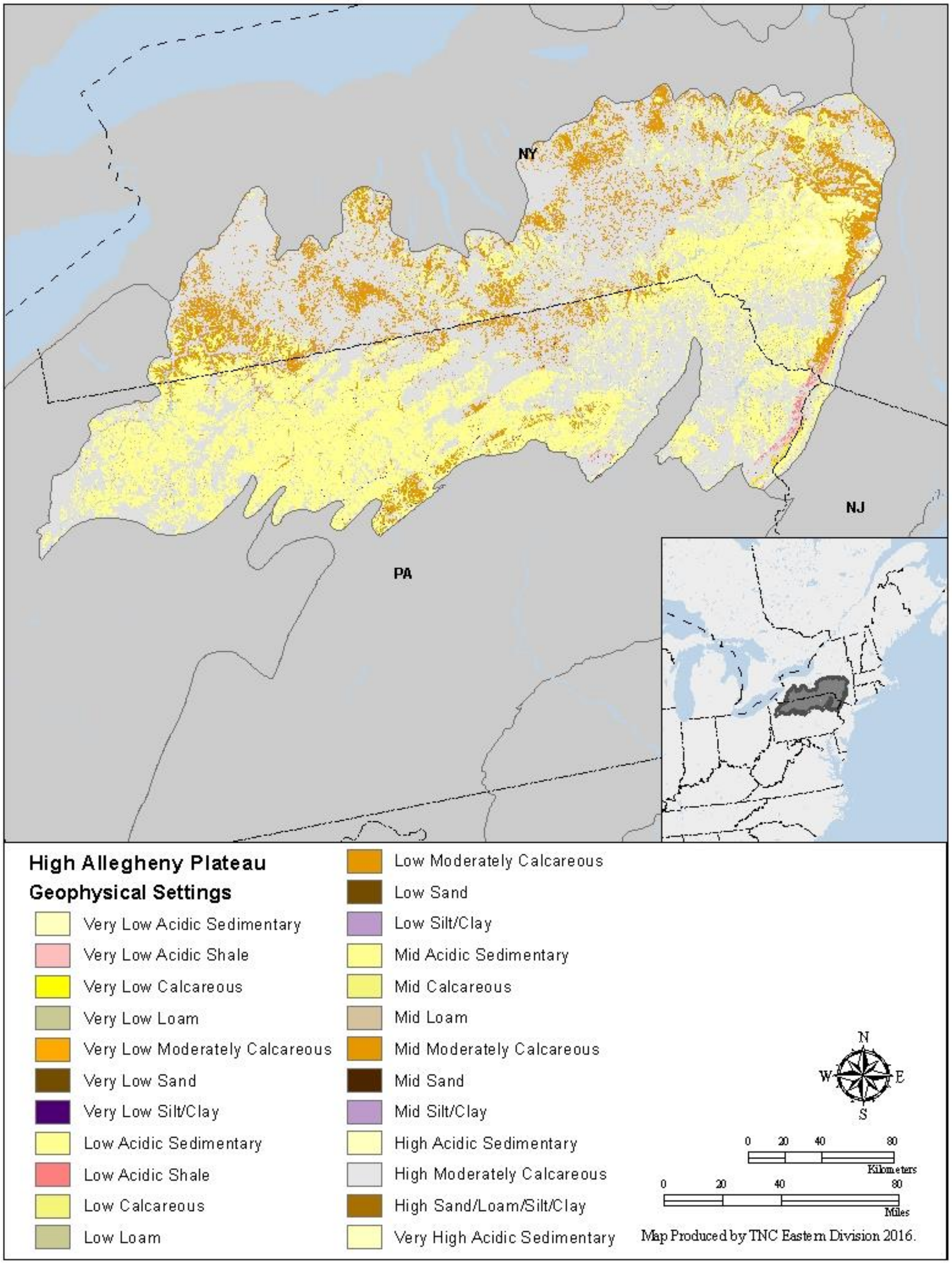


Figure 4.38 High Allegheny Plateau assessed as most resilient. The map shows only the grid cells that score above the mean for estimated resilience as compared to others in in their ecoregion; each high scoring grid cell is colored based on its corresponding geophysical setting. This map reveals how the settings are reflected in the resilience scores.



Interior Low Plateau

The Interior Low Plateau ecoregion occupies portions of six states in the Midwest and South East regions of the United States, Illinois, Indiana, Ohio, Kentucky, Tennessee and Alabama. Compared with other ecoregions, it is of average size, covering 47,769,500 acres; (74,639 square miles). Surficial geology is of two primary types: on the northern edges on the ecoregion in Ohio and Indiana, and over much of Illinois, Illinoian till dominates the landscape. To the south, the bulk of the ecoregion is characterized by unglaciated limestone and related geology. Elevation ranges from a high in Illinois of 1,060 at Williams Hill, to a low of 325 ft. along the Ohio River as it leaves the ecoregion in Illinois and Kentucky. Most of the ecoregion lies between 500 and 850 ft. in elevation. Much of the unglaciated portion of the ecoregion is characterized by rolling limestone plains punctuated with regions of fairly rugged topography, and 250 feet of relative topographic relief is common in many areas (maximum relative relief is over 500 ft).

Topography is mostly hilly and rolling, with areas of swampy alluvial valleys, deeply entrenched rivers and streams, and expansive karst plains. Several large rivers traverse the ecoregion, including the Ohio, Tennessee, Cumberland Kentucky and Licking Rivers. Originally the unglaciated portion of the ecoregion was dominated by expansive forest systems, although extensive prairies and barrens and oak savanna dominated portions of karst plains. Interspersed throughout the unglaciated ecoregion were caves, glades, and swamps, which today remain as biologically diverse conservation targets. The Illinoinan Tillplain was characterized by rolling topography that was dominated by a prairie forest ecotone in Illinois and forested in the eastern portions. (Text adopted from TNC ecoregional plan).

Read more at:
https://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/edc/reportsdata/terrestrial/ecoregional/ilp/Pages/default.aspx

Figure 4.39 Interior Low Plateau Resilience Estimates. _Areas in green score above average and are estimated to be more resilient based for their geophysical setting, based on landscape diversity and local connectedness. Areas in yellow are average. Areas in brown are below average and are estimated to be vulnerable to climate change and other factors.

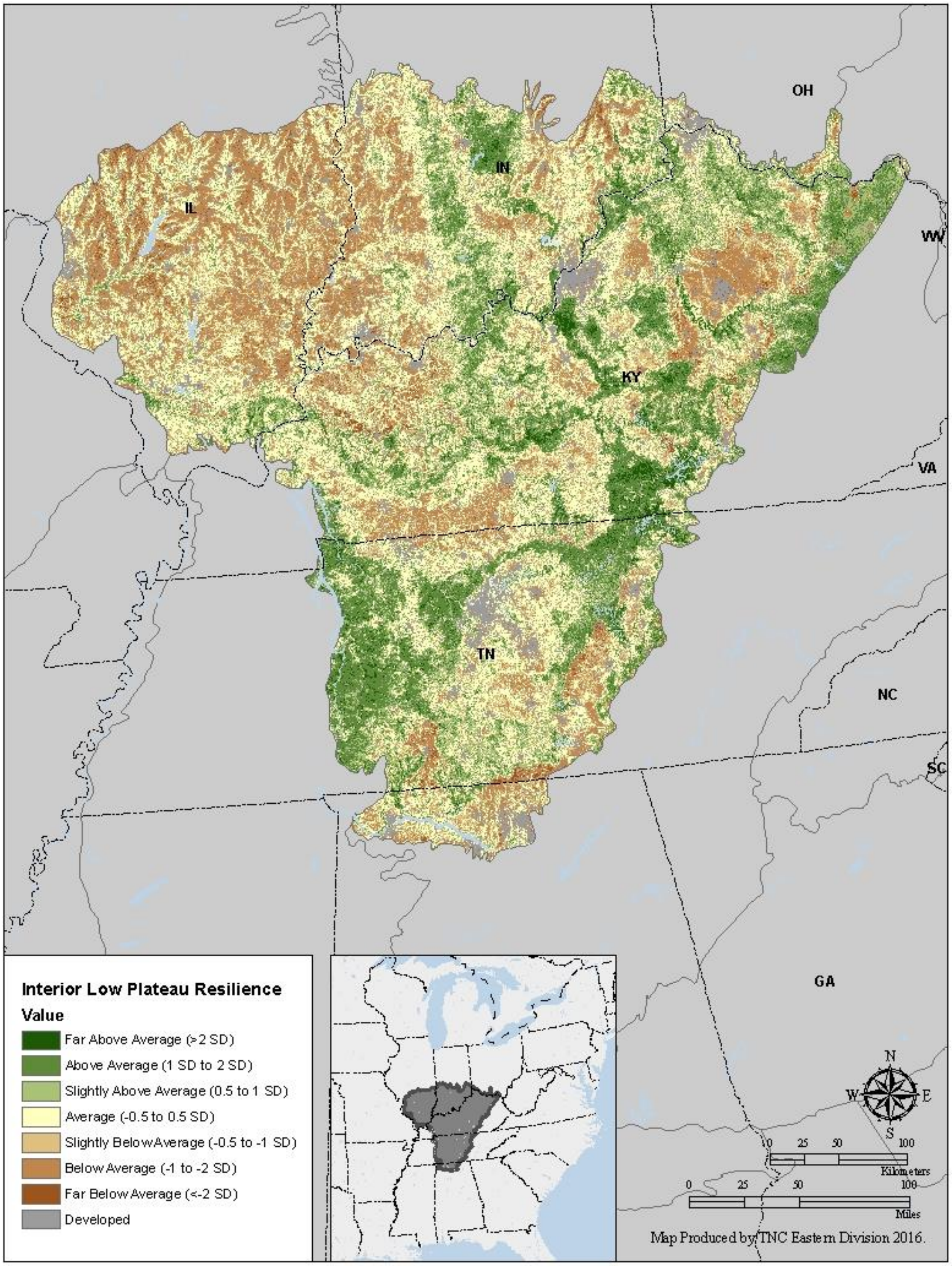


Figure 4.40 Interior Low Plateau Settings. The geophysical settings in this ecoregion that were created by combining an elevation zone and a geology class. These are the settings that are used for the stratification by setting for this ecoregion.

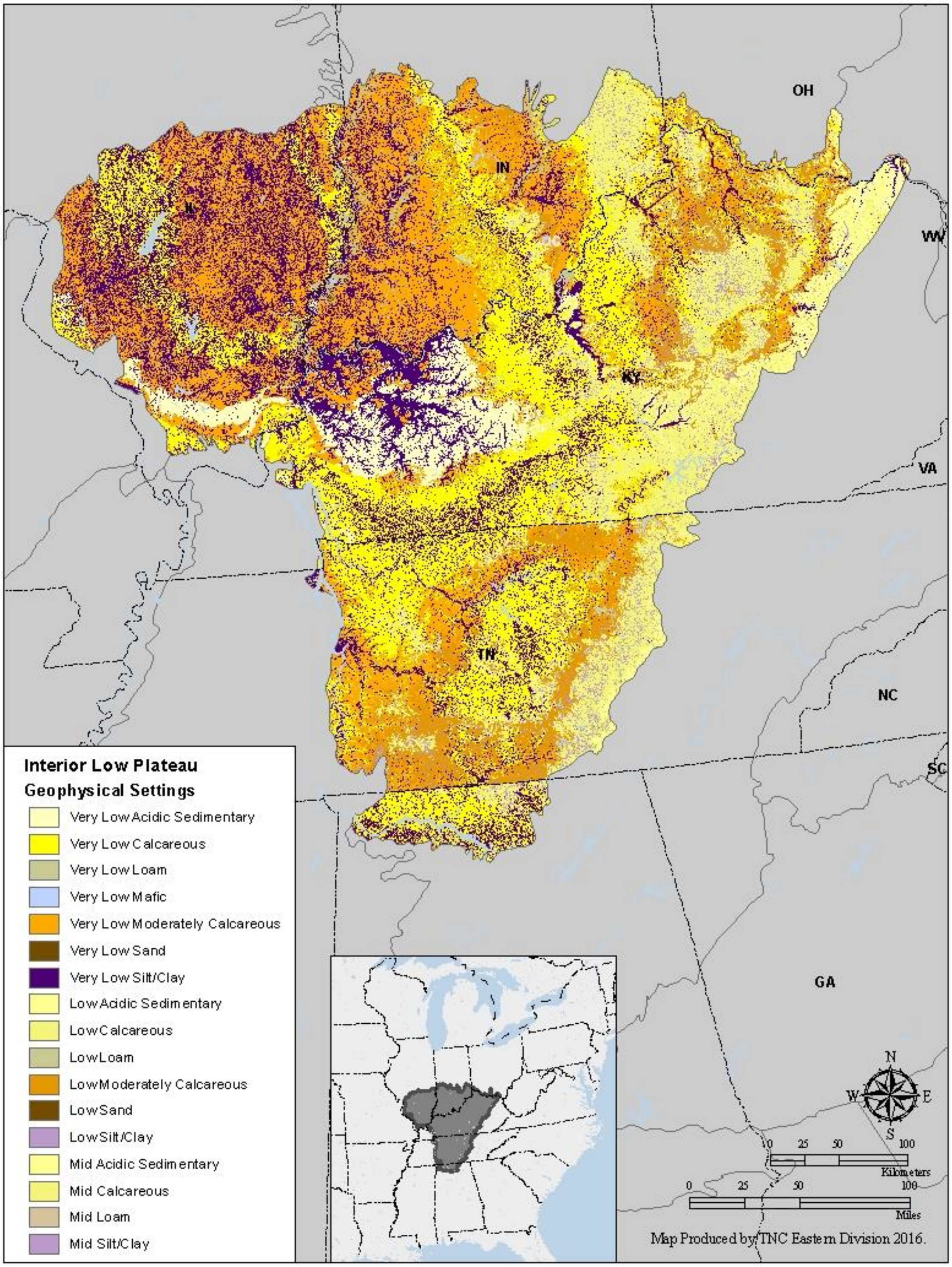
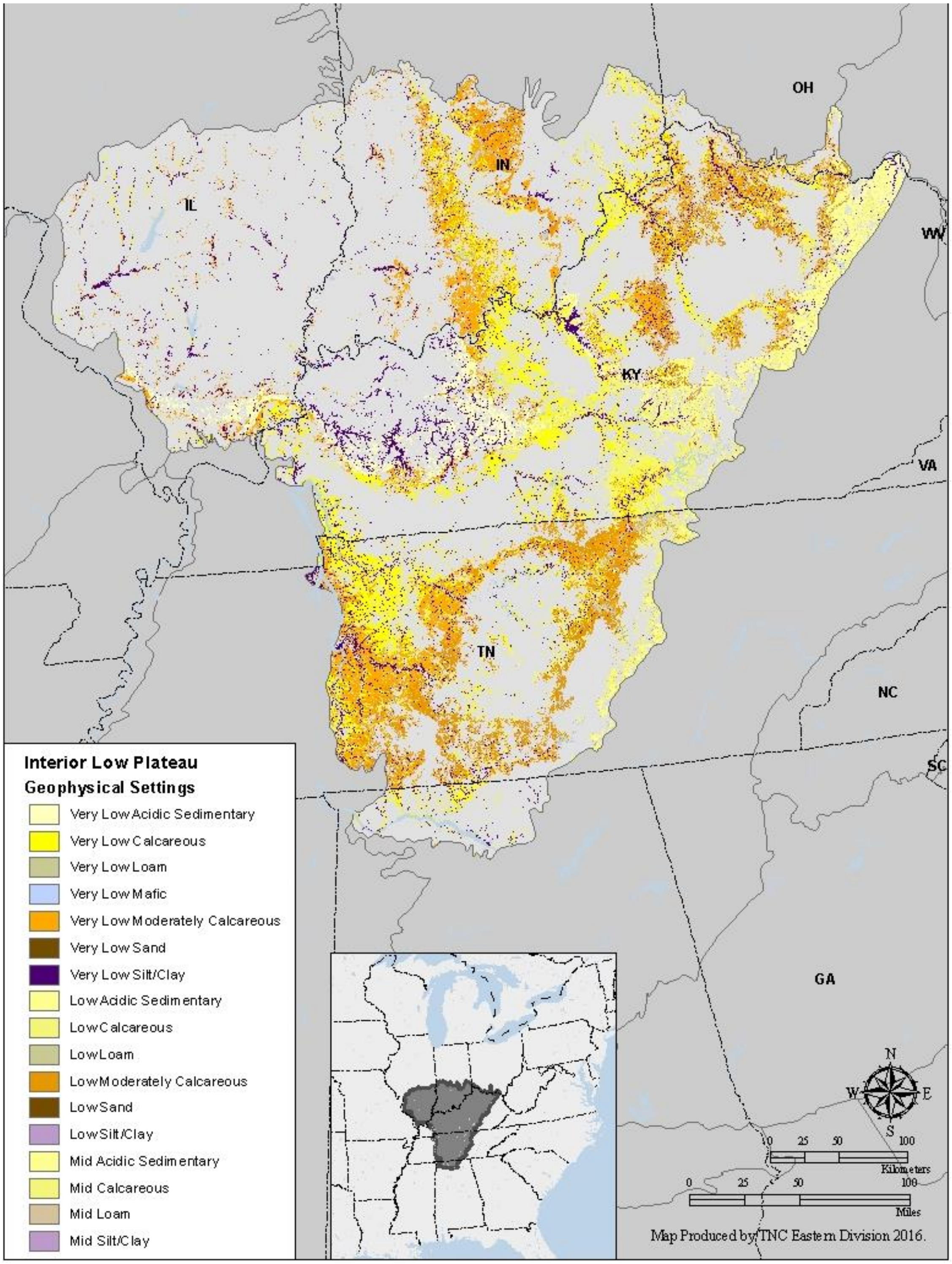


Figure 4.41 Interior Low Plateau Settings assessed as most resilient. The map shows only the grid cells that score above the mean for estimated resilience as compared to others in in their ecoregion; each high scoring grid cell is colored based on its corresponding geophysical setting. This map reveals how the settings are reflected in the resilience scores.



Northern Appalachian-Acadian

The Northern Appalachian –Acadian ecoregion includes mountainous regions, boreal hills and extensive
wetlands in Northern New England and Maritime Canada The geography includes a number of iconic forest landscapes including the Adirondack Mountains, Tug Hill, the northern Green Mountains, the White Mountains, the Aroostook Hills, New Brunswick Hills, the Fundy coastal section, the Gaspe peninsula, as well as the entire provinces of New Brunswick, Nova Scotia and Prince Edward Island. Although not as rich in species diversity as some ecoregions (estimated 5424 species) this region contains the most intact landscapes and some of the largest remaining forest ecosystems in the United States.

The region is 75-90 percent forested, with red spruce-balsam fir forest, sugar maple-beech-birch northern hardwoods and red spruce-northern hardwoods forming the dominant matrix. High elevation areas contain a variety of alpine communities, rocky summits, acidic cliffs and talus slope woodlands. Low lying areas contain extensive peatlands, floodplain forests, river-scoured grasslands and riverside seeps. Additionally, the region has an extensive coastline with features from tidal marshes to rocky shores. (Text adopted from TNC ecoregional plan).

Read more at:
https://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/edc/reportsdata/terrestrial/ecoregional/nap/Pages/default.aspx

Figure 4.42 Northern Appalachian-Acadian Resilience Estimates. Areas in green score above average and are estimated to be more resilient based for their geophysical setting, based on landscape diversity and local connectedness. Areas in yellow are average. Areas in brown are below average and are estimated to be vulnerable to climate change and other factors.

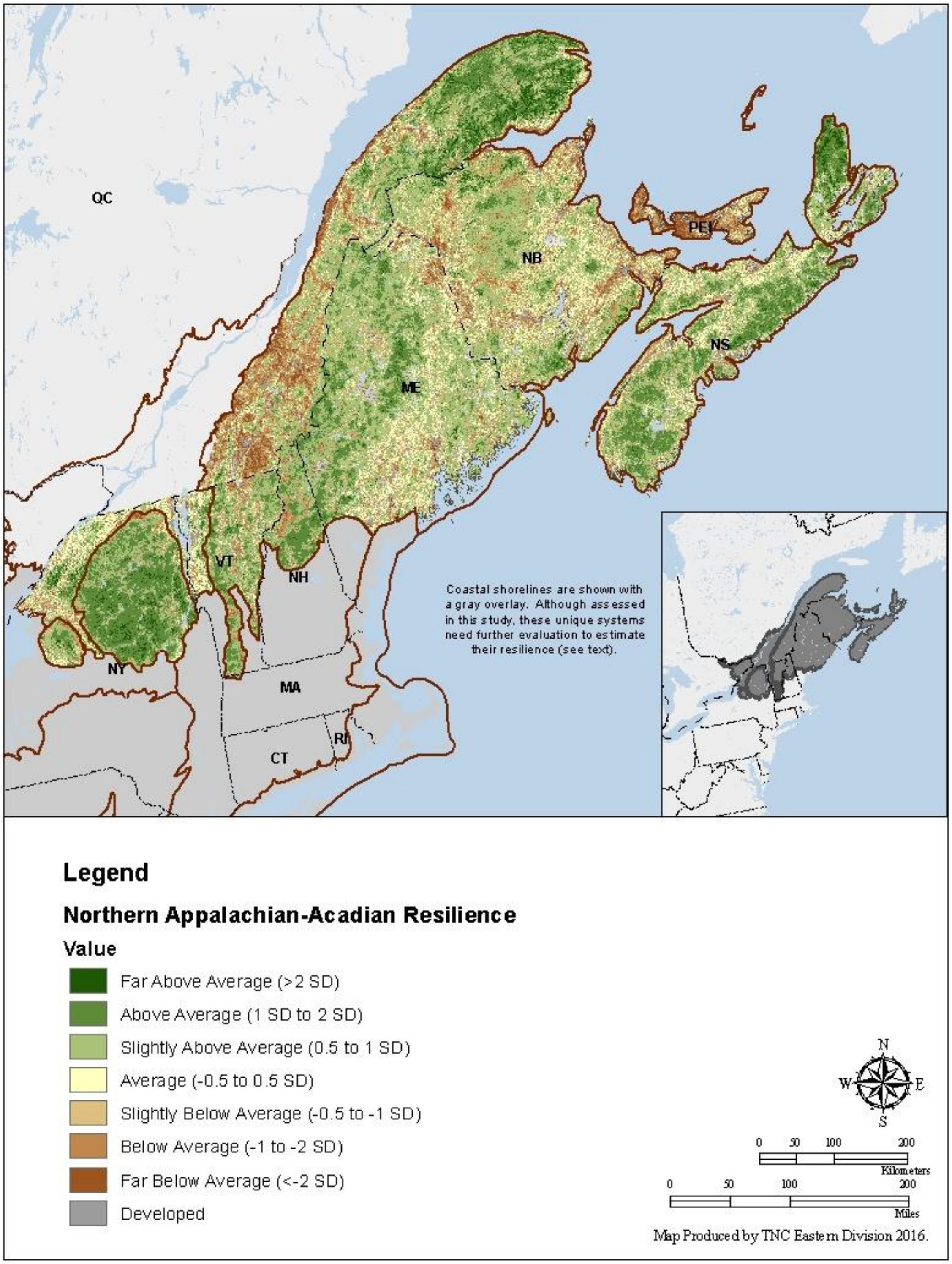


Figure 4.43 Northern Appalachian-Acadian Settings. The geophysical settings in this ecoregion that were created by combining an elevation zone and a geology class. These are the settings that are used for the stratification by setting for this ecoregion.

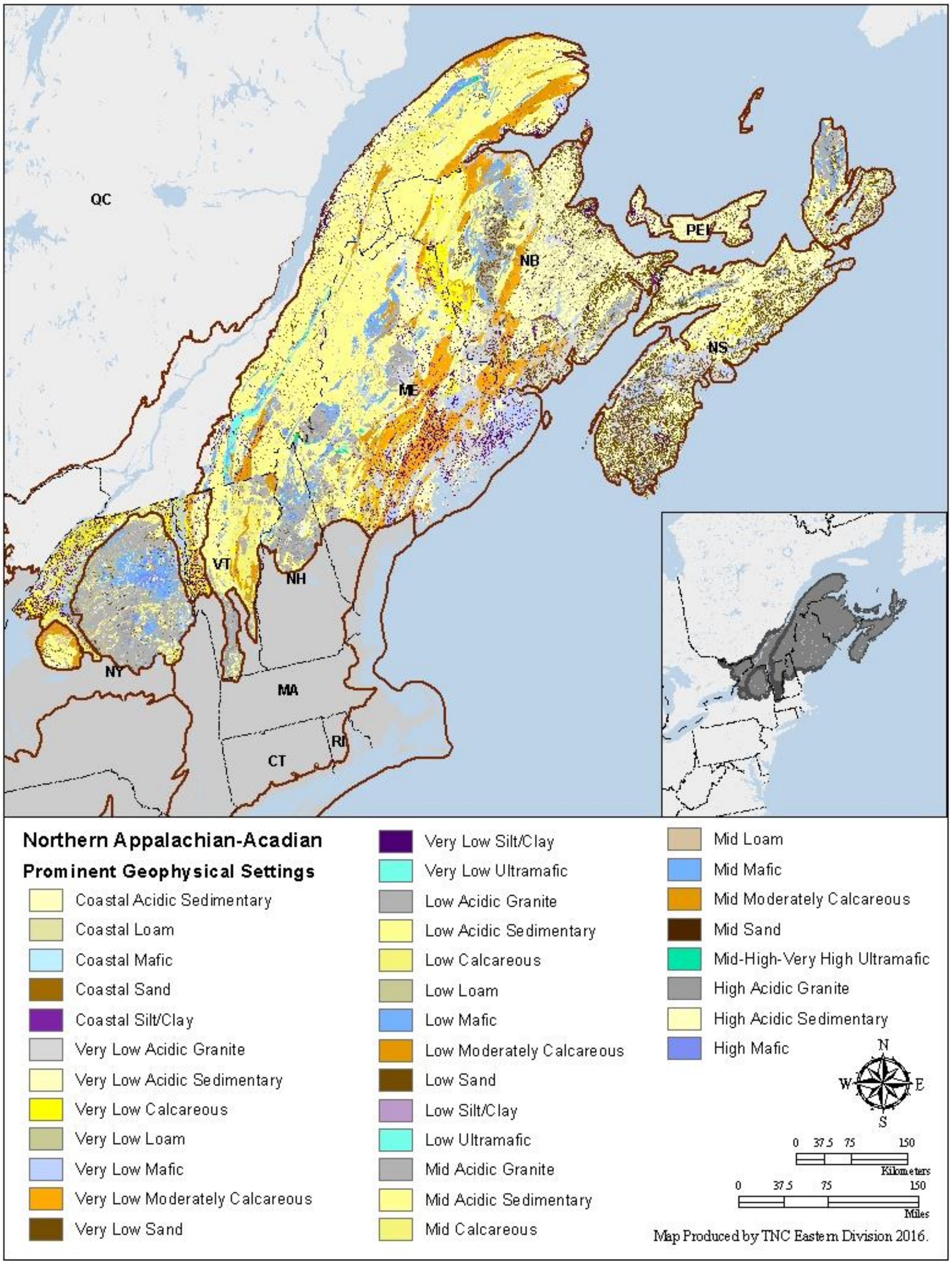
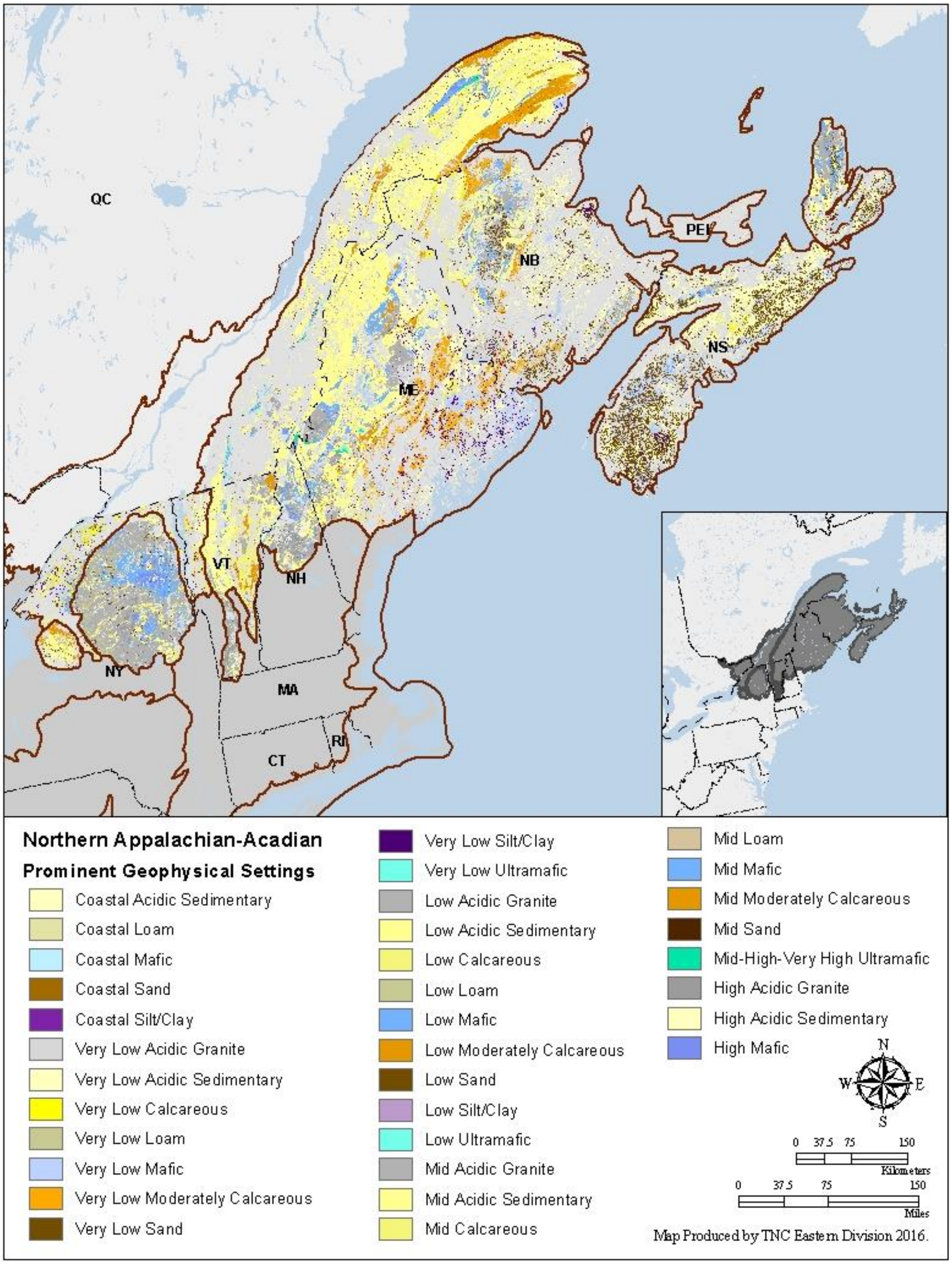


Figure 4.44 Northern Appalachian-Acadian Settings assessed as most resilient. The map shows only the grid cells that score above the mean for estimated resilience as compared to others in in their ecoregion; each high scoring grid cell is colored based on its corresponding geophysical setting. This map reveals how the settings are reflected in the resilience scores.



Southern Blue Ridge

The Southern Blue Ridge (SBR) Ecoregion is one of the most biologically significant ecoregions in the United States. A World Wildlife Fund study identified this ecoregion as globally outstanding, requiring immediate protection or restoration based on the extraordinary endemism and species richness of the forests (Rickets et al. 1999). The Southern Blue Ridge and surrounding Southern Appalachian Mountains have been found to have some of the highest concentrations of endangered species in the United States (Dobson et al. 1997). In addition, the ecoregion's ecosystems and species are considered at extreme risk for biotic impoverishment due to the risk of development.

The ecoregion is over 9.4 million acres in size and spans portions of Virginia, Tennessee, South Carolina, and Georgia, with the greatest portion falling in North Carolina. Almost 35% of the ecoregion is owned and managed by public agencies. The largest land management agency is the USFS, managing 26% of the land in the SBR. The extensive land ownership by public agencies and the re-growth of the forest from turn of the century logging has resulted in an ecoregion that is predominately forested.

Geographically, the SBR is part of the larger Southern Appalachian chain which stretches from Virginia to Alabama. The SBR is bounded on the east by the Piedmont Ecoregion and to the west by the Cumberlands and Southern Ridge and Valley Ecoregion. The eastern boundary is the Blue Ridge Escarpment that runs from Virginia into Georgia, with the western boundary being the metamorphic/sedimentary rock interface near the North Carolina - Tennessee border. The SBR ecoregion is unique because of the spatial and temporal heterogeneity of its geology, topography (slope, aspect and elevation) and floristics. This ancient remnant mountain region has undergone a myriad of geologic processes from the uplift of the earth's crust to volcanic intrusions and alluvial depositions, while escaping glaciation in the Pleistocene Period. These processes have produced a landscape of extreme variation with elevations ranging from 1500 feet to 6684 feet at the peak of Mt. Mitchell. The substrate includes a wide range of metamorphic, acid rocks with occasional inclusions of mafic and ultramafic rocks. Moreover, the region receives the highest rainfall in the US east of the Cascades, and is home to a range of climate types from warm temperate to boreal. The combination of these conditions and the fact that this region escaped glaciation has provided specialized habitat for the evolution and persistence of a vast flora and fauna, including over 400 endemic species—the most found in any ecoregion in North America. (text adopted from the TNC ecoregional plan).

Read more at:
https://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/edc/reportsdata/terrestrial/ecoregional/sbr/Pages/default.aspx

Figure 4.45 Southern Blue Ridge Resilience Estimates. Areas in green score above average and are estimated to be more resilient based for their geophysical setting, based on landscape diversity and local connectedness. Areas in yellow are average. Areas in brown are below average and are estimated to be vulnerable to climate change and other factors.

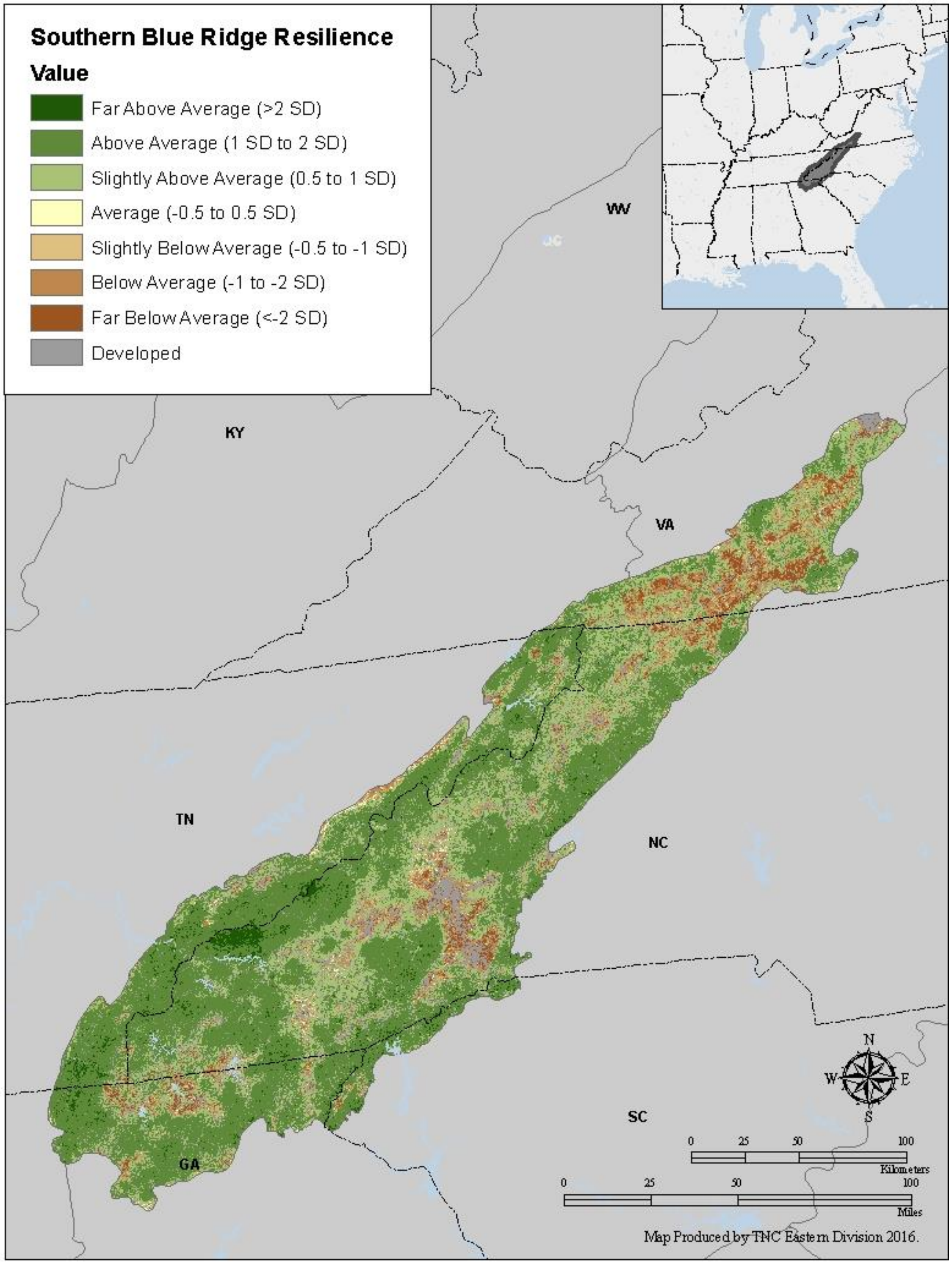


Figure 4.46 Southern Blue Ridge Settings. The geophysical settings in this ecoregion that were created by combining an elevation zone and a geology class. These are the settings that are used for the stratification by setting for this ecoregion.

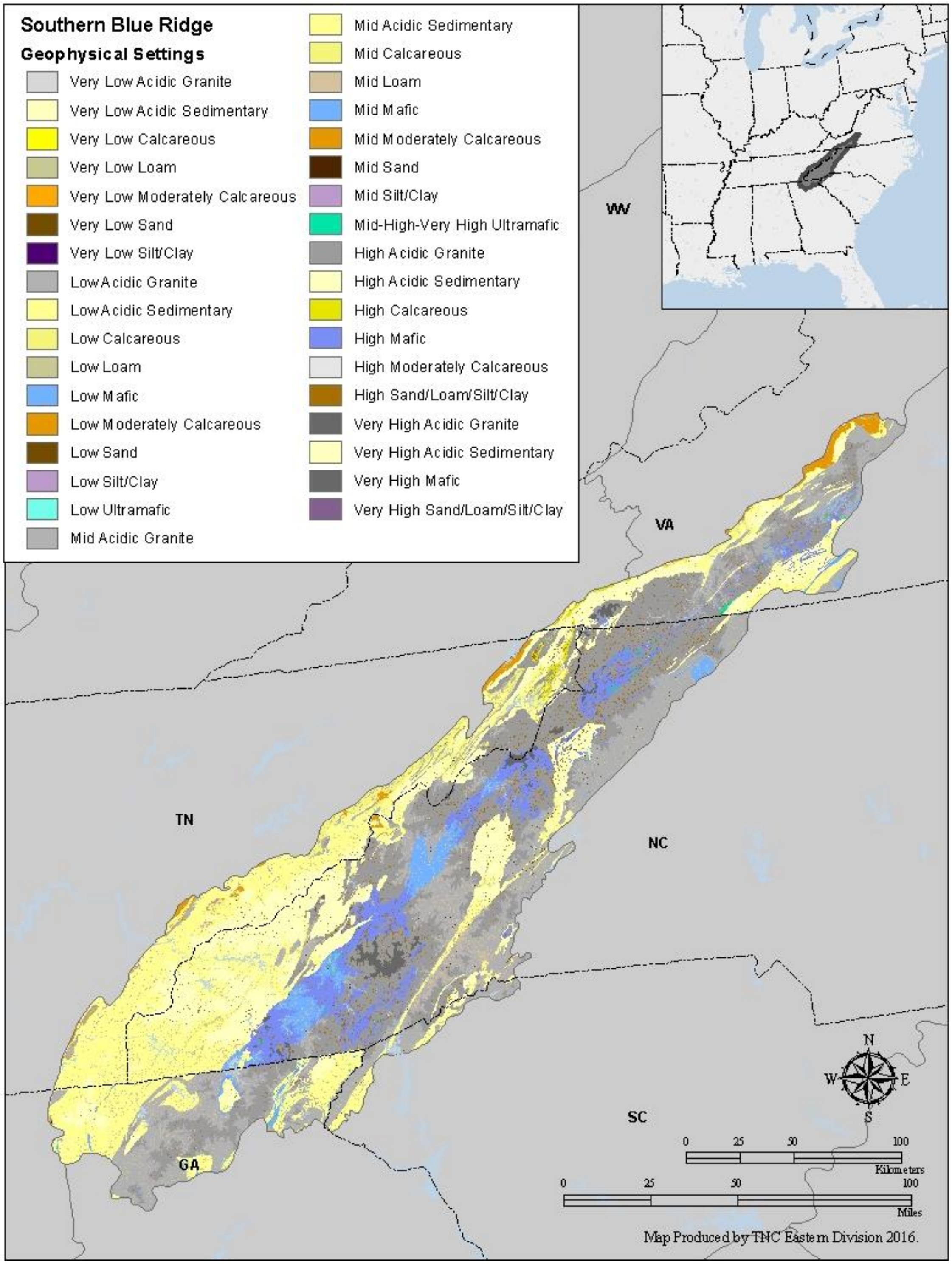
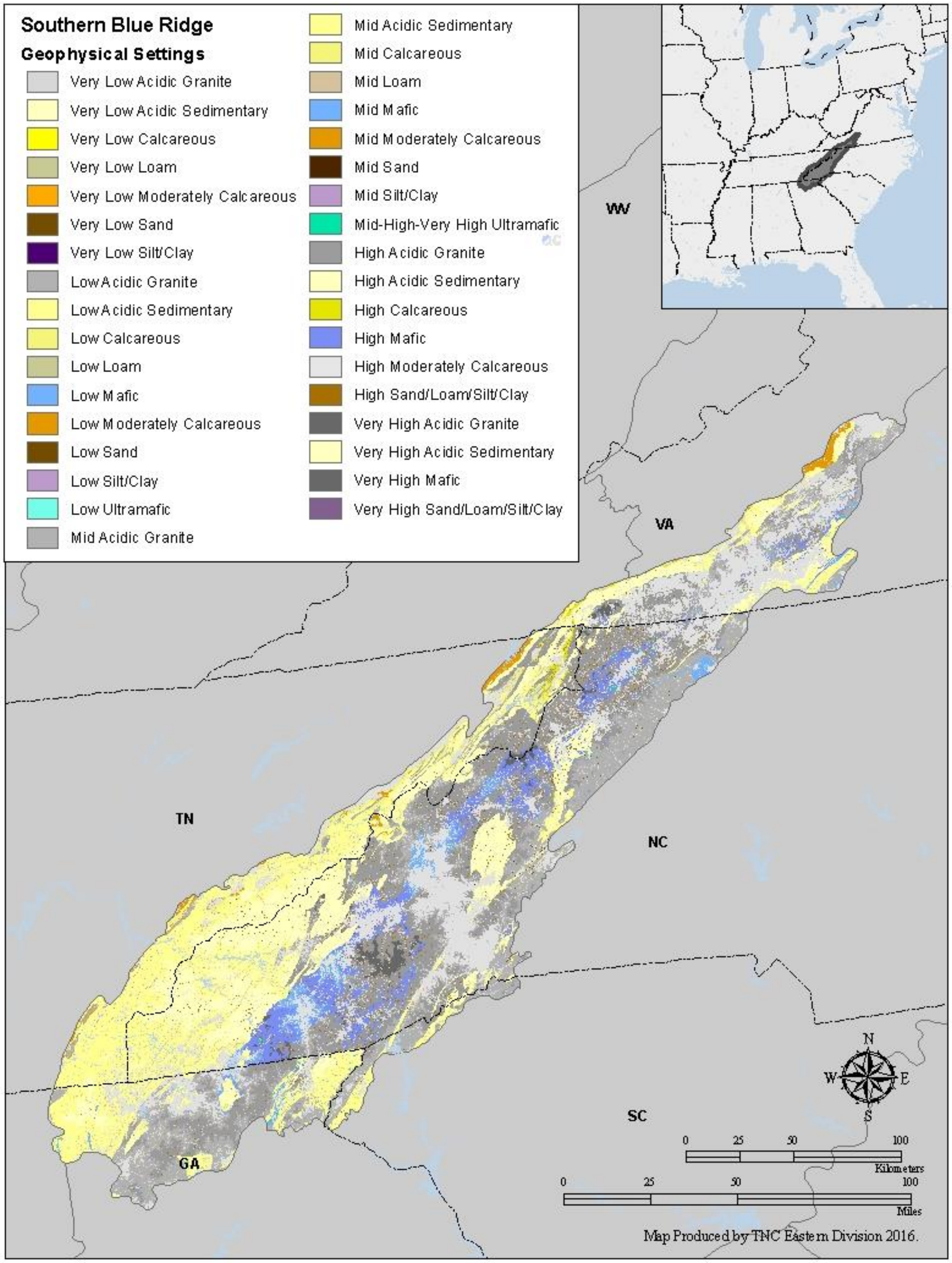


Figure 4.47 Southern Blue Ridge Settings assessed as most resilient. The map shows only the grid cells that score above the mean for estimated resilience as compared to others in in their ecoregion; each high scoring grid cell is colored based on its corresponding geophysical setting. This map reveals how the settings are reflected in the resilience scores.



Western Allegheny Plateau

The Western Allegheny Plateau planning unit consists of 26.7 million acres in parts of Kentucky, Pennsylvania, Ohio, New York, and West Virginia. It was created by combining two of Bailey's sections: the 7.3 million acre Western Glaciated Allegheny Plateau, which contains three subsections, and the 19.4 million acre Southern Unglaciated Allegheny Plateau, which contains seven subsections (Keys et al, 1995). (Text adopted from TNC ecoregional plan).

Figure 4.48 Western Allegheny Plateau Resilience Estimates. Areas in green score above average and are estimated to be more resilient based for their geophysical setting, based on landscape diversity and local connectedness. Areas in yellow are average. Areas in brown are below average and are estimated to be vulnerable to climate change and other factors.

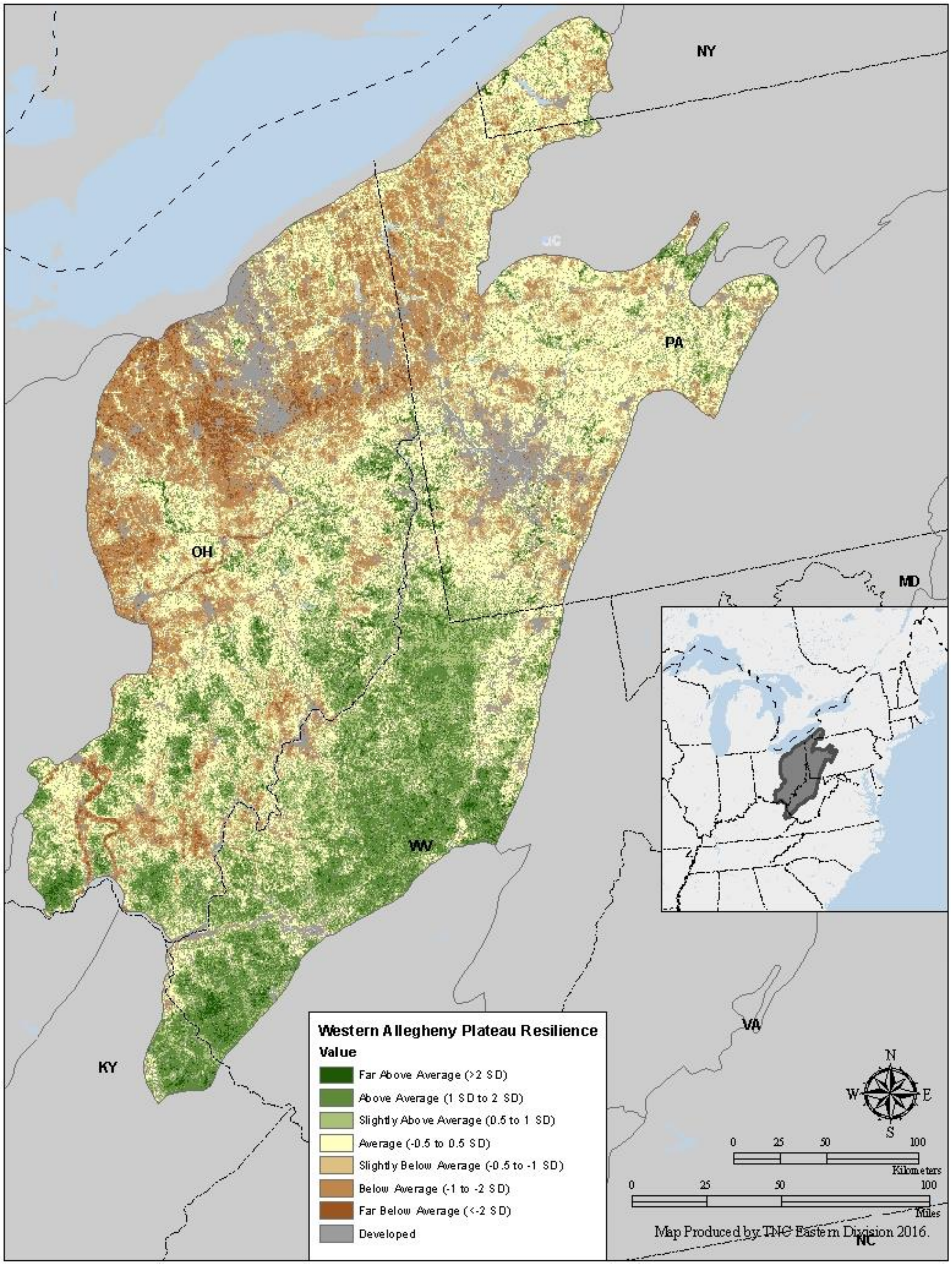


Figure 4.49 Western Allegheny Plateau Settings. The geophysical settings in this ecoregion that were created by combining an elevation zone and a geology class. These are the settings that are used for the stratification by setting for this ecoregion.

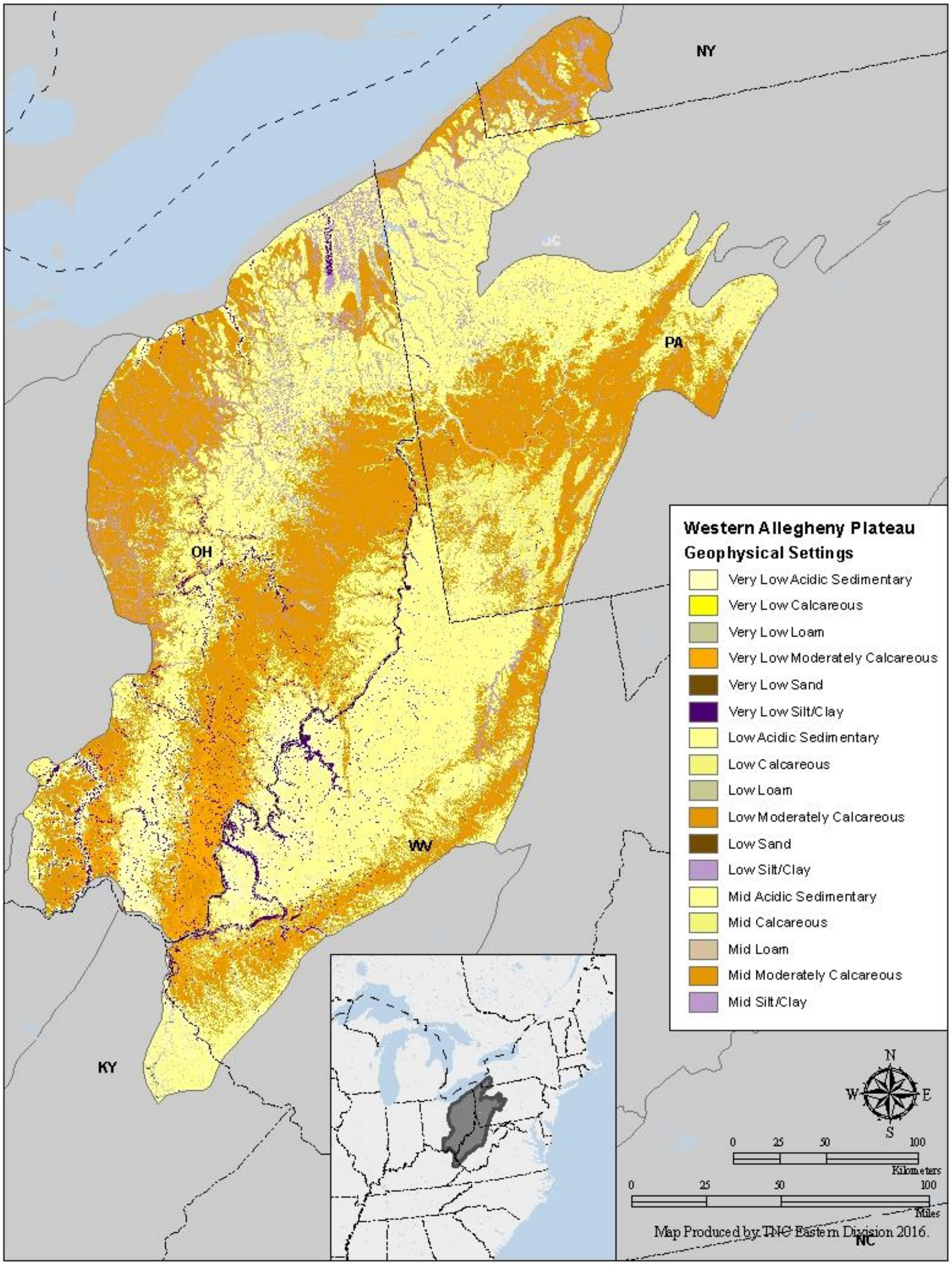
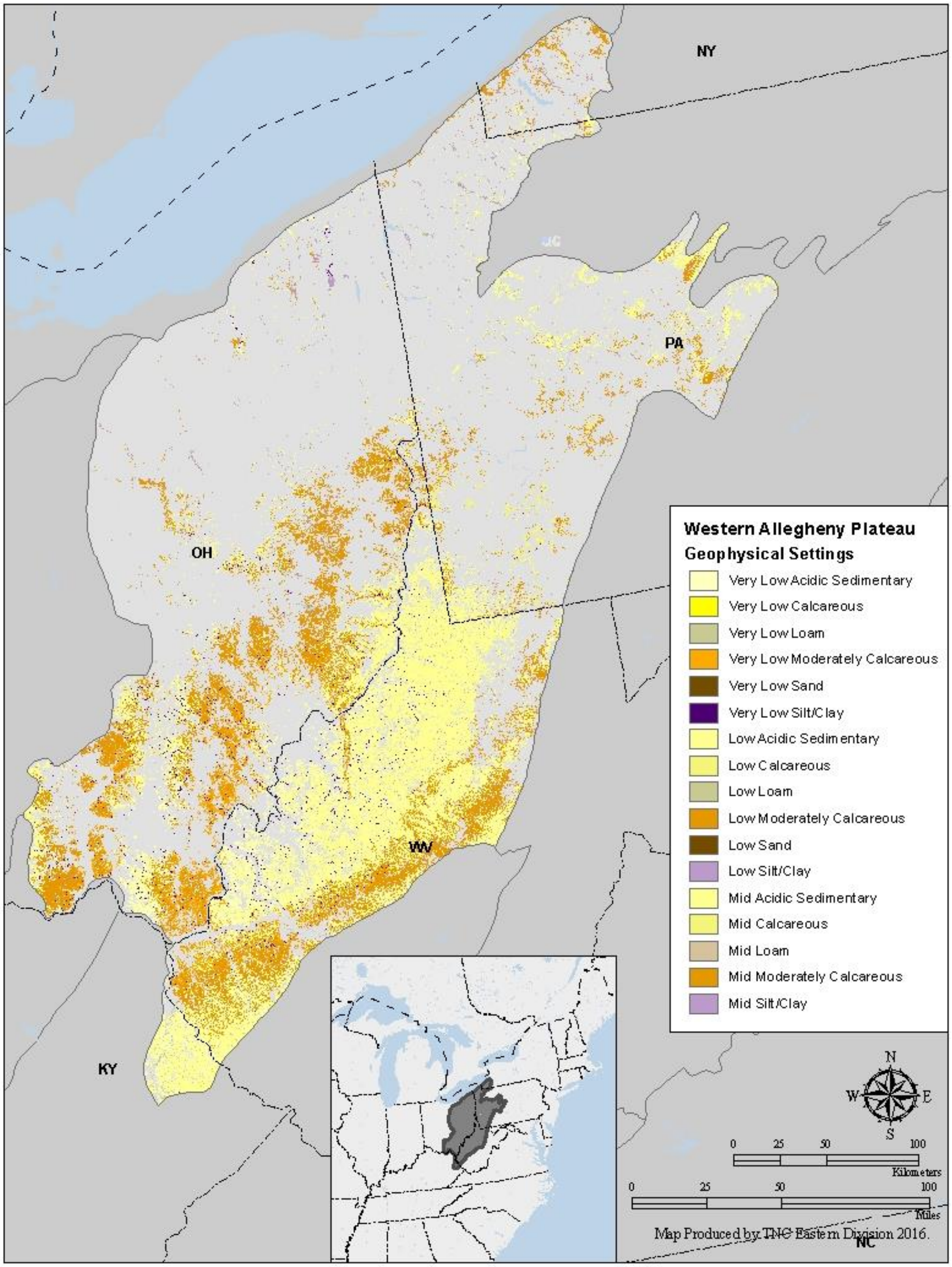


Figure 4.50 Western Allegheny Plateau Settings assessed as most resilient. The map shows only the grid cells that score above the mean for estimated resilience as compared to others in in their ecoregion; each high scoring grid cell is colored based on its corresponding geophysical setting. This map reveals how the settings are reflected in the resilience scores.



PIEDMONT ECOREGIONS

Lower New England and Northern Piedmont

The Lower New England and Northern Piedmont ecoregion is an extensive low-relief plain extending
from ME to PA with scattered high hills in the east and low mountains in the west. In the till covered
New England section, glacial features such as lake basins, eskers and drumlin fields are common. Welldrained coarse sandy soils are common in outwash areas. Farther south, in the un-glaciated piedmont (the "Northern Piedmont"), these features and their associated communities are less common. This region has the second highest estimated species diversity in the region: 5754 plants and animals.
The region is 60-70 percent forested with red oak-sugar maple forest, hemlock-white pine forest, maplebeech-birch northern hardwoods, and northern white pine-red oak forests forming the dominant matrix. A variety of fire-related communities, such as pitch pine-scrub oak barrens or serpentine barrens are typical, and forested swamps are widespread. Limestone regions contain calcareous swamps, fens and seeps. (Text adopted from TNC ecoregional plan).

Read more at:
https://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/edc/reportsdata/terrestrial/ecoregional/lne/Pages/default.aspx

Figure 4.51 Lower New England and Northern Piedmont Resilience Estimates. Areas in green score above average and are estimated to be more resilient based for their geophysical setting, based on landscape diversity and local connectedness. Areas in yellow are average. Areas in brown are below average and are estimated to be vulnerable to climate change and other factors.

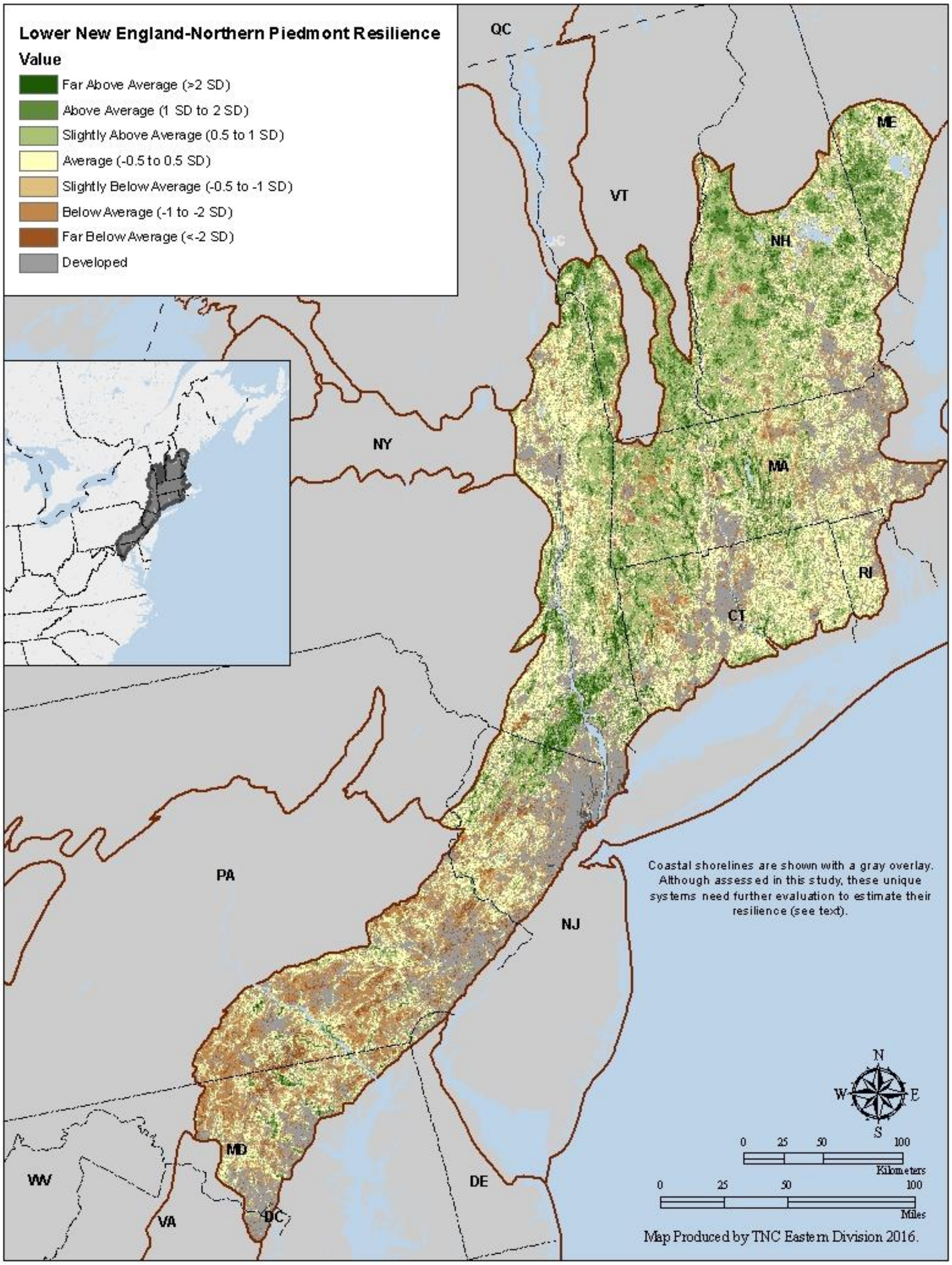


Figure 4.52 Lower New England and Northern Piedmont Settings. The geophysical settings in this ecoregion that were created by combining an elevation zone and a geology class. These are the settings that are used for the stratification by setting for this ecoregion.

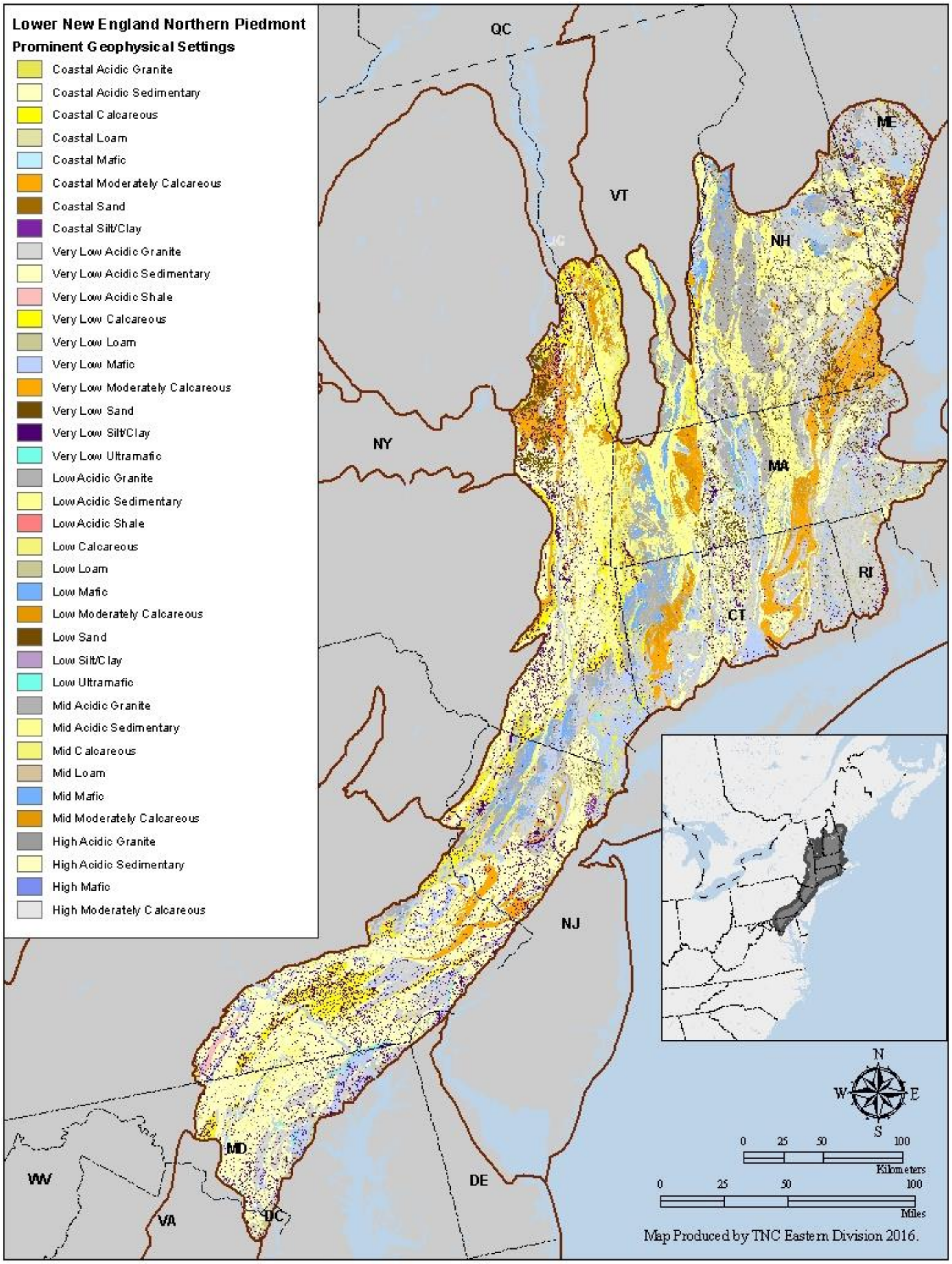
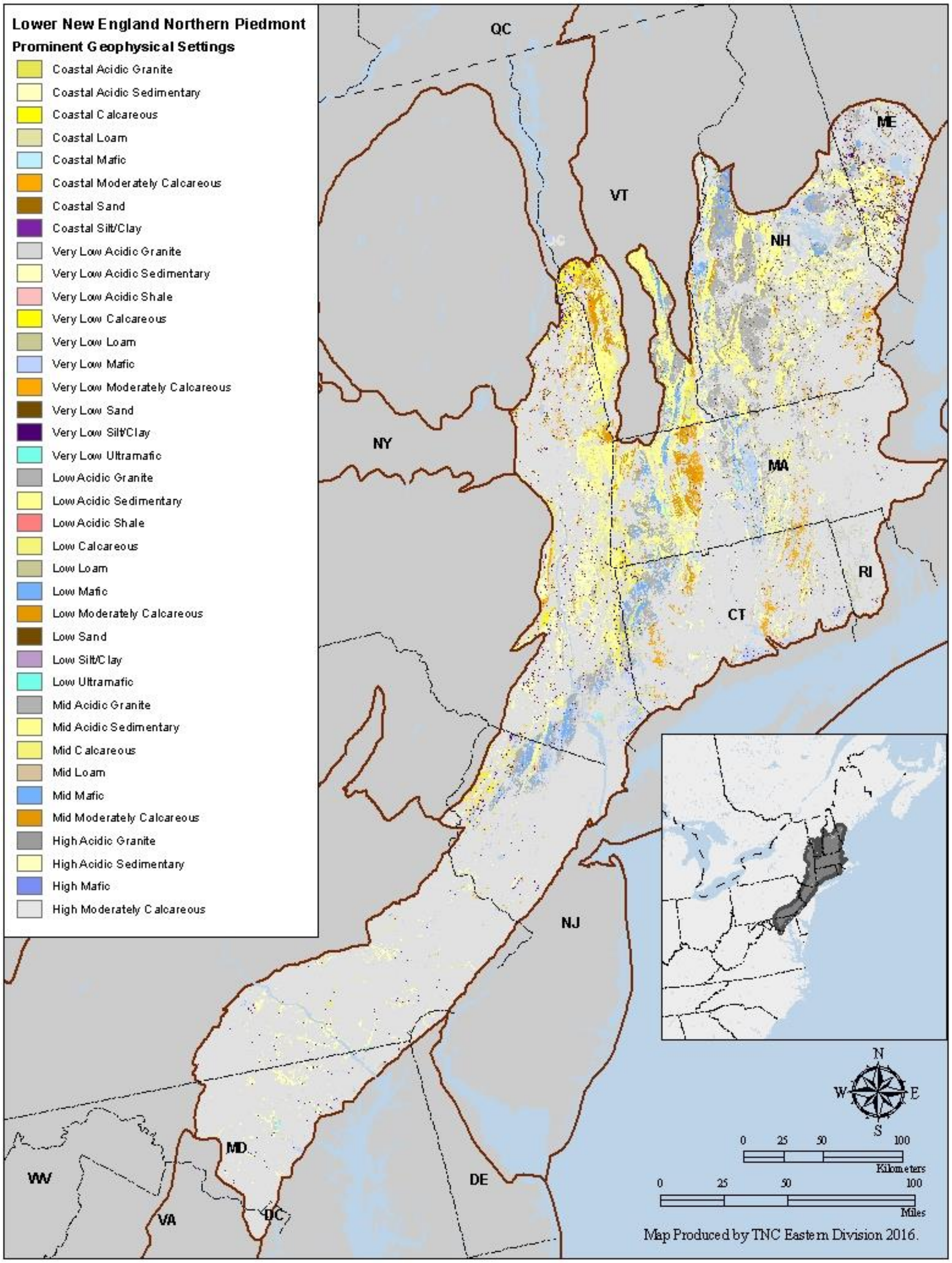


Figure 4.53 Lower New England and Northern Piedmont Settings assessed as most resilient. The map shows only the grid cells that score above the mean for estimated resilience as compared to others in in their ecoregion; each high scoring grid cell is colored based on its corresponding geophysical setting. This map reveals how the settings are reflected in the resilience scores.



Piedmont

Stretching from south central Maryland to east central Alabama the Piedmont Ecoregion is situated between the Blue Ridge and Ridge and Valley areas to the west and the Coastal Plain to the east and south. Low hills and metamorphic rock dominate the area with occasional monadnocks in the western portion of the ecoregion. Dominated by both deciduous and evergreen forests there are also some native grasslands. Most streams drain to the south and east onto the Coastal Plain. It is a highly fragmented landscape long used by humans for agricultural and industrial purposes. (Text adopted from TNC ecoregional plan).

Read more at:
https://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/edc/reportsdata/terrestrial/ecoregional/pmt/Pages/default.aspx.

Figure 4.54 Piedmont Resilience Estimates. Areas in green score above average and are estimated to be more resilient based for their geophysical setting, based on landscape diversity and local connectedness. Areas in yellow are average. Areas in brown are below average and are estimated to be vulnerable to climate change and other factors.

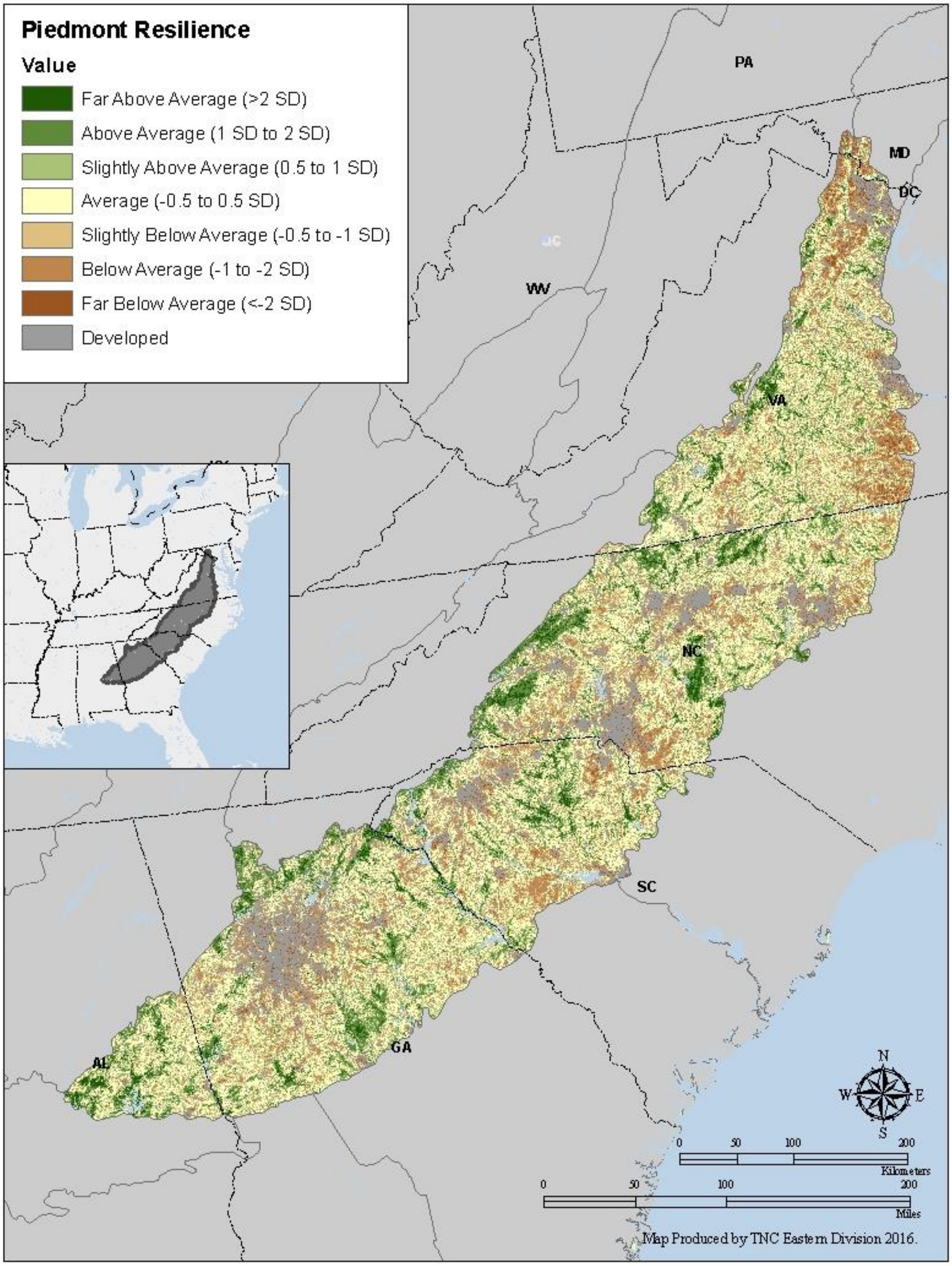


Figure 4.55 Piedmont Settings. The geophysical settings in this ecoregion that were created by combining an elevation zone and a geology class. These are the settings that are used for the stratification by setting for this ecoregion.

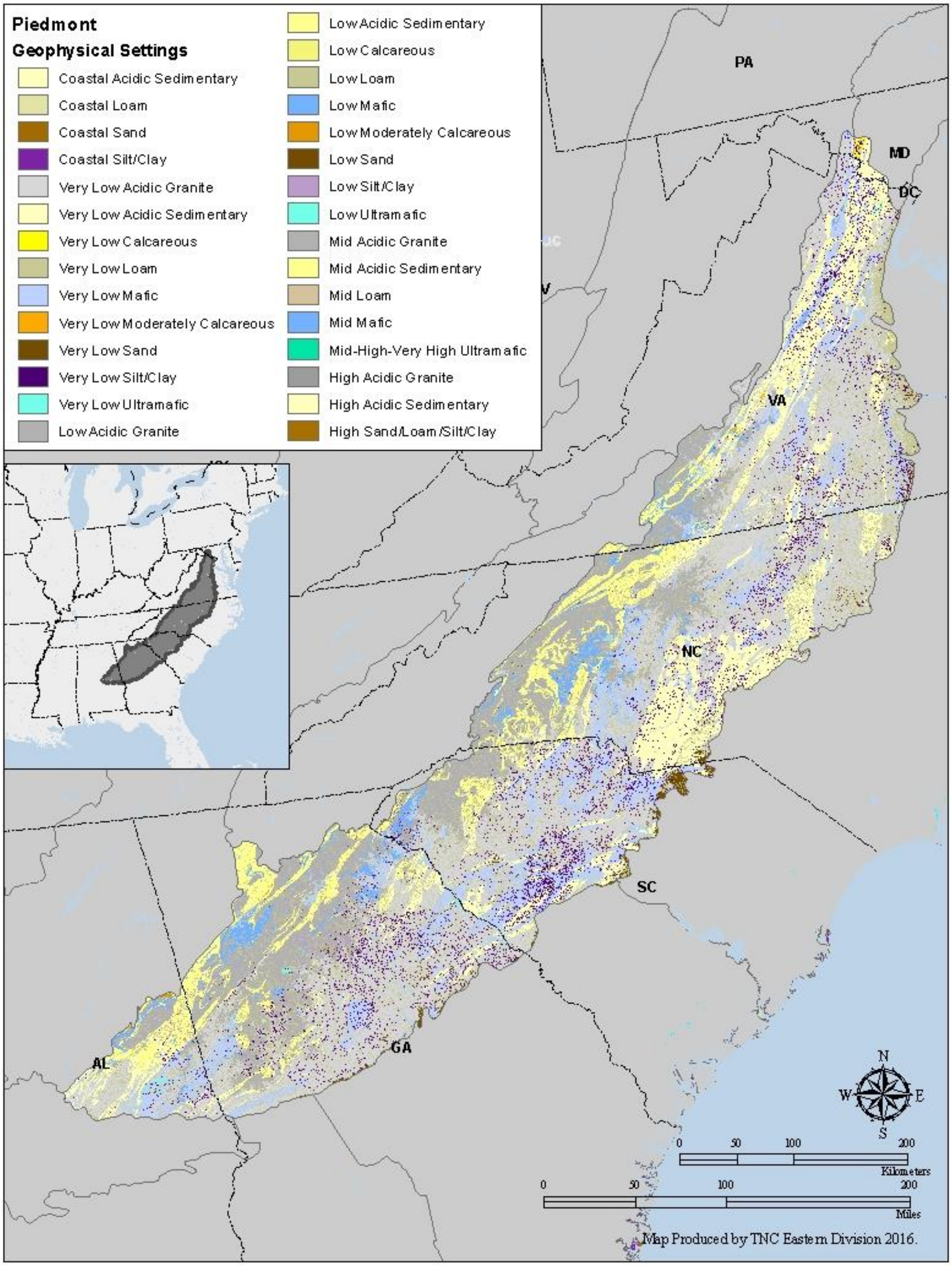
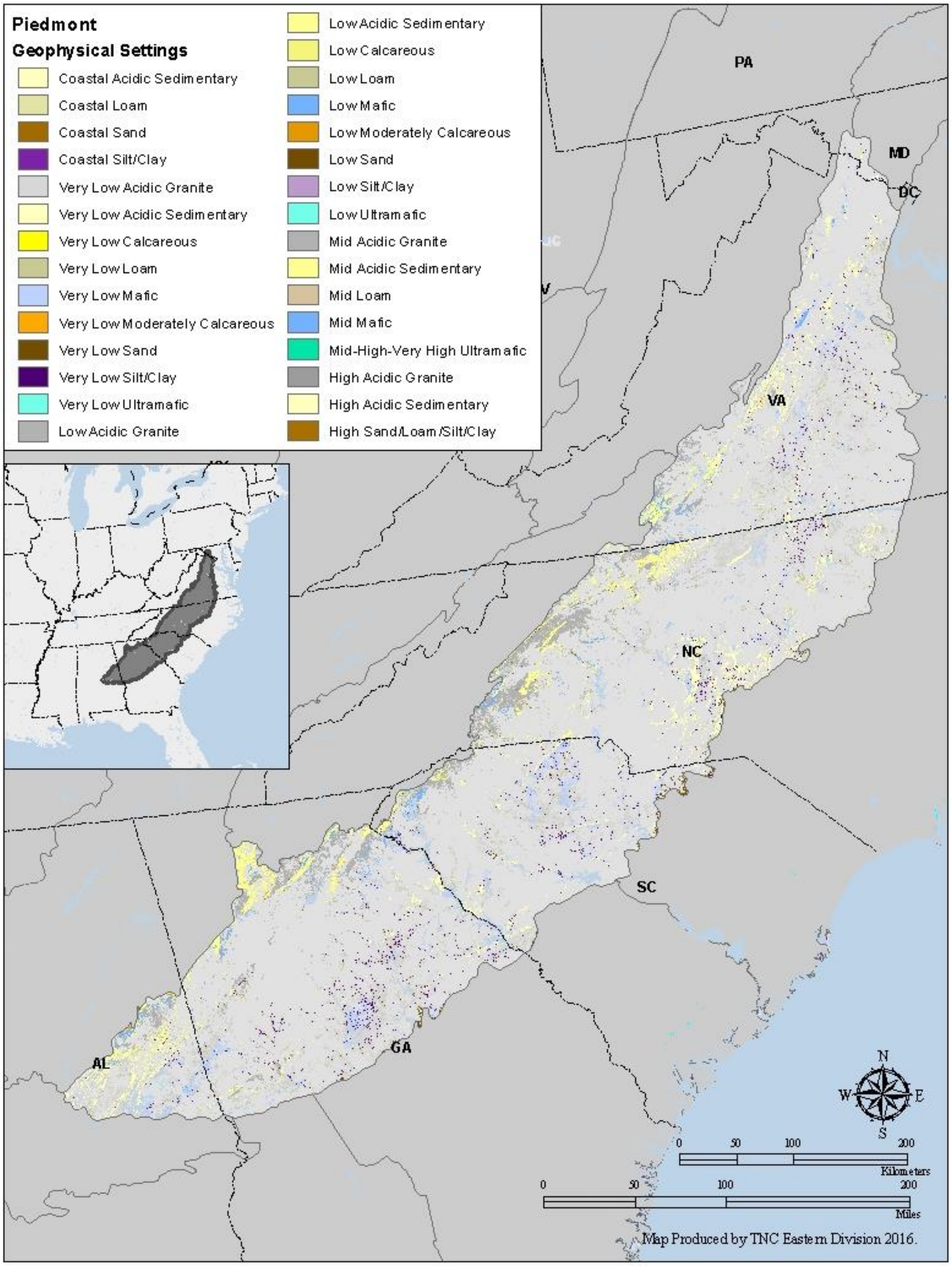


Figure 4.56 Piedmont Settings in Areas assessed as most resilient. The map shows only the grid cells that score above the mean for estimated resilience as compared to others in in their ecoregion; each high scoring grid cell is colored based on its corresponding geophysical setting. This map reveals how the settings are reflected in the resilience scores.

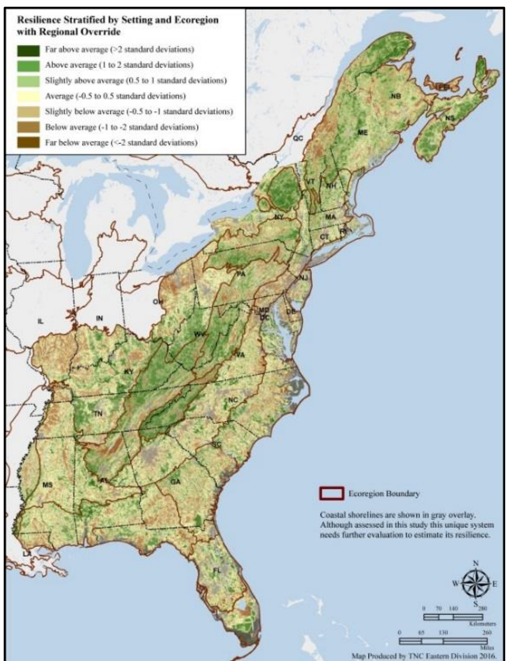


CHAPTER 5

Regional Results and Discussion

Results for Eastern North America

The regional maps were made be joining the ecoregion and partial ecoregion analyses together into a single map The results include six regional maps plus one map that does not use ecoregions:



The map above (shown full page as figure 5.1) is the final result of this project showing the places within each ecoregion that have the highest estimated resilience score and represent all settings.

Figure 5.1 Estimated resilience for all geophysical settings in the ecoregion

Figure 5.2 Resilient areas for each geophysical setting in the ecoregion

Figure 5.3 Comparison of Resilience Score Stratifications

Figure 5.4 Close-up of Southeast resilient areas

Figure 5.5 Close-up of Northeast resilient areas

Figure 5.6 Comparison of Resilient Sites 2016 Version with older Southeast resilient sites

Figure 5.7 Comparison of Resilient Sites 2016 Version with Northeast resilient sites

Figure 5.8 Landscape Diversity Stratified by Setting and Ecoregion

Figure 5.9 Local Connectedness Stratified by Setting and Ecoregion

Figure 5.10 Score Contribution of Landscape Diversity and Local Connectedness

Coastal Shorelines

Coastline ecosystems of the southeast are subject to a variety of climate related changes that threaten to alter or undermine their natural resilience. Foremost among these is sea level rise that has been conservatively estimated to reach one meter by 2100 (IPPC 2007). We did not address this issue, nor the related issues connected of sediment transport, accretion, or erosion rates, and this study should not be used to make determinations on the resilience of systems in the coastal zone. To make this clear on the maps we put a grey transparency over the 0-1 meter coastal zone, showing the area subject to sea level rise by 2060 while allowing users to see the underlying results.

Figure 5.1: The highest scoring areas for estimated resilience. Areas in green score above average and are estimated to be more resilient based for their geophysical setting, based on landscape diversity and local connectedness. Areas in yellow are average. Areas in brown are below average and are estimated to be vulnerable to climate change and other factors.

Figure 5.2: The most resilient examples of each geophysical setting in the region. This map shows only the grid cells above the mean for estimated resilience as compared to others in their ecoregion; each high scoring grid cell is colored based on its corresponding geophysical setting. This map reveals how the settings are reflected in the resilience scores.

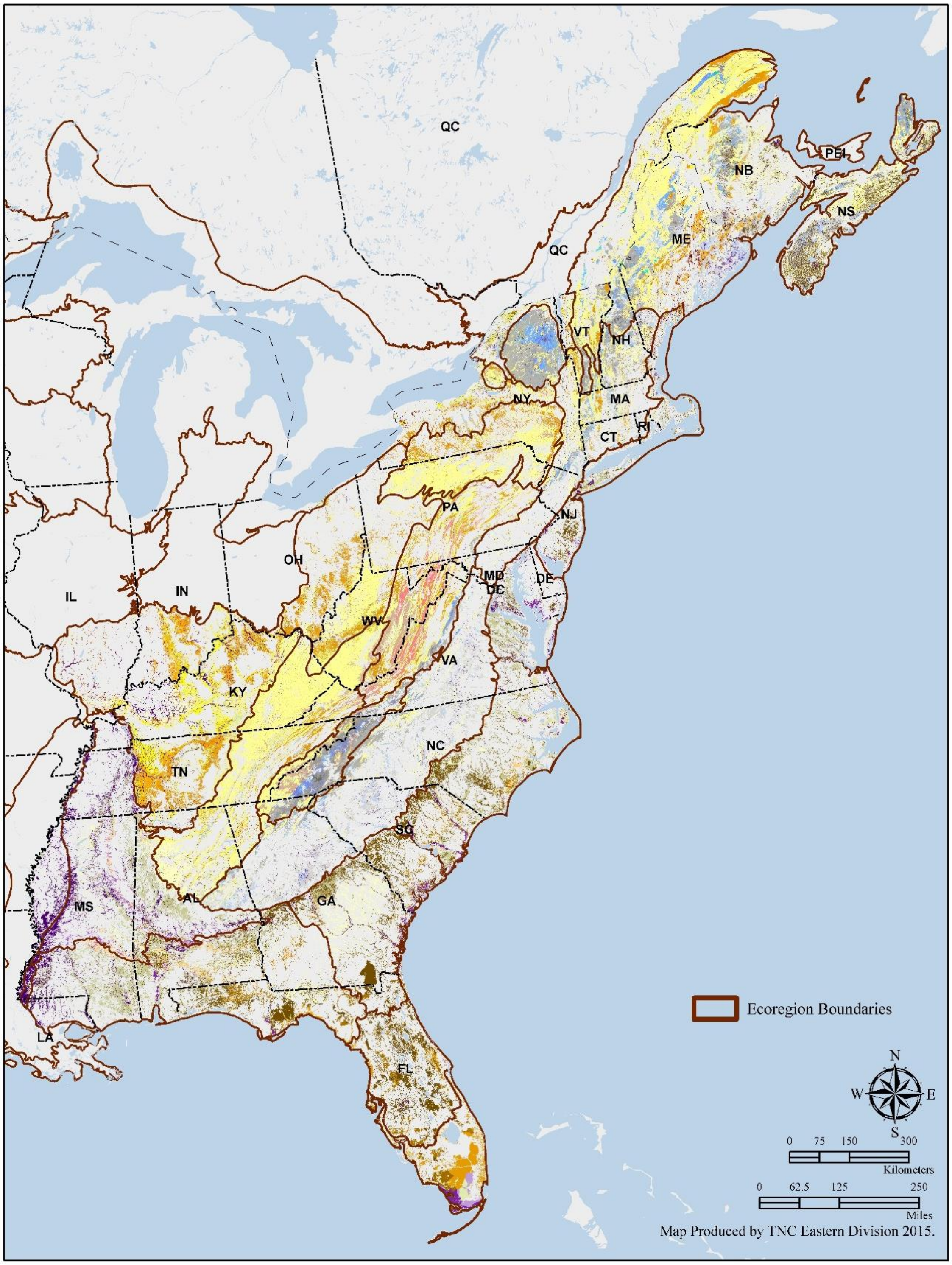


Figure 5.2b. Legend for Figure 5.2a

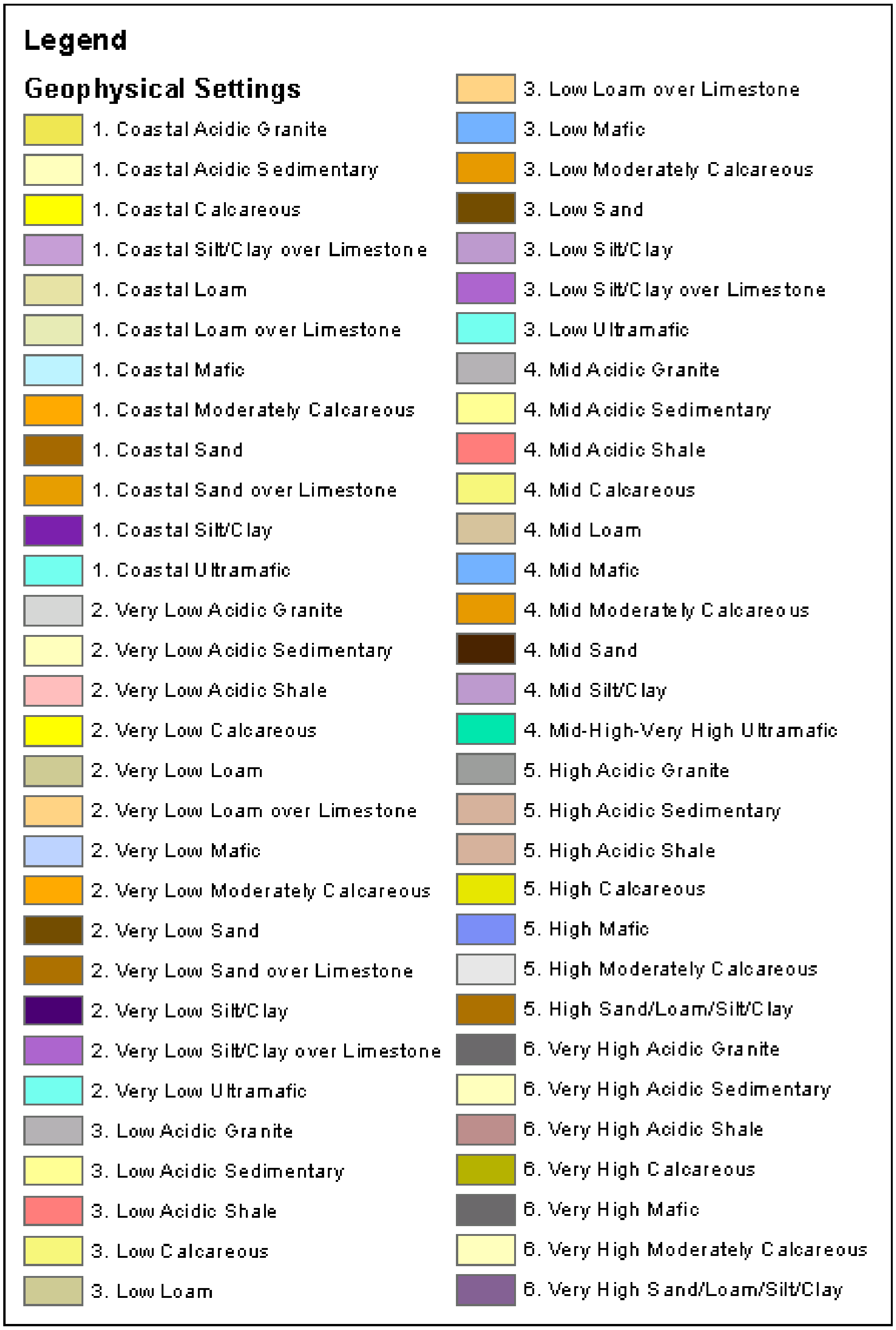


Figure 5.3: Comparison of Resilience Scores: A. Raw scores applied to the whole study area, B. The 61 geophysical settings, C. Scores applied to each geophysical setting, D. Scores applied to each geophysical setting within each ecoregion with regional override (sites greater than 0.5 SD above the mean in map A)**. Map D is the final map.**

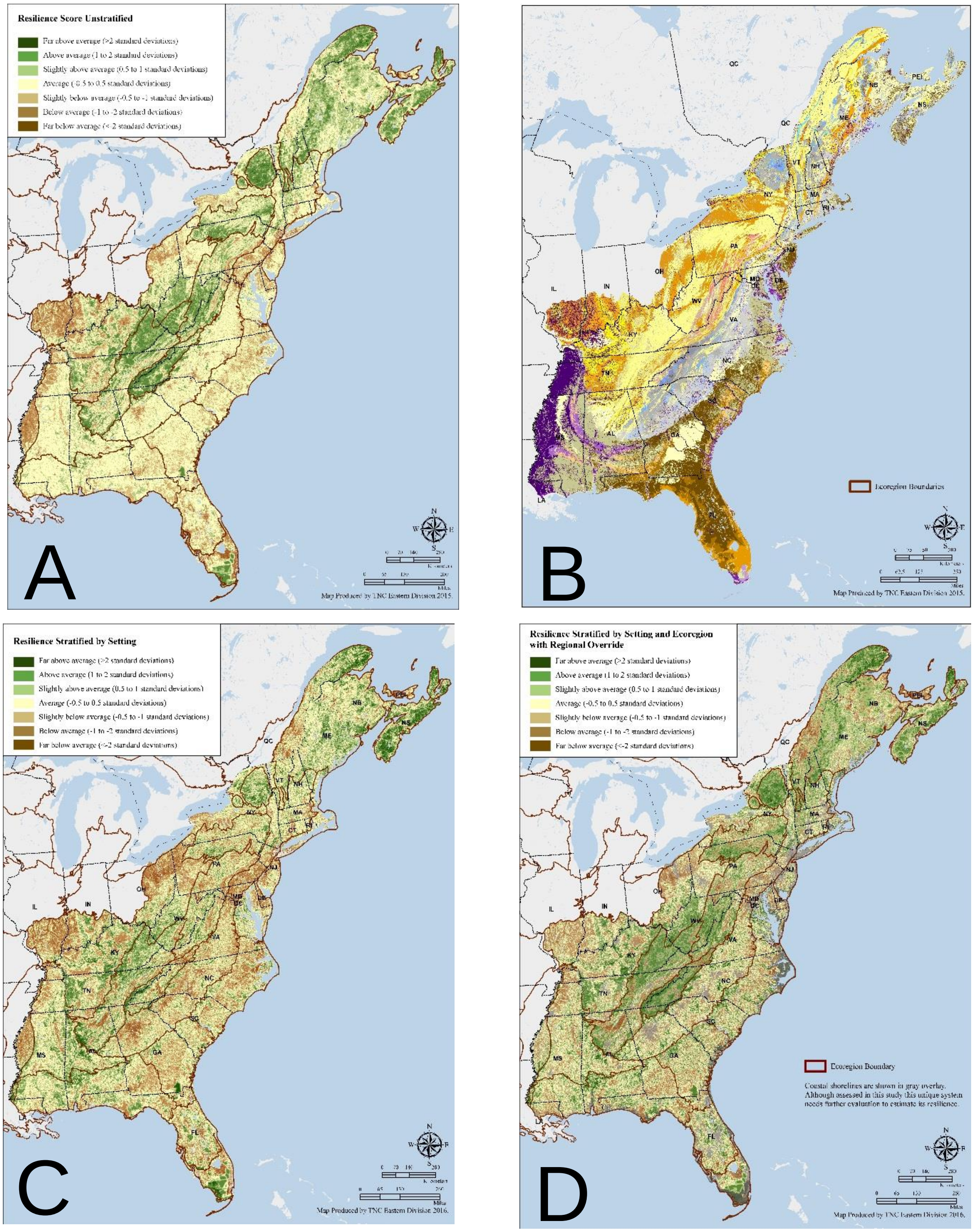


Figure 5.4: Close-up of the highest scoring areas for estimated resilience by setting and ecoregion for the Southeast.

Figure 5.5: Close-up of the highest scoring areas for estimated resilience by setting and ecoregion for the Northeast.

Figure 5.6: Comparision of the resilience scores in the 2016 "Resilient Sites for Terrestrial Conservation in Eastern North America" (this report, main map) and the previous results from the 2014 report "Resilient Sites for Terrestrial Conservation in the Southeast Region" (inset).

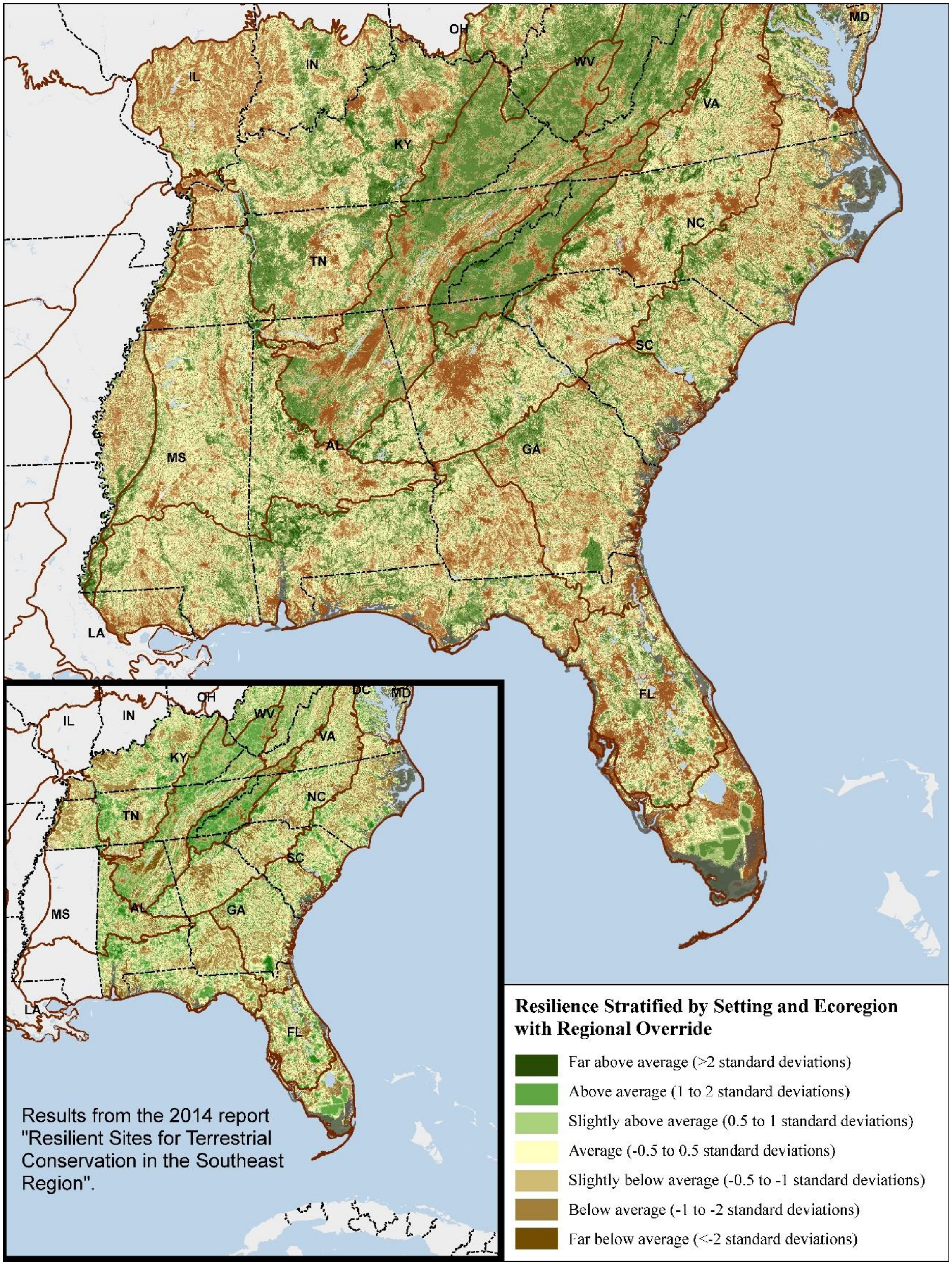


Figure 5.7: Comparision of the resilience scores in the 2016 "Resilient Sites for Terrestrial Conservation in Eastern North America" (this report, main map) and the previous results from the 2012 report "Resilient Sites for Terrestrial Conservation in the Northeast and Mid-Atlantic Region" (inset).

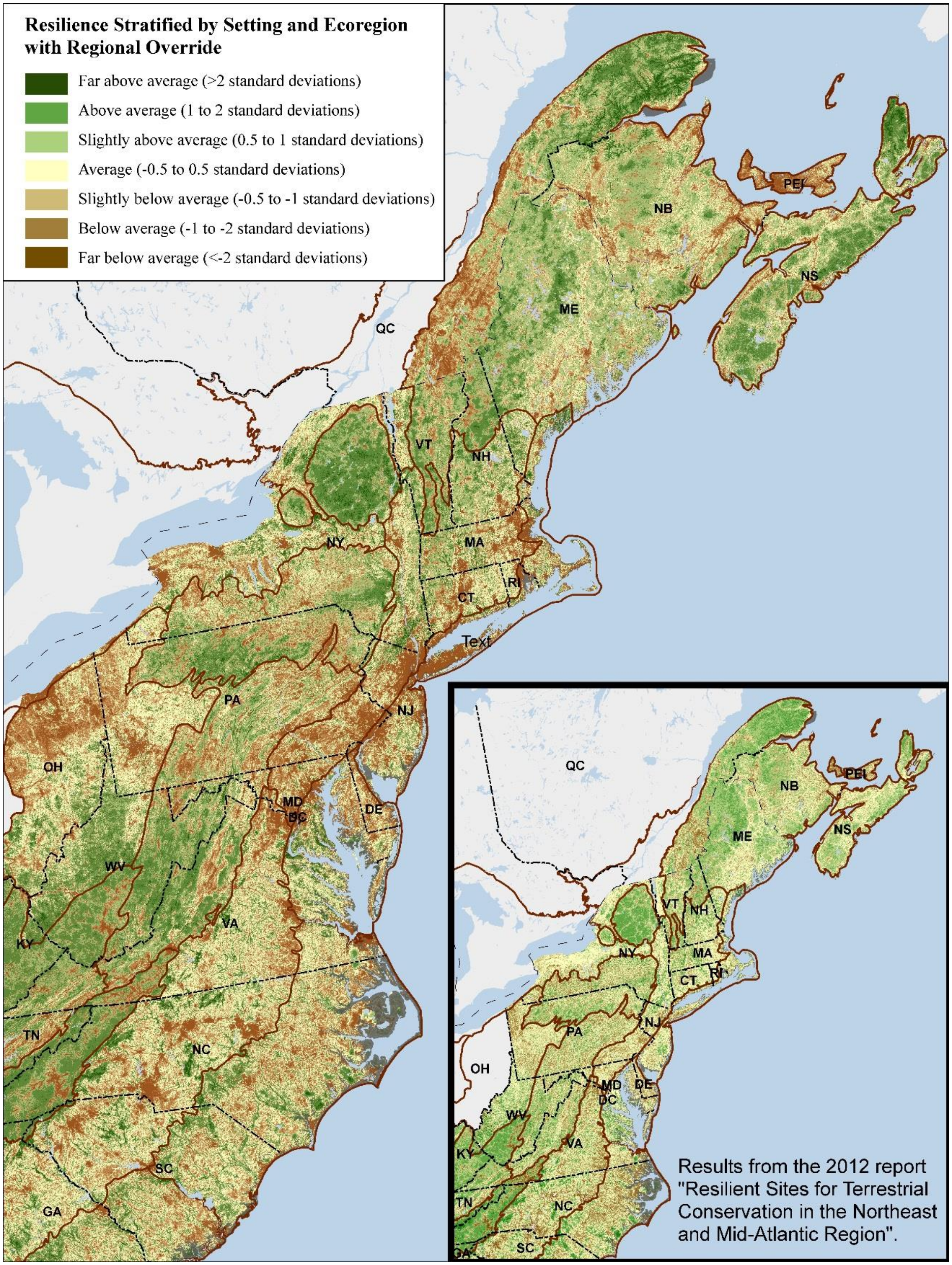
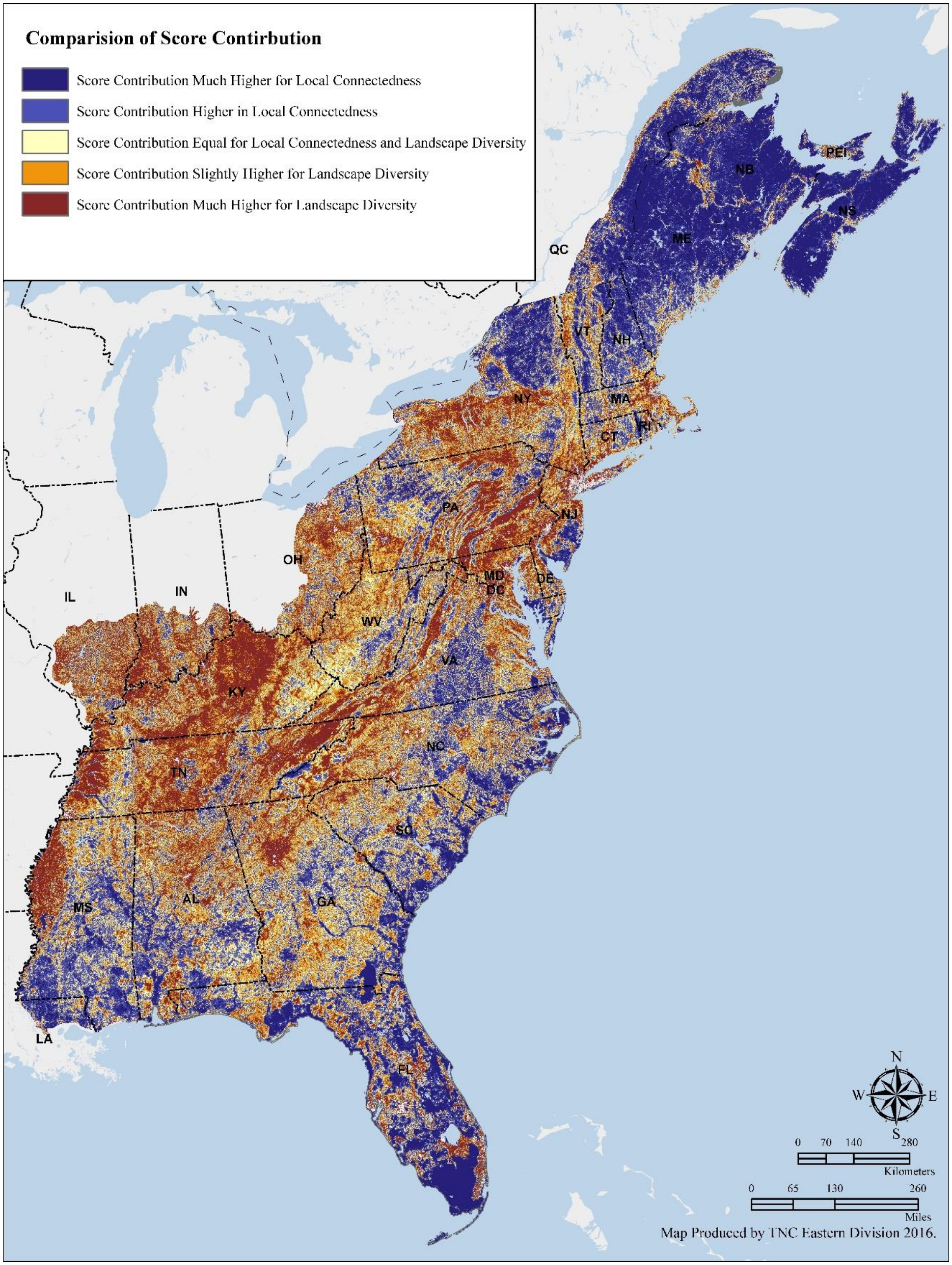


Figure 5.8: Landscape Diversity Stratified by Setting and Ecoregion with Regional Override.

Figure 5.9: Local Connectedness Stratified by Setting and Ecoregion with Regional Override.

Figure 5.10: Comparision of Score Contribution. Grid Cells in blue have more score contibution from local connectedness. Gridcells in Brown have more score from landscape diversity.



Discussion

This project identifies the 179 million acres of land across Eastern North America that has the highest estimated resilience relative to the type of geophysical setting it represents and the ecoregion it is located in. We emphasize that this analysis is based on those attributes that appear to be predictive of site resilience and that could be mapped at a regional scale. Although we made the analysis as transparent, comparable, and consistent as possible, we approached resilience to climate change as a relative concept because there are no clear absolute thresholds. Scientists have limited understanding of how climate-induced changes will interact with each other, how those interactions will play out on the landscape, and how systems will transform. By conserving all types of geophysical settings and using site resilience criteria to select places for conservation action, we one could expand the variety of diversity conserved and increase the odds probability of its persistence over time. An advantage of this approach is that it is robust to uncertainty in predictions of climate change impacts. This approach, however, is not intended to replace basic conservation principles such as the importance of reserve size, threat reduction, and appropriate land management; rather, it is a coarse-filter strategy (sensu Hunter et al. 1988) for making informed decisions when facing large uncertainties.

The amount of resilient area shown on the map (the green) reflects the highest scoring one-third of each setting in the region and it is not an absolute measure of how much area is equally resilient to climate change. Some geophysical settings such as high-elevation granite had an average score that was relatively high, whereas other settings like low elevation limestone had an average score that is relatively low. For the results to be understood in a meaningful context, practitioners using these datasets for planning will need to keep in mind what geophysical setting they are aiming to conserve and realize that all of these valuations are comparative – no absolute thresholds for resiliency were identified.

Current research is reinforcing the importance of landscape diversity in enabling a species to persist through a changing climate, and the value of connectivity in facilitating range shifts and adaptation has strong historical evidence and widespread agreement among the scientific community. Still, there is much uncertainty about how the effects of climate change will play out. Moreover, we did not account for all possible changes such as sea level rise in the coastal shoreline areas; nor does this analysis take into account other aspects of local condition that may also play an important role in resilience such as past or current land uses. Thus we suggest that this analysis, and the accompanying datasets, be used in conjunction with supplementary information such as local studies, feasibility analyses, and the specific types and estimated viability of features included in TNC's portfolio sites.

This report is a revision and integration of two previous studies on identifying resilient sites for terrestrial conservation, one in the Northeast (Anderson et al. 2012) and one in Southeast (Anderson et al. 2014). This 2016 update combines and (we hope) improves on methods to make a unified map for the Eastern United States. We received extensive feedback on the first versions, and most of it came from conservationists thoughtfully applying the results to place that they knew well. This ground testing was largely reassuring, but it also revealed important ecological variations that we had missed (such as with soils and wetlands) or gaps in the datasets (such as missing roads or misclassified barrens). We have done our best to incorporate all the good suggestions into this revised version, but certainly there will still be discrepancies. As you can see in figures 5.6 and 5.7, the general patterns from the original reports and this 2016 Update are very similar but there are place where the results shifted substantially. We encourage users to examine sites at a local scale, to see how the improved methods effected the local results.

This report is the companion piece to **Resilient and Connected Landscapes for Terrestrial Conservation in Eastern North America** (Anderson et al. 2016b), which focuses on identifying a connected network of resilient sites with confirmed biodiversity and connectivity values. The second report expands on the resilient sites identified in this report, prioritizing resilient sites by biological features and types of regional flow, such as diffuse intact areas and riparian climate corridors, that are expected to facilitate range shifts under climate change. The report ends with a series of conservation strategy maps that show, for example, the amount of carbon stored in the resilient network, or how the network might be used to influence the siting of energy infrastructure.

References

Anderson, M.G., A. Barnett, M. Clark, A. Olivero Sheldon, J. Prince. 2016. Resilient and Connected Landscapes for Conservation across Eastern North America. The Nature Conservancy, Eastern Conservation Science.

Anderson, M.G. Weaver, K. Ferree, C, Olivero, A. and J. Prince. 2015. Enduring Features for Conservation. The Nature Conservancy, Eastern Conservation Science, Eastern Regional Office. Boston, MA.

Anderson, M.G., M. Clark, and A. Olivero Sheldon. 2014. Estimating Climate Resilience for Conservation across Geophysical Settings. Conservation Biology 28 (4) 1523-1739. http://dx.doi.org/10.1111/cobi.12272

Anderson, M.G., A. Barnett, M. Clark, C. Ferree, A. Olivero Sheldon, and J.Prince. 2014. Resilient Sites for Terrestrial Conservation in the Southeast Region. The Nature Conservancy, Eastern Conservation Science. 127 pp.

Anderson, M.G., M. Clark, and A. Olivero Sheldon. 2012 Resilient Sites for Terrestrial Conservation in the Northeast and Mid-Atlantic Region. The Nature Conservancy, Eastern Conservation Science. 168pp.

Anderson M.G. and C. Ferree. 2010. Conserving the Stage: climate change and the geophysical underpinnings of species diversity. PLoS ONE. 5(7):E11554.doi:10.1371/journal.pone.0011554.

Anderson, M.G. 1999. Viability and Spatial Assessment of Ecological Communities in the Northern Appalachian Ecoregion. PhD dissertation. Univ. of New Hampshire. 224 pp.

Andrew J. Suggitt, Phillipa K. Gillingham, Jane K. Hill, Brian Huntley, William E. Kunin, David B. Roy and Chris D. Thomas Article first published online: 16 JUL 2010 DOI: 10.1111/j.1600-0706.2010.18270.x © 2011 The Authors Issue Oikos Volume 120, Issue 1, pages 1–8, January 2011

Bailey, R.G. 1995. Description of the ecoregions of the United States. 2nd edition revised and expanded. USDA Forest Service Miscellaneous Publication 1391, Washington, DC. 108p. with separate map at 1:7,500,000.

Beier, P and B. Brost 2010. Use of Land Facets to Plan for Climate Change: Conserving the Arenas, Not the Actors. Conservation Biology 24:701-710.

Beier, P., Spencer, W., Baldwin, R.F., and McRae, B.H. 2011. Towards best practices for developing regional connectivity maps. Conservation Biology. (In press).

Bennie, J., Huntley B., Wiltshire A., Hill M., and Baxter R. 2008. Slope, aspect and climate: Spatially explicit and implicit models of topographic microclimate in chalk grassland, Ecological Modelling, Volume 216, Issue 1, 10 August 2008, Pages 47-59, ISSN 0304-3800, Bennie, J., M.O. Hill, R. Baxter and B. Huntly. 2006. Influence of Slope and Aspect on Long-term Vegetation Change in British Chalk Grasslands. Journal of Ecology, 94: 355–368.

Botkin, D.B., Saxe, H. Araujo, M.B., Betts, R., Bradshaw, R.H.W., Cedhagen, T., Chasson, P, Dawson, T.P., Etterson, J.R., Faith, D.P. Ferrier, S., Guisan, A., Hansen, A.S., Hilbert, D.W., Loehle, C., Margules, C. 2007. Forcasting the Effects of Global Warming on Biodiversity. BioScience. Vol. 57 No. 3.

Canada digital elevation data. [computer file]. 2011. Minister of Natural Resources, Canada, 1997-2011.

Chen, I. C., Hill, J. K., Ohlemüller, R., Roy, D. B., & Thomas, C. D. 2011. Rapid range shifts of species associated with high levels of climate warming. Science, 333(6045), 1024-1026.

Conacher, A.J., and J.B. Darymple. 1977. The nine unit land-surface model: an approach to geomorphic research: Geoderma. 18:1-154.

Compton, B.W, McGarigal, K, Cushman S.A. and L.G. Gamble. 2007. A resistant-kernel model of connectivity for amphibians that breed in vernal pools. Conservation Biology 21: 78-799. http://www.umasscaps.org/

Crowley, J. M. 1967. Biogeography. Can. Geogr. 11:312-326.

Dobkin, D. S., L Olivieri, and P.R. Ehrlich. 1987. Rainfall and the Interaction of Microclimate with Larval Resources in the Population Dynamics of Checkerspot Butterflies (Euphydryas editha) Inhabiting Serpentine Grassland. Oecologia. 72(2). 161-166.

Duke Energy (2014). Transmission Rights of Way. http://www.duke-energy.com/safety/right-of-way-management/transmission.asp

Fels, J., and K. C. Matson. 1997. A cognitively-based approach for hydrogeomorphic land classification using digital terrain models. Proceedings, Fourth International Conference on Integrating GIS and Environmental Modeling. Santa Fe, NM, CD.

Ferrari, I and Ferrarini A. 2008. From Ecosystem Ecology to Landscape Ecology: a Progression Calling for a Well-founded Research and Appropriate Disillusions Landscape Online 6, 1-12.

Ferree, C. and M.G. Anderson. 2015. Terrestrial Habitat Map for Northeast US and Atlantic Canada. The Nature Conservancy, Eastern Conservation Science, Eastern Regional Office. Boston, MA.

Fisette T., A. Davidson, B. Daneshfar, P. Rollin, Z. Aly and L. Campbell, 2014. "Annual space-based crop inventory for Canada: 2009–2014," 2014 IEEE Geoscience and Remote Sensing Symposium, Quebec City, QC, 2014, pp. 5095-5098.

FNAI. 2012. Florida Natural Areas Inventory: Wetlands: http://www.fnai.org/FF_Disclaimer.cfm.

FNAI. 2015. Florida Cooperative Land Cover Map (CLC). Accessed January 2016. http://www.fnai.org/landcover.cfm

Forman, R.T.T. 1995. Land Mosaics: the ecology of landscapes and regions. Cambridge, 656 pp.

Forman, R.T.T.and Godron, M. 1986 Landscape Ecology. Wiley Press, USA 640 pp.

Fremier, Alexander, M. Kiparsky, S. Gmur, J. Aycrigg, R. Kundis Craig, L. K. Svancara, D. D. Goble, B. Cosens, F. Davis, J. M. Scott. 2015. A Riparian Conservation Network for Ecological Resilience. Biological Conservation. Vol. 191, 29-37.

Fry, J., Xian, G., Jin, S., Dewitz, J., Homer, C., Yang, L., Barnes, C., Herold, N., and Wickham, J., 2011. Completion of the 2006 National Land Cover Database for the Conterminous United States, PE&RS, Vol. 77 (9): 858-864.

GeoBase - Canadian Council on Geomatics (CCOG). 2004. Government of Canada, Natural Resources Canada, Surveyor General Branch. http://ows.geobase.ca/wms/geobase_en

Gesch, D.B.2007, The National Elevation Dataset, in Maune, D., ed., Digital Elevation Model Technologies and Applications: The DEM Users Manual, 2nd Edition: Bethesda, Maryland, American Society for Photogrammetry and Remote Sensing, p. 99-118.

gSSURGO 2014. Gridded Soil Survey Geographic Database for the Conterminous United States. United States Department of Agriculture, Natural Resources Conservation Service. Available from the NRCS geospatial data gateway, online at https://gdg.sc.egov.usda.gov/ Accessed December 1, 2014.

Gunderson, L.H., 2000. Ecological Resilience--In Theory and Application. Annual Review of Ecology and Systematics, Vol. 31. (2000), pp. 425-439.

Hampel, F.R., E.M. Ronchetti, P.J. Rousseeuw and W.A. Stahel (1986) Robust Statistics: The Approach based on Influence Functions. Wiley.

Hansen, M.C, Potapov, P.V., Moore, R. Hancher, M., Turubanova, S.A., Tyukavina, A., Thau, D. Stehman, S.V. Goetz, S.J. Loveland, T.R. Kommareddy, A., Egorov, A., Chini, L., Justice, C.O., and J. R. G. Townshend. 2013. High-Resolution Global Maps of 21st-Century Forest Cover Change Science 342, 850; DOI: 10.1126/science.1244693. Downloaded from www.earthenginepartners.appspot.com/

Heller, N.E. and Zavaleta E.S. 2009. Biodiversity management in the face of climate change: A review of 22 years of recommendations. Biological Conservation 142; 14-32.

Hijmans, Robert J. 2015. raster: raster: Geographic data analysis and modeling. R package version 2.1-49. http://CRAN.R-project.org/package=raster.

Homer, C.G., Dewitz, J.A., Yang, L., Jin, S., Danielson, P., Xian, G., Coulston, J., Herold, N.D., Wickham, J.D., and Megown, K., 2015, Completion of the 2011 National Land Cover Database for the conterminous United States-Representing a decade of land cover change information. Photogrammetric Engineering and Remote Sensing, v. 81, no. 5, p. 345-354

Hunter, M.L. and Sulzer, A. 2002. Fundamentals of Conservation Biology. Wiley.

IPPC 2007. Climate Change 2007 Synthesis report. Intergovernmental Panel on Climate Change. Pachauri, R.K. and Reisinger, A. (Eds.) IPCC, Geneva, Switzerland. 104 pp.

Krosby, M., Tewksbury, J., Haddad, N.M., Hoekstra, J. 2010. Ecological Connectivity for a Changing Climate. Conservation Biology, Volume 24, No. 6, 1686–1689.

Lawler, Joshua J., D. Ackerly, C. Albano, M. G. Anderson, S. Dobrowski, J Gill, N. Heller, R. Pressey, E. Sanderson, S. Weiss. 2015. The Theory Behind, and the Challenges of, Conserving Nature's Stage in a Time of Rapid Change. Conservation Biology. 29(3). Pages 618 – 629.

Lenoir, J., Gégout, J. C., Guisan, A., Vittoz, P., Wohlgemuth, T., Zimmermann, N. E.,& Svenning, J. C. 2010. Going against the flow: potential mechanisms for unexpected downslope range shifts in a warming climate. Ecography, 33(2), 295-303.

Lindenmayor, D. and Fischer, J. 2006. Habitat fragmentation and Landscape change. Island Press. 352 pp

Luoto, M. and R.K. Heikkinen. 2008. Disregarding topographical heterogeneity biases species turnover assessments based on bioclimatic models. Global Change Biology 14 (3) 483–494.

McCune, B. and Grace, J.B. 2002. Analysis of Ecological Communities. MjM software design. Oregon USA. 300 pp. www.pcord.com.

Meiklejohn, K., Ament, R. and Tabor, G. 2010. Habitat Corridors & Landscape Connectivity: Clarifying the Terminology. Center For Large Landscape Conservation. www.climateconservation.org.

Ministère des Ressources naturelles. 2014. Forgen-Tergen Écoforestière forest inventory data, Géoboutique Québec. Quebec City.

Moeys, J. with contributions from Wei Shangguan. (2012). Soiltexture: Functions for soil texture plot, classification and transformation. R package version 1.2.9. http://CRAN.R-project.org/package=soiltexture.

Naiman, R. J., Decamps, H., & Pollock, M. 1993. The role of riparian corridors in maintaining regional biodiversity. Ecological applications, 3(2), 209-212.

National Wetlands Inventory. 2013. http://www.fws.gov/wetlands/Data/State-Downloads.html.

National Road Network. 2015. Government of Canada; Natural Resources Canada; Earth Sciences Sector; Canada Centre for Mapping and Earth Observation. Accessed January 2016.

New Brunswick Forest Inventory Database. 2012. NB Department of Natural Resources, Fredericton, NB.

NB Wetlands Inventory. 2006. NB DNR, Fredericton, NB

Nova Scotia Forest Inventory and NS Wetlands Inventory. 2014. NS Department of Natural Resources, Kentville, NS & Truro, NS.

NRCS. 2009. Natural Resources Conservation Service (NRCS), United States Department of Agriculture. Soil Survey Geographic (SSURGO) Database for FL, GA, AL, MS, TN, KY, SC, NC, VA, WV. December 30, 2009 snapshot.

Open Space Institute. 2009. Industrial forest Classification dataset.
Openstreet Map. 2015. OpenStreetMap contributors. https://www.openstreetmap.org/
Parcel Point. 2013. Parcel Boundary Map Data. http://www.corelogic.com/products/parcelpoint.aspx.
Pebesma, E.J., R.S. Bivand. 2005. Classes and methods for spatial data in R. R News 5 (2), http://cran.r-project.org/doc/Rnews/.
PEI Corporate Land Use Inventory. 2010. Prince Edward Island Department of Agriculture & Forestry, Charlottetown, PEI.
R Core Team. 2013. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.
Randin, C.F.. Engler, R., Normand, S.. Zappa, M.. Zimmermann, N., Pearman, P.B., Vittoz, P., Thuiller, W. and A. Guisani. 2008. Climate change and plant distribution: local models predict high-elevation persistence. Global Change Biology 15(6) 1557-1569.
Roger S. Bivand, Edzer Pebesma, Virgilio Gomez-Rubio. 2013. Applied spatial data analysis with R, Second edition. Springer, NY. http://www.asdar-book.org/.
Ruhe, R.H., and P.H. Walker.1968. Hillslope model and soil formation. Open systems: Trans. 9th. Internat. Cong. Soil Sci., v4, p551-560.
Schafale, M.P. and A.S. Weakley. 1990. Classification of the Natural Communities of North Carolina: third approximation. North Carolina Natural Heritage Program. Division of Parks and Recreation. Department of Environment and Natural Resources. MSC 1615. Raleigh, NC 27611.
Soil Survey Staff. 2015. The Gridded Soil Survey Geographic (gSSURGO) Database for [State Name]. United States Department of Agriculture, Natural Resources Conservation Service. Available online at https://gdg.sc.egov.usda.gov/. June 2015 (FY2016 official release).
Southeast GAP Land Cover Dataset. 2010. Biodiversity and Spatial Information Center, USGS North Carolina Cooperative Fish and Wildlife Research Unit, NC State University. http://www.basic.ncsu.edu/segap/DataServer.html.
Suggitt, A. J., Gillingham, P. K., Hill, J. K., Huntley, B., Kunin, W. E., Roy, D. B. and Thomas, C. D. (2011), Habitat microclimates drive fine-scale variation in extreme temperatures. Oikos, 120: 1–8.
Tingley, M.W., Estes, L.D. Estes and D.S. Wilcove. 2013. Climate change must not blow conservation off course. Nature 500 271-272.
The Nature Conservancy. 2005. Florida Peninsula Ecoregional Plan. Prepared by the Core Technical and Planning Team of The Nature Conservancy and the University of Florida Geoplan Center. Tallahassee and Gainesville, Florida.
U.S. Environmental Protection Agency (USEPA) and the U.S. Geological Survey (USGS). 2012. National Hydrography Dataset Plus – NHDPlus. Version 2.01.

USDA Forest Service 2007. Ecological Subregions: Provinces, Sections, and Subsections of the Conterminous United States. http://fsgeodata.fs.fed.us/other_resources/ecosubregions.php.

Van Der Putten, W.H., Macell, M. and M.E. VIsser. 2010. Predicting species distribution and abundance responses to climate change: why it is essential to include biotic interactions across trophic levels. Phil. Trans. R. Soc. B 12 July 2010 vol. 365 no. 1549 2025-2034. doi: 10.1098/rstb.2010.0037.

Venables, W. N. & Ripley, B. D. 2002. Modern Applied Statistics with S. Fourth Edition. Springer, New York. ISBN 0-387-95457-0.

Ventyx Corporation (2014) Velocity Suite: Transmission lines constrained or congested, transmission lines (In service by voltage class), and Natural Gas Pipelines (In service). http://www.ventyx.
com/en/enterprise/business-operations/business-products/velocitysuite.
Accessed October 2014.

Vivan-Smith, G. 1997. Microtopographic Heterogeneity and Florsistic Diversity in Experimental Wetland Communities. Journal of Ecology 85(1): 71-82.

Weiss, S. B., D. D. Murphy, and R. R. White. 1988. Sun, slope, and butterflies: Topographic determinants of habitat quality for *Euphydryas editha bayensis*. Ecology 69:1386.

Willams, D. 2010. Forests of the Great Smoky Mountains National Park: A Naturalist's Guide to Understanding and Identifying Southern Appalachian Forest Types. CreateSpace IPP.

Willis, K.J. and Bhagwat, S.A. 2009. Biodiversity and Climate Change. Science 326: 807.

Yeakley J. A., W. T. Swank, L. W. Swift, G. M. Hornberger, H. H. Shugart. 1998. Soil moisture gradients and controls on a southern Appalachian hillslope from drought through recharge. Hydrology and Earth System Sciences Discussions, European Geosciences Union. 2 (1), pp.41-49.

APPENDIX

I

Detailed Data Sources and Methods

Elevation

U.S. Geological Survey. 2002-2008.National Elevation Dataset (NED) 30m. Sioux Falls, SD http://ned.usgs.gov/

Gesch, D.B., 2007, The National Elevation Dataset, in Maune, D., ed., Digital Elevation Model Technologies and Applications: The DEM Users Manual, 2nd Edition: Bethesda, Maryland, American Society for Photogrammetry and Remote Sensing, p. 99-118.

Gesch, D., Oimoen, M., Greenlee, S., Nelson, C., Steuck, M., and Tyler, D., 2002, The National Elevation Dataset: Photogrammetric Engineering and Remote Sensing, v. 68, no. 1, p. 5-11.

Calculating the Uncorrelated Elevation Range

To generate a raster of uncorrelated elevation range we used a robust regression (Hampel et al. 1986) to factor out the elevation range explained by the landform variety and measure the residual variation explained only by true elevation changes. The regression calculated a bivariate regression raster with log-transformed elevation range as the dependent variable and landform variety as the independent variable. The regression was calculated using a randomized subsample of pixels stratified by the three subregions (Coastal Plain, Piedmont, and Mountains) and fitted using an iterated re-weighted least squares algorithm (Detail in appendix II). Different sample sizes were explored before selecting the final model for each ecoregion. In the large Coastal Plain ecoregion, the final model used 250,000 samples and had a mean residual error of 0.00306. The Piedmont ecoregion model used 50,000 samples and had a mean residual error of 0.00291. The Mountains ecoregion model consisted of 100,000 samples with a mean residual error of 0.01107. A raster of the regression residuals was generated for each ecoregion and then back-transformed to create a grid of elevation range unexplained by landform variety. All analyses were conducted in R 3.1.2 (R Core Team 2014) using the raster Regression.R script written by Dr. Jeffrey S. Evans, Senior Landscape Ecologist at The Nature Conservancy (personal communication, October 8, 2013) and the following R packages: *raster* (Hijmans 2015); *sp* (Pebesma & Bivand 2005; Bivand et al. 2013); and *MASS* (Venebles & Ripley 2002). In the Coastal Plain ecoregion, the average elevation range unexplained by landform variety was 0.16 m with a standard deviation of 0.73 m and a maximum of 51.46 m. The Piedmont ecoregion had a mean of 0.09 m and a standard deviation of 0.57 m with a maximum unexplained elevation range of 24.35 m, while the Mountains ecoregion had a mean of 0.47 m, a standard deviation of 1.60 m, and a maximum of 35.93 m. Because the NED has a vertical accuracy of 2.44 meters we ignored elevation ranges below this threshold.

Landforms

Several steps were taken to prepare the 17-class landform raster for use in the landform variety calculation. First, to ensure that all rivers were classified as open water, flowlines from the National Hydrography Dataset Plus version 2 (NHDPlus v2) hydrography (USEPA & USGS 2012) were assigned to one of seven stream and river size classes (Olivero & Anderson 2008) based on the NHDPlus v2 divergence-routed cumulative drainage area (km^2). All flowlines classified as small rivers and larger were selected and converted to a 30-m grid that was merged on top of the landforms as open water. As the resilience analysis does not consider coastal and marine processes or sea level rise, all landform pixels that coincided with the NHDPlusv2 polygons coded as sea, ocean, or nearshore were converted to null values so they would not be included in the analysis.

Geology

VT: Ratcliffe, N.M., Stanley, R.S., Gale., M.H., Thompson, P.J., and Walsh, G.J., 2011, Bedrock geologic map of Vermont: U.S. Geological Survey Scientific Investigations Map 3184, scale 1:100,000, 3 sheets. With review of ECS 9 classes as of 6/2015 by Vermont Team: Marjorie Gale, Eric Sorenson, Elizabeth Thompson, Robert Zaino, and Dan Farrell.

MA: Zen, E-an, Goldsmith, R., Ratcliff, N.L., Robinson, P., and Stanley, R.S., [compilers], 1983, Bedrock geologic map of Massachusetts: U.S. Geological Survey, 3 map sheets, scale 1:250,000

DE: Spoljaric, Nenad and Jordan, Robert R., 1966, Generalized Geologic Map of Delaware, State of Delaware, Delaware Geological Survey, scale ca. 1:300,000.

Quebec: Geological Map of Québec – 2012 Edition. Department of Natural Resources Geology Quebec
DV 2012-06. Zone_geologique.shp. Also Geological Map of Québec – 2008 Edition. Department of Natural Resources Geology Quebec DV 2012-06. Zone_geologique.shp

New Brunswick, Prince Edward Island, and Nova Scotia. Bedrock from TNC Ecological Land Units 2008.

All Other Bedrock Data downloaded 10-18-2013 from http://mrdata.usgs.gov/geology/state/

AL: Szabo, M. W., Osborne, E. W., Copeland, C. W. Jr., Neathery; T. L., 1988, Geologic Map of Alabama, Geological Survey of Alabama Special Map 220, scale 1:250,000.

CT: Connecticut Geological and Natural History Survey, DEP, in cooperation with the U.S. Geological Survey, 2000, Bedrock Geology of Connecticut, data format: shapefile, file name: bedrock, downloaded from: http://magic.lib.uconn.edu/cgi-bin/MAGIC_DBsearch2.pl?Geography=37800&Loc=0000 on 9/18/2003, scale 1:50,000.

FL: Scott, T. M., Campbell, K. M., Rupert, F. R., Arthur, J. D., Missimer, T. M., Lloyd, J. M., Yon, J. W., and Duncan, J. G., 2001, Geologic Map of the State of Florida, Florida Geological Survey & Florida Department of Environmental Protection, Map Series 146. C.L. Dicken polygon edits. Additionally, when using US001 state boundary file, water polygons have been generated.

GA: Lawton, D.E., and others, 1976, Geologic Map of Georgia: Georgia Geological Survey, scale = 1:500,000. 1:500k GEOLOGY COVER: geology.zip available at Georgia GIS Data Clearinghouse http://gis1.state.ga.us/index.asp Do a theme search category "geology", keyword "geology" Data was indicated to be "free" therefore public domain Information available at site: Title: Geology Location: Georgia Scale: 1:500,000 File Format: ArcInfo Export File Projection: Lambert Conformal Conic Originator: Georgia Department of Natural Resources Index: Published: 1999 Updated: 10/9/2000 Abstract: Purpose: For more information about this dataset please visit the Georgia Department of Natural Resources.

IL: Willman, H.B., and others, (compilers), 1967, Geologic Map of Illinois: Illinois State Geological Survey, scale= 1:500,000, paper.

IN: Gray, Henry H., Ault, Curtis, H., and Keller, Stanley, J., 1987, Bedrock geologic map of Indiana: Dept. of Natural Resources, Indiana Geological Survey, Miscellaneous Map 48, scale = 1:500,000

KY: Noger, M.C., compiler, 1988, Geologic map of Kentucky: sesquicenntennial edition of the Kentucky Geological Survey: U.S. Geological Survey and the Kentucky Geological Survey, scale 1:500,000.

LA: United States Geological Survey, 1998, Digital Overlay of the Geologic Map of Louisiana: U.S. Geological Survey, Biological Resources Division, National Wetlands Research Center, Product Id USGS-NWRC 1984-02-0001, http://www.nwrc.usgs.gov/.

MD: Cleaves, E.T., Edwards, J., Jr., Glaser, J.D., 1968, Geologic Map of Maryland: Maryland Geological Survey, Baltimore, Maryland, scale 1:250,000.

MS: Moore, William Halsell, 1969, reprinted 1985, Geologic Map of Mississippi, Compiled by Bicker, A. R., Jr., a revision of the geologic map published by the MS Geological Survey in 1945 in cooperation with the USGS, revised from data submitted by Dr. E. E. Russell of MS State University from published reports of the MS Geological Survey and from field revisions, Mercury Maps Inc., Jackson, MS. USGS Open-File Report 2005-1323

Preliminary integrated geologic map databases for the United States : Alabama, Florida, Georgia, Mississippi, North Carolina, and South Carolinahttp://pubs.usgs.gov/of/2005/1323/

NC: The North Carolina Dept. of Environment, Health, and Natural Resources, Division of Land Resources, NC Geological Survey, in cooperation with the NC Center for Geographic Information and Analysis, 1998, Geology - North Carolina (1:250,000), coverage data file geol250. The data represents the digital equivalent of the official State Geology map (1:500,000 scale), but was digitized from (1:250,000 scale) base maps.

NJ: Dalton, R. F., Herman, G. C., Monteverde, D. H., Pristas, R. S., Sugarman, P. J., Volkert, R. A., 1999, New Jersey Department Of Environmental Protection, Bedrock Geology and Topographic Base Maps of New Jersey: New Jersey Geological Survey CD Series CD 00-1; ARC/INFO (v. 7.1) export file: geology.e00, scale 1:100,000, unit description files: cslegend.pdf and nlegend.pdf, metadata: metast.pdf.

NY: NYS Museum, NYS Geological Survey, NYS Museum Technology Center, 1999, 1:250,000 Bedrock geology of NYS, data is distributed in ARC/INFOr EXPORT format (with ".e00" extension) in 5 seperate files based on printed map sheets, http://www.nysm.nysed.gov/gis.html.

OH: Digital Ohio map from CD produced as a result of a contract between the U.S. Geological Survey and the Ohio Geological Survey. Released with permission of the Ohio Geological Survey, June 2005. USGS Open-File Report 2005-1324 Preliminary integrated geologic map databases for the United States : Kentucky, Ohio, Tennessee, and West Virginia http://pubs.usgs.gov/of/2005/1324/

PA: Berg, T. M., Edmunds, W. E., Geyer, A. R., and others, compilers, 1980, Geologic map of Pennsylvania: Pennsylvania Geological Survey, 4th ser., Map 1, 2nd ed., 3 sheets, scale 1:250,000.

Pennsylvania Bureau of Topographic and Geologic Survey, Department of Conservation and Natural Resources, 2001, Bedrock Geology of Pennsylvania, edition: 1.0, digital map. Retrieved from internet 9-30-2004; <http://www.dcnr.state.pa.us/topogeo/map1/bedmap.aspx> DL Data: pageoexp.zip

SC: Horton, J.Wright, and Dicken, Connie L., 2001, Preliminary Geologic Map of the Appalachian Piedmont and Blue Ridge, South Carolina Segment: U.S. Geological Survey, Open-File Report 01-298, CD

Newell, Wayne L., Prowell, David (retired), Krantz, David, Powars, David, Mixon, Robert (retired), Stone, Byron, and Willard, Debra, in review, Surficial Geology and Geomorphology of the Atlantic Coastal Plain: U.S.G.S. Open File Report,

TN: Geology available at Tennessee Spatial Data Server which can be found at http://www.tngis.org/geology.html which links to a USGS Water Resources Division site: http://water.usgs.gov/lookup/getspatial?geo250k Tennessee Spatial Data Server site notes: Thanks goes to Jim Julian for researching this improved geology layer from the Tennessee Division of Geology. **Note** - The Tennessee Division of Geology does not endorse this coverage, stating this version is still incomplete and not fit for distribution. Polygon edits made my C.L. Dicken based on paper source (TN002).

VA: Digital Representation of the 1993 Geologic Map of Virginia", 2003, CD ROM (ISO-9660) contains image file, expanded explanation in pdf, and ESRI shapefiles, viewing software not included. This is a digital version of "Geologic Map of Virginia" published in 1993. Available from: https://www.dmme.virginia.gov/commerce/

WV: Digital version of 1968 printed map available from http://wvgis.wvu.edu/data/data.php with the specific data available from http://wvgis.wvu.edu/data/dataset.php?action=search&ID=43

USGS Open-File Report 2005-1324
Preliminary integrated geologic map databases for the United States : Kentucky, Ohio, Tennessee, and West Virginia http://pubs.usgs.gov/of/2005/1324/

Soils

Soil Texture

SSURGO: Natural Resources Conservation Service 2014, United States Department of Agriculture. Soil Survey Geographic (SSURGO) Database January 15, 2014 snapshot

STATSGO: Natural Resources Conservation Service, United States Department of Agriculture. State Soil Geographic (STATSGO) Data Base for the Conterminous United States. December 30, 2009 snapshot

Soils sand, silt, and clay percent in the 0-20cm depth zone grids were provided at 30m resolution based on the 1/15/2014 SSURGO snapshot dataset by Norman B. Bliss, Ph.D. , Principal Scientist ASRC Research and Technology Solutions, Contractor to the USGS Earth Resources Observation and Science Center, Sioux Falls, SD 57198 bliss@usgs.gov . The aggregation method was a weighted average, where the weighting factor is the mass of soil fines (soil particles less than 2 mm diameter). This weighting thus accounts for the thickness of the horizon within the soil profile and the component percentage of the component in the map unit. The representative value (or percent total) for sand, silt, and clay provided was the result of dividing a particular texture type, for example sand (in grams) by the total mass_fines (in grams) and multiplying by 100%. The definition is comparable to the definition of "representative value" in the original SSURGO data. The data came to us as .img national 30m grids and the following were converted to ArcGIS grids for further processing.

The percent sand, silt, and clay grids were combined to yield a new dataset where each pixel contained the 3 values of the source grids. Soil groups were then developed by the The Soil Texture Wizard package, a set of R functons for working with soil texture data by Julian Moeys 2012 (http://cran.r-project.org/web/packages/soiltexture/vignettes/soiltexture_vignette.pdf) . This program assigns to each combination of sand, silt, and clay an output soil type from the USDA Soil Triangle. Before assignment to these types, the records were first normalized so the percent of sand, silt, and clay equaled 100% if they did not already equal 100%. These rare cases where the percent sand, silt, and clay did not equal 100% were either small rounding errors in the source data or were due the presence of organic material content in the soils. The Wizard tool plotted each combination of sand, silt, and clay values onto the USDA soil triangle and reported the soil texture class. All pixels with reported sand, silt, and clay totals > 0 were analyzed and the output saved into the grid Sasicl_2014_v (pixels with Values). The resultant classification yielded 12 "first class" soil texture types.

To seamlessly map the soil texture groups across east, we then worked to integrate the STATSGO2 soil texture data for large areas where SSURGO soil texture data was not available. Given the finer mapping scale of the SSURGO (1:12,000 to 1:24,000) vs. the STATSGO2 (1:250,000) data, any geographic area covered by SSURGO should be represented with the soil texture class from the SSURGO finer data. However, SSURGO was not available for all areas. It was missing for a handful of counties and was missing in a few other large areas such as some National Parks or other areas where soils information was not publically available at the SSURGO level. After study of the areas missing SSURGO data, we decided to fill large missing areas >10,000 acres in size with the courser STATSGO2 data. The STATSGO2 dataset was converted to a raster on the 12 soil types and mosaicked into the large >= 10,000 acre holes. Missing areas < 10,000 acres were then filled in by simply expanding the surrounding classes into the missing area using the Euclidean nearest neighbor "nibble" command. Many of these smaller missing areas were wide river or lake features.

Soil Map Unit Diversity

Soil Survey Staff. The Gridded Soil Survey Geographic (gSSURGO) Database for **[see list below in Step 1a].** United States Department of Agriculture, Natural Resources Conservation Service. Available online at https://gdg.sc.egov.usda.gov/. June 2015 (FY2016 official release).

The following steps detail how the 10-m gridded SSURGO data for each state in the Coastal Plain stratification unit was processed and used in the soil diversity analysis.

1. Download gridded SSURGO data by state from the NRCS geospatial data gateway
    a. List of states downloaded June 2015:
        - Alabama
        - Connecticut
        - Delaware
        - District of Columbia
        - Florida
        - Georgia
        - Illinois
        - Indiana
        - Kentucky
        - Maine
        - Maryland
        - Massachusetts
        - Mississippi
        - New Hampshire
        - New Jersey
        - New York
        - North Carolina
        - Ohio
        - Pennsylvania
        - Rhode Island
        - South Carolina
        - Tennessee
        - Vermont
        - Virginia
        - West Virginia
2. Unzip initial file
    a. Unzip “gssurgo_g_STATEABBREVIATION” file
    b. Within gdb, select 10m raster grid, called “MapunitRaster_STATEABBREVIATION_10m”
    c. Join “mapunit” table in the gdb to the grid using “MUKEY” and “Mapunit Key”
    d. Export joined table as dbf file
3. Run R script to clean up duplicate map unit names (munames). Script makes the following changes to the map unit names:

a. Remove all commas before removing duplicate munames
b. Remove all dashes and replace with a single space
c. Remove all capitalization (convert all text to lower case)
d. Combine "Coastal beaches" and "Beaches" into a single type: 4000
e. Classify all soils with urban as 5000
f. Combine soil types if eroded
    i. eroded, moderately eroded, severely eroded
g. Create "Anthropogenic" code (5000):
    i. Dam
    ii. Dumps
    iii. Dumps-Pits complex
    iv. Dumps, sediment basins
    v. Pits
    vi. Mine pits
    vii. Mine pits and dumps
    viii. Pits, borrow
    ix. Pits, gravel
    x. Pits, kaolin
    xi. Pits, mine
    xii. Pits, mines
    xiii. Pits, quarries
    xiv. Pits, quarries, limestone
    xv. Pits, quarry
    xvi. Udorthents-Pits complex
    xvii. Udorthents-Pits complex, clayey
    xviii. Udorthents-Pits complex, gently sloping to steep
    xix. Udorthents-Pits complex, sandy
    xx. Udorthents-Pits complex
    xxi. Urban land and borrow pits
    xxii. Borrow pits
    xxiii. Pits-Udorthents complex, 0 to 45% slope
    xxiv. Pits-Udorthents complex, gently sloping
    xxv. Quarries
    xxvi. Quarry
    xxvii. Urban land
    xxviii. Urban land, 0 to 10 percent slopes
    xxix. Urban land, 2 to 10 percent slopes
    xxx. Made land
h. Create water code = 6000
    i. water
    ii. Miscellaneous water
    iii. Miscellaneous Water

    iv. Fresh water swamp - keep as separate – different than open water
4. Join the first csv file created from the R script called "muvalue.csv" to the SSURGO 10m grid using the VALUE field
5. Then join the second csv file created from the R script called "STATENAME_cp_mapunits_nodups.csv" to the grid by the "STATENAME_cp_mapunits_nodups.csv.MUNAME"
6. In ArcGIS, use Lookup to reclass the SSURGO grid using the "STATENAME_cp_mapunits_nodups.csv.VALUE" code in the second join table
7. Run focal variety of the SSURGO map units with 100-acre circular search radius
    a. Set landform slopes to NoData; all values except
        i. Slope bottom flat (value = 41)
        ii. Moist flats (value = 39)
        iii. Wet flats (value = 31)
        iv. Dry flats (value = 30)
    b. Resample landform flats to 10 m
    c. Extract SSURGO map units by landform flats
    d. Set SSURGO water (value = 6000) and SSURGO urban (value = 5000) to NoData
    e. Run focal variety with search radius = 358.9088
8. To address inflated variety values due to county line issues, run the following steps:
    a. Select all county lines
    b. Euclidean distance of 380 m of county lines
    c. Con to set Euclidean distance values to 100
    d. Merge 100 county line strip on top of focal variety output
    e. Set 100 to NoData
    f. Run focal average of the neighboring areas' focal variety
        i. Search radius of 2x Euclidean distance (760 m)
    g. Extract new strip of focal average by NoData zone
    h. Convert to integer
    i. Merge on top of focal variety and Z score results
9. We still saw distinct county lines dramatically in the dataset even after regional Z scoring. We decided we need to Z score by county the raw dataset
    a. Take counties shapefile and run zonal statistics to get mean and SD of soilflat_fvarcst30a in each county
    b. Make 30m grid of the county mean
    c. Make 30m grid of the county standard deviation
    d. Use above for new Z grid within each county: Map Algebra ("soilflat_fvarcst30a" - "cnty_varmean") / "cnty_varstd" = zsoilflat_fvarcst30a_cnty

Roads: 2012 TIGER/Line Shapefiles. Prepared by the U.S. Census Bureau, 2012

Topologically Integrated Geographic Encoding and Referencing (TIGER) products are spatial extracts from the Census Bureau's MAF/TIGER database, containing features such as roads, railroads, rivers, as well as legal and statistical geographic areas. They are developed by the U.S. Department of Commerce, Geography Division, U.S. Census Bureau and available for download at http://www.census.gov/geo/maps-data/data/tiger.html

Railroads: Tele Atlas North America, Inc. 2009. U.S. and Canada Railroads. 1:100,000. ESRI® Data & Maps: StreetMap. 2009 Data Update: North America. Redlands, California, USA. U.S. and Canada Railroads represent the railroads of the United States and Canada.

Land Cover: U.S. Geological Survey. 2011. National Land Cover Dataset 2006. Sioux Falls, SD http://www.mrlc.gov/nlcd2006_downloads.php

NLCD 2011 Land Cover provides an updated circa 2011 land cover layer (raster) for the conterminous United States for all pixels. The resultant product for the Eastern US distinguishes 15 land cover classes: Open Water, Developed Open Space, Developed Low Intensity, Developed Medium Intensity, Developed High Intensity, Barren Land (Rock/Sand/Clay), Deciduous Forest, Evergreen Forest, Mixed Forest, Shrub/Scrub, Grassland/Herbaceous, Pasture/Hay, Cultivated Crops, Woody Wetlands, and Emergent Herbaceous Wetlands.

Canadian Land Cover sources were: **Quebec** - Forgen-Tergen Écoforestière forest inventory data, Géoboutique Québec, Ministère des Ressources naturelles, Quebec City, 2014. **New Brunswick** - New Brunswick Forest Inventory Database, NB Department of Natural Resources, Fredericton, NB, 2012, New Brunswick Wetlands Inventory, NB DNR, Fredericton, NB, 2006, **Prince Edward Island** - PEI Corporate Land Use Inventory, Prince Edward Island Department of Agriculture & Forestry, Charlottetown, PEI, 2010. **Nova Scotia** - Nova Scotia Forest Inventory and NS Wetlands Inventory, NS Department of Natural Resources, Kentville, NS & Truro, NS, 2014

Geomantics 2004, National Hydro Network (NHN), for which the standard was officially adopted by the Canadian Council on Geomatics (CCOG) in August 2004National Hydrology Network for Canada Waterbody dataset and burned the water on top of the land use information.

Ecoregion Boundaries:
These follow the published TNC ecoregional boundaries with one exception. The boundary between the Tropical Florida and the Florida Peninsula ecoregions was not satisfactory with a number of science staff in Florida. The Peninsula Florida ecoregion extended southward along the Florida Gulf of Mexico and Atlantic Ocean coasts while

it bowed northward at the interior of the Florida Peninsula. This ignored the temperature moderating effect of the Gulf and the ocean, making the climate warmer along the coast further to the north in Florida. The upward pointing bow, it was felt, should actually be a downward pointing bow. To model this desired new boundary between the two ecoregions, climate data was acquired from the Prism Climate Group of the Northwest Alliance for Computational Science and Engineering (recommended to us by Gary Knight of FNAI). http://www.prism.oregonstate.edu/

We downloaded climate data to illustrate the Average Minimum Temperature for January 1981 - 2010 (in degrees Celsius). A map was produced and provided to the Florida TNC science staff to solicit their best recommendation for the new boundary. The boundary between nine and ten degrees (Average Minimum Temperature for January 1981 - 2010) was agreed upon and adopted for use as the new interface between the Tropical Florida and Florida Peninsula ecoregions.