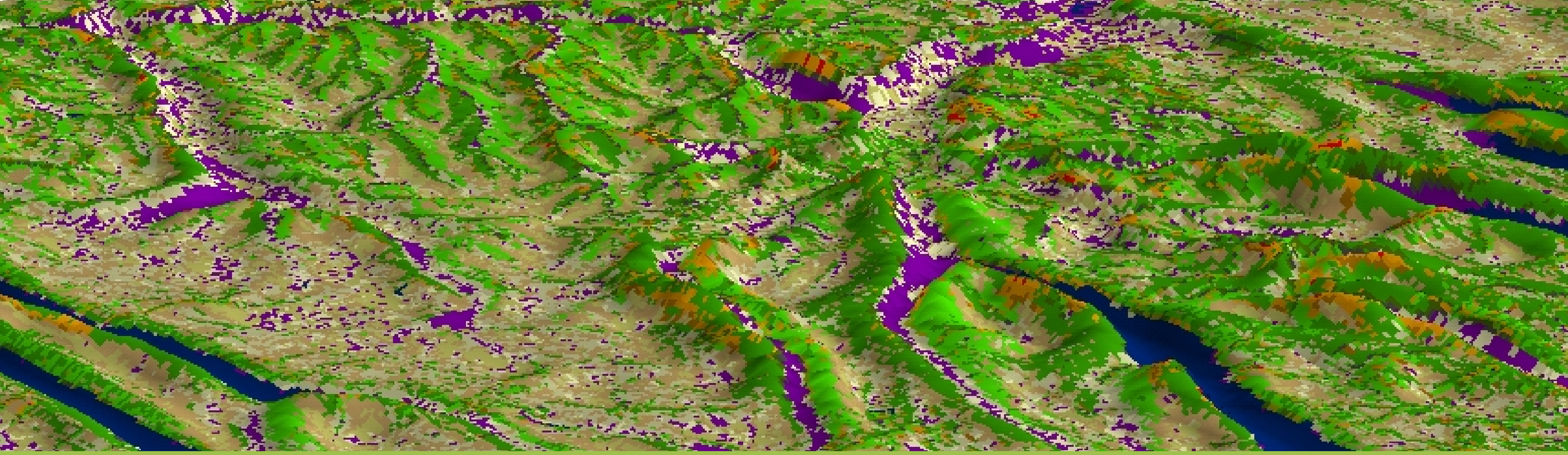

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Resilient Sites for Terrestrial Conservation
in the Northeast and Mid-Atlantic Region

The Nature Conservancy · Eastern Conservation Science
Mark G. Anderson, Melissa Clark, and Arlene Olivero Sheldon

January 30th 2012

Acknowledgements

This project would not have been possible without the expertise contributed by Brad McRae of The Nature Conservancy and Brad Compton of University of Massachusetts both who have created powerful new tools for measuring permeability. They were always willing to listen to our questions, provide guidance in using the tools correctly, and, in some cases, run the analysis for us. Charles Ferree also contributed to the mapping and modeling of landforms, and in calculating the landform variety and elevation range metrics.

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CHAPTER 1

Introduction

Climate change is expected to alter species distributions. As species move to adjust to changing conditions, conservationists urgently require a way to prioritize strategic land conservation that will conserve the maximum amount of biological diversity despite shifting distribution patterns (IPCC 2007). Current 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.

The central idea of this project is that by mapping key geophysical settings and evaluating them for landscape characteristics that buffer against climate effects, we can identify the most resilient places in the landscape. Ideally, these places will conserve the full spectrum of physical arenas that create and support species diversity. Additionally, each individual place will offer a range of microclimates and options for species movement, thus maintaining landscape functionality and improving the chances of species' survival in a changing climate. Our approach is based on observations that species diversity is highly correlated with geophysical diversity in the Northeast and Mid-Atlantic (Anderson and Ferree 2010), that species take advantage of the micro-climates available in complex landscapes, and that species can move to adjust to climatic changes if the area is permeable. Thus, the characteristics of geophysical representation, landscape complexity and landscape permeability, are primary concepts in this research.

This report has three basic parts: first, we ensure that all **geophysical settings are represented** in a conservation network (Chapter 2); second, we make certain that the **sites** within a network are **selected for characteristics that increase resilience** (Chapter 3); and third, we ensure that the sites are regionally well **connected** (Chapter 4). The latter two sections introduce new methodologies to quantify the physical and structural aspects of the landscape and explain how we identify important linkages between sites. The metrics developed for estimating site resilience are discussed in the chapters and include models that measure a site's physical complexity (landform variety, elevation range, and wetland density) and permeability (local connectedness and regional flow patterns). Finally, each metric is calculated for a 13-state U.S. region and the Maritime Provinces of Canada. The results sections of this report (Chapters 5 and 6) identify the network of sites with the highest estimated resilience within each ecological region. As part of the results, we compare the resilient sites identified in the report with sites previously identified for their significant biodiversity.

We use the term "**resilience**" (Gunderson 2000) to refer to the capacity of a site to adapt to climate change while still maintaining diversity, but we do not assume that the species currently located at these sites will necessarily be the same species present in a century or two. Instead, we presume that if conservation succeeds, each setting will support species that thrive in the conditions defined by the physical setting. For example, low elevation limestone valleys will support species that benefit from calcium rich soils, alkaline waters, and cave or karst features, while acidic outwash sands will support a distinctly different set of species. Each **geophysical setting**, in turn, contains a variety of **species habitats** and **natural communities**. A limestone valley, for example, may contain fens, marshes, and riverine wetlands, as well as forests, grasslands or barrens on flats or gently sloping dry terrain. These communities are often associated with the variety of landforms present; our intent was to identify resilient examples of a geophysical setting that encompass a variety of habitats.

The value of conserving a spectrum of physical settings is based on extensive empirical evidence (Anderson and Ferree 2010), but there are further conservation choices to make concerning geophysical representation. For example, out of all the possible low elevation limestone valleys that could be conserved, which one is the most likely to remain functional and sustain its biological diversity? The second section of this report 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 complexity**, refers to the number of microhabitats and climatic gradients available within a given area. Complexity is measured by counting the variety of landforms present in a small area, and modifying that slightly by the elevation range and the density of wetlands. Because topographic diversity buffers against climatic effects, the persistence of most species within a given area increases in landscapes with a wide variety of microclimates (Weiss et al. 1988). **Landscape permeability**, the second factor, is defined as the number of barriers and degree of fragmentation within a landscape. A highly permeable landscape promotes resilience by facilitating range shifts and the reorganization of communities. Roads, development, dams, and other structures create resistance that interrupts or redirects movement and, therefore, lowers landscape 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, the so-called “Quaternary conundrum” (Botkin et al. 2007).

The report structure follows the structure described in this introduction: representing all geophysical settings, estimating site resilience and linking sites into networks. The results section presents and describes the results with respect to individual **1000-acre sites** within **ecological regions**. The ecoregions have been previously defined by The Nature Conservancy based on the subsections delineated by the U.S. Forest service and Canadian Provinces (Anderson 1999). Because each region represents an area of similar physiography and landscape features, it is thus an appropriate natural unit in which to evaluate geophysical representation and to compare and contrast sites.

Summary: Resilience concerns the ability of a living system to adjust to climate change, to moderate potential damages, to take advantage of opportunities, or to cope with consequences; in short, its capacity to adapt. In this project we aim to identify the most resilient examples of key geophysical settings (e.g. sand plains, granite mountains, limestone valleys, etc.) to provide conservationists with a nuanced picture of the places where conservation is most likely to succeed over centuries. The project had three parts: 1) identifying and mapping the geophysical settings, 2) developing a quantitative estimate of resilience for each setting based on landscape complexity and permeability, and 3) identifying key linkages that may be important in facilitating climate-induced regional movements. The final products include the identification of sites with high or low estimated resilience and overlays of these sites with the TNC portfolio of important biodiversity sites. The products were presented in an ecoregional context, highlighting sites with the highest estimated resilience for each setting within each ecoregion.

Defining Sites and Geophysical Settings

This section describes the process of characterizing local landscapes (sites) and classifying them into distinct geophysical settings. Although the settings were defined by physical characteristics, they differ in the flora and fauna they support, and in their inherent resilience; the latter differences reflecting both historical management and ecological character. A classification enabled us to compare resilience characteristics among sites that represent similar geophysical settings. For example, the region's high granite mountains are both largely intact and topographically complex, whereas low coastal sandplains are both highly fragmented and relatively flat. By comparing characteristics among sites of the same type (e.g. among all low coastal sandplain sites) we could identify the most resilient examples of each setting, recognizing that some settings are inherently more vulnerable than others.

Our choice of classification factors was guided by previous work to understand the physical factors that underlie the region's biodiversity patterns. Specifically, geology classes and elevations zones follow those described in Anderson and Ferree (2010) and found to be tightly correlated with species diversity patterns in this region. (see: http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0011554)

The Sites - 1,000 Acre Hexagons: Our primary unit of analysis was a 1,000-acre hexagon. We chose this unit because the size allowed assessment of relatively fine-scale detail, and because the hexagon shapes match edge-to-edge to perfectly tessellate the entire landscape – like a soccer ball. The entire 13-state region subdivides into 156,581 hexagons and we calculated the variables described below for each one, plus the three Canadian Maritime Provinces and the lower portion of Quebec. Additionally, the size of the unit allowed us to maintain the sensitivity of the exact location of the rare species ("element occurrences") and allowed for some spatial error in those locations. We refer to each hexagon as a "site" but in later sections the individual hexagons aggregate to form larger "conservation areas," or larger patches of the setting. The full extent of each setting in the region is the sum of all the variously-sized patches and sites that share the same physical characteristics.

We attributed each hexagon with basic information about its land and water features, its geographic context, and the species and communities it currently contains. The attributes ranged from simple location information, such as the state and ecoregion that contained the hexagon, to the specific geophysical characteristics described below. *Note that some of the analyses described later in this report were done at finer or coarser scales, and these were then summarized to the hexagon scale – see figure 5.1 in Chapter 5 for an illustration.*

Geophysical Settings: Information on geology, elevation, and landforms was used to characterize the physical attributes of each hexagon, and these attributes were used to identify sets of hexagons that represent the same geophysical setting. Throughout this report, we use descriptive terms to refer to these characteristics, but each one was mapped using carefully defined quantitative criteria. For example, what we descriptively call a flat summit (the level top of a mountain or ridge) is defined in mapping terms as a landform with 0-2 degrees slope, found in the highest land position. We provide maps and illustrations to help users understand how the characteristics lay out on the landscape and further explanation of the landform model is given in Chapter 4. Additionally, greater detail about the process of defining and mapping each attribute is provided in Appendix II and in Anderson (1999) and Anderson and Ferree (2010).

The geophysical categories used to define the setting were:

Elevation Zones (Map 3.1)

These zones correspond to major changed in vegetation patterns (see Anderson 1999)

Low: 0' to 800' elevation, includes coastal (0-20') and very low oak-pine zones
Mid: 800' to 2500' elevation, includes current northern hardwood and transition zones
High: 2500' to 3600'+, includes current spruce-fir and alpine zones

Geology Classes (Map 3.2)

To create a regional geology map, the state and provincial digitized geological maps were compiled and synthesized; the large array of individual bedrock and surficial sediment types were grouped into one of these major classes. The nine categories were based on the chemical and physical properties of the soils derived from them, and are correlated with regional biodiversity patterns (see Anderson and Ferree 2010 and appendix for full listing).

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: This group included any 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.

Acidic Granitic: 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: (ultrabasic) 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.

Coarse Surficial Sediment: This group includes deep unconsolidated sand and gravel.

Fine Surficial Sediment: This group includes deep unconsolidated silt and mud.

Landform Types (Map 3.3)

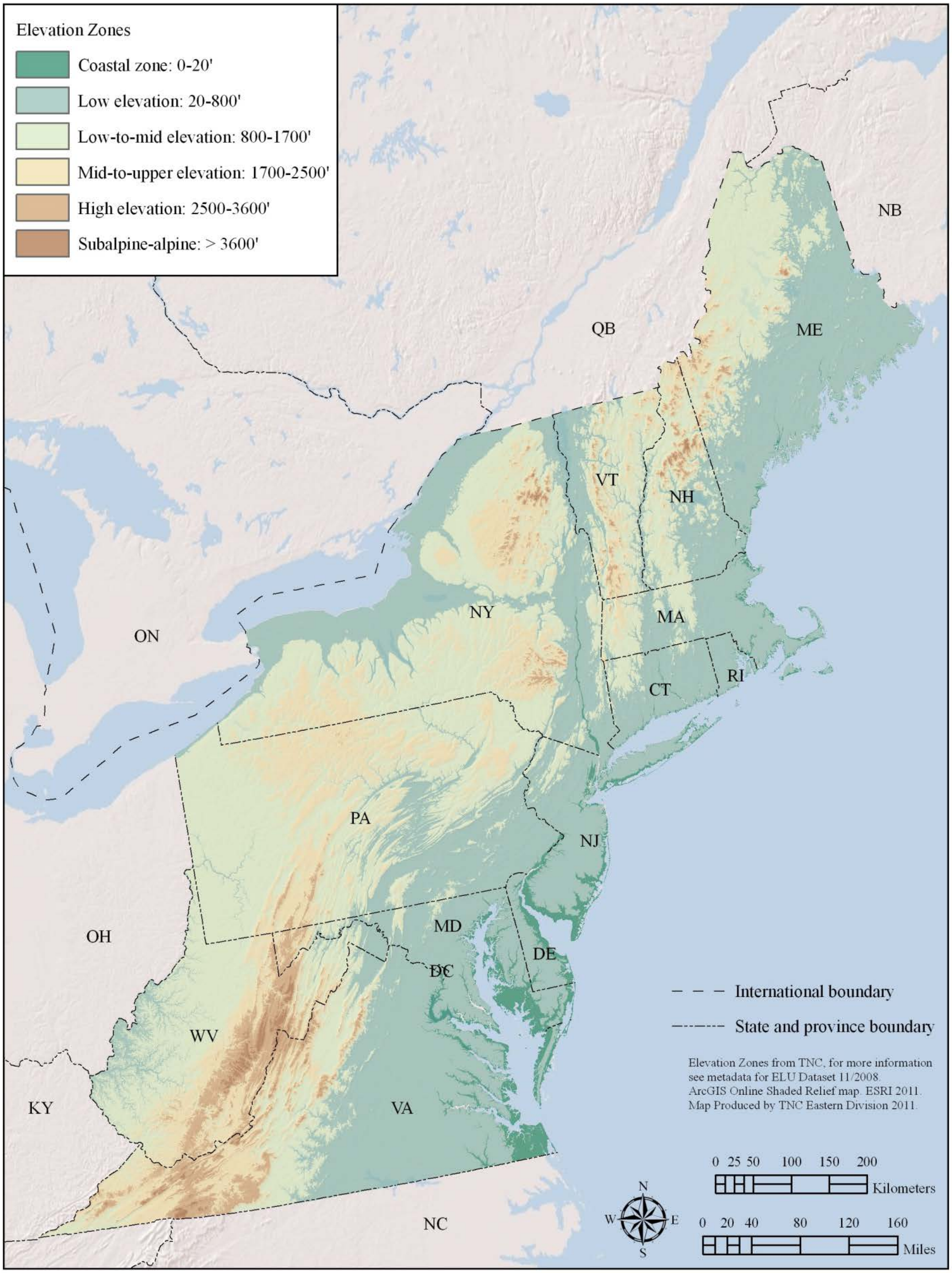
The landform modeling is described in detail in Chapter 4.1 and in Appendix II, and images of how each mapped type fit within a landscape are provided. Although any numbers of landforms can be delineated, we used an eleven-unit model:

1) Cliff/steep slope (includes cliffs, and steep slopes of warm and cool aspects)
2) Summit/ridgetop (includes flat summit, upper ridges, and slope crests)
3) Northeast sideslope (includes moderately steep sideslopes of cooler aspects)
4) Southwest sideslope (includes moderately steep sideslopes of warmer aspects)
5) Cove/slope bottom (includes slope bottom flats, and coves of warm and cool aspects)
6) Low hill
7) Low hilltop flat
8) Valley/toeslope
9) Dry flat
10) Wet flat
11) Water (includes lakes, ponds, rivers and estuaries)

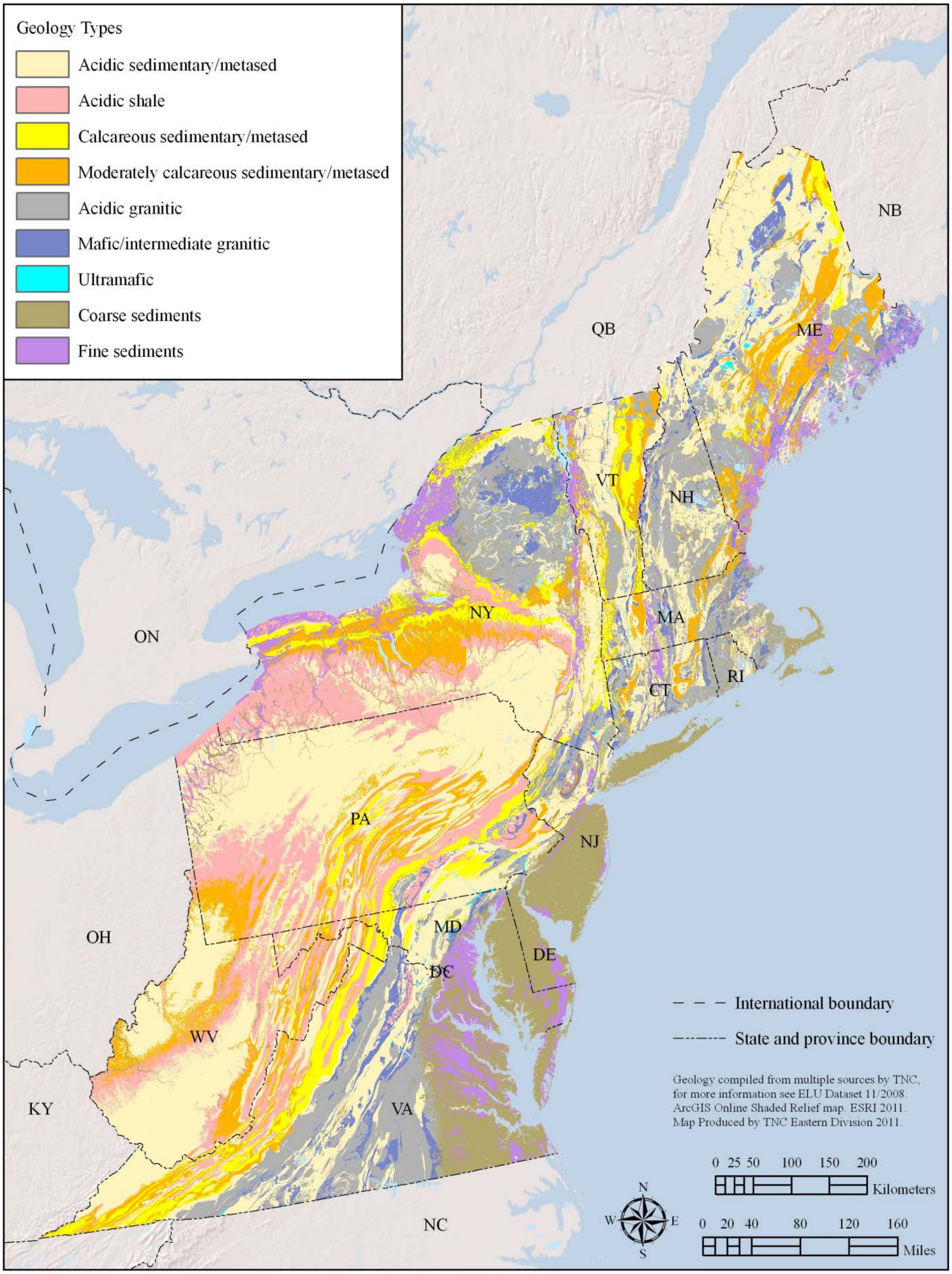
Species and Natural Community Information

Each geophysical setting supports a variety of **species habitats** and **natural communities**. A limestone valley, for example, may contain fens, marshes, and riverine wetlands associated with wet flats and streams, as well as forests, grasslands, and barrens associated with flats or gently sloping dry terrain. The variety of landforms present often determines the variety of communities and habitats. To quantify the types of species and communities currently found in each setting we overlaid locations of rare species and exemplary natural communities tracked and inventoried by the State Natural Heritage field inventory programs. Sensitive locations were used with permission, and are not available for redistribution. For the overlays, all source occurrence datasets (points and polygons) were converted to point features based on the polygon's centroid. Point location with adequate precision to overlay with 1,000 acre hexagons were then tagged with the identification of the hexagon in which they fell. If multiple occurrences of the same species or community fell in the same hexagon, the number of occurrences was recorded, but the attributes of the hexagon were only counted once for that feature. The results of the species overlays are included in Appendix III along with more details on the mapping and overlay of the species known locations. The results of the community overlays are included in the descriptions of each setting because, although we expect the composition of these communities to rearrange, they give a clear idea of the types of ecosystems that the setting supports and will likely remain present in some future form.

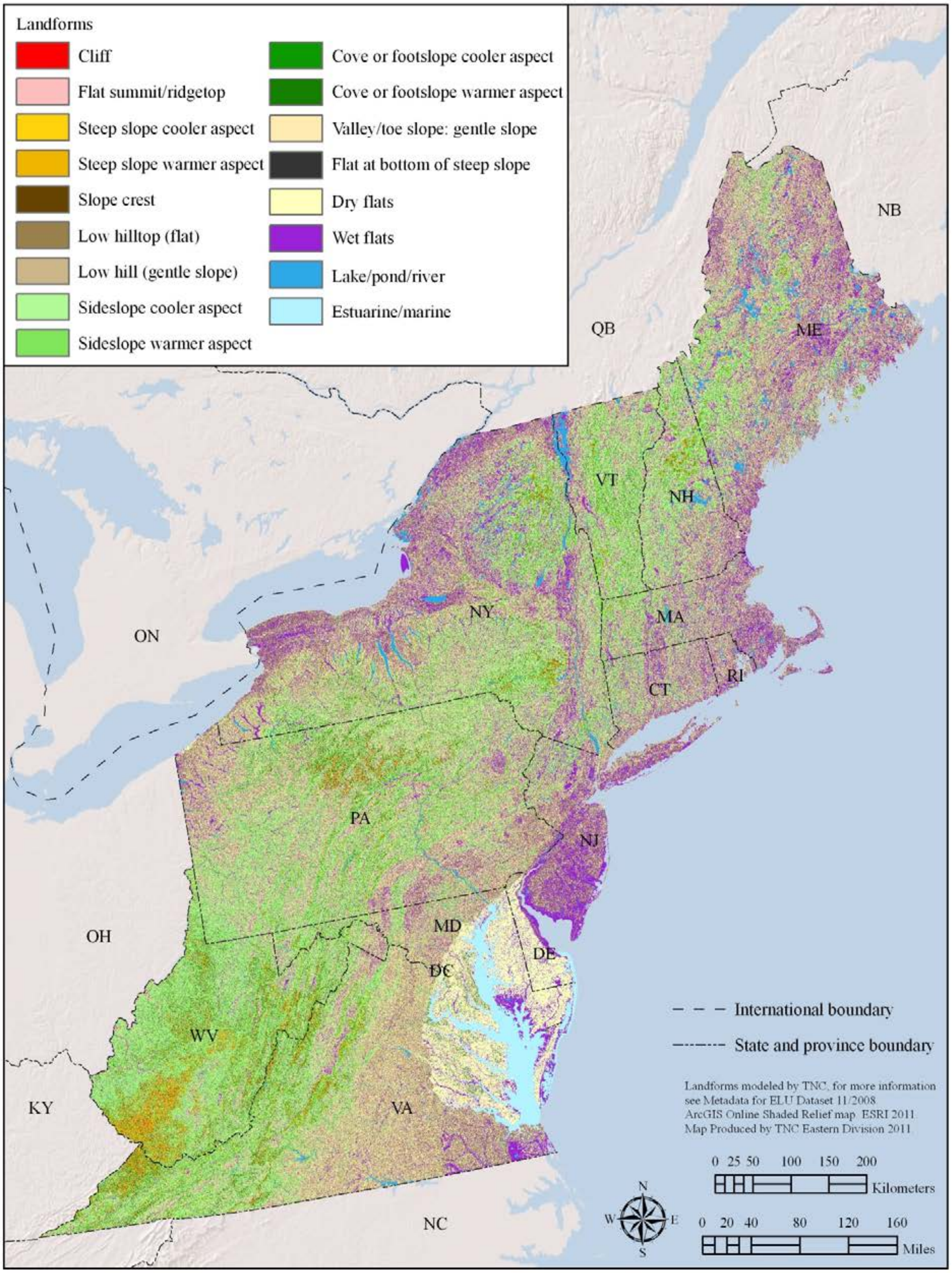
Map 3.1: Elevation zones. The three zones are further subdivided into six on this map.



Map 3.2: The nine geology classes used in this report.



Map 3.3: Landform types. Note that in this map some of the eleven basic landform types are further subdivided by aspect or location (see text) .



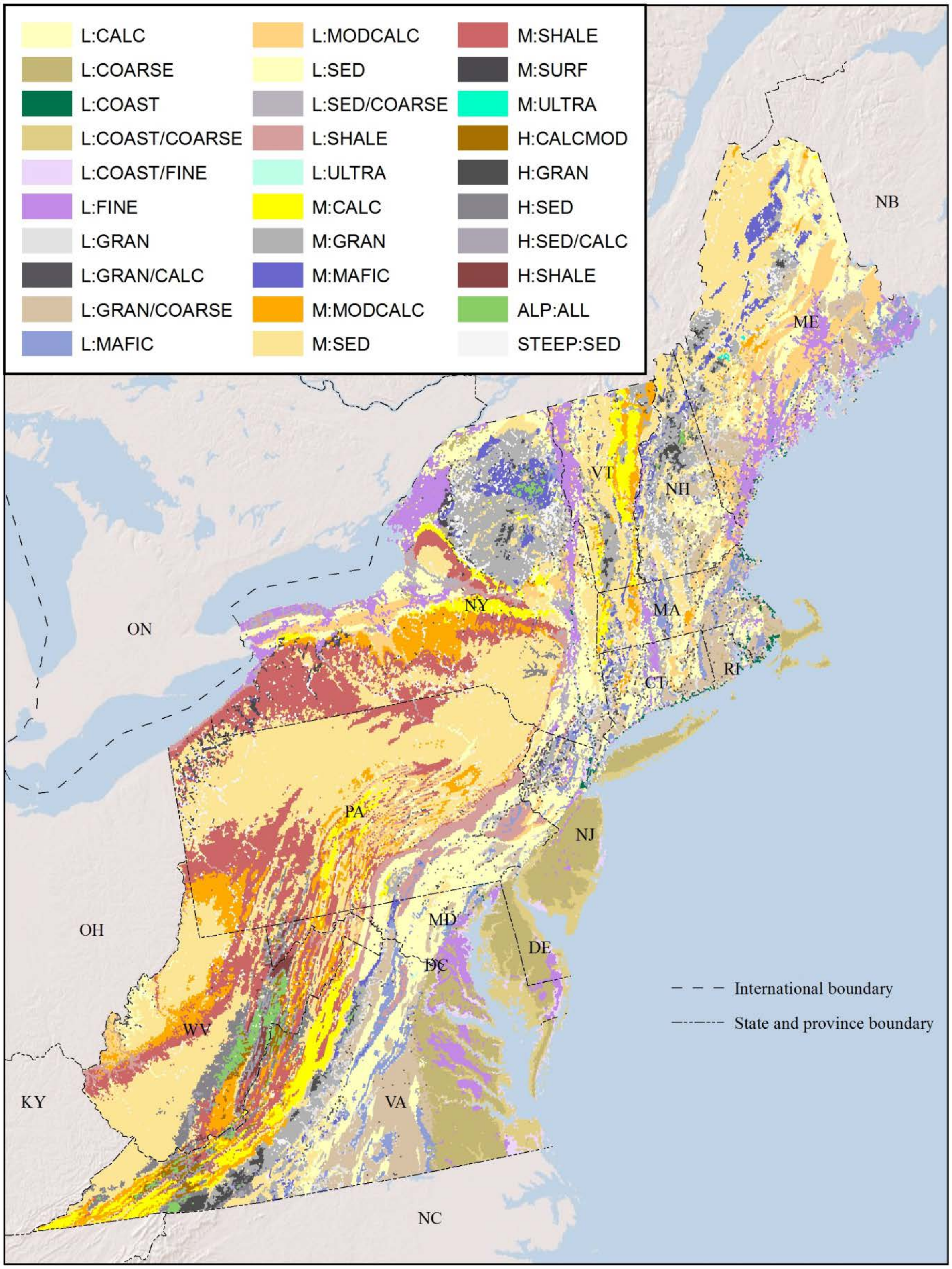
Grouping Hexagons into Geophysical Settings: We tabulated the abundance and percentage of each physical element described above for each hexagon, and this information formed the basis for measuring similarity among hexagons. Specifically, we classified all hexagons into geophysical settings based on their geological composition (nine classes) and elevation zones (three classes); potentially 27 distinct settings (e.g. low elevation granite). First, we identified and tagged all the homogenous hexagons composed 80 percent or more of a single elevation zone and single geologic class. Second, we used a cluster analysis to assign the hexagons with more heterogeneous compositions into the most similar setting based on elevation, geology and landform.

For example, a single hexagon, classified as high elevation granite, might be composed of:
90 percent high elevation granite
10 percent high elevation mafic
50 percent side slopes
35 percent steep slopes
15 percent summits
5 percent wet flat
0 percent all other attributes

The above example could be assigned to a group by a simple query of attribute values and applying the 80 percent criteria, and this method worked for the vast majority of hexagons. For more heterogeneous hexagons we used quantitative clustering to determine which geophysical group the unclassified had the most attributes in common with. Clustering was performed using a hierarchical cluster analysis (PCORD, McCune and Grace 2002) using the Sorenson similarity index applied to the geophysical attributes (including landforms), using a flexible beta linkage technique with Beta set at ¬25 (McCune and Grace 2002). After clustering the samples, we performed an indicator species analysis (Dufrene and Legendre 1997) to identify the geophysical attributes that were the most faithful and exclusive to each setting. Because of the large size of the dataset, much of the clustering was performed in batches. The classified hexagons were then rejoined with the main coverage to create a single unified coverage.

Results: The results indicated that one of the potential 27 settings did not occur in the region (i.e.. high elevation ultramafic); however, four other distinct settings were identified that consisted of intermixed complexes of two settings (low elevation granite and coarse sand) or extreme landforms (extremely steep slopes). In the end, we recognized 30 distinct geophysical settings, and assigned each of the 150,000+ hexagons into one of them. The settings are described and mapped below (Map 3.4), and evaluated in chapter 5. They included 15 low elevation settings, 8 mid elevation settings, 6 high elevation setting and 1 miscellaneous high slope setting.

Map 3.4: Geophysical Settings used in this Report. The settings are combinations of an elevation zone and a geology class such as "low elevation calcareous" (L:CALC). *See Appendix I for the corresponding map showing Maritime Canada and the full Northern Appalachian-Acadian extent.*



Descriptions of the Settings.

The descriptions are organized by three broad elevation zones, and the number of settings decreases with increasing elevation. *Information on the species and communities that are currently located in the setting are based on Natural Heritage occurrences, and are provided to give users an indication of the type of biodiversity that this setting favors. We do not expect these species or communities to occur in these settings in all parts of the region or to stay the same in the future, but we do expect the future composition to be of a similar character.*

LOW ELEVATION: Coastal and Very Low Elevation Settings.

Settings below 800' including coastal plains, large floodplains, river mouths and deltas, coastal shorelines, beaches and dunes, tidal marshes and other low elevation settings.

Rare species currently found across most of these settings includes the following: Vertebrates: Cooper's hawk, grasshopper sparrow, pied-billed grebe, red-headed woodpecker, sharp-shinned hawk, yellow-breasted chat, american bittern, bobolink, long-eared owl, red-shouldered hawk, vesper sparrow, yellow rail, upland sandpiper, black tern, eastern meadowlark, common nighthawk, brown thrasher, spotted turtle, carpenter frog, tiger salamander, New England cottontail, glassy darter. Invertebrates: eastern lampmussel, eastern pond mussel, fragile papershell, tidewater mucket, yellow lampmussel, glassy darter

Geophysical Settings in the Low Elevation Group

Non-coastal settings: the non-coastal low elevation settings occur above 20' and below 800', these are the most abundant and widespread environments in the region.

Low Elevation Coarse Sand (L-COARSE): Coastal plain settings with oak-pine forest, pine barrens, coastal plain ponds. Numerous rarities.

Low Elevation Granite (L-GRAN): Rocky bedrock-based acidic setting with hilltop woodlands.

Low Elevation Mixed Granite and Coarse Sand (L-GRAN/COARSE): A common setting supporting acidic forests, inland dunes, and many rarities.

Low Elevation Fine Silt (L-FINE): Fertile silt or clay setting in old lake beds and floodplains.

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

Low Elevation Sedimentary and Coarse Sand (L-SED/COARSE): Uncommon setting characterized by river bluffs, shoreline marshes, dry forests and acidic wetlands.

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

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

Low Elevation Granitic and Calcareous (L-GRAN/CALC): Mixed settings with pockets of limestone communities embedded in an acidic granitic matrix.

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

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

Coastal settings: we present the information on the coastal zone for completeness and interest; however, the methods presented here have numerous problems in the coastal zone. Foremost among these, is that the data sets are inconsistent in their coastal boundaries and most of the coastal hexagons extend into the "ocean" outside of this analysis. Thus, **the generated numbers and calculations for these settings are not trustworthy and the results may be misleading**. On the settings maps (Map 3.4), these three settings can be seen as to fringe the coastal boundary.

Coastal Bedrock Settings (L-COAST/BED): Maritime settings under 20' elevation where bedrock of any type predominates. Forests and swamps.

Coastal Coarse Sand (L-COAST/COARSE): Maritime settings under 20' elevation on coarse sand. Beaches, dunes, swales and sandplains.

Coastal Fine Silt (L-FINE): Maritime settings under 20' elevation on fine silts and mud. Coastal tidal marshes, salt marsh, river mouths, swamps.

Mid Elevation: Settings from 800’ to 2500’.

Communities in this elevation zone that are inventoried and monitored by the State Natural Heritage Programs: boreal conifer swamp, limestone / dolomite barren, acidic shrub swamp, ridgetop dwarf-tree forest, high-energy riverbank community, allegheny oak forest, broadleaf-conifer swamp, maple-basswood rich mesic forest, boreal acidic cliff, hemlock forest. intermediate fen, montane dry calcareous forest, northern new england calcareous seepage swamp, rich hemlock-hardwood peat swamp, spruce-fir swamp, glacial bog, hemlock palustrine forest, hillside graminoid-forb fen, ice cave talus community, mountain acidic woodland, mountain acidic seepage swamp, seepage forest, acidic rocky summit/rock outcrop community, spruce flats, acidic talus slope woodland.

Rare Species in this elevation zone that are inventoried and monitored by the State Natural Heritage Programs: Vertebrates: Shenandoah salamander, West Virginia spring salamander, peregrine falcon, golden eagle, blackpoll warbler,yellow-bellied flycatcher, bluebreast darter, spotted darter, Tippecanoe darter, rock vole, eastern massasauga, timber rattlesnake, Invertebrates: Franz's cave isopod, Henrot's cave isopod, Elk River crayfish, Helma's net-spinning caddisfly, Harris's checkerspot, rubifera dart, New England bluet, yellow lance, northern riffleshell, snuffbox, Atlantic pigtoe, longsolid, clubshell, round pigtoe, Plants: northern monk's-hood, musk root, shale barren rockcress, Bartram shadbush, piratebush, blue ridge bittercress, Hammond's yellow spring beauty, Schweinitz' sedge, spreading pogonia, blunt manna-grass, auricled twayblade, drooping bluegrass

Geophysical Settings in the Mid Elevation Group
These are settings that occur above 800’ and below 2500’.

Mid Elevation Granite (M-GRAN): Mountainous settings supporting natural communities typical of acid nutrient-poor shallow-soil environments

Mid Elevation Mafic (M-MAFIC): Mountainous settings often intermixed with granite, but derived from volcanic basalts or intrusive igneous rocks, and supporting a richer flora and fauna.

Mid Elevation Acidic Sedimentary (M-SED): Resistant ridges and high plateaus composed of sandstone, siltstone, or conglomerates. This abundant setting supports many common acidic forests types.

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

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

Mid elevation Acidic Shale (M-SHALE): Settings on unstable shale slopes often supporting a unique flora and sedimentary-like shale lowlands

Mid Elevation Surficial Sediments (M-SURF): Valley or flat settings with surficial deposits of sand or silt: floodplains and shorelines.

Mid elevation Ultramafic (M-ULTRA): Very rare settings on toxic serpentine soils high in nickel and chromium supporting stunted trees and a unique flora.

High Elevation: Settings over 2500'.

Communities in the elevation zone that are inventoried and monitored by the State Natural Heritage Programs: alpine krummholz, alpine peatland, grass bald, montane yellow birch-red spruce forest, montane spruce-fir forest, mountain fir forest, mountain peatland, high-elevation seepage swamp, high-elevation cove forest, northeast boreal heathland, northeast moist subalpine heathland, northern new england cold-air talus, red spruce-fraser fir /southern mt cranberry forest, red spruce / great laurel forest.

Rare Species in this elevation zone of that are inventoried and monitored by the State Natural Heritage Programs: Vertebrates: Cheat Mountain salamander, Cow Knob salamander, Peaks of Otter salamander , Bicknell's thrush, candy darter, cheat minnow, Virginia northern flying squirrel, southern rock vole, southern water shrew, virginia big-eared bat, Invertebrates: White Mountain fritillary, hudsonian whiteface, bog copper, White Mountain butterfly, Katahdin arctic, Spruce Knob threetooth, Plants: bog rosemary,dwarf white birch, sand-heather, long-stalked holly, Marcescent sandwort, Robbins' cinquefoil, northern meadow-sweet, small cranberry.

High Elevation Granite or Mafic (H-GRAN): Bedrock mountain setting of intrusive granitic rock, plutons of mafic rock or volcanic basalts.

High Elevation Sedimentary (H-SED): Bedrock mountain setting of sandstone, quartzite, conglomerate or other resistant sedimentary rocks .

High Elevation Mixed Sedimentary and Calcareous (H-SED/CALC): Mountains and ridges of resistant sandstone intermixed with valleys or lowlands of limestone or other calcareous bedrock.

High Elevation Calcareous and Moderately Calcareous (H-CALC/MOD): Mountainous landscapes of rich limestone or dolomite.

High Elevation Acidic Shale (L-SHALE): Settings on stable and unstable shale slopes.

Alpine and Subalpine (ALP-ALL): Very high elevation settings over 2500' on any substrate with systems dominated by extreme wind and cold. Alpine areas often have stunted trees (krumholz) and unique floras.

CHAPTER

Estimating Resilience

3

A central premise of this report is that the physical characteristics of a landscape can buffer an area from the direct effects of a changing climate by offering a connected array of microclimates that allow species to persist. We call this quality the site's adaptive capacity, or its **resilience**. In this section we describe the concepts, methods, and data used to estimate the relative resilience of any given site. The two factors important to the estimate - landscape complexity and landscape permeability – are discussed separately, because the tools for assessing and measuring them are distinctly different.

Section 1: Landscape Complexity

Background: The actual climate experienced by an individual organism at a given point on the ground may differ dramatically from the regional norm because the land's surface features break up climate into a variety of microclimates influenced by landforms like hills, hollows, and water bodies. As the climate changes, these microclimates offer options to resident species, and in response to climatic changes, species are likely to shift their locations slightly to take advantage of this variation and stay within their preferred temperature and moisture regimes. Thus, the variety of microclimates present in a landscape, what we term the site's **landscape complexity,** can be used to estimate the capacity of the site to maintain species and functions. We measured landscape complexity as a function of topography, elevation range, and moisture gradients.

Topography describes the natural surface features of an area, and these natural features can be grouped into local units known as landforms (e.g. cliffs, summits, coves, basins, valleys). Landforms are a primary edaphic controller of species distributions, even without climatic considerations, due to the variation in rates of erosion and deposition, in soil depth and texture, in nutrient availability, and in the distribution of moisture. Each landform, then, represents a local expression of solar radiation, soil development, and moisture availability; a variety of landforms results in a variety of meso and micro climates. When climate is considered, landform variation increases the persistence of species and buffers against direct climate effects by providing many combinations of temperature and moisture within a local neighborhood.

Researchers have documented how topographic variation can create surprisingly large temperature ranges in close proximity. For example, in South Carolina's Blue Ridge Mountains south-facing slopes were measured at 104^0 in July, while a few hundred yards away the sheltered ravines were a cool 79^0 (P. McMillan, personal communication, October 2010). Weiss et al. (1988) measured micro-topographic thermal climates in relation to butterfly species and their host plants, and concluded that areas of high local landscape complexity, even on a scale of tens of meters, appear particularly important for long-term population persistence under variable climatic conditions. Extinctions predicted from coarse-scale climate envelope models have recently come into question because many current models fail to capture the effects of topographic and elevation diversity in creating "microclimatic buffering" (Willis and Bhagwat 2009). For example, Randin et al. (2008) found that 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. Similarly, a model that included topographic diversity and elevation range predicted only half the species loss of butterflies in a mountainous area compared to a model based solely on climate (Luato and Heikkinen 2008).

We hypothesized that sites with a large variety of landforms and long elevation gradients will retain more species throughout a changing climate by offering ample microclimates and thus more options for rearrangement. However, we found that in areas with very little topographic diversity, we needed a finer-scale indicator of subtle micro topographic features, to distinguish between otherwise similar landscapes. We chose wetland density as a surrogate for micro-topography in flat landscapes after experimenting with several rugosity measures. Our final measure of landscape complexity was based on landform variety, elevation range and, in flats, wetland density. Below we describe how we measured each of these landscape elements.

Landform Variety: To be explicit about the number of microclimatic settings created by an area's surface features we created a landform model that delineated local environments with distinct combinations of moisture, radiant energy, deposition, and erosion. The model, based on Ruhe and Walker's (1968) five-part hillslope model of soil formation, and Conacher and Darymple's (1977) nine-unit land surface model, categorizes various combinations of slope, land position, aspect, and moisture accumulation (Figure 3.1 and 3.2). The methods to develop the model were based on Fels and Matson (1997) and are described in Anderson (1999) and in Appendix II. The major divisions are based on relative land position and slope (Figure 3.3) with side slopes further subdivided by aspect, and flats further subdivided by flow accumulation. The landform model can distinguish an unlimited number of landform units, but we used a simple 11 unit model that captures the major differences in settings and combines some landform types that typically occur as pairs (e.g. cliff/steep slope, cove/slope bottom) so they did not skew the results. The types include the following (Figure 3.1-3.3):

Cliff/steep slope	Cove/slope bottom,	Dry flat
Summit/ridgetop	Low hill	Wet flat
NE sideslope	Low hilltop flat	Water/lake/river
SE sideslope	Valley/toeslope	

To calculate the **landform variety** metric we tabulated the number of landforms within a 100-acre circle around every 30-meter cell in the region using a focal variety analysis on the 11 landform types. Scores for each cell ranged from 1 to 11 (Map 3.1, Figure 3.4 a. & b.) with a mean of 6.05 and a standard deviation of 1.85.

With respect to climate change, our assumption was that separate landform settings will retain their distinct processes despite a changing climate. For example, a hot dry eroding upper slope will continue to offer a climatic environment different from a cool moist accumulating toe slope.

Figure 3.1: Topographic position and basic relationship to community types. The diversity of landforms within certain geologic settings leads to distinct expressions of biological diversity.

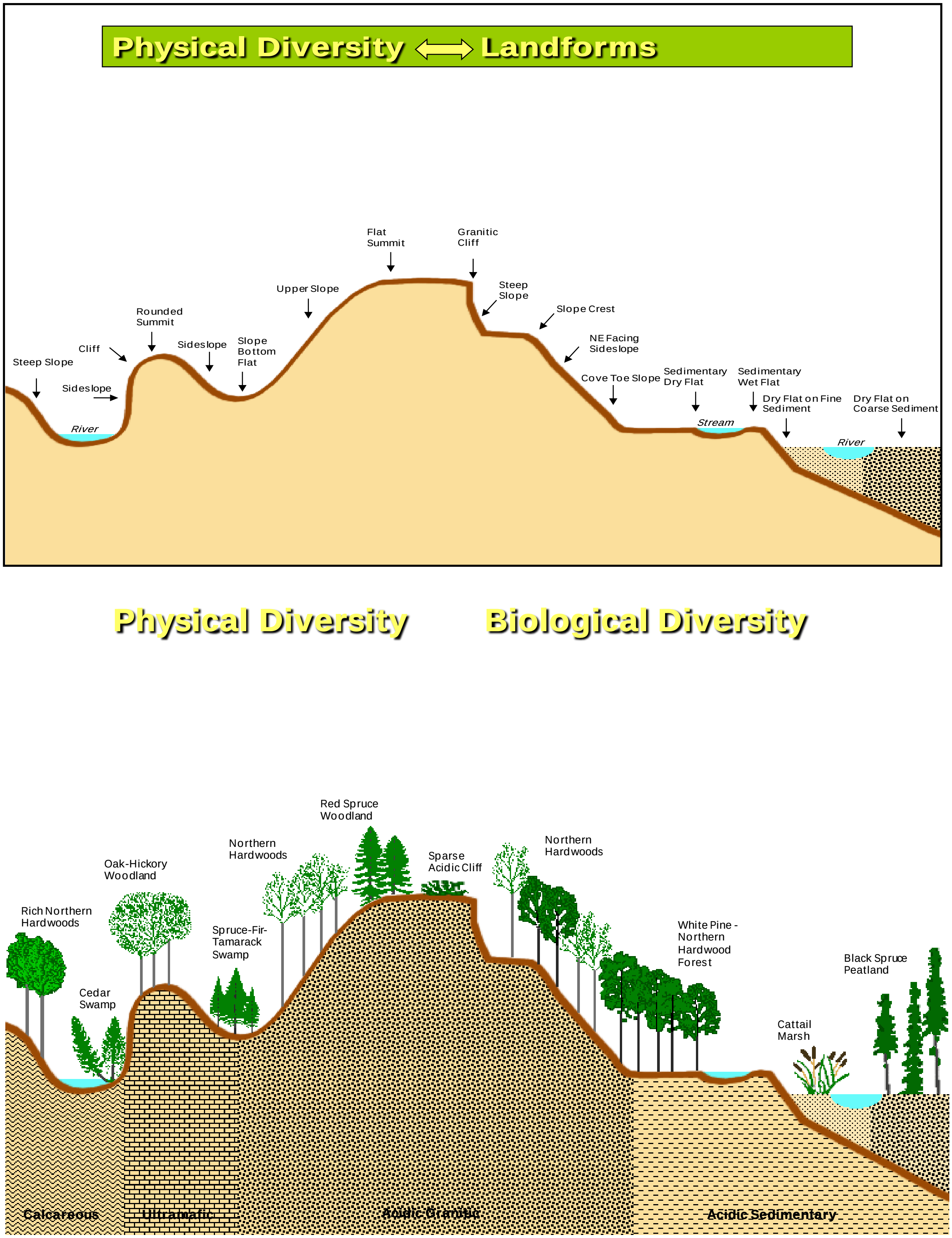


Figure 3.2: An 11-unit landform model mapped for Mount Mansfield, VT. This graphic shows how the landforms lie across on the landscape.

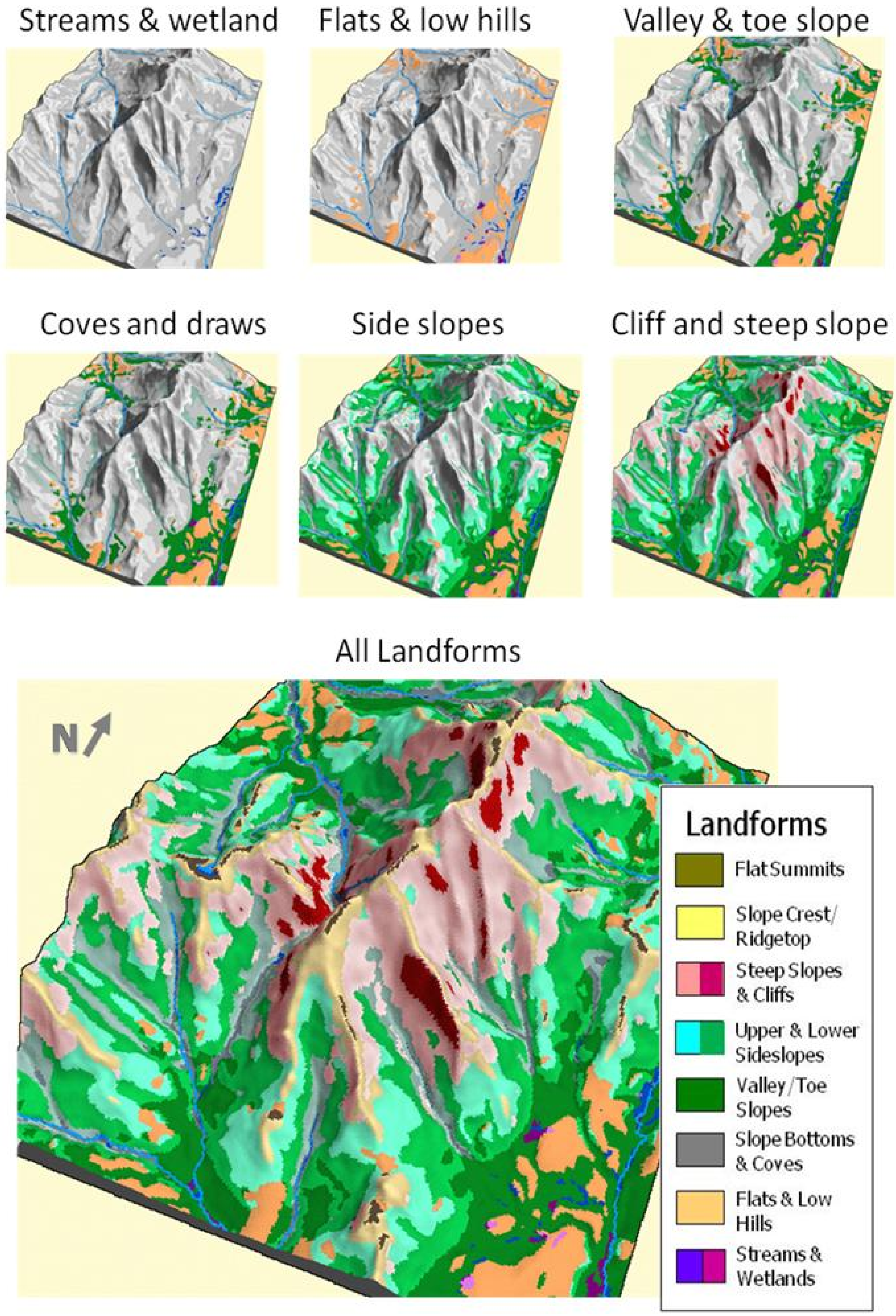
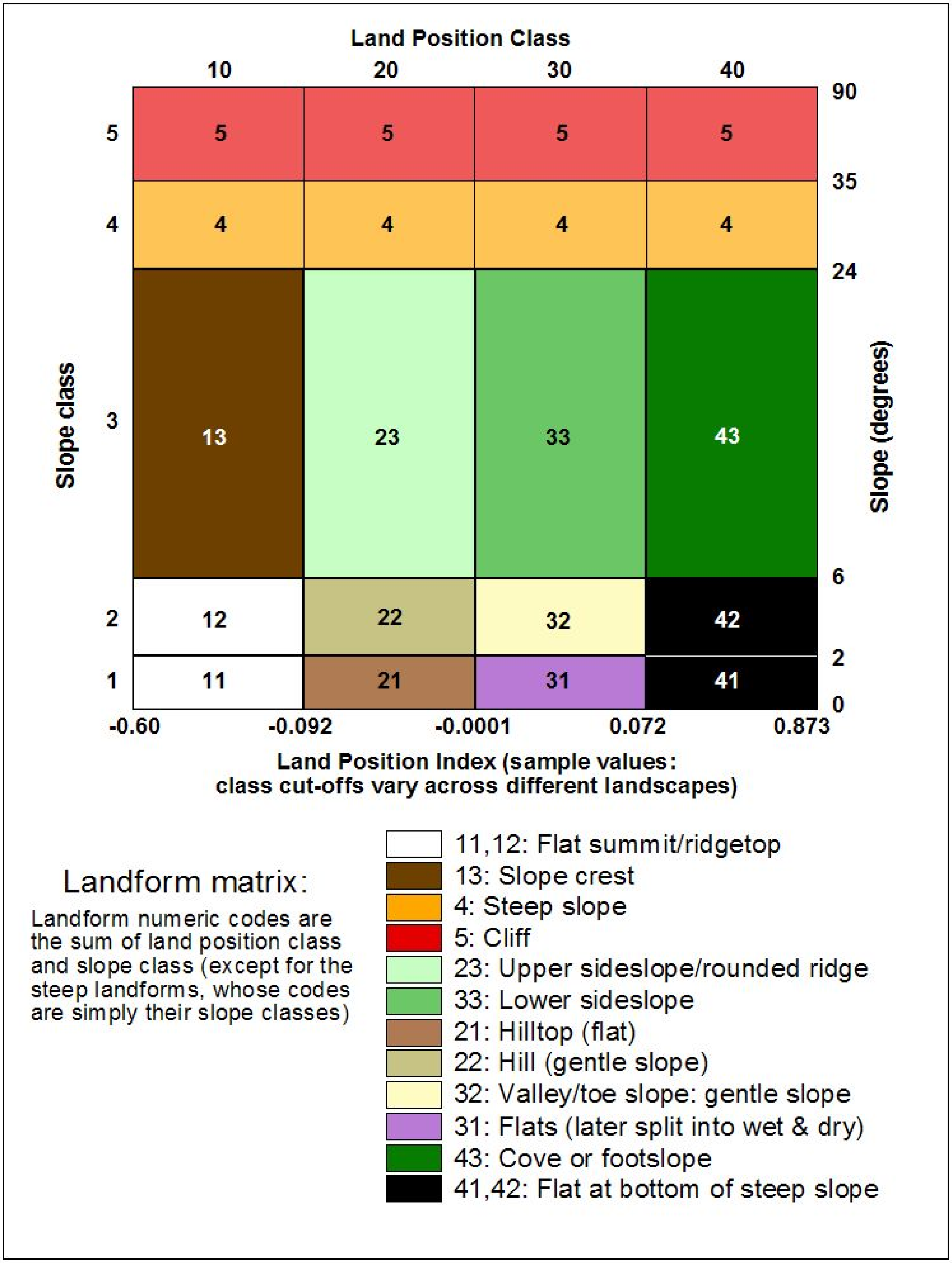


Figure 3.3: The underlying slope and land position model used to create the mapped landform grids. Adapted from Fels and Matson 1997

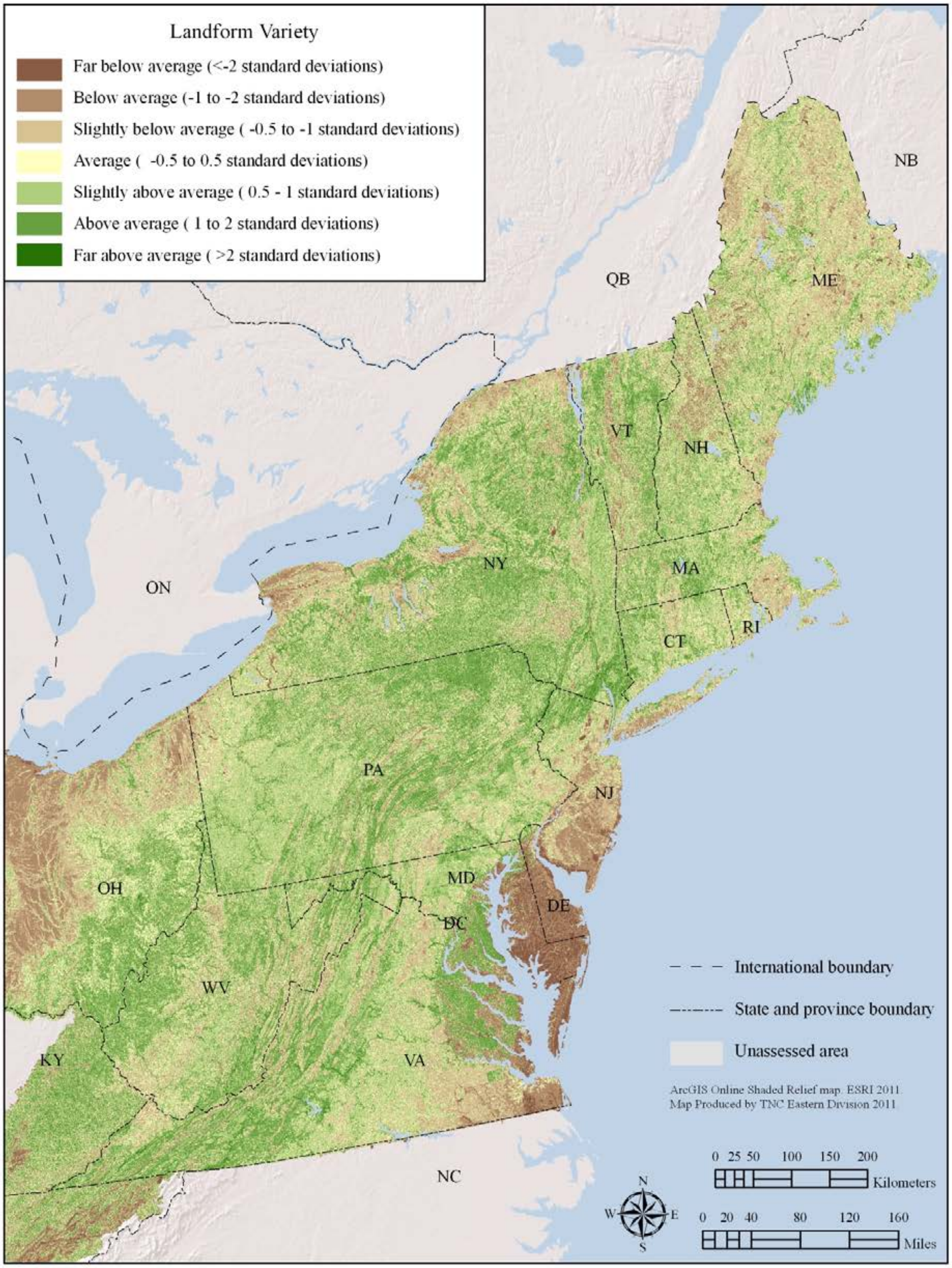


The landform model describes major difference in local climatic settings, but it is theoretically possible to detect smaller gradations in topography, or to distinguish between settings that have the same landform diversity, but longer or shorter elevation gradients. We experimented with a variety of ways to measure these nuances and settled on the two described below after comparing the results at known sites and talking with practitioners about the results.

Elevation Range: Species distributions may increase or decrease in elevation in concert with climate changes, particularly in hilly and mountainous landscape where the effects of elevation are magnified by slope. In flat landscapes, small elevation changes may have a dramatic effect on hydrologic processes such as flooding. To measure local elevation range we created an elevation range index by compiling a 30-meter digital elevation model for the region (USGS 2002) and using a focal range analysis to tabulate the range in elevation within a 100-acre circle around each cell. Scores for each cell ranged from 1 to 795 meters (Map 3.2, Figure 3.4 c) with a mean of 59.4 m and a standard deviation of 54.3. The data were highly skewed towards zero and were log transformed for further analysis (mean 3.64 and standard deviation of 1.08).

Wetland Density**:** A large part of this region is flat and wet, the result of past glaciations. Moreover, climate models disagree on whether the region will get wetter or drier, or both. In these flat areas, landform variety is low, elevation change is minimal, and wetlands are extensive. Visual examination of the landform variety and elevation range maps described above suggested that this information alone did not always provide enough separation between sites, with respect to the long term resilience of extensive wetland areas. Further, modeled measures of moisture accumulations had the highest rates of error in extremely flat landscapes. After experimentation with local rugosity measures, we determined that directly measuring wetland density provided the best available gauge of small and micro-scale topographic diversity and patterns of freshwater accumulation. We assumed that areas with high density of wetlands had higher topographic variation, and therefore offered more options to species, and that small isolated wetlands were more vulnerable to shrinkage and disappearance than wetlands embedded in a landscape crowded with other wetlands. Thus, our hypothesis was that wetland dependent species and communities would be more resilient in a landscape where there was a higher density of wetland features corresponding to more opportunities for suitable habitat nearby.

Map 3.1: Landform variety. This map counts the number of landforms (11 possible) in a 100-acre circle around a central cell, and compares it to the regional average. *See Appendix I for the corresponding map showing Maritime Canada and the full Northern Appalachian-Acadian extent.*



Map 3.2: Elevation range. This map measures the elevation range in a 100-acre circle around a central cell and compares it to the regional average. *See Appendix I for the corresponding map showing Maritime Canada and the full Northern Appalachian-Acadian extent.*

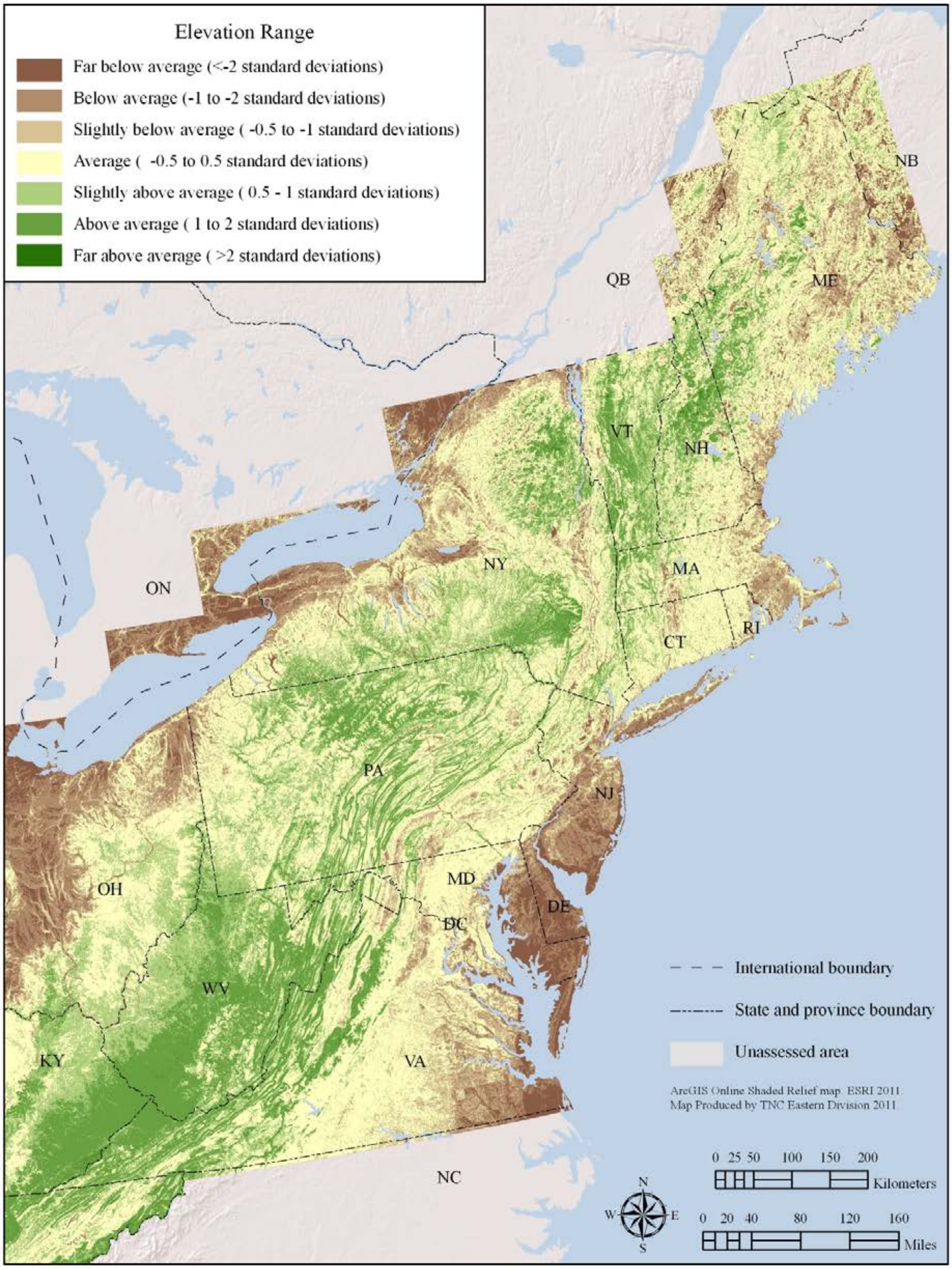
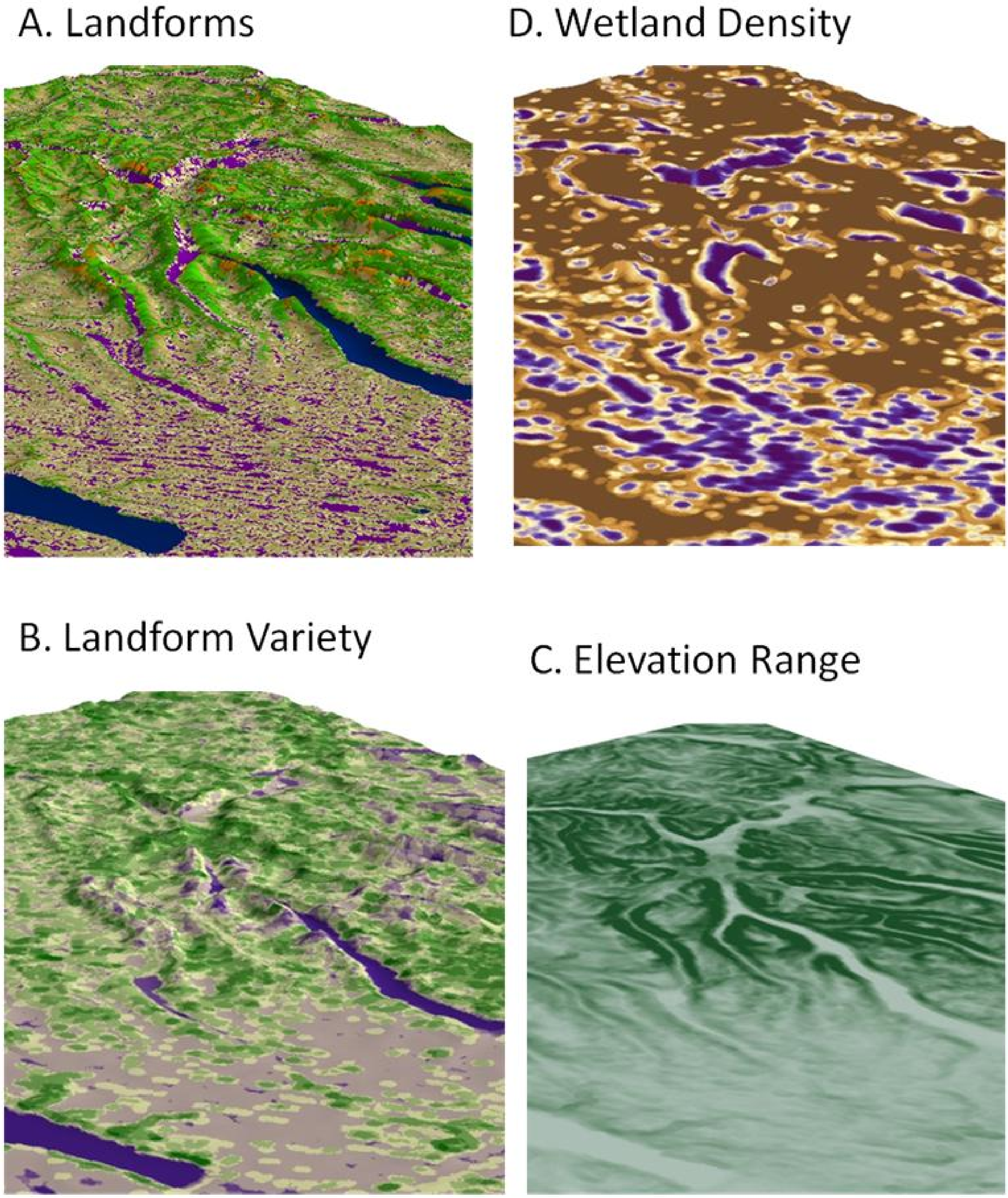


Figure 3.4 a-d: A three-dimensional look at the metrics of landscape complexity, Finger Lakes region of NY. All metrics are measured in 100-acre circles around every point (30-m cell) on the landscape. A. Landforms show the original landform model. B Landform Variety show the number of landforms with dark green as high and dark purple as low. C. Elevation Range shows the range of elevation with darker greens indicating a wider range. D. Wetland density is shown with purple as high and brown as low.



To assess the density of wetlands, we created a wetland grid for the region by combining the National Wetland Inventory, NLCD (2001) wetlands, and Southern Atlantic GAP programs wetlands datasets (http://www.basic.ncsu.edu/segap/index.html). We revised this source wetland dataset using the landform models to identify and remove erroneously mapped wetlands on summits, cliffs, steep slopes, and ridgetop landforms. To match the 100-acre scale of landform variety and elevation range, we generated the percent of wetlands within a 100-acre circle for each 30-meter cell in the region using a focal sum function in GIS. Additionally, to gauge the wetland density of the larger context, we generated the percent of wetlands of an area one magnitude larger (1000 acre circle) around each 30-meter cell in the region (Note: for the coastal areas where much of the area within the 100-acre or 1000 acre circles was actually ocean, the percent of wetlands was based on only the percent of the land area, not ocean area, within the 100-acre or 1000 acre circle around each cell).

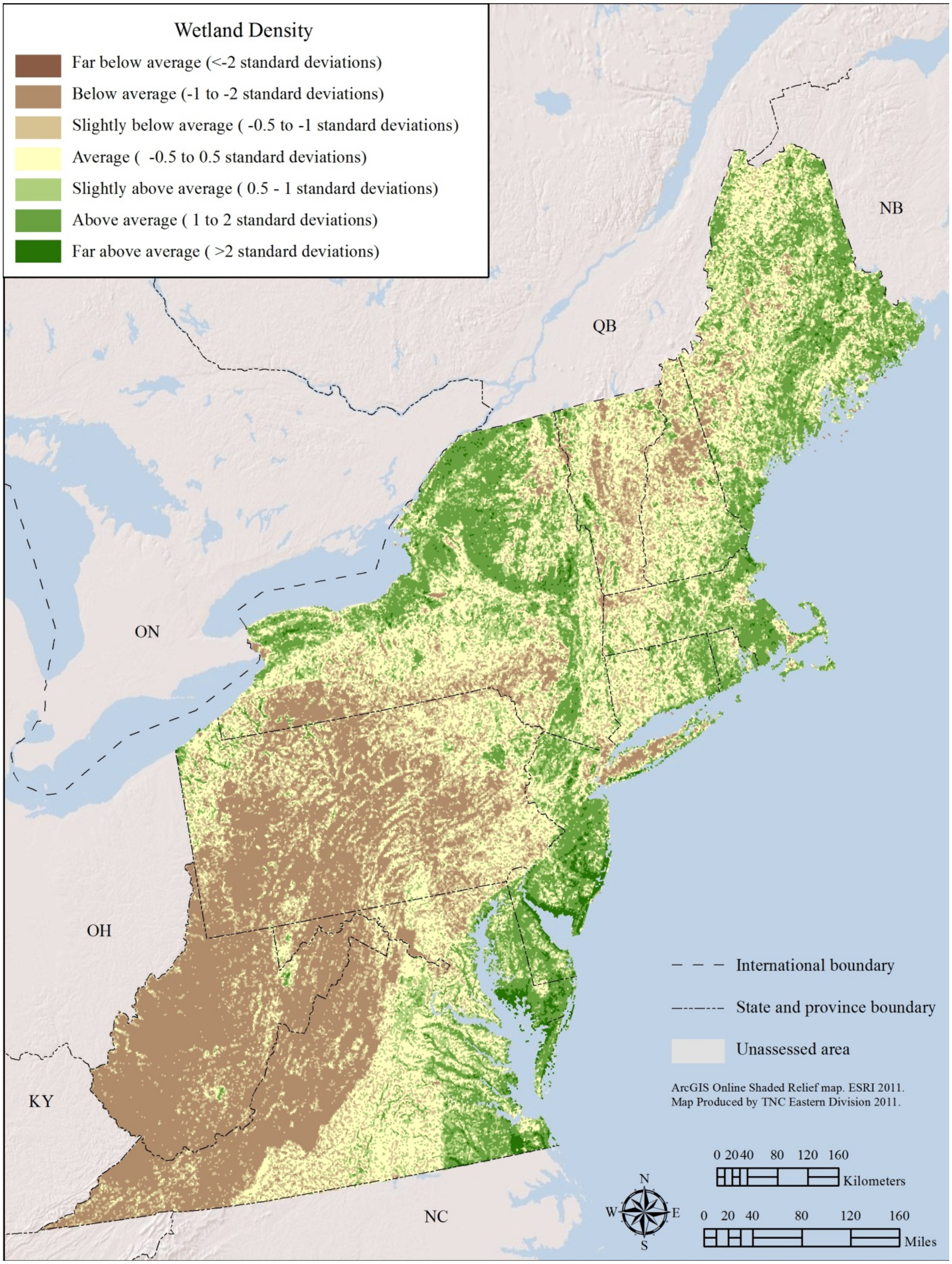
To summarize the wetland density for each cell, we combined the values from search distances, weighting the 100-acre wetland density twice as much as the 1000 acre wetland density and summing the values into an integrated metric. Lastly, we log-transformed the values to approximate a normal distribution and divided by the maximum value to yield a dataset normalized between 0-100 (Map 3.3, Figure 3.4d). Raw scores for each cell ranged from 0 to 100 percent with a mean of 7.1 percent and a standard deviation of 15.6 percent for the 100-acre search radius and a mean of 7.1 percent and standard deviation of 12.4 percent for the 1000 acre radius. The combined weighted value had a mean of 10.5 and standard deviation of 21.1. *Finally, wetland density metrics were only applied to cells that had close to zero slope as defined by their landforms (hilltop flat, gentle slope, wetflat, dry flat, and valley/toe slope).*

<u>Landscape Complexity Combined Index:</u> To create a standardized metric of landscape complexity (LC) we transformed all three indices (landform variety (LV), elevation range (ER), and wetland density (WD) to standardized normal distributions ("Z-scores" with a mean of 0 and standard deviation of 1) then combined them into a single index.

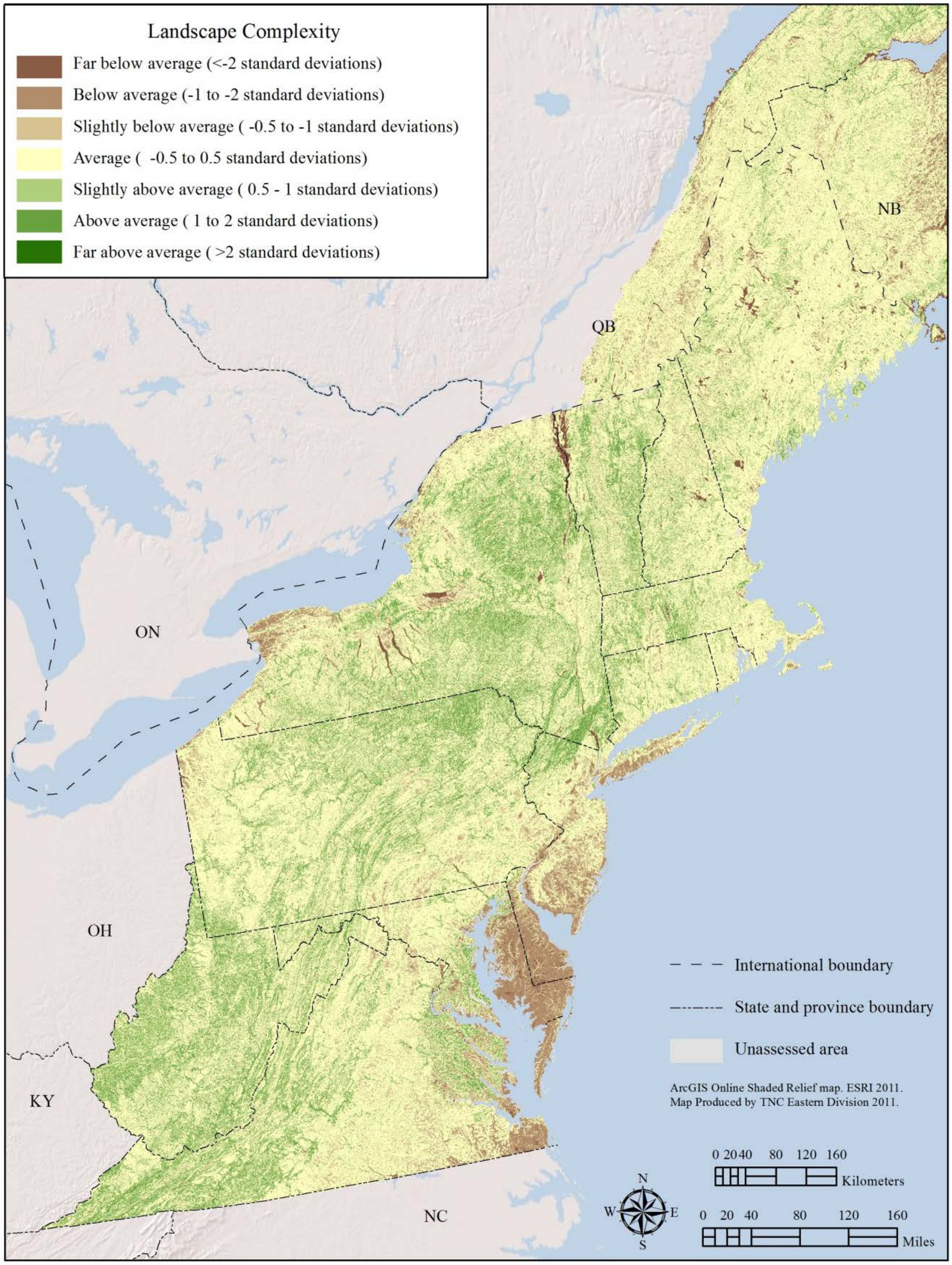
In the combined index we weighted landform variety twice as much as the other two values because of the importance of this feature in creating well defined microclimates (Map 3.4). Further, wetland density was only added when the setting was a flat landform (dry flat, wet flat, slope bottom flat). The final index was:

Landscape Complexity
Flats = (2 LV + 1 ER + 1WD)/4
Slopes = (2 LV + 1 ER)/3

Map 3.3: 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. *See Appendix I for the corresponding map showing Maritime Canada and the full Northern Appalachian-Acadian extent.*



Map 3.4: Landscape complexity. This map estimates the degree of landscape complexity of a cell based on the combined values of landform variety, elevation range and wetland density, and compares it to the regional average. *See Appendix I for the corresponding map showing Maritime Canada and the full Northern Appalachian-Acadian extent.*



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 few extinctions (Botkin et al. 2007). Now, however, pervasive landscape fragmentation disrupts ecological processes and impedes the ability of many species to respond, move, or adapt to changes. The concern is that broad-scale 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 then, 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.

We use the term '**permeability**' 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 broader and more inclusive 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 similar habitat within the landscape, and the quality of the converted lands separating these fragments. Essentially, we wanted to create a surface that revealed the implications of the physical landscape structure with respect to the continuous flow of natural processes, including not only the dispersal and recruitment of plants and animals, but the rearrangement of existing communities. Hence we use the term "ecological flows" or just "flows" 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,** started with a focal cell and looked at the resistance to flows outward in all directions through the cell's local neighborhood. The second, **regional flow patterns**, looked at broad east-west and north-south flow patterns across the entire region and measures how flow patterns become slowed, redirected, or channeled into concentration areas, due to the spatial arrangements of cities, towns, farms, roads, and natural land. Regional flow patterns are discussed in Chapter 4 because the results were not used as an estimate of site resilience, but rather for connections linking sites into resilient networks.

Our basic assumption in both models was 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. developed next to developed, or natural next to natural), then there is no disruption in permeability. Contrasting elements are presumed less permeable because of differences in structure, surface texture, chemistry, or temperature, which alters flow patterns (e.g. developed land adjacent to natural land). Our premise was that organisms and processes can, and do, move from one landscape element to another, but that sharp contrasts alter the natural patterns, either by slowing down, restricting, or rechanneling flow, depending on the species or process. We expect the details of this to be complex and that in many cases, such as with impervious surfaces, some processes may speed up (overland flow) while others (infiltration) slow down.

Both of the models discussed below are based on land cover / land use maps consisting of three basic landscape elements subdivided into finer land cover types, and we used these categories in the weighting schemes described below.

Natural lands: 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, unintentional, and not the dominant process.

Agricultural or modified lands: landscape elements where natural processes are modified by direct, sustained, and intentional human intervention. This usually involves 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: 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.

Our analyses were intentionally focused on natural lands, but we recognize that there are species that thrive in both developed and modified lands.

<u>Local Connectedness:</u> 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 (or 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 microclimates within its given neighborhood.

The method used to map local connectedness for the region was resistant kernel analysis, developed and run by Brad Compton using software developed by the UMASS CAPS program (Compton et al. 2007, http://www.umasscaps.org/). Connectedness refers to the connectivity of a focal cell to its ecological neighborhood when it is viewed as a source; in other words, it asks the question: to what extent are ecological flows outward from that cell impeded or facilitated by the surrounding landscape? Specifically, each cell is coded with a resistance value base on land cover and roads, which are in turn assigned resistance weights by the user. 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 the focal cell out to a maximum distance of three kilometers (Figure 3.5).

To calculate this metric, **resistance weights** were assigned to the elements of a land cover/road map. A variety of methods have been developed for determining resistance weights, in particular metrics of ecological similarity in community types (e.g. oak forest to oak forest assumed to be more connected than oak forest to spruce forest) have been used to good effect (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 as highly connected. We did not differentiate between forest types, and only slightly between open wetland and upland habitats (Table 3.1). Our assumption was that the requirements for movement and flows through natural landscape were less specific than the requirements for breeding, and that physical landscapes are naturally composed of an interacting mosaic of different ecosystems. Our goal was to locate areas where these arrays occur in such a way as to maintain their natural relationships and the connections between all types of flows, both material processes and species movements, not to maximize permeability for a single species (Hunter and Sulzer 2002, Ferrari and Ferrarini 2008, Forman and Godron 1986).

The resistance grid we created was based on a 90-meter classified land use map with roads embedded in the grid. The source data was the 2001 NLCD for United States and NALC 2005 for Canada that identify each grid cell as one of 16 classes of land cover (NALCMS 2005). We used 90-meter grid cells to make a reasonable processing time because the CAPS software program is computationally intense. Weights assigned to the land cover grid are shown in Table 3.1.

Table 3.1: Land Cover classes and the assigned resistance weights.

Land Cover Class	Land Element Category	Weight
Developed Medium Intensity/Minor Roads	Developed: Medium/High Intensity	100
Developed High Intensity/Major Roads	Developed: Medium/High Intensity	100
Developed Open Space	Developed: Low Intensity	90
Developed Low Intensity	Developed: Low Intensity	90
Pasture/Hay	Agriculture	80
Cultivated Crops	Agriculture	80
Barren Land (Rock/Sand/Clay)	Barren Land (Rock/Sand/Clay)	50
Open Water Natural	Water	50
Deciduous Forest	Natural	10
Evergreen Forest	Natural	10
Mixed Forest	Natural	10
Shrub/Scrub	Natural	10
Grassland/Herbaceous	Natural	10
Woody Wetlands	Natural	10
Emergent Herbaceous Wetlands	Natural	10

The final result was a grid of 90-meter cells for the entire region where each cell was scored with a local connectivity value from 0 (least connected) to 100 (most connected). Actual scores had a mean of 31.8 and standard deviation of 30.6 for the region (Map 3.5, Figure 3.6, 3.7, and 3.8)

Species Diversity as a Potential Resilience Factor: Ecosystems comprised of 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 (Petterson et al 1998). Conversely, depauperate systems, like some acidic bogs, have persisted over thousands of years with a very low diversity of species.

We did not include species diversity as a direct variable in estimating resilience, but instead created a weighting factor based on the relationship between latitude and diversity as a way of examining potential resilience gains due to increased diversity of species across latitude. The weighting is described in Chapter 4.

Figure 3.5: Examples of four resistant kernel cells shown against the land cover and roads map. The focal cell is the central point of each kernel and the spread, or size, of the kernel is the amount of constraints, so the score for the focal cell reflects the area around the cell. Kernel A is the most constrained; D is the least constrained.

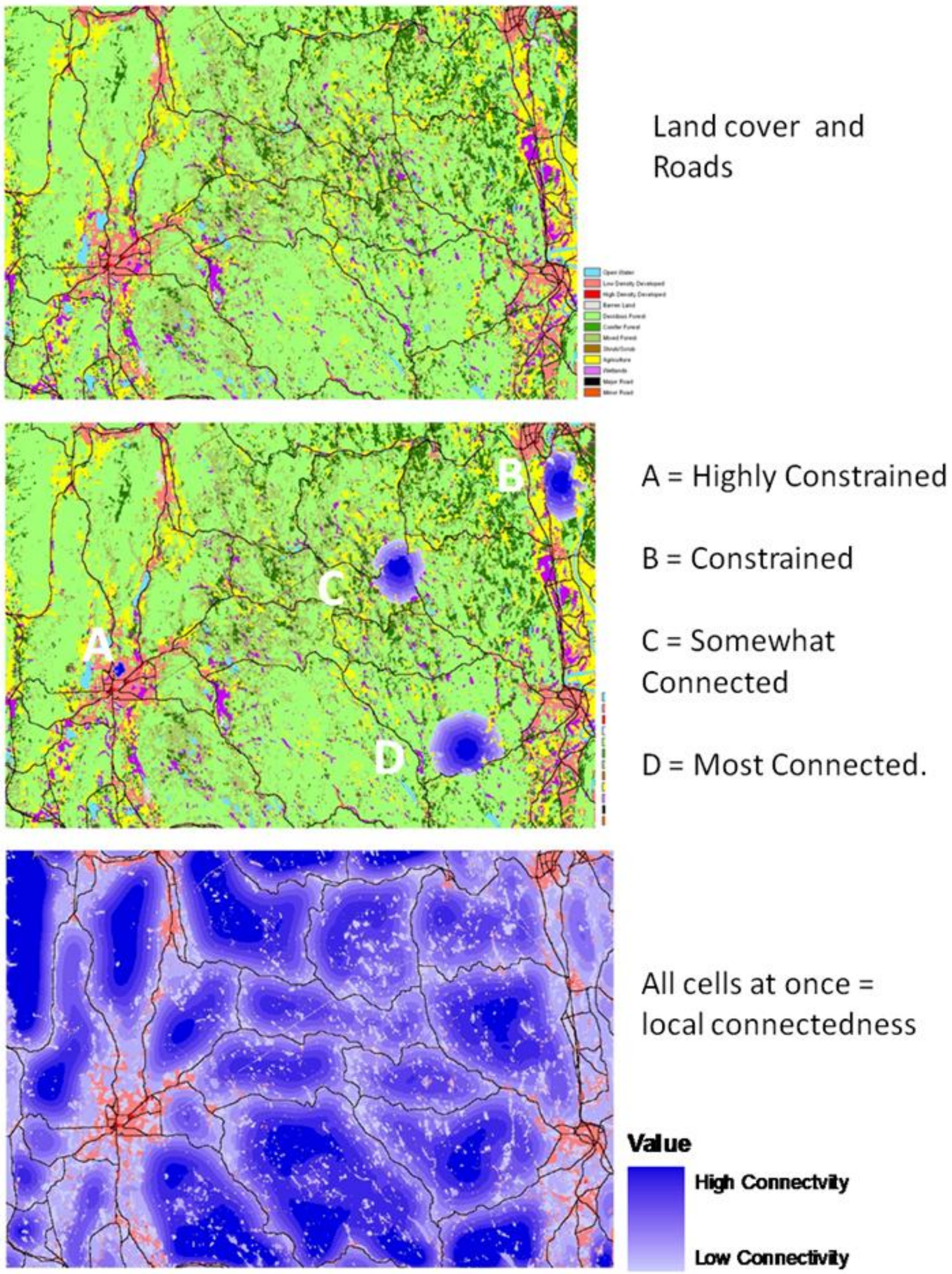


Figure 3.6: Detailed look at Kernel B in Figure 3.5. The top left image shows the topographic map for a rough location. The top right shows detail of the land use grid. The bottom left shows the aerial and the 3km circular resistant kernel distance. The bottom right shows the kernel spread. Kernel B 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.

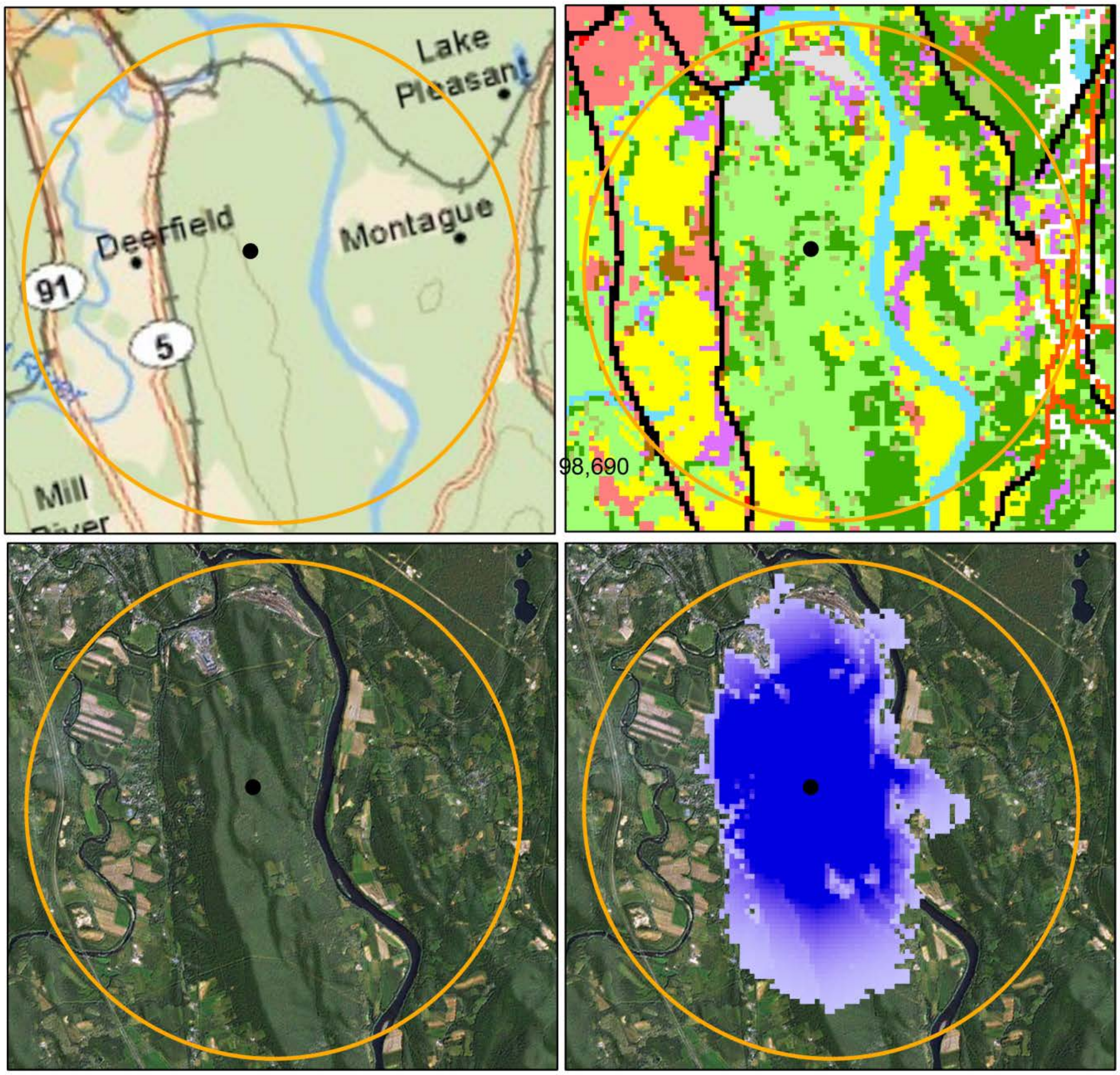


Figure 3.7: Visual comparison of local connectedness grid (top) with aerial photo of site (bottom). This shows a fragmented landscape on Prince Edward Island. The top image is a close up of the local connectedness surface with the site shown in blue outline. The bottom image shows a photo of the area with the approximate site area shown as a blue circle.

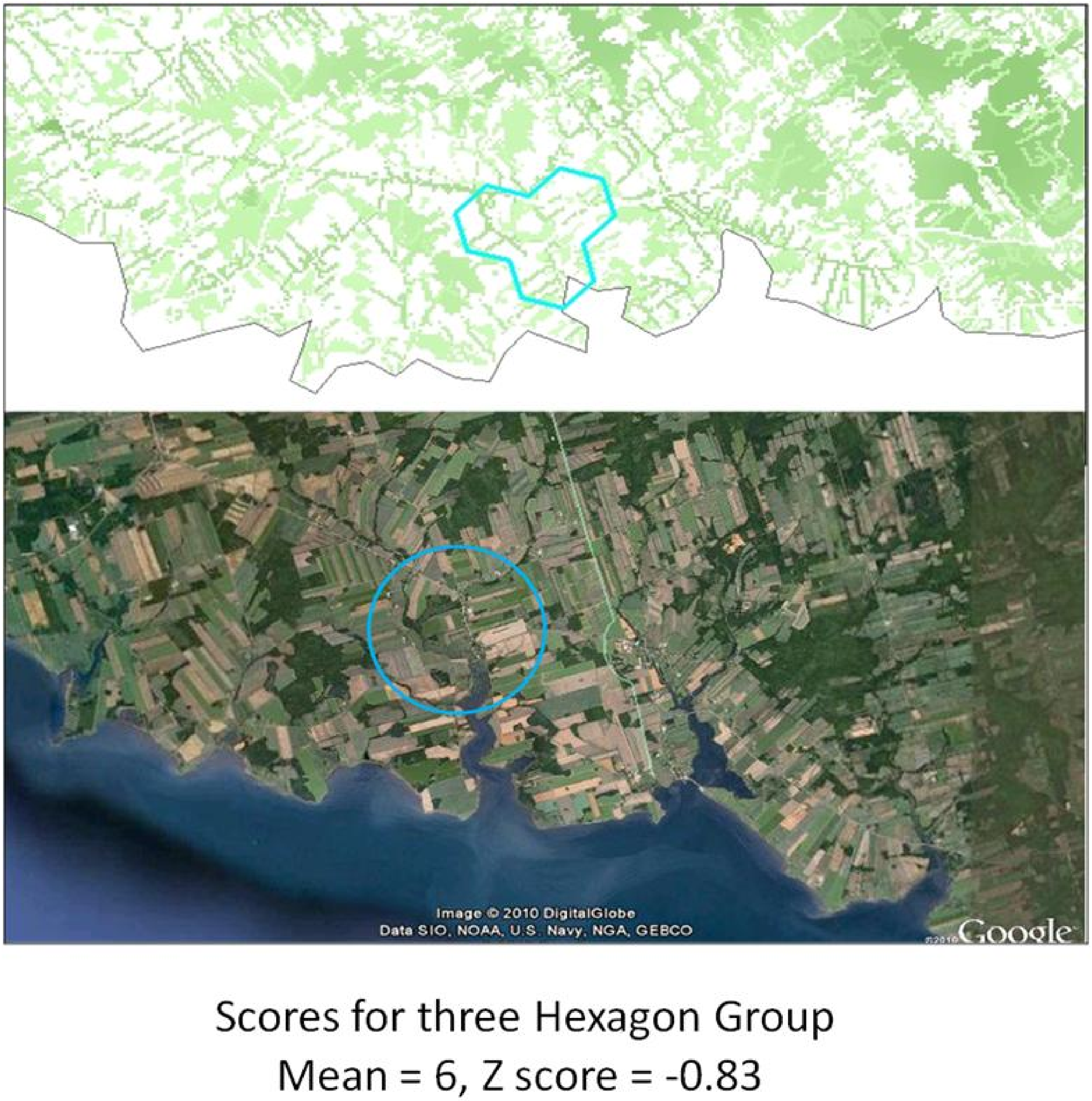
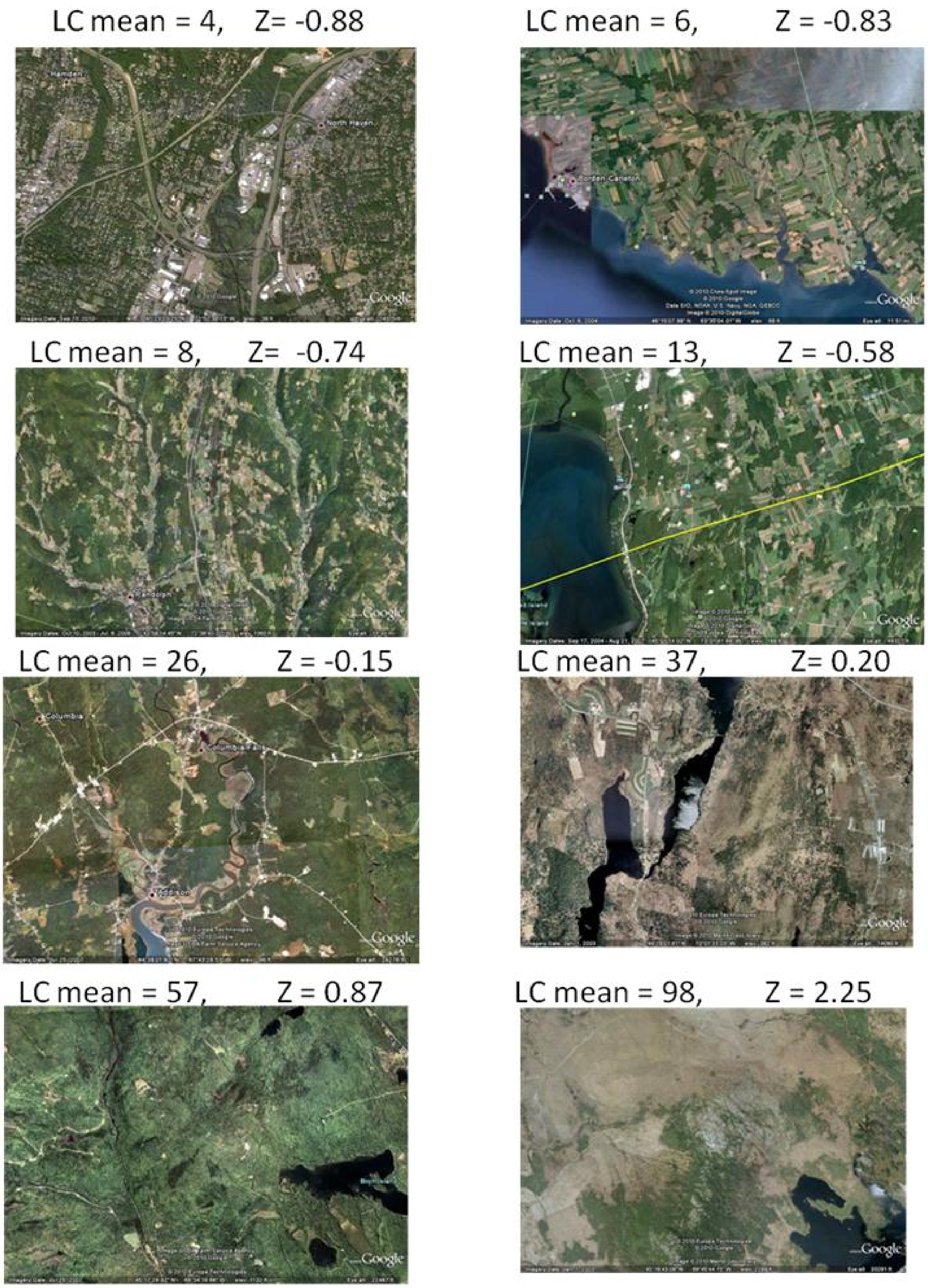
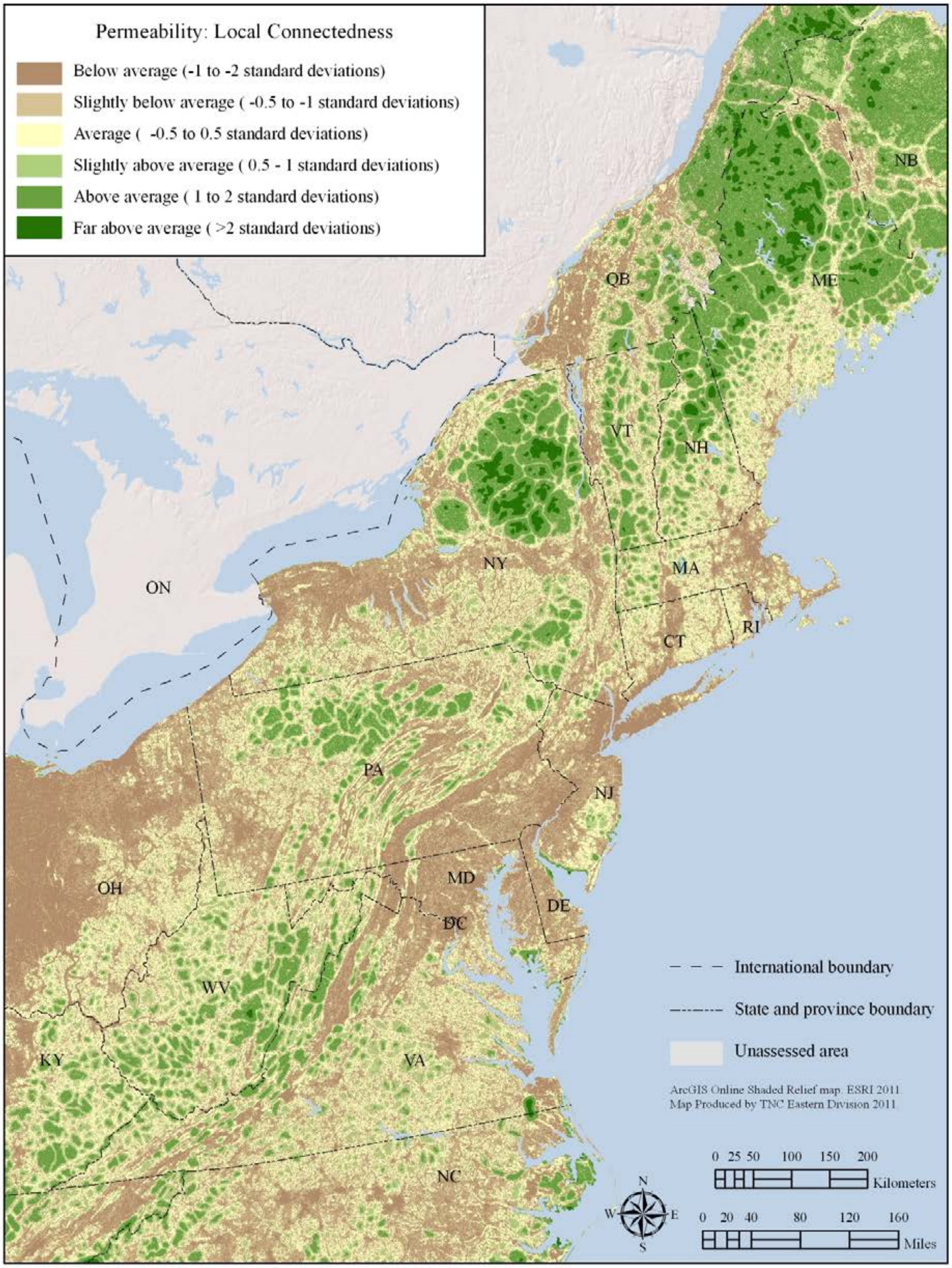


Figure 3.8: A gallery of satellite images and their corresponding local connectedness (lc) scores. The mean scores are based on a roughly circular site positioned at the center of each image (not shown). Z is units of standard deviation from the regional mean.



Map 3.5: Local connectedness. This map estimates the degree of connectedness of a cell with its surroundings within a three kilometer radius, and compares it to the regional average. *See Appendix I for the corresponding map showing Maritime Canada and the full Northern Appalachian-Acadian extent.*



Section 3: Combining Resilience Factors

In this section we describe our methods for combining the separate resilience factors into an integrated score. The integrated score is useful for thinking about how the factors combine to create resilience, but we encourage users to look closely at the individual factors because they reveal interesting and different information about the landscape

A Common Scale: In order to combine and compare resilience factors, we transformed each metric to standardized normalized scores (Z-scores) so that each had a mean of zero and a standard deviation of 1 (the standard normal distribution- see below). This ensured that the data sets could be combined with each factor receiving equal weight, allowing us to manipulate the weights systematically. Due to the large size of the source datasets, each dataset was transformed into an integer grid and the Z distribution was multiplied by 1000 (e.g. 1 standard deviation = value of 1000) for more efficient data processing and storage.

Using the mean μ ("mu"), and standard deviation σ ("sigma") of the scores for all cells in the region, we converted it into a z score by using the following formula on each individual score "x":

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

Landscape Complexity: Integrated Score: Because the variety of landforms was the factor most directly related to the number of microclimates based on the current literature, we gave twice the weight to this factor in the combined score:

Landscape Complexity = Flats (2*LV + 1* ER + 1 WD)/4) + Slopes (2*LV + 1* ER/3).
Where LV = landform variety, ER = elevation range, and WD = wetland density.

Estimates of Resilience: Integrated Score: We created a basic estimate of resilience for each cell by summing the Z-values for: 1) **local connectedness** and 2) **landscape complexity**, and taking the average. Both inputs had equal weights and we transformed the resultant grid into a Z distribution. Regional flow patterns were not used in this calculation.

Estimated Resilience = (LC1 +LC2)/2
Where LC1 = local connectedness and LC2 = landscape complexity

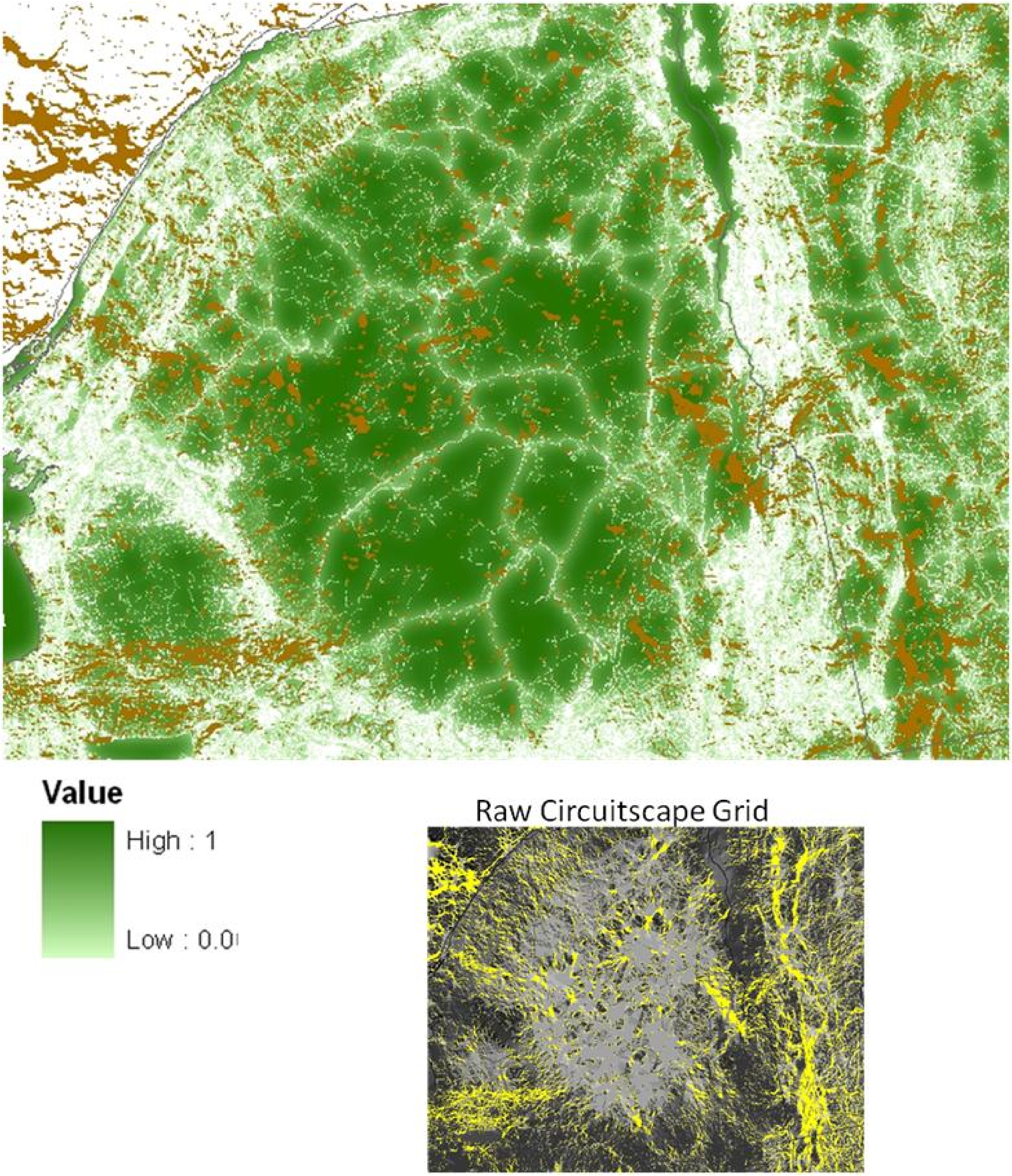
Regional Linkages

Regional Flow Patterns: The previously described "local connectedness" metric quantified the permeability of the landscape based on the local neighborhood surrounding every 90 m cell in the region, but the local connectedness metric did not account for broader scale movements such as directional range shifts, north-south migrations, or upslope dispersal patterns. This metric, **regional flow patterns**, was designed to identify potential larger-scale directional movements and pinpoint the areas where they are likely to become concentrated, diffused, or rerouted, due to the structure of the landscape. We used the software tool Circuitscape (McRae and Shah 2009), based on electric circuit theory, to model these larger flow patterns for the region. Like the local connectedness analysis, the underlying data for this analysis was land-cover and road data converted to a resistance grid by assigning weights to the cell types based on their similarity to cells of natural cover. However, instead of quantifying local neighborhoods, the Circuitscape program calculates a surface of effective resistance to current moving across the whole landscape. The output of the program, an effective resistance surface, shows the behavior of directional flows. Analogous to electric current or flowing water, the physical landscape structure creates areas of high and low concentrations similar to the diffuse flow, braided channels, and concentrated channels one associates with a river system. Three basic patterns can be seen in the output, as the current flow will: 1) *avoid* areas of low permeability, 2) *diffuse* in highly intact/highly permeable areas, or 3) *concentrate* in key linkages where flow accumulates or is channeled through a pinch point. Concentration areas are recognized by their high *current density*, and the program's ability to highlight concentration areas and pinch-points made it particularly useful for identifying the linkage areas that may be important to maintaining a base level of permeability across the whole region.

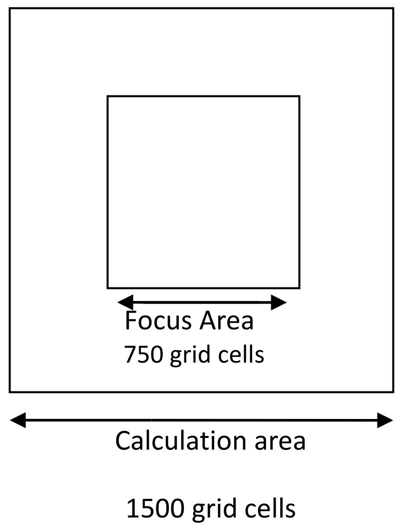
Before applying the model to the entire region we calibrated it by focusing on a few well-studied places that served as linkages between conservation areas, such as the region surrounding the Adirondacks (Figure 4.1). Our aim was to experiment with a variety of scales and parameters, until the model systematically identified these known linkages. The results in Figure 4.1 show where the Circuitscape analysis, overlaid on the local connectedness map, revealed directional flow concentration areas that are distinctly different from, and complementary to, the local connectedness analysis. In this figure, the highest flow concentration areas are mapped in brown on top of the local connectedness grid mapped in green. The figure illustrates where east-west ecological flows disperse and become diffuse in the highly intact central region of the Adirondacks (where local connectedness is very high), and how the flows concentrate in the broad linkages in and out of the Adirondacks, that are highlighted in several places and correspond well with key linkage areas identified through local studies. This was the scale of flow concentrations that we wanted to identify across the region, and the parameters described below reflect this scale.

The Circuitscape program "sees" the landscape as made up of individual cells. For this analysis we used a 270 meters cell size and each cell was coded with a resistance score? derived by assigning it a value based on land cover and roads, with a proportional weight. We used the same land cover maps supplemented with major and minor roads, and the same weighting scheme as for the local connectedness analysis (Chapter 3). In this weighting scheme, natural lands have the least resistance, agriculture or modified lands have more resistance and developed lands have the highest resistance (Table 3.1). In the Circuitscape program, the landscape is converted into a graph, with every cell in the landscape represented by a node (or a vertex) in the graph and connections between cells represented as edges in the graph with edge weights based on the average resistance of the two cells being connected (Shah and McRae 2008). The program performs a series of combinatorial and numerical operations to compute resistance-based connectivity metrics, calculating net passage probabilities for random walkers passing through nodes or across edges. Unlike a least cost path approach, Circuitscape incorporates multiple pathways, which can be helpful in identifying corridors (McRae and Beier 2007). More detail about the model, its parameterization, and potential applications in ecology, evolution, and conservation planning can be found in McRae and Brier (2007) and McRae and Shah (2009).

Figure 4.1: Flow concentration areas. This figure shows the flow concentration areas in brown overlaid on the resistant kernel analysis (green) for the Adirondack region. In this figure the flow concentration areas are regions where east-west flows become concentrated because the structure of the landscape provides limited options for movement. Areas within the center of the region have moderate scores because the flow is dispersed across a highly intact landscape.

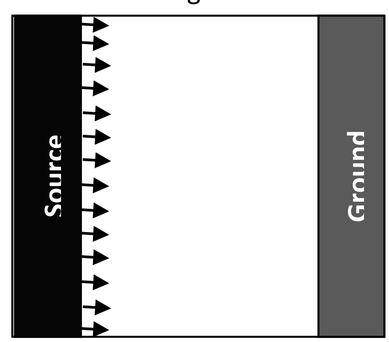


Circuitscape was originally designed to run resistance-based connectivity metrics from one focal area (habitat patch) to another. To get at overall landscape permeability, however, we measured current accumulation using continuous equal inputs across the entire landscape instead of providing a set of points/patches to connect. After many trials, test runs, and conversations with the software developer, we developed a method to get complete wall-to-wall coverage by running the model in gridded landscape squares where one whole side was assigned to be source and the other side the ground, repeating the run for each of four directions: east-west, west-east, north-south, south-north, and then summing the results. This method gave stable and repeatable results for the central region of each square (the focus area) but was subject to edge effect around the perimeter. Thus, to create a continuous surface we clipped out the central area of each square and tiled them together. Our final methods were as follows:



First, the study area was divided into 53 tiles – or calculation areas – comprised of 1500 cells by 1500 cells (~ 405 kilometers). Each tile was intersected with a land cover and road map coded for resistance using the weighting scheme in Table 3.1. (The analysis was run for all tiles with complete land cover information, but tiles that were solely water were ignored).

Second, within each tile we identified a focus area that was one quarter the size of the total calculation area. In the final results we used only the results from the central focus area because the results in this region stayed consistent even as the calculation area is increased. This eliminated the margin of the calculation area, which appeared, based on many trials to have considerable noise created by the starting points.



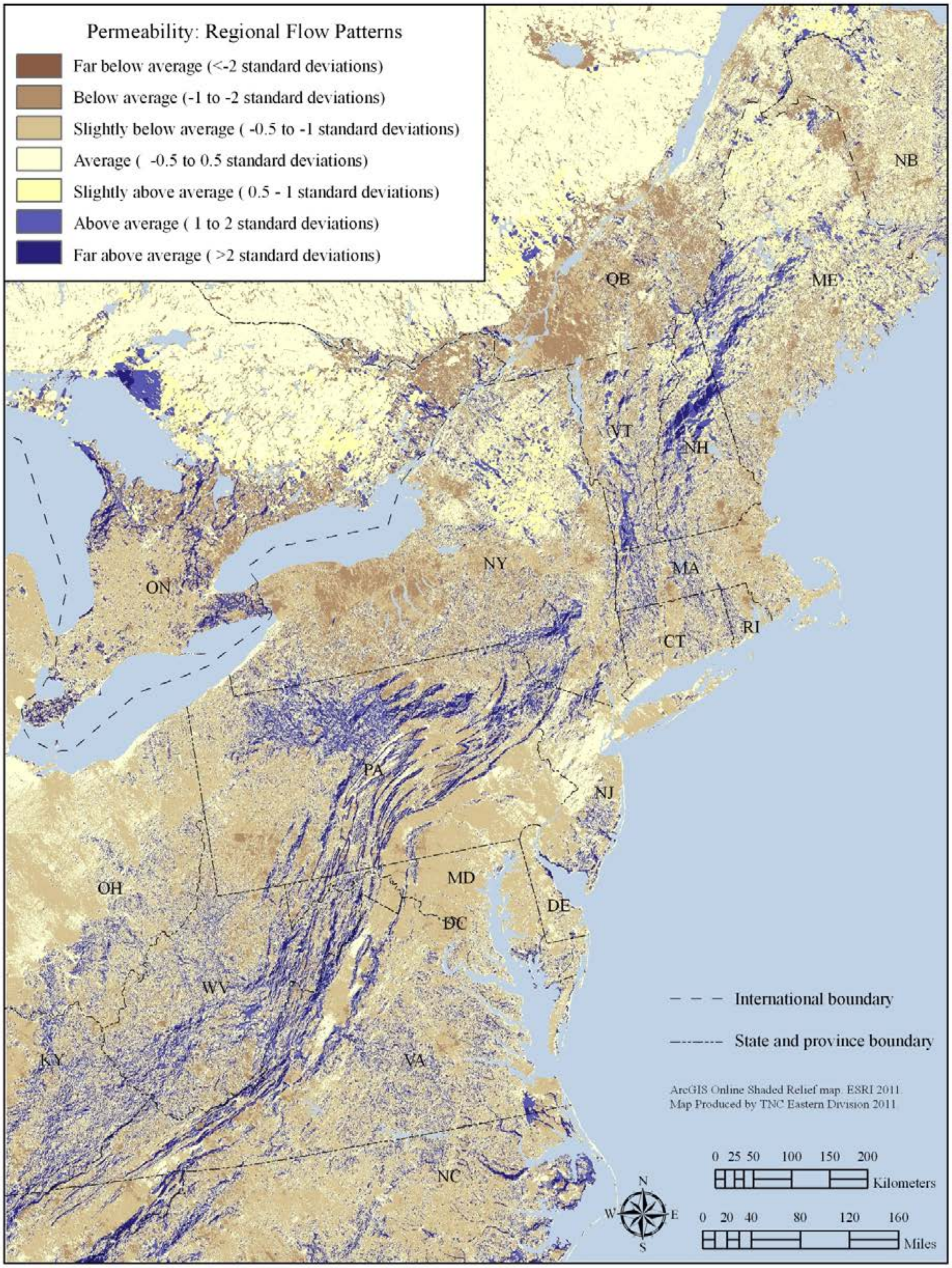
Third, we ran Circuitscape for each of the 53 calculation areas. To calculate the resistant surface, we set one side of the square to be the source and the other side area to be the ground. Current was injected into the system from each grid cell on the source side of the square. Because current seeks the path of least resistance from the source cells to any grid cell on the ground side, a square run with the west edge as source and the east side as ground will not produce the same current map as a square run with the east edge as source and west edge as ground. To account for these differences, we ran the program for all four of the direction possibilities - west to east, east to west, north to south, south to north, and summed the results.

Lastly, the focus area was clipped out of each calculation area and joined together to create a continuous coverage of results for the region (Map 4.2). The square focus areas had scores that were normalized to their calculation area, and we also created a surface where all scores were normalized to the whole region. When we compared these two results we found that the former map, normalized to each calculation area, was more effective at highlighting local concentration areas and pinch points while still revealing regional scale patterns as well. Thus, the results we used in the analysis and shown here, were normalized to the calculation area.

Integration with Other Metrics: The flow concentration attribute differs from the previous resilience metrics in that it was primarily concerned with the resilience of the entire network, not necessarily an individual site, thus we did not integrate this attribute directly into the cell and hexagon-based resilience score, but treated it as a separate score providing information on the importance of the site's location in maintaining large scale processes.

Notes on the use of Circuitscape: As suggested by McRae we did try using the source side as focal region. This allowed the current to flow not from every point on the source side, but to flow from the optimum point on the source side to the ground side. This did show the most direct flow of current from the source to the ground, but did not represent how current would flow through the landscape as a whole. Additionally, the primary reason for using the 270 m grid cell was that Circuitscape is a memory intensive program and we ran the program for a very large area. This also had the nice property of highlighting meaningful groups of cell at the scale of interest to us. At the 30-meter scale, more individual grid cells are highlighted making the patterns more dispersed. To change the spatial resolution from 90-meters eastern region dataset to 270 meters the aggregate function was used. When aggregating, the maximum value of the 9 smaller 90-meter grid cells was used. This insured that the barriers (roads, developed areas) were not averaged out. Cell size is important, but as long as it remains fine enough to capture relevant landscape elements, such as narrow corridors and barriers, the program has great flexibility to get similar results with varying cell size (McRae et al 2008). The developers note that it is particularly important to capture absolute barriers (such as roads and railroads) to movement that may not be detectable at larger cell sizes (McRae et al 2008). A 270 meter grid cell size is much smaller than was used in published case studies. For a landscape genetic example using wolverine, McRae and Beier (2007) used a grid cell size of 5 kilometers, which they thought was course enough for computation on a desktop computer, but allowed them to capture major landscape features and minimizing categorization errors.

Map 4.2: Regional flow patterns. This map shows areas of concentrated flow (above average), diffuse or dispersed flow (average) and low or blocked flow (below average).



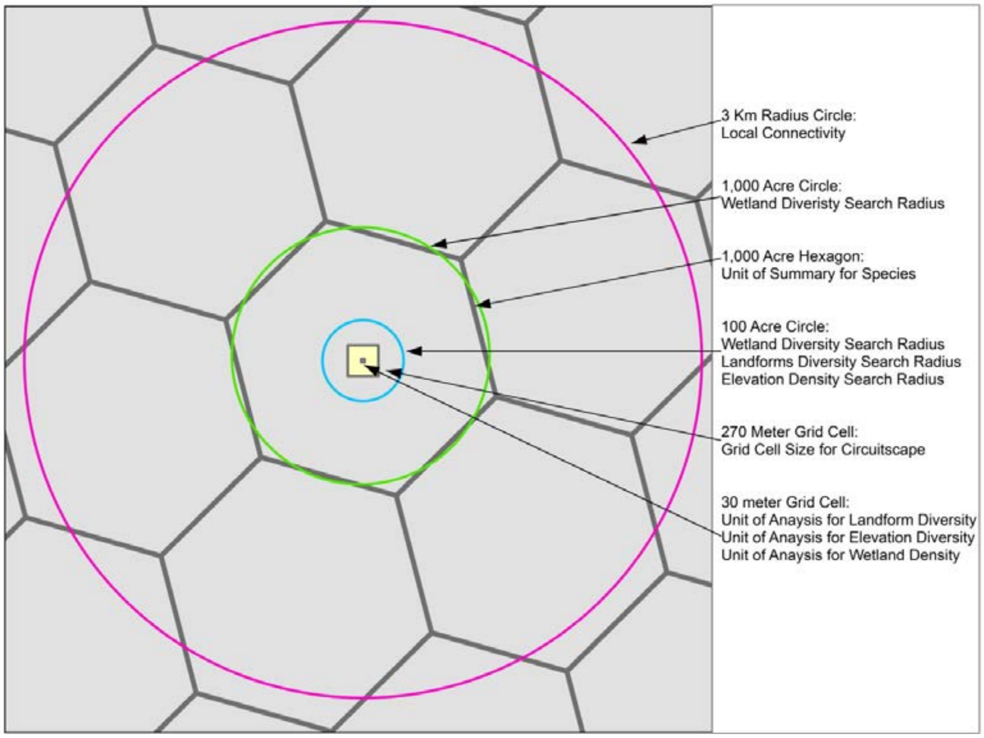
Results:

Scores for the Settings

This section describes how we applied the estimates and attributes of resilience to each site to identify the most resilient areas of each geophysical setting. The maps are accompanied by examples of the species and communities that are currently located within the setting, and a summary of the setting's level of securement. Integrated maps are presented following the maps of individual settings.

To estimate a score for an individual hexagon, we combined information collected across a variety of scales: from a 100-acre circle to a 3 kilometers radius. The information was summarized at the scale of a 30-meter cell and then re-summarized into a 1000 acre hexagon scale (Figure 5.1). Our goal was to combine the data such that each layer contributed equally to the final scores, unless intentionally weighted.

Figure 5.1: The variety of local neighborhood sizes used in this assessment. The information was all tagged to the 30-meter cell (the smallest center point) and summarized by 1000 acre hexagons. Landscape variety, elevation range, and wetland density all used a 100-acre search radius around each 30-meter cell, with the later also weighted by a 1000 acre search. The regional flow patterns were assessed as a 270 meter grid (the square box). Local connectivity was scored to the 30-meter cell, but evaluated over a search radius covering 3 kilometer (pink circle).



Sites (1000 Acre Hexagons): We attributed each hexagon with information and scores for the resilience factors described in the previous chapters: landform variety, elevation range, wetland density, local connectedness, regional flow concentrations, and the integrated variables of landscape complexity and estimated resilience. For each factor, we calculated the minimum, maximum, range, mean, standard deviation, sum, variety, majority, minority, and median for each hexagon using zonal statistics in ArcGIS Toolbox. Additionally, we overlaid point locations of rare species and natural communities compiled from the 13 State Natural Heritage program's ongoing inventory.

Individual Geophysical Settings: 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. The end of this chapter presents each setting individually with a list of the associated communities and rare species, the geophysical characteristics, the securement status, and the final resilience scores (Maps 5.1 - 5.17). The content and structure of each page is shown below.

LAYOUT AND CONTENT OF THE SETTINGS PAGES

ABREVIATION: NAME OF SETTING

Description: *Short description of key characteristics of this setting*

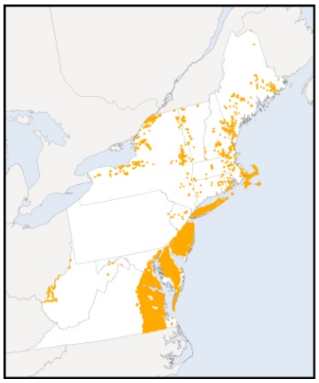


Figure: *a map of the distribution of the setting, exaggerated to make it easy to see single cell (compare with the map below).*

Example: Current Communities
Examples of natural communities located primarily within this setting, and that are inventoried and monitored by the State Natural Heritage Programs

Securement status: *The total amount of this setting that falls on secured land (GAP 1, 2 or3, top row), and the percentage of each resilience category that falls on each type of secured land (Rows 4-8). In this example the 4 percent secured as Gap 1 or 2 is composed of 1 percent on far above average sites.*

Resilience Score Category	Percents			Acres
	GAP1 or 2	GAP3	Unsecured	Total Acres
L:COARSE	4%	6%	90%	9,653,844
1: Far Below Average	0%	1%	18%	1,782,104
2: Below Average	0%	1%	13%	1,298,121
3: Average	2%	2%	34%	3,663,419
4: Above Average	1%	1%	12%	1,316,133
5: Far Above Average	1%	2%	14%	1,594,067

Map: *A map of the setting with each cell colored by its resilience score category, either above or below the average for the setting.*

Results by Setting: This section presents the descriptions, maps and results for each of 28 geophysical settings.

Low Elevation	**20 – 800 feet,**	**Maps 5.1 to 5.12**
Coastal*	**0 – 20 feet,**	**Maps 5.13 to 5.15**
Mid Elevation	**800-2500 feet**	**Maps 5.16 to 5.23**
High Elevation	**> 2500 feet**	**Maps 5.24 to 5.29**
Steep Slopes		**Map 5.30**

LOW ELEVATION SETTINGS

Low Elevation Coarse Sand (L-COARSE): Coastal plain settings with oak-pine forest, pine barrens, coastal plain ponds. Numerous rarities.

Low Elevation Granite (L-GRAN): Bedrock based setting with hilltop woodlands

Low Elevation Mixed Granite and Coarse Sand (L-GRAN/COARSE): A common setting supporting acidic forests, inland dunes, and many rarities.

Low Elevation Fine Silt (L-FINE): Fertile silt or clay setting in old lake beds and floodplains

Low Elevation Mafic (L-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 Acidic Sedimentary (L-SED): Widespread settings on sandstone, siltstone, conglomerate, and equivalent meta-sedimentary rock, usually overlain with shallow till and supporting many common acidic forests types.

Low Elevation Sedimentary and Coarse Sand (L-SED/COARSE): Uncommon setting characterized by river bluffs, shoreline marshes, dry forests and acidic wetlands.

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

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

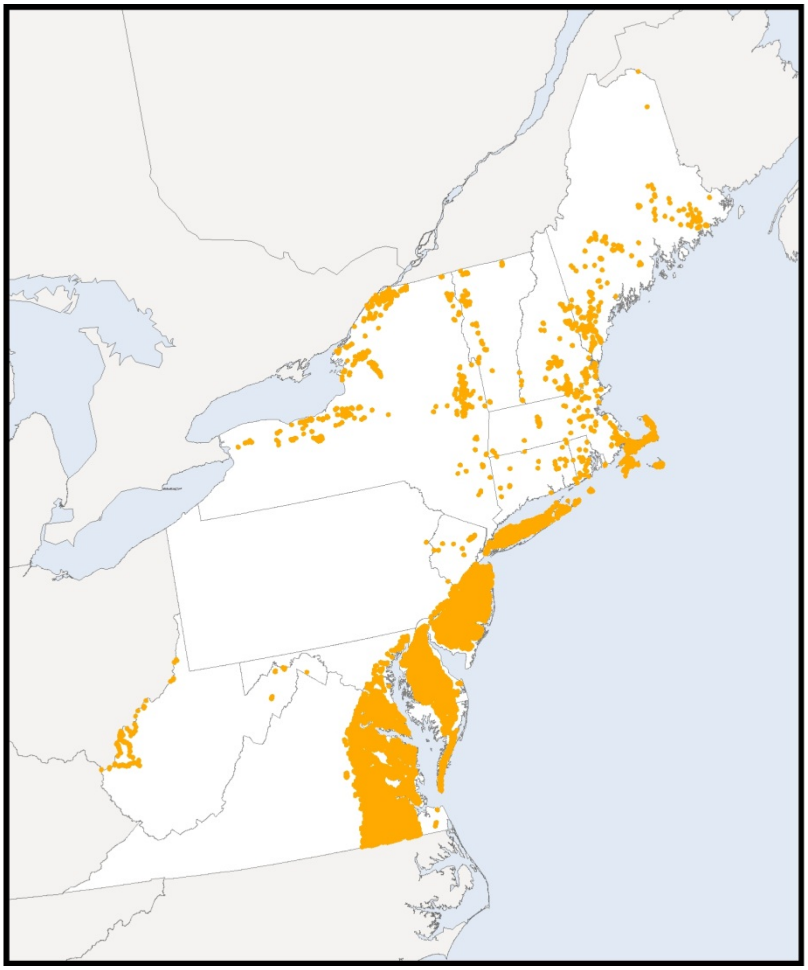
Low Elevation Granitic and Calcareous (L-GRAN/CALC): Mixed settings with pockets of limestone communities embedded in an acidic granitic matrix.

Low Elevation Acidic Shale (L-SHALE): Settings on unstable shale slopes often supporting a unique flora and sedimentary-like shale lowlands

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

Low Elevation Coarse Sand Settings (L-Coarse)

Description: Settings defined by deep sand and other coarse unconsolidated sediments at elevations below 800’ and above 20’. This environment is characterized by acidic nutrient-poor soils, and supports a variety of distinctive communities, such as fire dependent Pitch Pine barrens.



Example: Current Communities
Uplands: Dry oak-pine forest, Dwarf pine plains, Pitch pine - heath barrens, Pitch pine woodlands, Beech-tulip tree woodland, White oak- sweetgum forest, Coastal oak-beech forest, Coastal oak-hickory forest, Coastal plain floodplain Forest, Inland dune community, Riverwash hudsonia barren, Inland beach strand, Sandplain heathland.

Wetlands: Atlantic white cedar swamp, Coastal plain peatland-sphagnum bog, Buttonbush swamp, Coastal plain pond and pondshore, Coastal plain poor fen, Fresh tidal marsh, Pine barrens shrub swamp, White oak-sweetgum forest red maple-blackgum swamp. riverside ice meadow, acidic level fen,

Securement status: 10 percent secured, 5 percent on above average sites.

Resilience Score Category	Percents			Acres
	GAP1 or 2	GAP3	Unsecured	Total Acres
L:COARSE	4%	6%	90%	9,653,844
1: Far Below Average	0%	1%	18%	1,782,104
2: Below Average	0%	1%	13%	1,298,121
3: Average	2%	2%	34%	3,663,419
4: Above Average	1%	1%	12%	1,316,133
5: Far Above Average	1%	2%	14%	1,594,067

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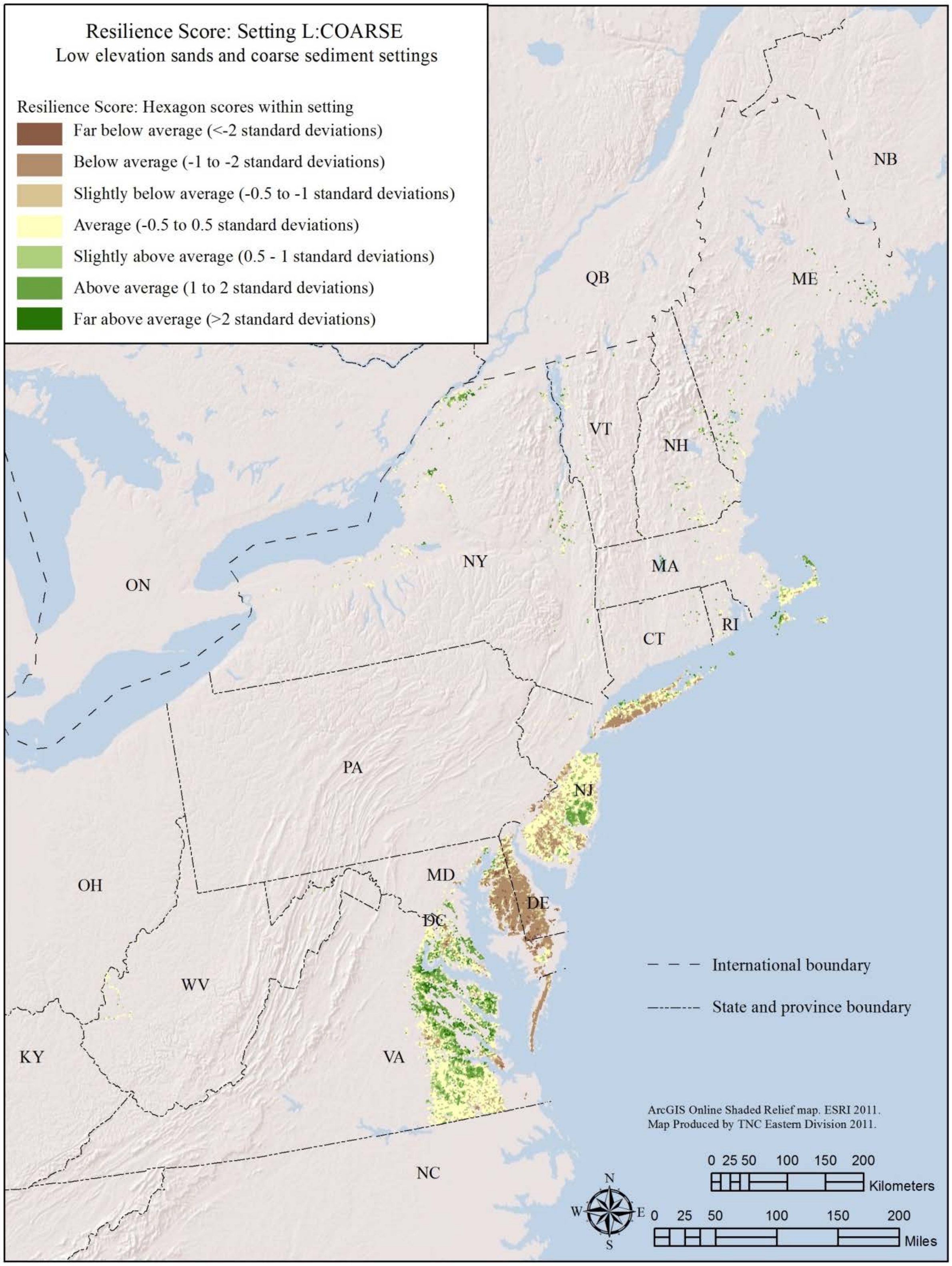
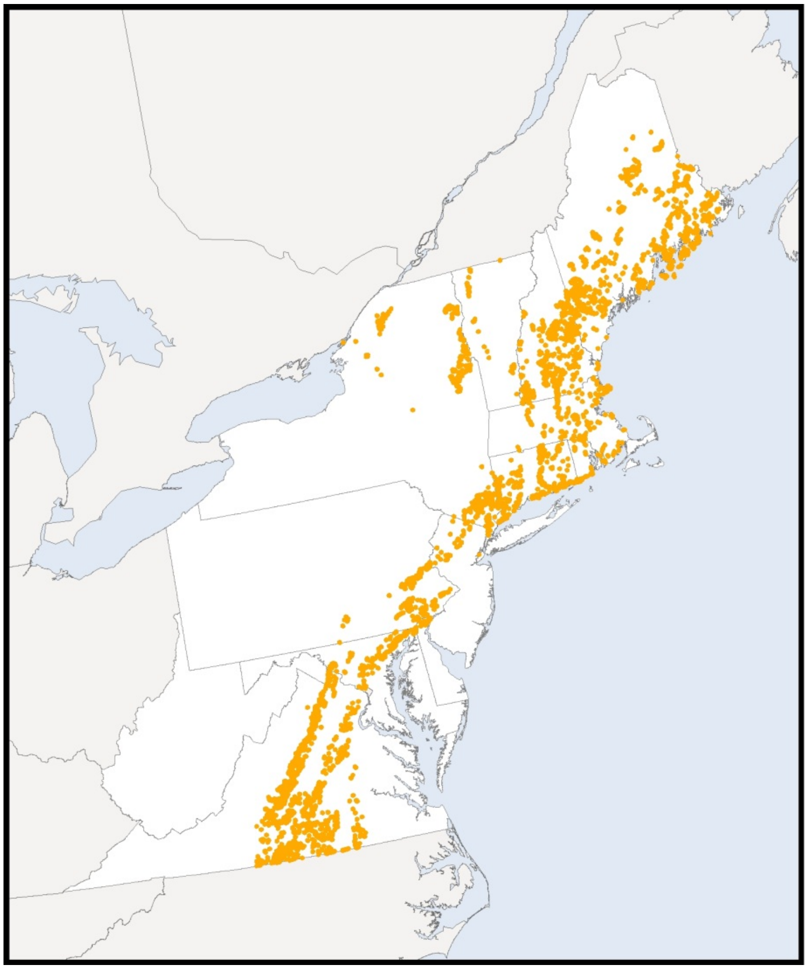
Map 5.1: Resilience scores for L-COARSE



Low Elevation Granite Settings (L-GRAN)

Description: Settings underlain by granitic bedrock at low elevation below 800’ and above 20’. These settings support a variety of shallow soil bedrock-based hilltop woodlands, and poorly drained wetlands.



Example: Current Communities

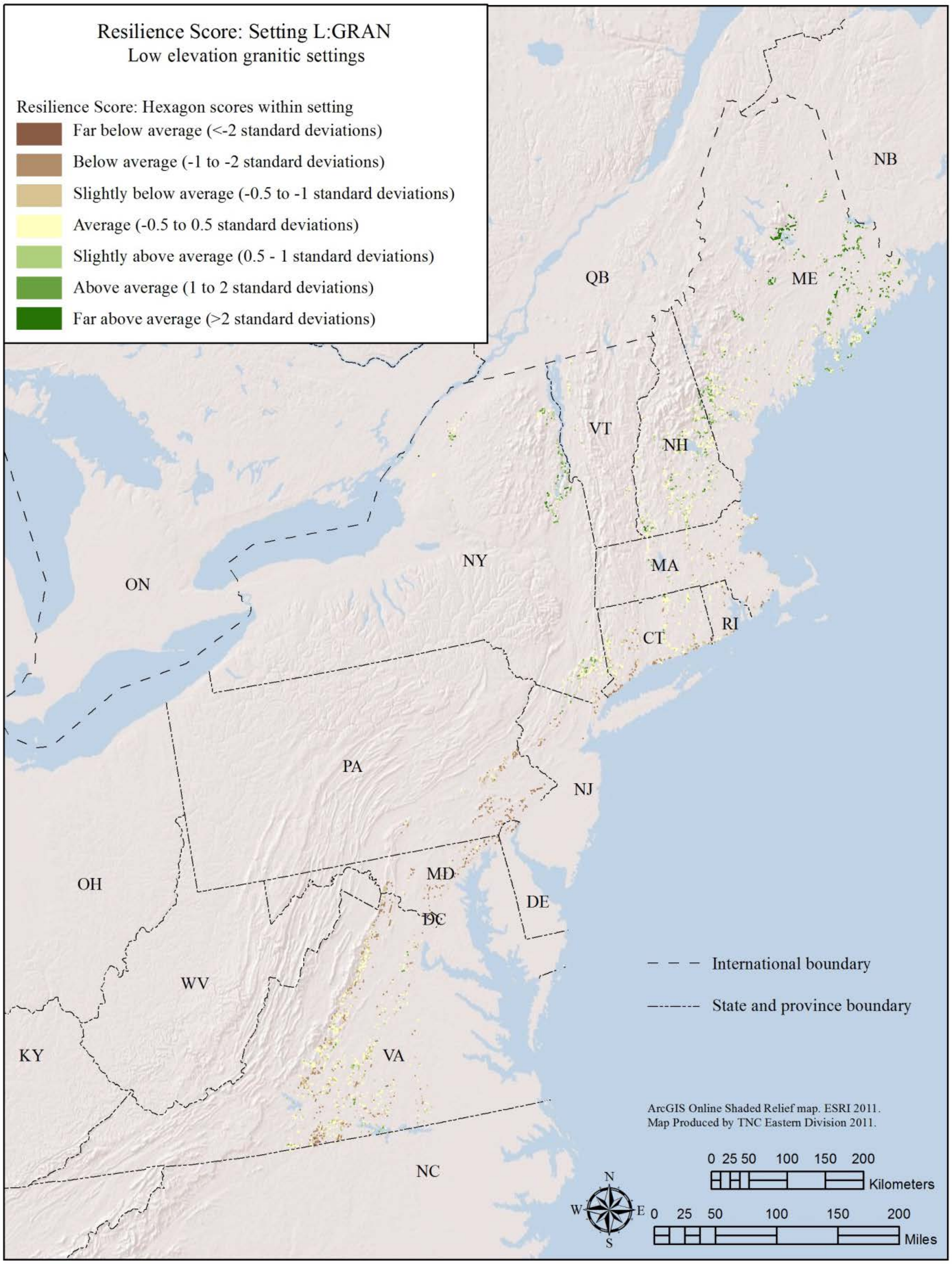
Upland: Jack pine woodland, Spruce slope forest, Red pine woodland, Pitch pine woodland, Mesic transitional acidic forest, Pitch pine-oak-heath rocky summit, Acidic rocky summit, Herbaceous low riverbank, Rocky summit grassland,
Acidic talus community, Riverside prairie

Wetland: Alluvial swamp, Level bog, Acidic seepage swamp, High brackish tidal riverbank marsh, Tidal creek bottom
Graminoid emergent marsh, Red maple-sweetgum swamp

Securement Status; 10 percent secured, 4 percent on above average sites.

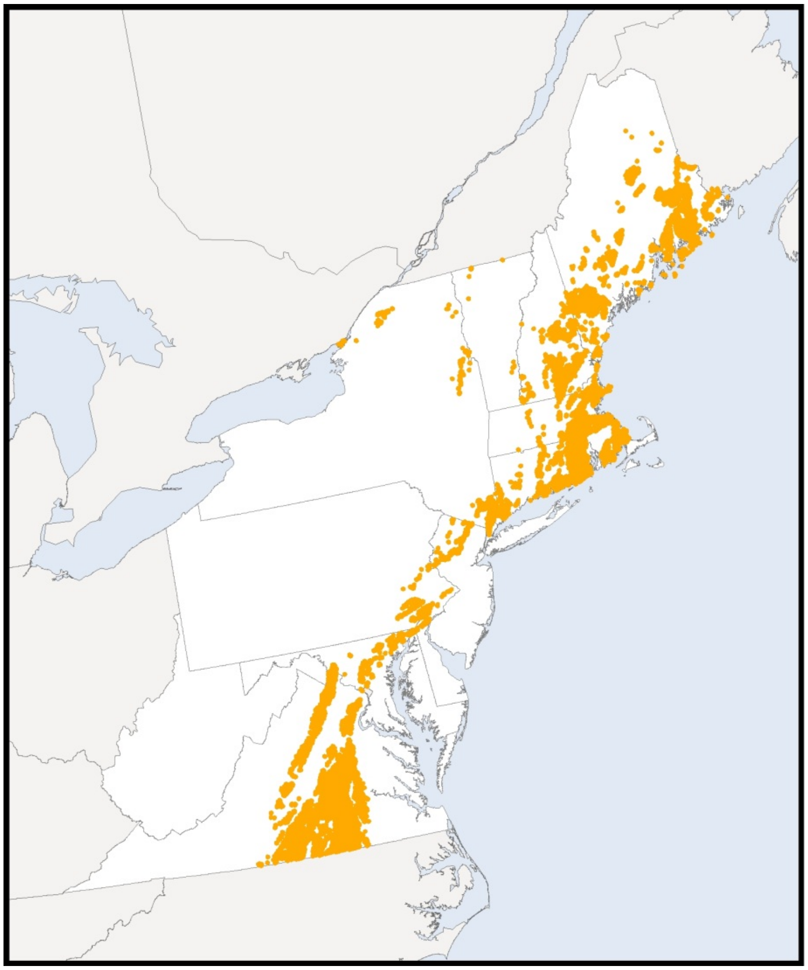
Resilience Score Category	Percents			Acres
	GAP1 or 2	GAP3	Unsecured	Total Acres
L:GRAN	3%	7%	90%	2,968,251
1: Far Below Average	0%	0%	17%	503,104
2: Below Average	0%	1%	16%	486,007
3: Average	1%	2%	36%	1,153,061
4: Above Average	0%	1%	11%	374,033
5: Far Above Average	1%	2%	12%	452,047

Map 5.2: Resilience scores for L-GRAN



Low Elevation Mixed Settings of Granite and Coarse Sediments (L-GRAN/COARSE)

Description: A common setting of coarse sand underlain by granitic bedrock at low elevation below 800’ and above 20’ with characteristics of both coarse sand and granitic settings.



Example Communities

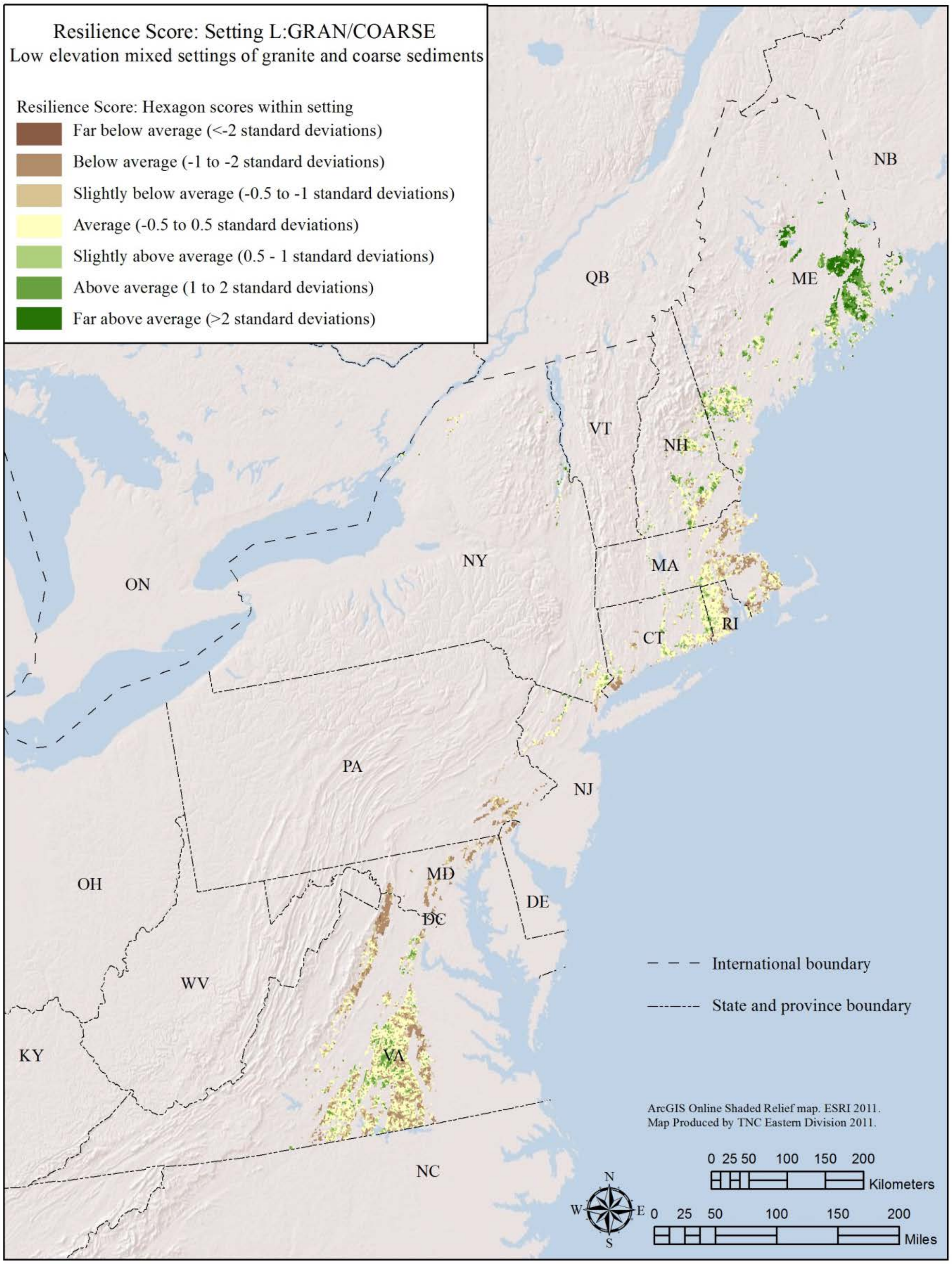
Upland: Mixed oak forest, Inland dune/sand barren, Pitch pine - scrub oak community, Ridgetop chestnut oak forest, Chestnut oak woodland, Dry transitional forest on sand, Inland beach strand community, Acidic rocky summit/outcrop.

Wetland: Coastal plain floodplain swamp, Graminoid marsh, Highbush blueberry thicket, Coastal plain quagmire, acidic basin swamp, Acidic level fen, Hemlock - hardwood pocket swamp, Perched hemlock-hardwood swamp, Level bog, Blackgum/red maple basin swamp, Atlantic white cedar swamp, Floating kettlehole bog, Outwash seepage forest, Red maple - sensitive fern swamp

Securement Status: 10 percent secured, 4 percent on above average sites.

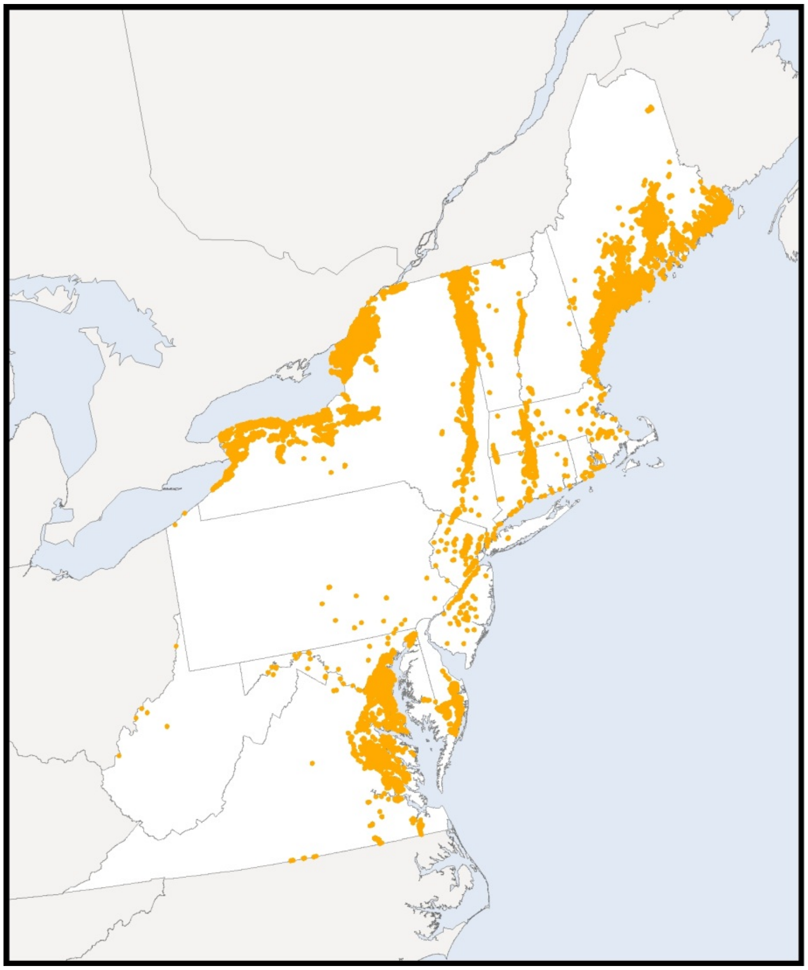
Resilience Score Category	Percents			Acres
	GAP1 or 2	GAP3	Unsecured	Total Acres
L:GRAN/COARSE	2%	8%	91%	8,737,741
1: Far Below Average	0%	0%	15%	1,318,126
2: Below Average	0%	1%	19%	1,716,168
3: Average	1%	3%	35%	3,341,293
4: Above Average	0%	1%	10%	1,040,062
5: Far Above Average	1%	2%	12%	1,322,092

Map 5.3: Resilience scores for L-GRAN/COARSE



Low Elevation Settings in Silt and Fine Sediment (L-FINE)

Description: Flat or rolling settings in silt or clay at low elevation below 800’ and above 20’. Fertile settings in ancient lake beds, clayplains, or active floodplains.



Example Communities

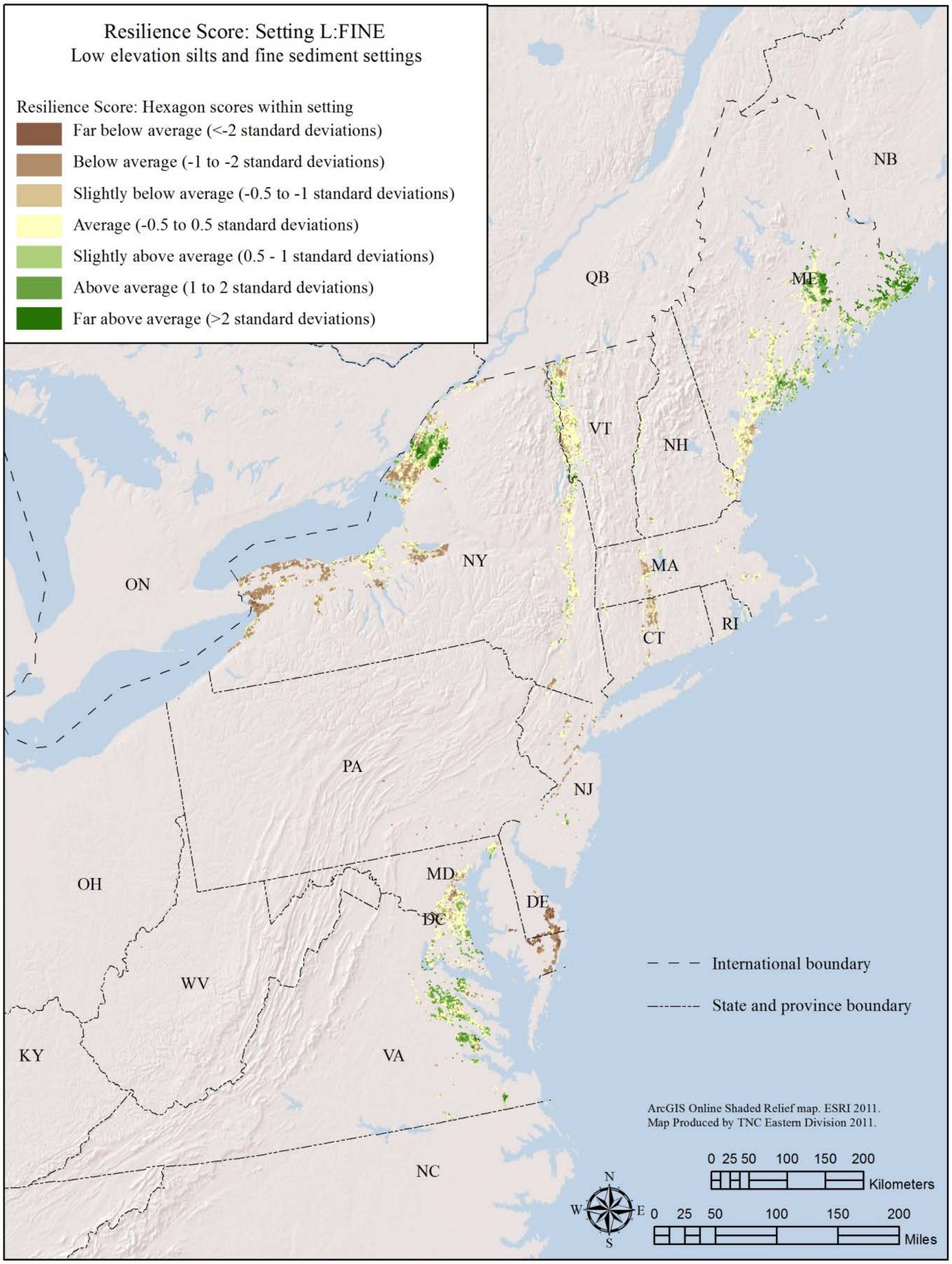
Upland: Basic oak - hickory forest, Loblolly pine savanna, Valley clayplain forest, Red maple floodplain forest. Major river floodplain, Silver maple-sensitive fern riverine floodplain forest, Lake sediment/river terrace forest, Coastal plain bottomland hardwoods, Pine barren savanna, Swamp white oak floodplain forest

Wetland: Piedmont seepage bog, Domed bog ecosystem, Seepage forest and marsh, Red maple-white pine-huckleberry swamp, Sheep laurel shrub bog, Wild rice marsh, Lakeshore grassland, Pitch pine saturated woodland, Tidal riverbank marsh, Acidic level fen, Alluvial marsh, Buttonbush swamp, Deep broadleaf marsh, Swamp white oak basin swamp,

Secured status: 6 percent secured, 3 percent on above average sites.

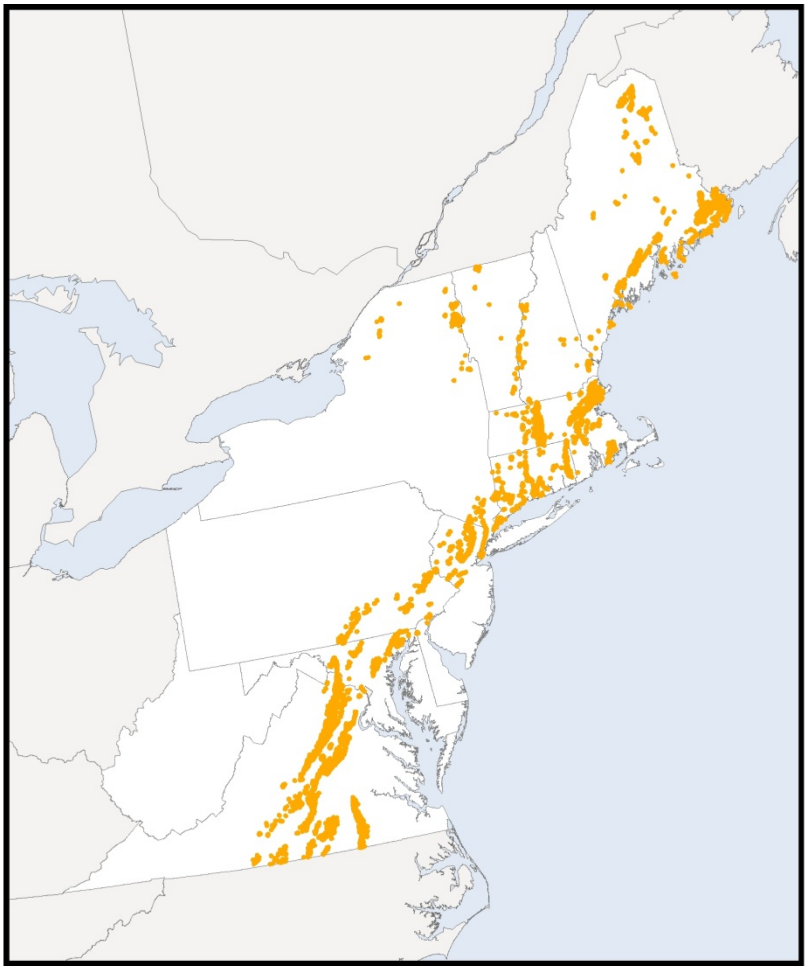
Resilience Score Category	Percents			Acres
	GAP1 or 2	GAP3	Unsecured	Total Acres
L:FINE	2%	4%	93%	7,730,679
1: Far Below Average	0%	0%	15%	1,223,165
2: Below Average	0%	1%	15%	1,246,106
3: Average	1%	1%	37%	3,015,227
4: Above Average	0%	1%	12%	1,032,073
5: Far Above Average	1%	1%	13%	1,214,108

Map 5.4: Resilience scores for L-FINE



Low Elevation Settings on Mafic Bedrock (L-MAFIC)

Description: Low elevation settings under 800' and above 20' in volcanic basalts (traprock) and other mafic bedrocks. Mafic (from **Ma**gnesium and **f**err**ic**) bedrock is resistant to weathering and forms distinctive ridges or ring dikes in some areas. Soils derived from this parent material may support a flora similar to calcareous rocks or to the ultra-mafic serpentines.



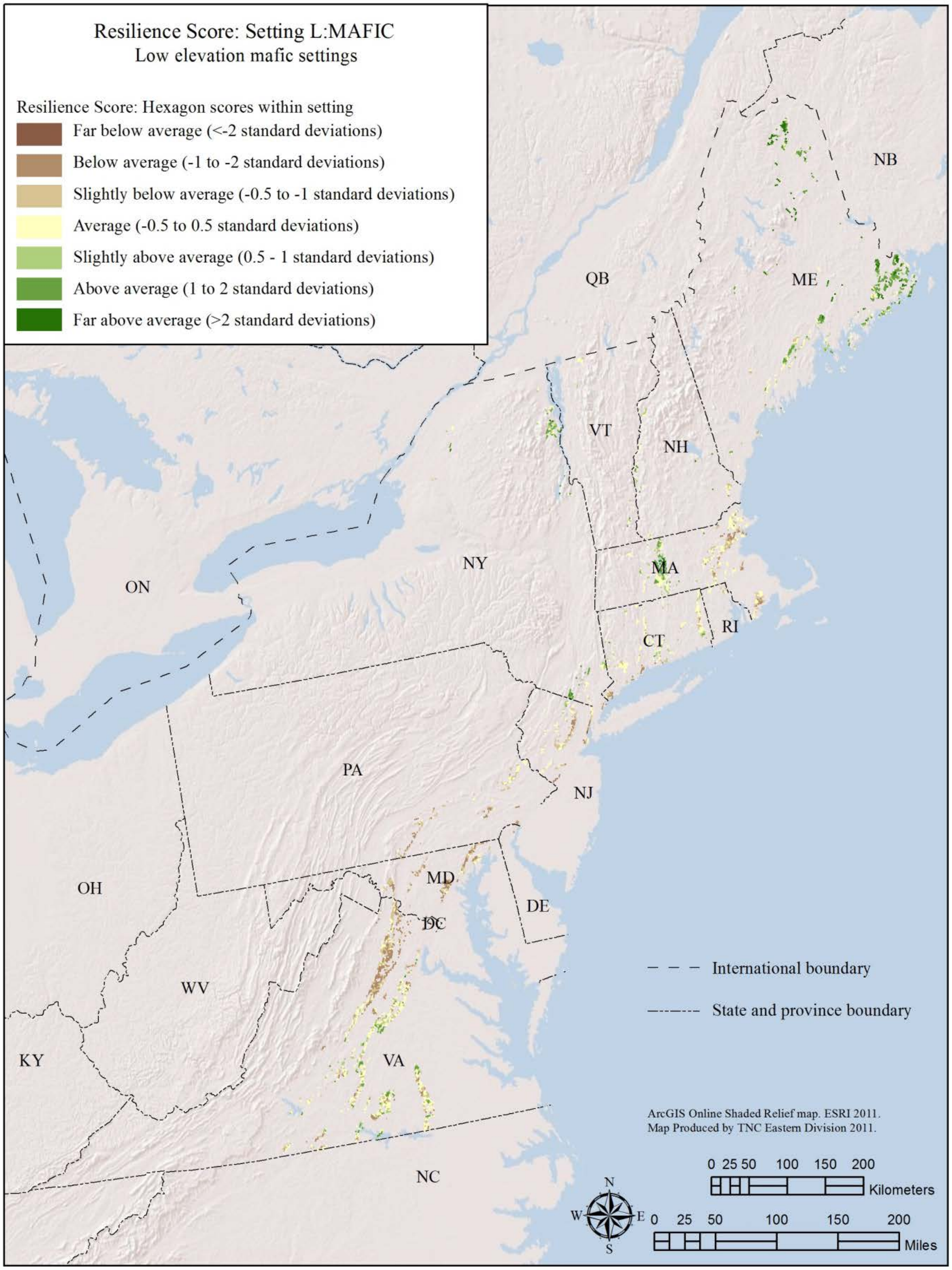
Example Communities
Upland: Traprock glade/rock outcrops, Serpentine barrens, Rich mesic forest, Dry rich forest, Maritime spruce-fir forest, Subacidic cold talus forest, subacidic Rocky summit/outcrop, Rocky summit grassland, Calcareous shoreline outcrop,

Wetland: Circumneutral seep, Basin swamp, Forest seep community, Acidic shrub fen, Acidic Atlantic white cedar basin swamp, calcareous fen, Alluvial Atlantic white cedar swamp, Alluvial red maple swamp, Red maple-sweetgum swamp

Securement status: 9 percent secured, 4 percent on above average sites.

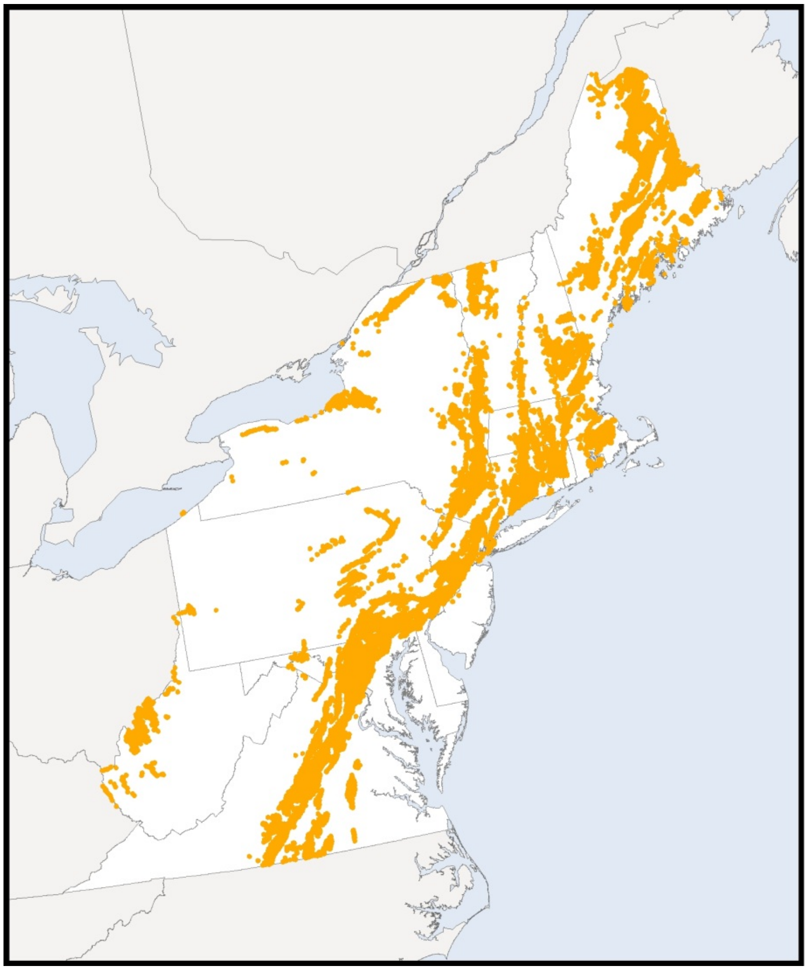
Resilience Score Category	Percents			Acres
	GAP1 or 2	GAP3	Unsecured	Total Acres
L:MAFIC	2%	7%	91%	3,271,264
1: Far Below Average	0%	0%	15%	499,075
2: Below Average	0%	1%	20%	692,033
3: Average	1%	2%	32%	1,164,115
4: Above Average	0%	1%	9%	343,012
5: Far Above Average	1%	3%	14%	573,029

Map 5.5: Resilience scores for L-MAFIC.



Low Elevation Acidic Sedimentary Settings (L-SED)

Description: A widespread setting on sandstone, siltstone, conglomerate, slate, and other acidic sedimentary or metasedimentary bedrocks at low elevations below 800‘and above 20’. Common acidic forest types are found here as well as extensive river systems.



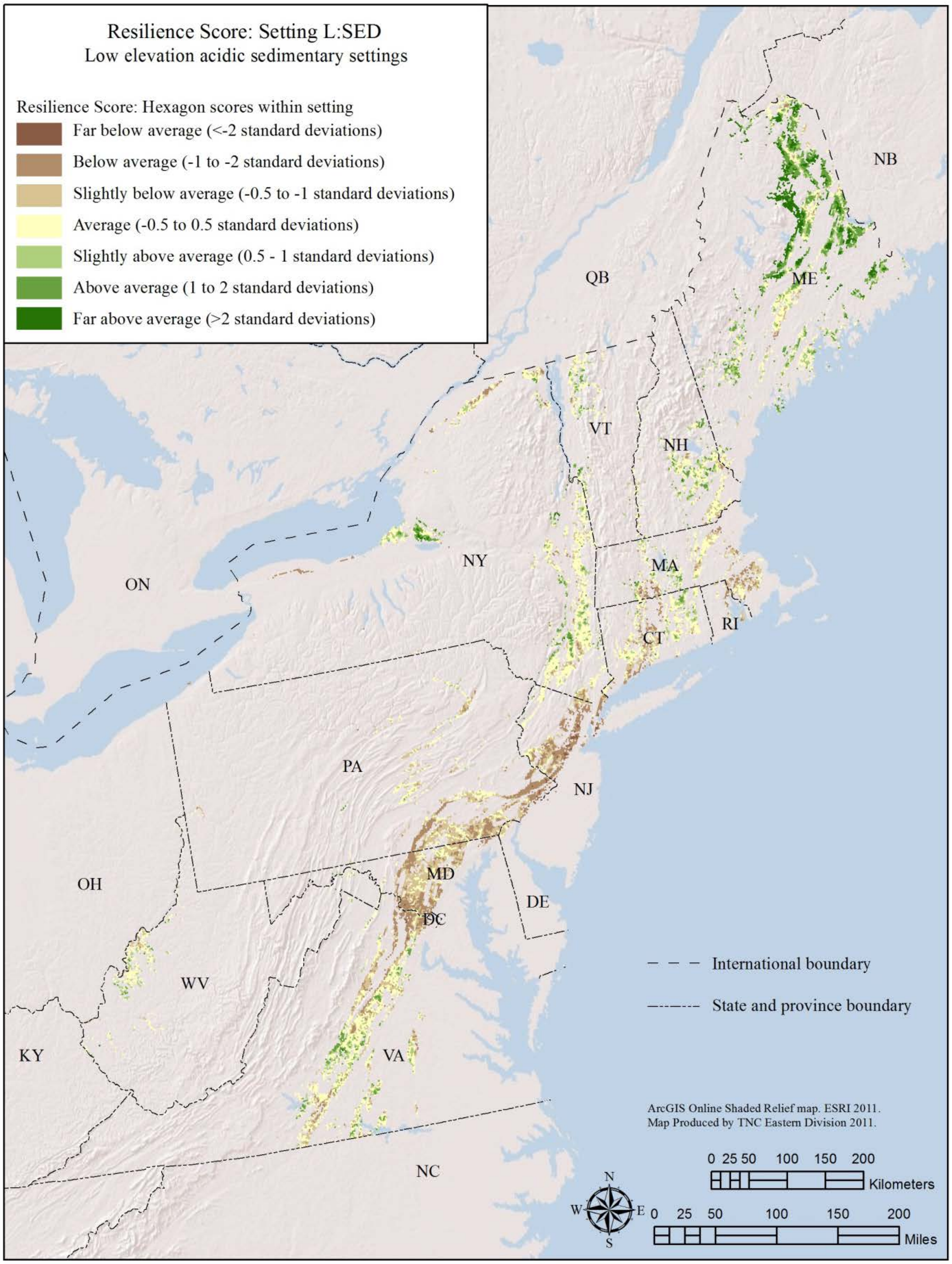
Example Communities
Upland: Chestnut oak-sweet birch/mountain laurel forest, Red spruce - mixed conifer woodland, Rich cove/mesic slope forest, Dry rich forest on acidic soil, Dry central hardwood forest **,** Circumneutral shoreline outcrop, Riverside Outcrop Barren, Sycamore-silver maple floodplain, Circumneutral cliff, High-energy riverbank community, Pitch pine-heath barrens, cold talus forest, River gravel community

Wetland: Appalachian - Acadian basin swamp, Black spruce woodland bog, Red maple alluvial swamp, Riverside meadow, Deep broadleaf marsh, Seepage marsh, Oxbow pond, Acidic broadleaf swamp, Hemlock swamp, Perched bog

Securement status: 6 percent secured, 3 percent in above average sites

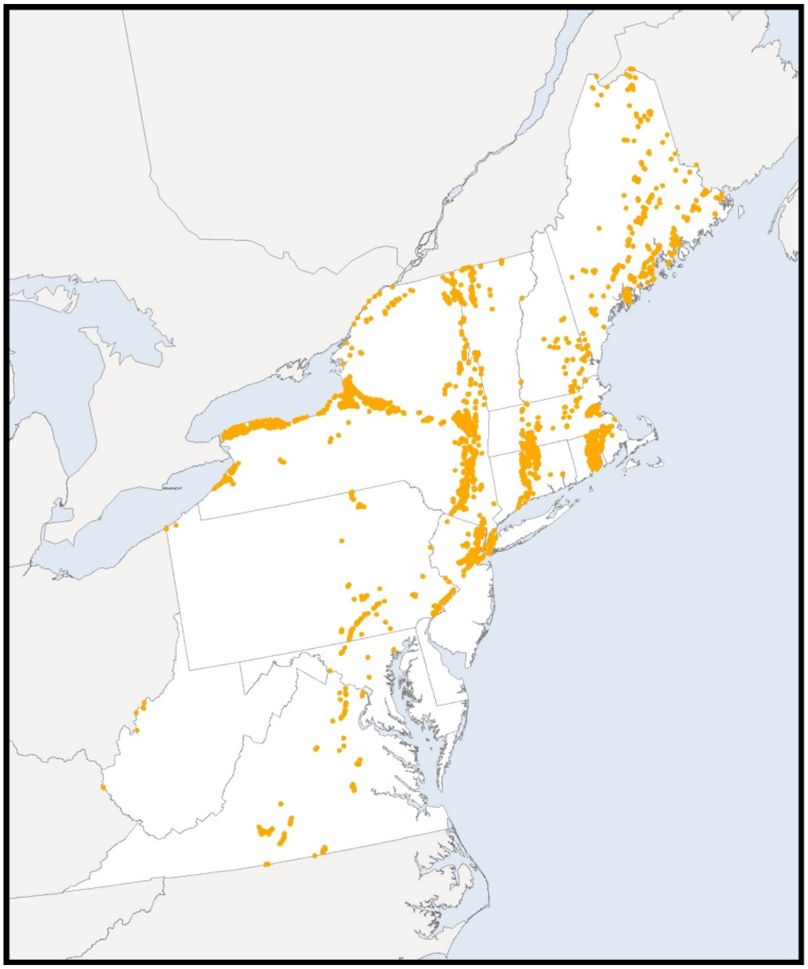
Resilience Score Category	Percents			Acres
	GAP1 or 2	GAP3	Unsecured	Total Acres
L:SED	1%	5%	94%	13,982,991
1: Far Below Average	0%	0%	14%	1,972,999
2: Below Average	0%	1%	20%	2,938,238
3: Average	1%	2%	35%	5,221,505
4: Above Average	0%	1%	11%	1,617,076
5: Far Above Average	0%	2%	14%	2,233,173

Map 5.6: Resilience scores for L-SED.



Low Elevation Mixed Settings of Sedimentary Bedrock and Coarse Sediments (L-SED/COARSE)

Description: Substrates of sandstones and other sedimentary or metasedimetary bedrock mixed with with deep coarse unconsolidated sands at low elevations below 800'and above 20'.



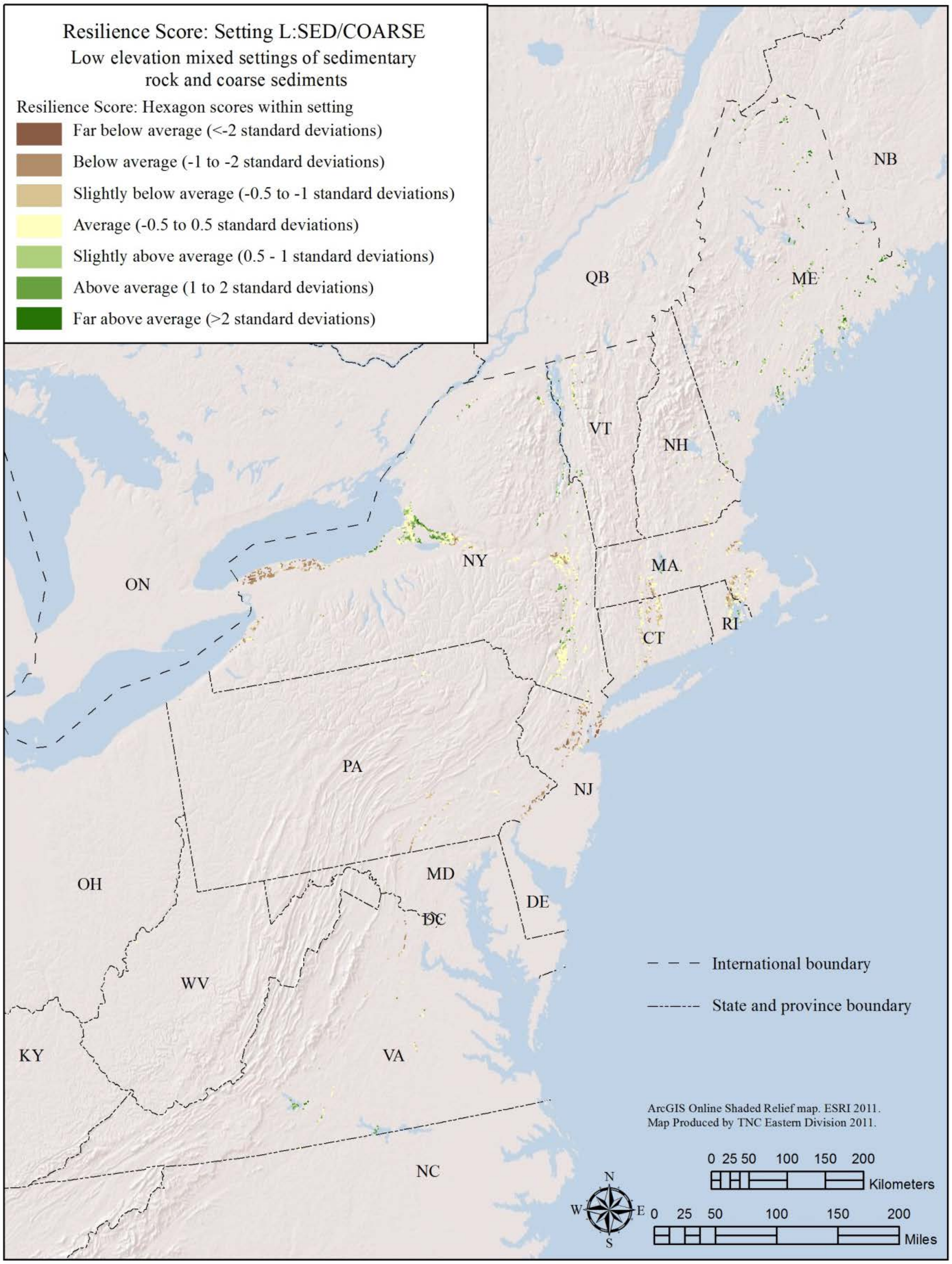
Example Communities
Upland: Northern white cedar rocky summit, Pitch pine-scrub oak barrens and heaths, Mesic maple-ash-hickory-oak Forest, New England dry sandy riverbluff, Shoreline outcrop

Wetland: Pine barrens vernal pond, Buttonbush swamp, Mesotrophic dimictic lake, Floodplain forest, Deep bulrush marsh, Alluvial atlantic white cedar swamp, Red maple-sweetgum swamp, Deep emergent marsh, Silver maple-ash swamp

Securement Status: 4 percent secured, with 1 percent on above average sites.

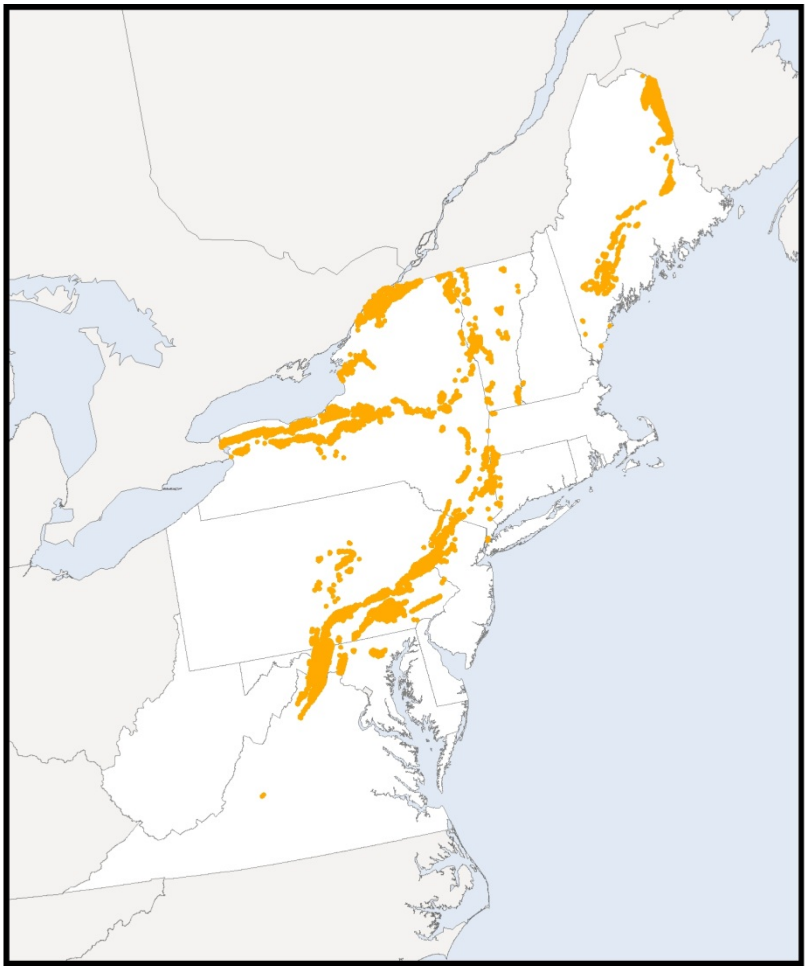
Resilience Score Category	Percents			Acres
	GAP1 or 2	GAP3	Unsecured	Total Acres
L:SED/COARSE	1%	3%	96%	2,012,143
1: Far Below Average	0%	0%	15%	297,035
2: Below Average	0%	0%	18%	367,048
3: Average	1%	1%	39%	816,993
4: Above Average	0%	0%	10%	212,043
5: Far Above Average	0%	1%	14%	319,024

Map 5.7: Resilience scores for LSED/COARSE



Low Elevation Calcareous Settings (L-Calc)

Description: Settings on limestone, dolomite, marble and other calcareous substrates at low elevations below 800'and above 20'. These fertile alkaline soils are considered prime land for agriculture and timber production. They support a high density of distinctive communities and rare species, including unique cave fauna.



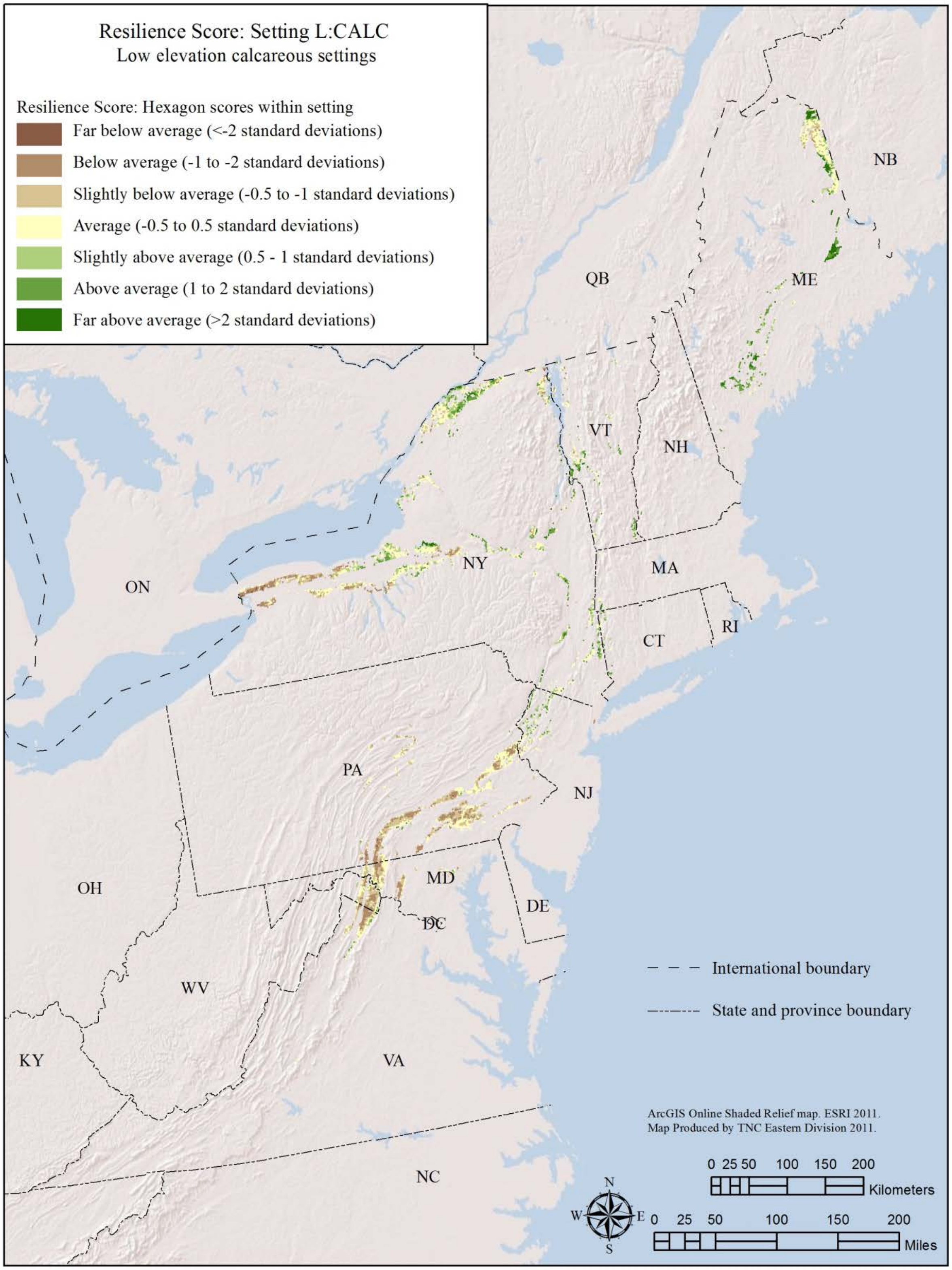
Example: Current Communities
Upland: Dry circumneutral forest, Inland calcareous lake shore, Limestone bluff cedar-pine forest, Limestone woodland, Dry-mesic calcareous forest, Calcareous rocky summit, Circumneutral cliffs, Riverside outcrop, Great lakes dunes, Red cedar rocky summit, Calcareous cliff.

Wetland: Highly alkaline lake, Red maple-hardwood swamp, Calcareous seepage swamp, Circumneutral fen, Red maple-tamarack peat swamp, Rich graminoid fen, Riverside seep, Calcareous spring marsh / muck fen, Calcareous fen, Silver maple-ash swamp, Red maple-northern white cedar swamp, Rich shrub fen, Calcareous sloping fen

Securement Status: 3 percent secured, 1 percent on above average sites.

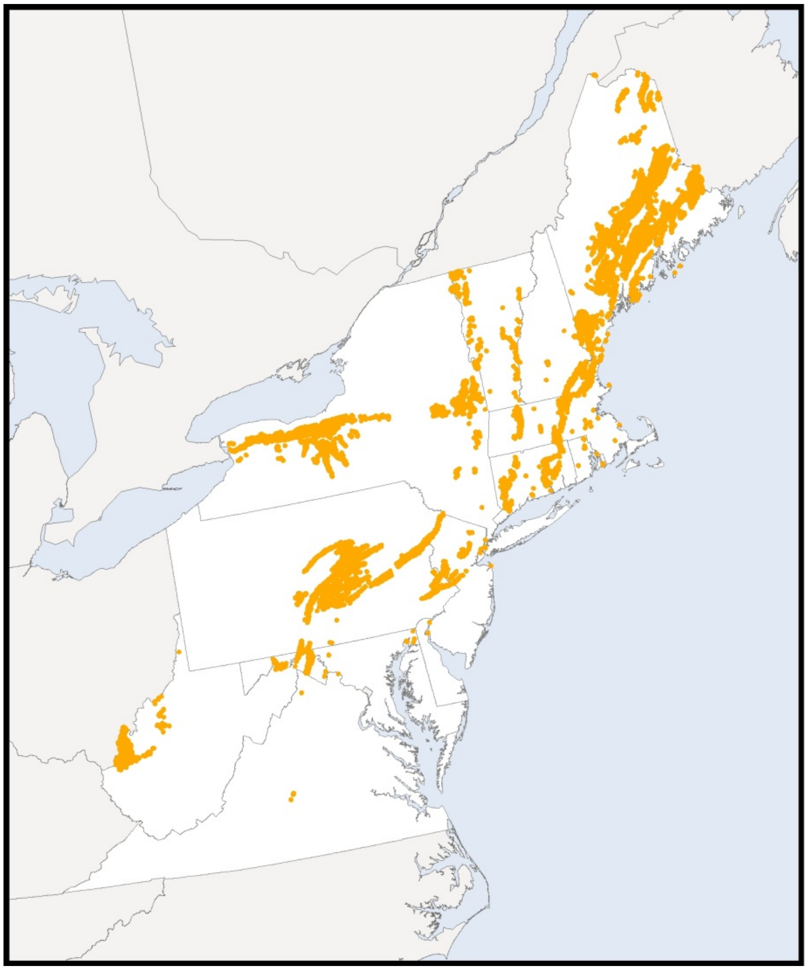
Resilience Score Category	Percents			Acres
	GAP1 or 2	GAP3	Unsecured	Total Acres
L:CALC	1%	2%	97%	4,687,406
1: Far Below Average	0%	0%	14%	672,088
2: Below Average	0%	0%	21%	1,016,066
3: Average	0%	0%	35%	1,678,188
4: Above Average	0%	0%	11%	562,020
5: Far Above Average	0%	1%	15%	759,044

Map 5.8 Resilience scores for L-CALC.



Low Elevation Moderately Calcareous Settings (L-MODCALC)

Description: Bedrock settings of calcareous shales and sandstones often mixed with limestone. These fertile settings share many qualities with the calcareous settings but are slightly more common and less extreme in their properties. The term "circumneutral" refers to soils or water with a pH around 7.



Example: Current Communities
Upland: Dry oak forest, oak-hickory forest, Mesic appalachian oak - hickory forest, Sandplain grassland, Subacidic cliffs, Calcareous riverside outcrop, Small-river floodplain forest, Rivershore grassland, outcrob and cobble shore, Hardwood floodplain forest. Rich northern hardwood forest

Wetland: Calcareous riverside seep, Kettlehole bog-pond, Calcareous seepage swamp, Outwash seepage forest, Red maple - sensitive fern swamp, Alluvial marsh, Calcareous riverside seep, Swamp white oak basin swamp, Circumneutral broadleaf swamp, Circumneutral seepage swamp

Securement Status: 7 percent secured, 4 percent of above average sites.

Resilience Score Category	Percents			Acres
	GAP1 or 2	GAP3	Unsecured	Total Acres
L:MODCALC	1%	6%	92%	6,544,450
1: Far Below Average	0%	0%	15%	994,080
2: Below Average	0%	0%	17%	1,173,169
3: Average	1%	1%	36%	2,507,095
4: Above Average	0%	1%	11%	794,063
5: Far Above Average	0%	3%	13%	1,076,044

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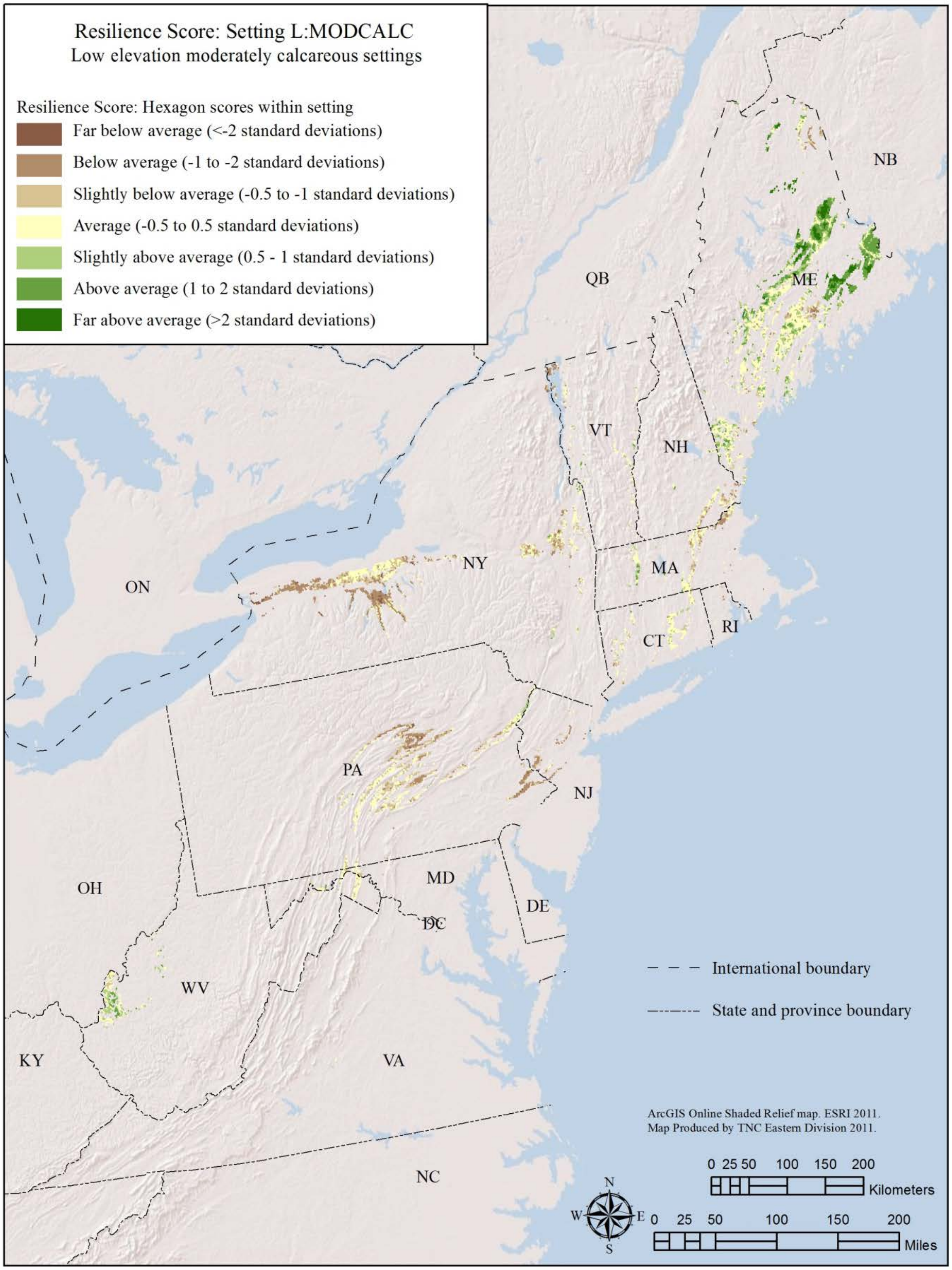
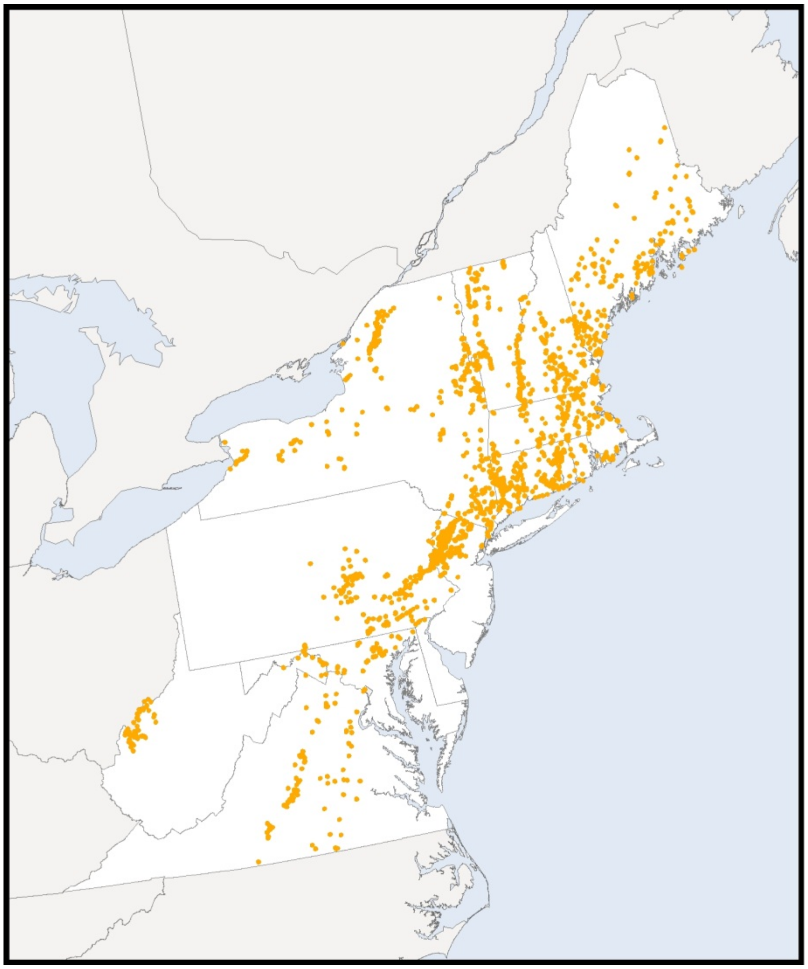
Map 5.9 Resilience scores for L-MODCALC.



Low Elevation Mixed Granite and Limestone (L-GRAN/CALC)

Description: Mixed bedrock settings dominated by calcareous substrates intermixed with granite. These settings often have pockets of unique limestone communities embedded within a rocky granitic setting with sloping topography.



Example: Current Communities
Upland: Chestnut oak woodland, Coastal forest/woodland, Beech-white oak forest, Oak-hickory forest, Small-river floodplain forest, Dry-mesic calcareous forest, Calcareous woodland, Mixed hardwood-conifer forest, Limestone woodland, Calcareous talus slope woodland.

Wetland: Leatherleaf boggy fen, Calcareous riverside seep, Riverside outcrop, Coastal interdunal marsh/swale, Kettlehole wet meadow, Atlantic white cedar swamp, Floating kettlehole bog, Oxbow pond, Calcareous seepage swamp, Acidic shrub fen, Rich graminoid fen, Calcareous sloping fen, Pitch pine bog, Calcareous fen, Deep bulrush marsh

Secured Status: 12 percent secured, 5 percent on above average sites.

Resilience Score Category	Percents			Acres
	GAP1 or 2	GAP3	Unsecured	Total Acres
L:GRAN/CALC	5%	7%	88%	1,518,169
1: Far Below Average	0%	1%	14%	218,050
2: Below Average	0%	1%	17%	270,967
3: Average	2%	3%	36%	621,134
4: Above Average	1%	1%	11%	196,992
5: Far Above Average	1%	2%	11%	211,026

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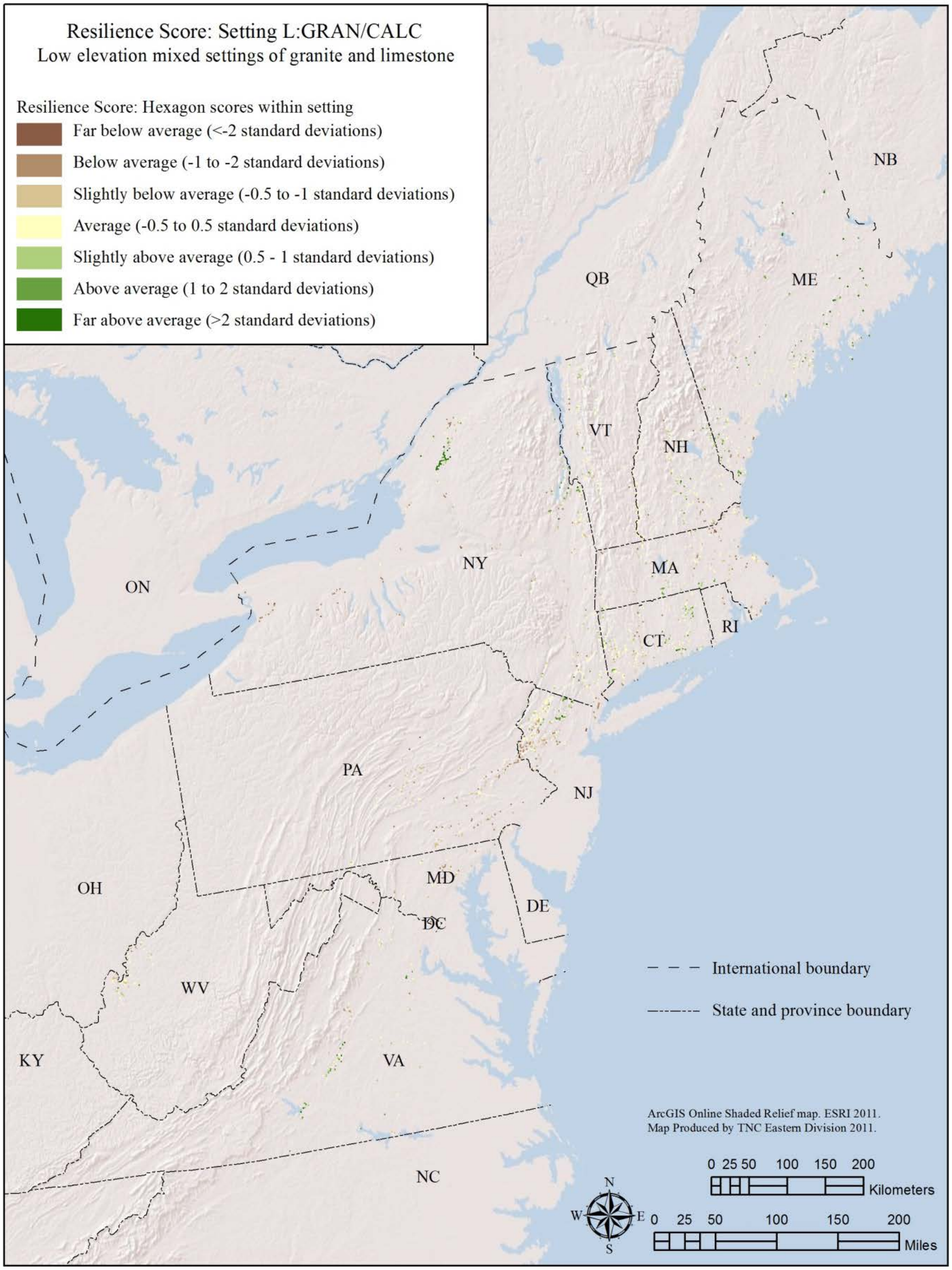
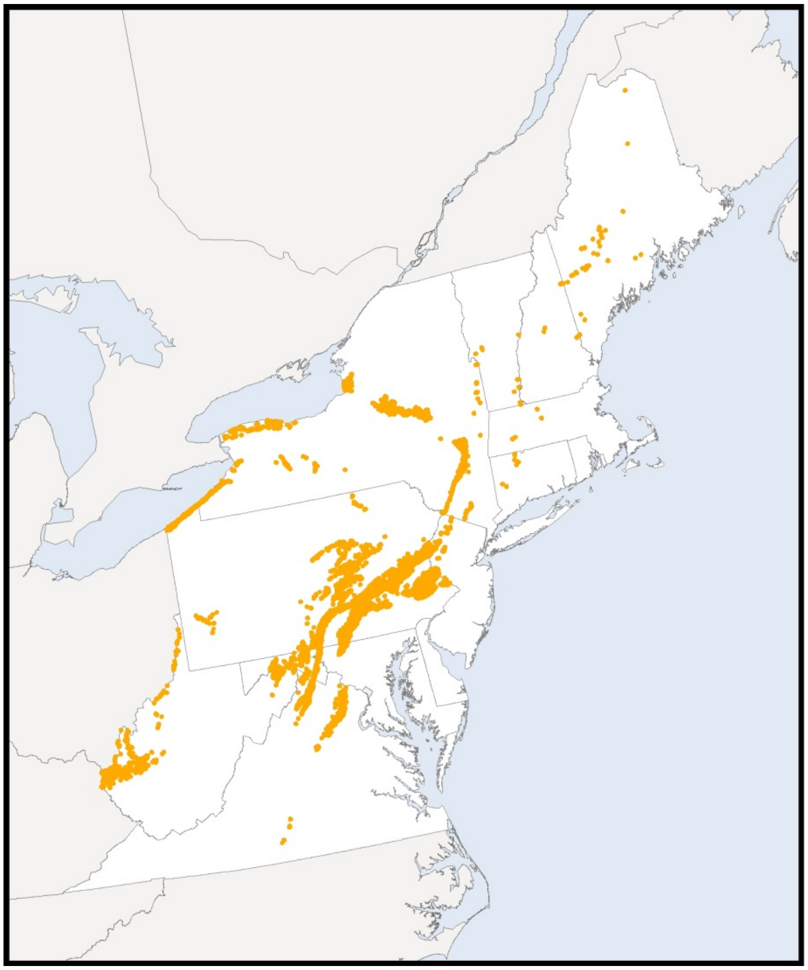
Map 5.10: Resilience scores for LGRAN/CALC



Low Elevation Shale Settings (L-SHALE)

Description: Low elevation settings below 800’ and above 20’ defined by fissile exfoliating shales. On slopes, a unique flora has developed adapted to these unstable substrates. On flats the communities are similar to other sedimentary types.



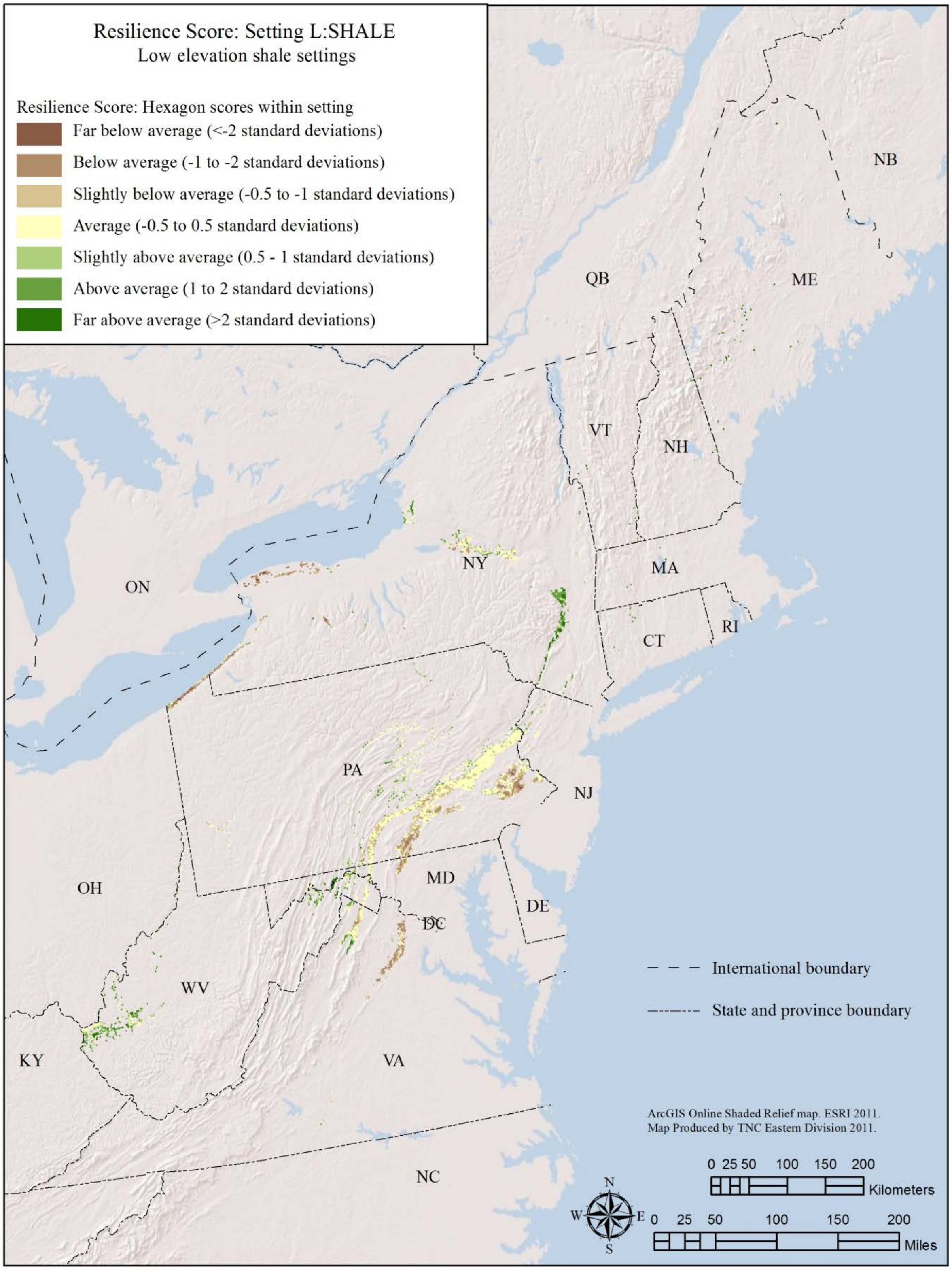
Example Communities
Upland: Shale barren, Shale barren vegetation, Shale cliff/rock outcrop community, Riparian forest

Wetland: Red maple-green ash swamp, Circumneutral broadleaf swamp, Acidic talus forest/woodland, Basin graminoid-forb fen, High-gradient clearwater creek,
Hemlock-hardwood swamp.

Secured Status: 3 percent secured, 1 percent on above average sites.

Reslience Score Category	Percents			Acres
	GAP1 or 2	GAP3	Unsecured	Total Acres
L:SHALE	1%	2%	96%	3,376,359
1: Far Below Average	0%	0%	13%	456,044
2: Below Average	0%	0%	18%	629,054
3: Average	0%	1%	40%	1,398,116
4: Above Average	0%	0%	10%	347,039
5: Far Above Average	0%	1%	15%	546,105

Map 5.11: Resilience scores for L-SHALE



.Low Elevation Ultramafic Bedrock (L-Ultra)

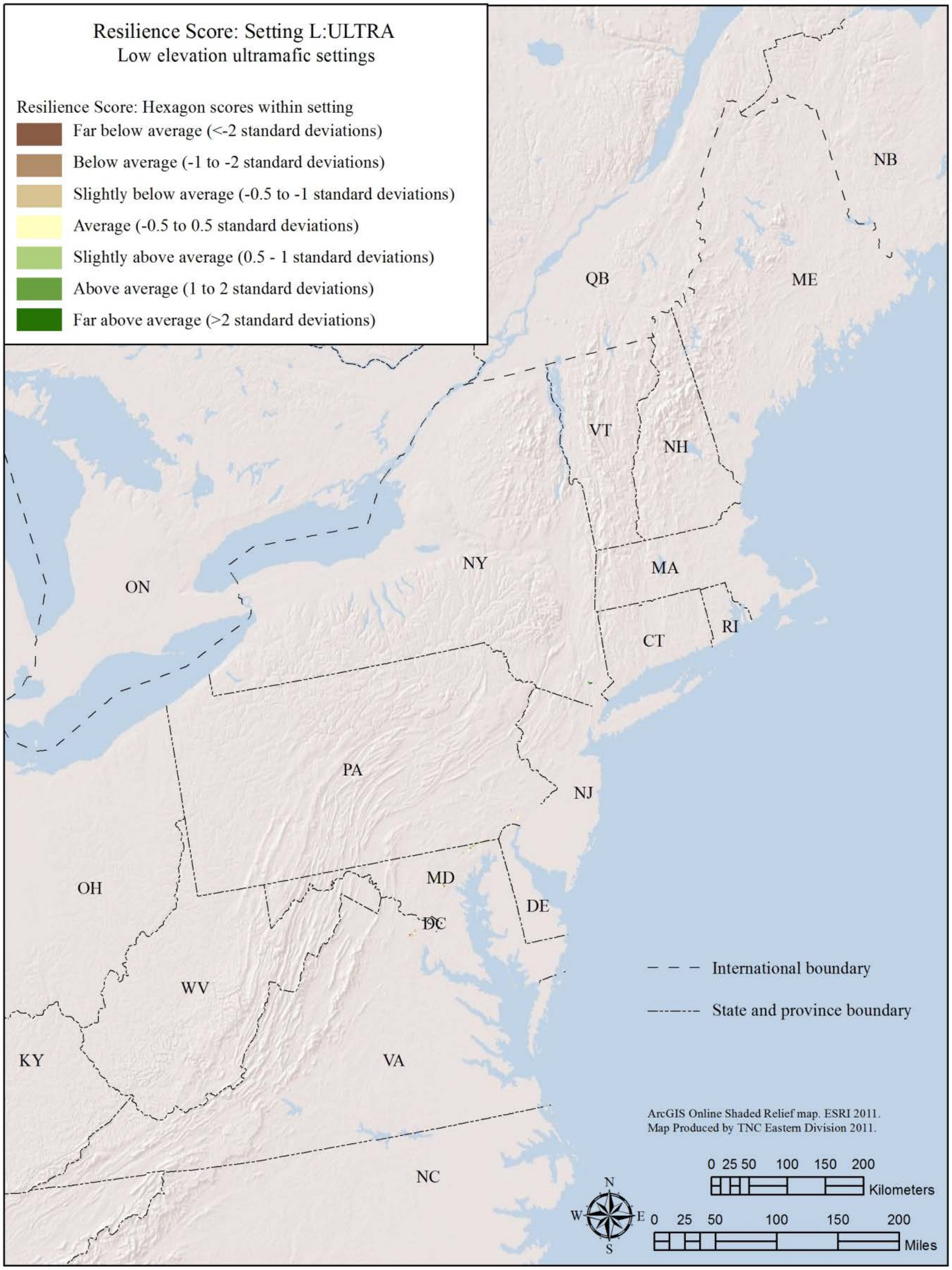
Description: Rare setting in serpentine and other ultra mafic bedrock at low elevation below 800'. Ultra mafic soils are high in magnesium and low in calcium, and typically have elevated amounts of chromium and nickel. Because these soils are toxic to many plants a unique flora has developed that tolerate these conditions. Serpentine barren communities are full of rarities but are only prominent where the bedrock is directly exposed. Fire appears to maintain these communities.

Example Communities
Eastern Serpentine Barren

Securement status: 8 percent secured, 5 percent on above average sites

Resilience Score Category	Percents			Acres
	GAP1 or 2	GAP3	Unsecured	Total Acres
L:ULTRA	6%	2%	91%	36,007
1: Far Below Average	0%	0%	11%	3,995
2: Below Average	0%	0%	27%	10,002
3: Average	4%	0%	30%	12,004
4: Above Average	2%	1%	11%	4,999
5: Far Above Average	1%	1%	13%	5,007

Map 5.12: Resilience scores for L- ULTRA



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LOW ELEVATION COASTAL SETTINGS

Settings that occur in the maritime zone under 20' elevation. Maps 5.13-5.15.

CAVEAT: COASTAL SETTINGS WERE NOT ADEQUATELY ASSESSED BY THIS STUDY AS WE DID NOT CONSIDER SEA LEVEL RISE AND COASTAL PROCESSES. ADDITIONALLY THERE ARE INCONSISTENCIES IN THE MAPPING OF THE INTERTIDAL ZONE BETWEEN DIFFERENT DATASETS THAT GIVE RISE TO DATA ARTIFACTS IN THE ANALYSIS.

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With these caveats we present the information here to complete the analysis but suggest not using the results to inform decisions until further evaluation is conducted (or something).

Coastal Bedrock Settings (L-COAST/BED): Maritime settings under 20' elevation where bedrock of any type predominates. Forests and swamps. .

Coastal Coarse Sand (L-COAST/COARSE): Maritime settings under 20' elevation on coarse sand. Beaches, dunes, swales and sandplains

Coastal Fine Silt (L-FINE): Maritime settings under 20' elevation on fine silts and mud. Coastal tidal marshes, salt marsh, river mouths, swamps.

Coastal Maritime Settings on any Bedrock (L-COAST)

Description: Areas below 20’ on granite, mafic, or sedimentary bedrock. Coastal regions characterized by rocky outcrops, bluffs and flats.

Example: Current Communities
Upland: Maritime Oak - Holly Forest, Oak-tulip tree forest, Coastal Shrubland, Alder Shrub Thicket, , Dune Grassland, Pitch Pine Dune Woodland, White Oak - Red Oak Forest.

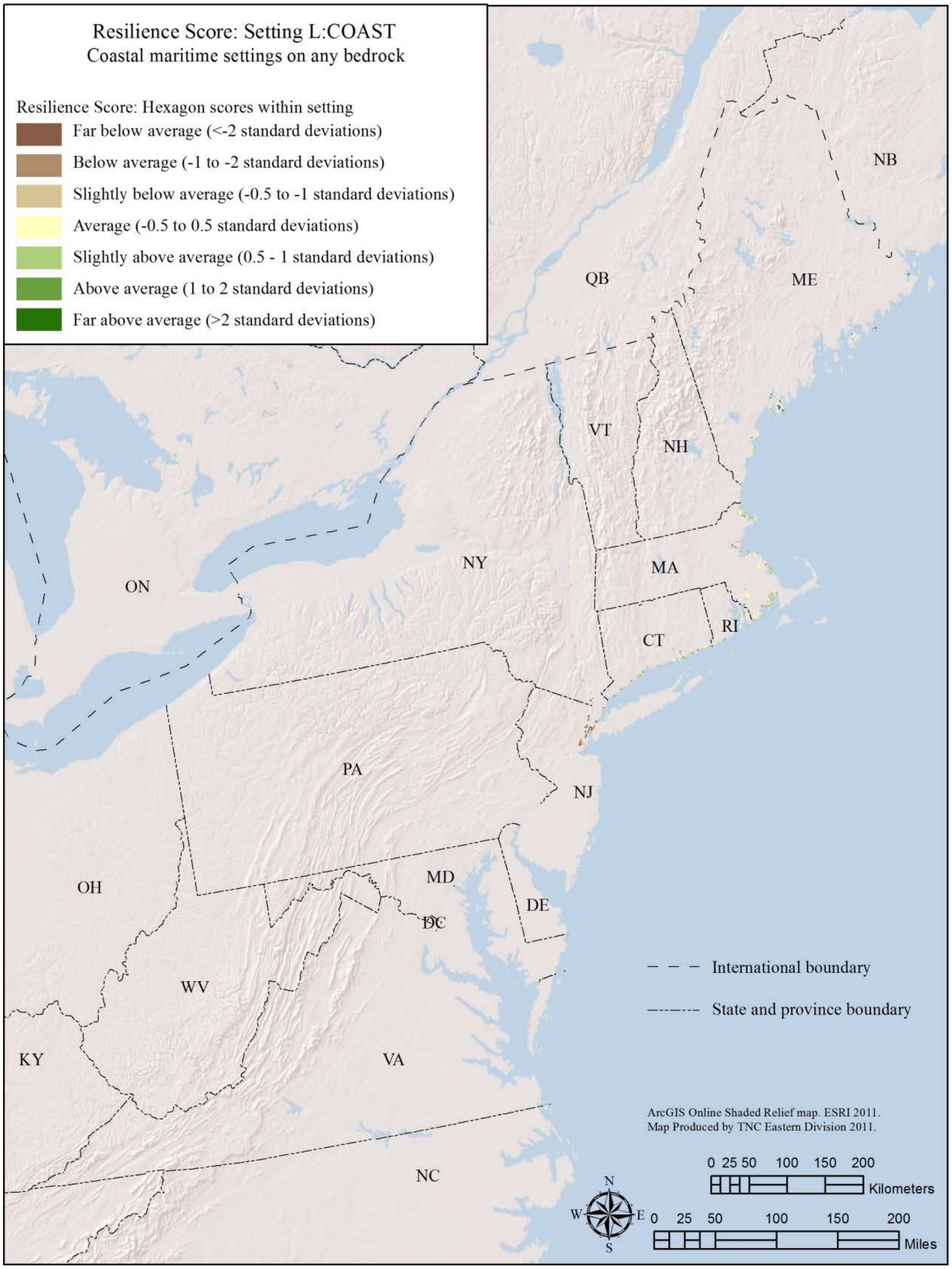
Wetland: Sea-level Fen, Freshwater tidal swamp, Hemlock - Hardwood Pocket Swamp, Coastal salt pond, Perched Hemlock-hardwood Swamp, , Tidal Creek Bottom, Brackish Intertidal Marsh, Pitch Pine Bog, Acidic Graminoid Fen, Raised Level Bog, Poor fen

Coastal settings were not adequately assessed by this study as we did not consider sea level rise and coastal processes. Additionally, there are inconsistencies in the mapping of the intertidal zone.

Securement status: 12 percent secured total. 34 percent of above average sites are unsecured.

Resilience Score	Percents			Acres
	GAP1 or 2	GAP3	Unsecured	Total Acres
L:COAST	4%	8%	88%	317,009
1: Far Below Average	0%	1%	15%	50,993
2: Below Average	0%	1%	14%	49,003
3: Average	1%	3%	25%	92,998
4: Above Average	2%	2%	31%	110,016
5: Far Above Average	1%	1%	3%	13,999

Map 5.13: Resilience scores for L-COAST.



Coastal Maritime Settings on Sand (L-COAST/COARSE)

Description: Coastal settings below 20 m dominated by coarse unconsolidated sand.

Example: Current Communities
Upland: Dune, beach and sandflats, Coastal dune woodland, Coastal oak-beech forest, Coastal oak-heath forest, Coastal plain pond shore, Fluvial terrace woodland, Maritime Dune grassland, Maritime heathland, Maritime pitch pine dune woodland, Maritime red cedar forest, Maritime shrubland, Sandplain heathland

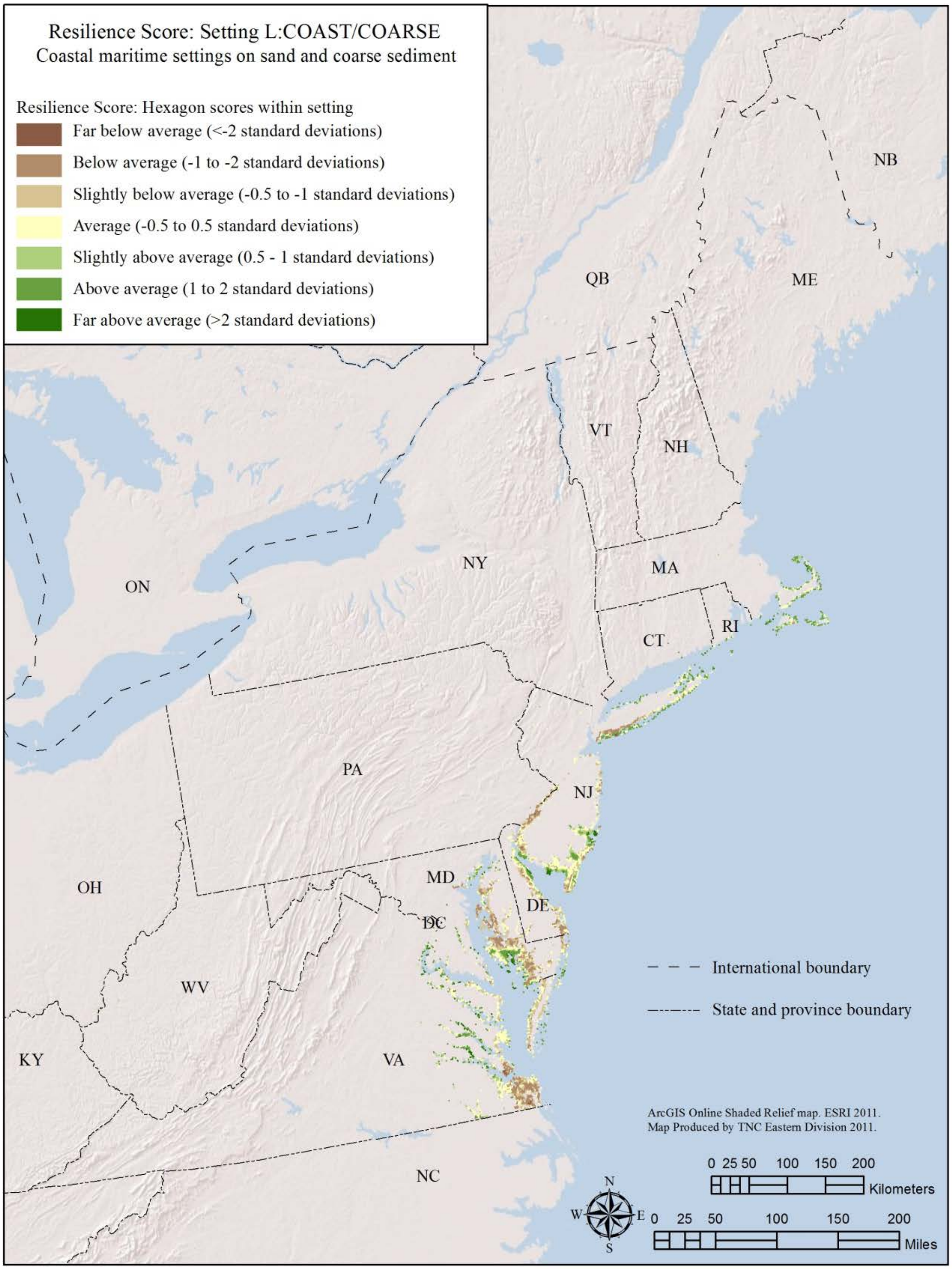
Wetland: Interdunal swales, shores, and meadows, Cape May lowland Swamp, Coastal Atlantic White Cedar swamp, Coastal plain poor fen, , Freshwater intertidal marsh and mudflat, , Pine barrens shrub swamp, Salt panne, Saltwater tidal creek, Sandplain Heathland, Level Bog,

Coastal settings were not adequately assessed by this study as we did not consider sea level rise and coastal processes.

Securement Status: 17 percent secured, 9 percent on above average sites.

	Percents			Acres
Resilience Score Category	**GAP1 or 2**	**GAP3**	**Unsecured**	**Total Acres**
L:COAST/COARSE	8%	9%	83%	3,854,386
1: Far Below Average	0%	1%	15%	613,057
2: Below Average	1%	2%	20%	843,060
3: Average	2%	3%	27%	1,241,187
4: Above Average	2%	1%	7%	386,027
5: Far Above Average	3%	2%	14%	771,055

Map 5.14: Resilience scores for L-COAST/COARSE.



Coastal Maritime Settings on Fine Sediment (L-COAST/FINE)

Description: Coastal areas under 20' on fine silts, clays and organic muds.

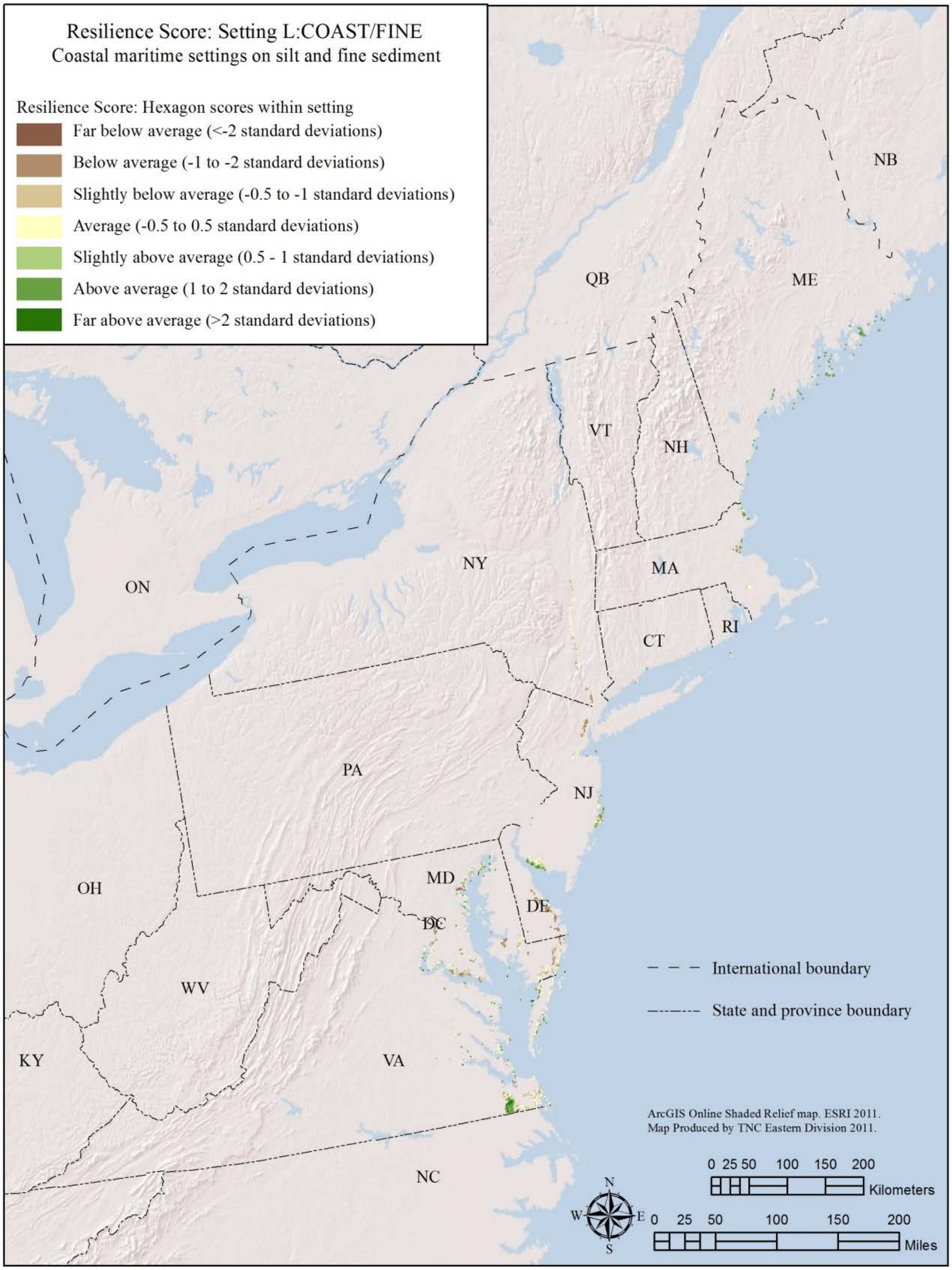
Example: Current Communities
Wetlands: High salt marsh, low salt marsh, sea level fen, red maple-oak-magnolia swamp, Atlantic white cedar-green ash swamp, Freshwater tidal swamp and marsh , Brackish marsh, Brackish Intertidal Flat, Tidal Creek Bottom, Atlantic White Cedar Basin Swamp, Freshwater intertidal mudflats

Coastal settings were not adequately assessed by this study as we did not consider sea level rise and coastal processes. Additionally, there are inconsitencies in the mapping of the intertidal zone.

Securement status: 23 percent secured. 12 percent on above average sites

Resilience Score Category	Percents			Acres
	GAP1 or 2	GAP3	Unsecured	Total Acres
L:COAST/FINE	14%	9%	77%	984,073
1: Far Below Average	0%	1%	17%	177,017
2: Below Average	1%	2%	16%	185,051
3: Average	4%	3%	23%	295,990
4: Above Average	2%	1%	7%	96,989
5: Far Above Average	7%	2%	15%	229,027

Map 5.15: Resilience scores for LCOAST/ FINE.



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MID ELEVATION SETTINGS

Settings that occur between 800’ and 2500’. These are the most abundant and widespread environments in the region. Maps 5.16-5.23

Mid Elevation Granite (M-GRAN): Mountainous settings supporting natural communities typical of acid nutrient-poor shallow-soil environments

Mid Elevation Mafic (M-MAFIC): Mountainous settings often intermixed with granite, but derived from volcanic basalts or intrusive igneous rocks, and supporting a richer flora and fauna.

Mid Elevation Acidic Sedimentary (M-SED): Resistant ridges and high plateaus composed of sandstone, siltstone, or conglomerates. This abundant setting supports many common acidic forests types.

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

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

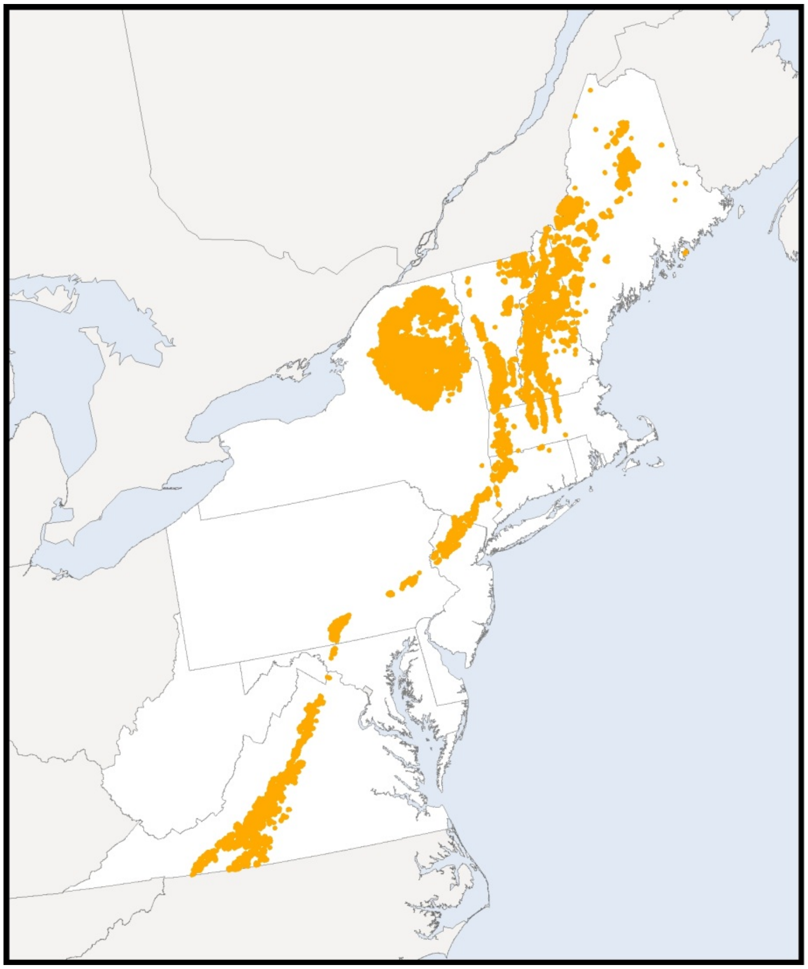
Mid Elevation Acidic Shale (M-SHALE): Settings on unstable shale slopes often supporting a unique flora and sedmentary-like shale lowlands

Mid Elevation Surfical Sediments (M-SURF): Valley or flat settings with surficial depostits of sand or silt: floodplains and shorelines.

Mid Elevation Ultramafic (M-ULTRA): Very rare settings on toxic serpentine soils high in nickel and chromium supporting stunted trees and a unique flora.

Mid Elevation Granitic Settings (M-GRAN)

Description: Settings on granite, granidoirite, gneiss and other acidic granitic bedrocks at mid elevations between 800' and 2500'



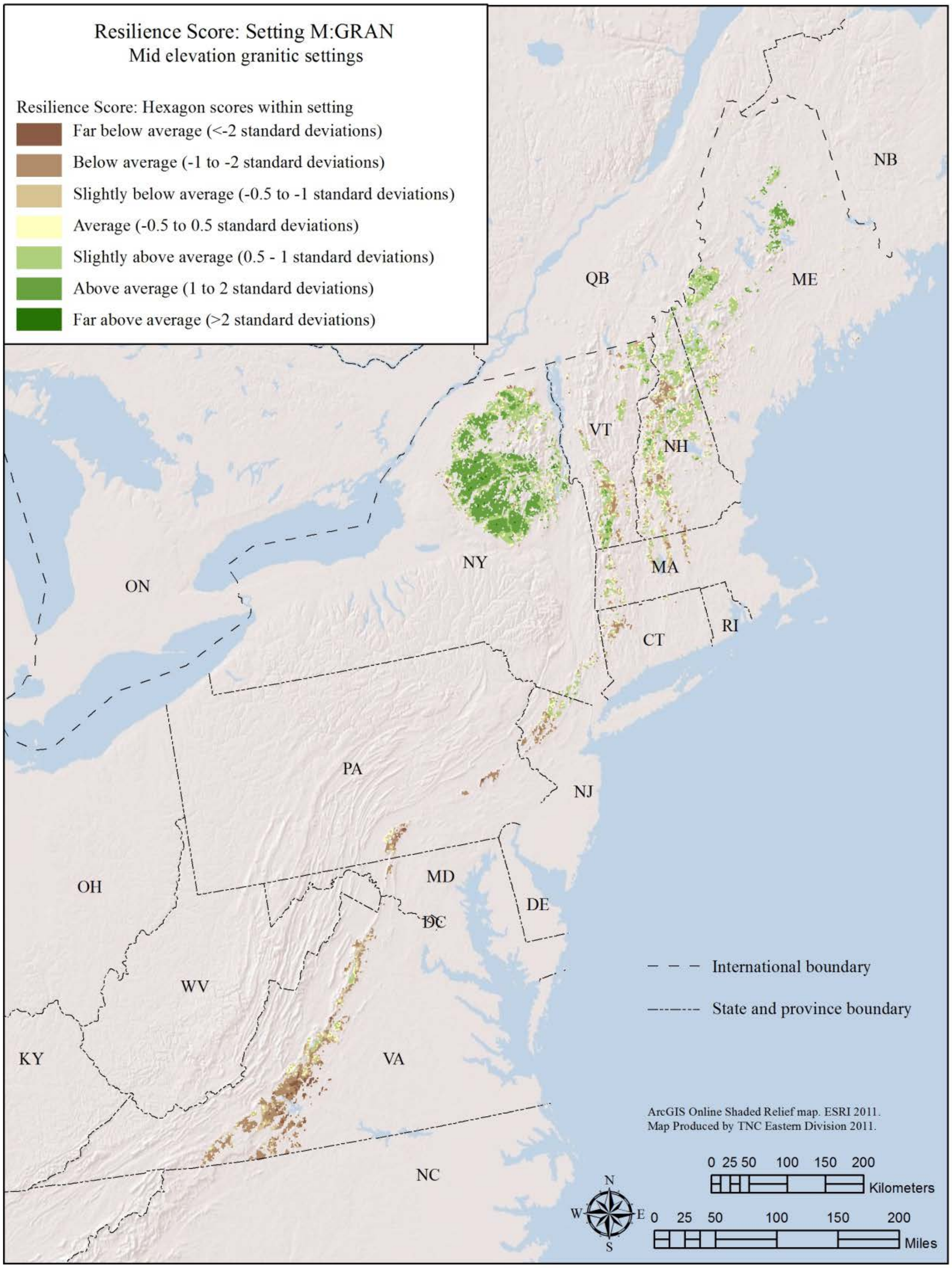
Example: Current Communities
Upland: Boreal talus woodland, Dry transitional forest on acidic bedrock/till, Dry subacidic forest, Jack pine rocky summit, Acidic rocky summit, Montane spruce/fir forest, Mesic hardwood forest on acidic bedrock, Pine-northern hardwood forest, Cold-air talus forest/woodland, Mesic central hardwood forest, Silver maple floodplain forest, Boreal acidic cliff, Hemlock forest, High-energy riverbank community, Lowland spruce/fir forest

Wetland: Basin marsh, Riverside meadow, Patterned fen ecosystem, Hardwood-conifer swamp, Blackgum/red maple basin swamp, Acidic seepage swamp, Acidic red/black spruce basin swamp, Seepage forest, Forested bog, Black spruce swamp

Securement Status: 43 percent secured, 35 percent on above average sites.

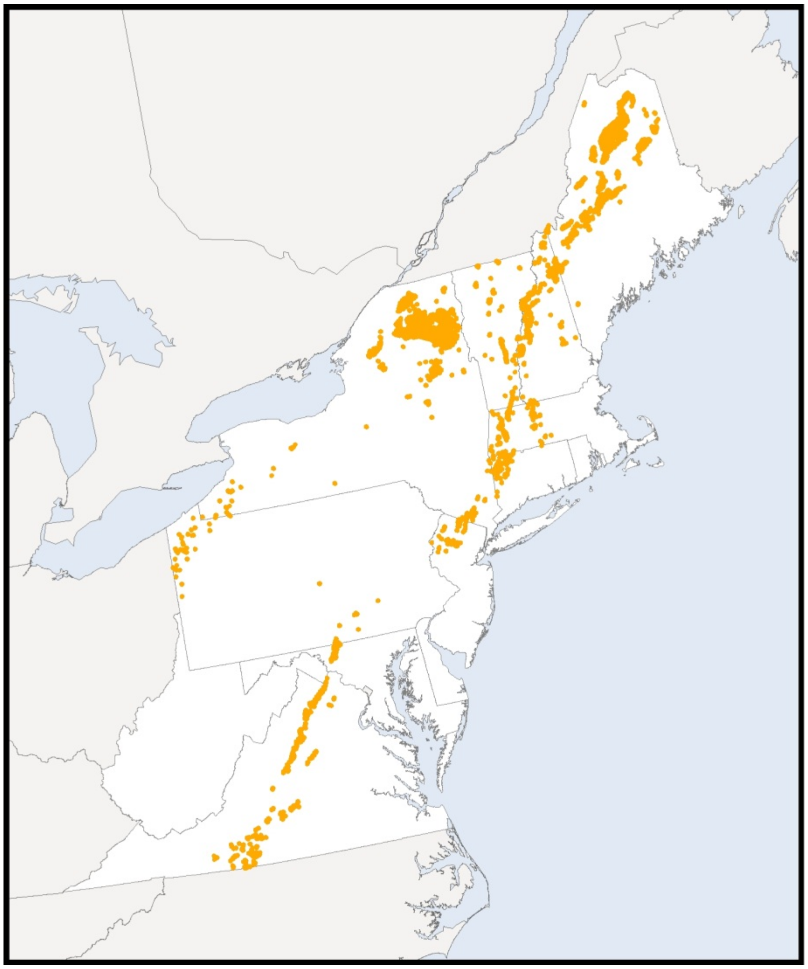
Resilience Score Category	Percents			Acres
	GAP1 or 2	GAP3	Unsecured	Total Acres
M:GRAN	24%	19%	57%	8,719,652
1: Far Below Average	0%	1%	17%	1,591,133
2: Below Average	1%	3%	11%	1,304,062
3: Average	1%	2%	6%	769,036
4: Above Average	8%	9%	17%	2,980,241
5: Far Above Average	14%	4%	5%	2,075,179

Map 5.16: Resilience scores for MGRAN.



Mid Elevation Mafic Settings (M-MAFIC)

Description: Settings on volcanic basalts, greenstones and other mafic rocks at mid elevations between 800’ and 2500’



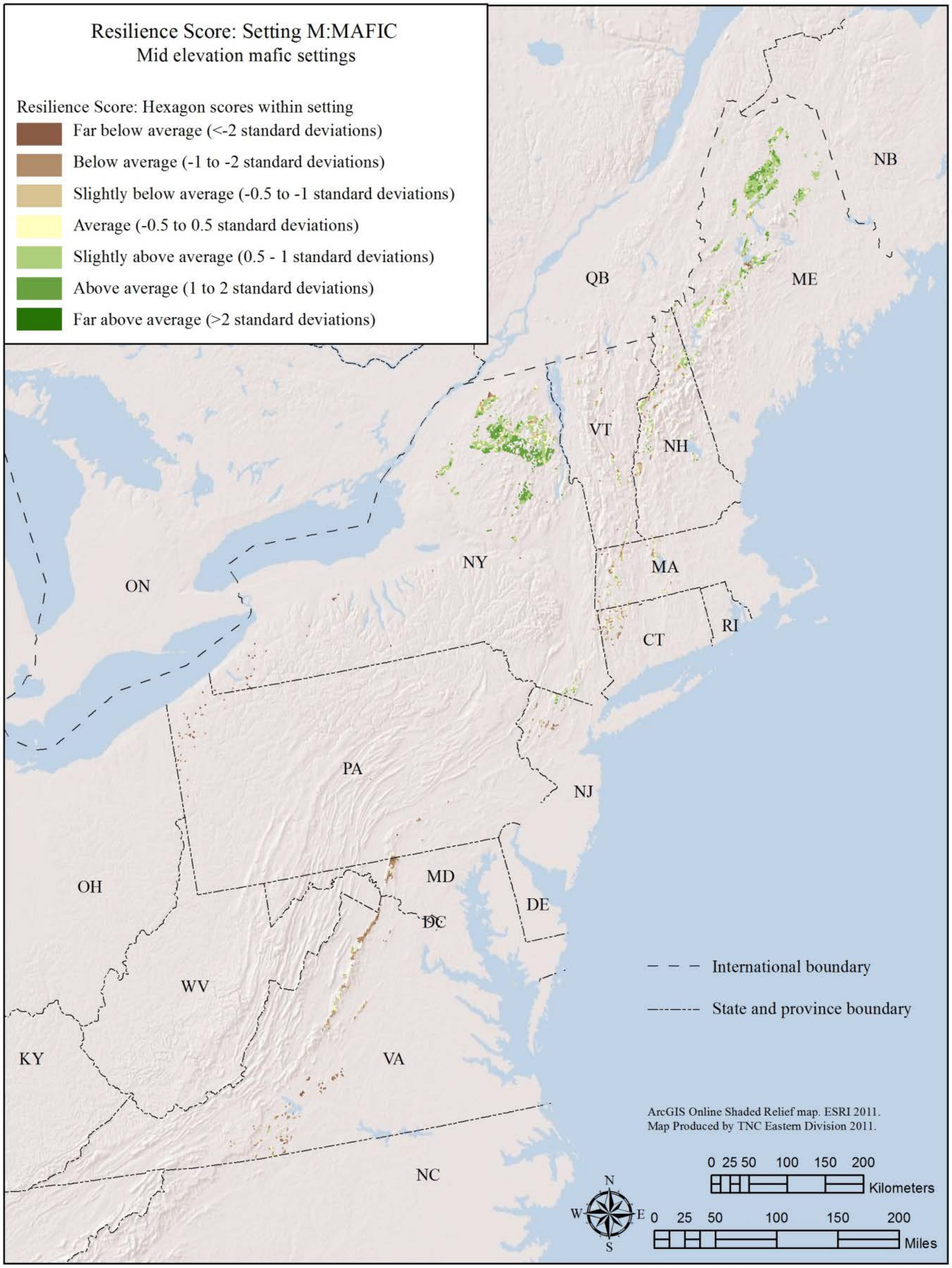
Example Communities
Upland: Chestnut oak forest, Pinus strobus-larix laricina-mixed shrub, Ice cave talus, Central appalachian northern hardwood forest, Semi-rich mesic sugar maple-beech forest, Dry-mesic calcareous forest, Maple - basswood - ash forest, Calcareous cliff, Lichen / bryophyte boulderfield, Rich mesic forest, Acidic talus forest, Spruce slope forest, Rich cove / slope forest, Mountain / piedmont basic woodland

Wetland: Acidic seepage forest, High-elevation seep, Robust emergent marsh, Circumneutral forest seep, Inland Atlantic white cedar swamp, Calcareous seepage swamp, Kettlehole level bog, Circumneutral seepage swamp, Northern white cedar seepage forest, Shrub fen, Sedge meadow, Inland poor fen, Rich fen

Secured Status: 40 percent secured, 31 percent on above average sites.

Resilience Score Category	Percents			Acres
	GAP1 or 2	GAP3	Unsecured	Total Acres
M:MAFIC	21%	19%	60%	2,701,209
1: Far Below Average	1%	1%	16%	489,057
2: Below Average	1%	1%	9%	332,023
3: Average	1%	2%	6%	237,024
4: Above Average	8%	10%	23%	1,093,062
5: Far Above Average	8%	5%	7%	550,044

Map 5.17: Resilience scores for M-MAFIC



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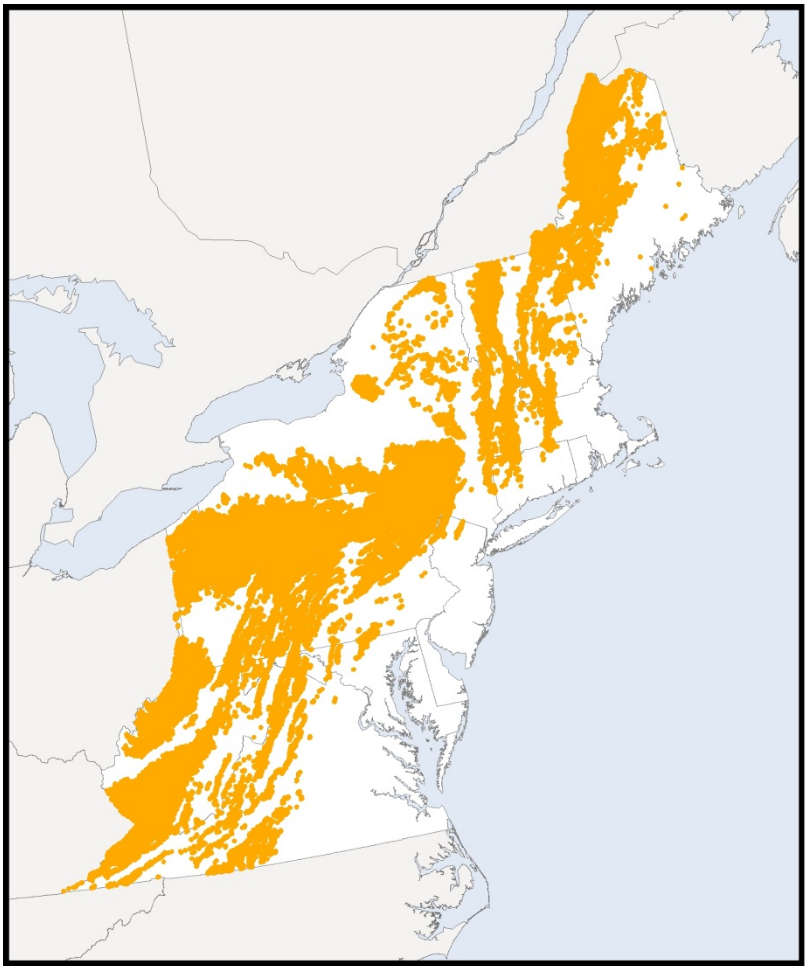
Mid Elevation Sedimentary Settings (M-SED)

Description: Settings on sandstone, siltstone, mudstone, conglomerate, and other acidic sedimentary or metasedimetary bedrocks at mid elevations between 800' and 2500'.



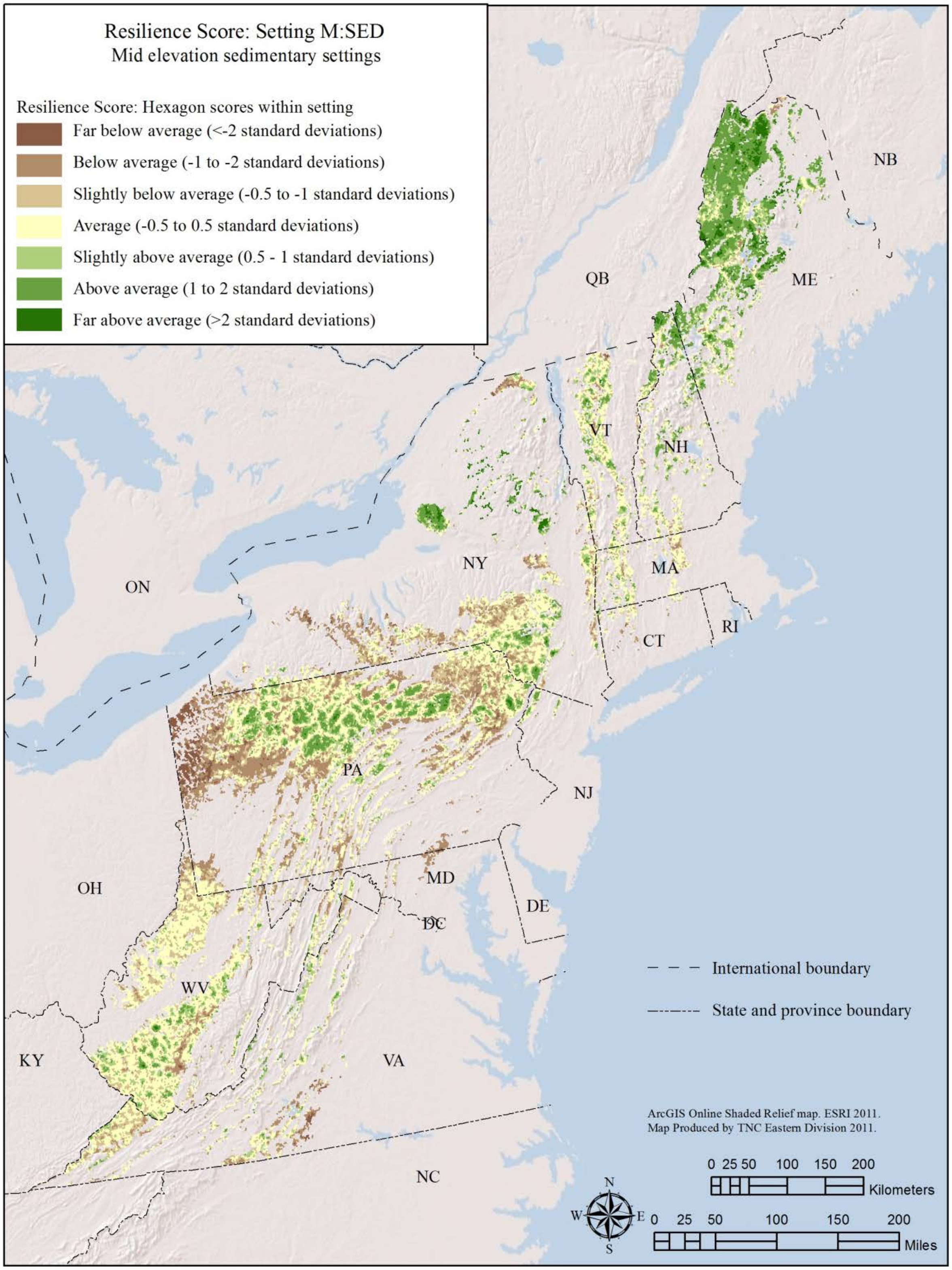
Example Communities
Upland: Hemlock- white pine forest, Hemlock slope forest, Mesic scrub oak-pitch pine barrens, Northern conifer forest, Northern hardwood-conifer forest, Allegheny Oak forest, Chestnut oak- red oak - poverty grass forest, Rich mesophytic forest, Ridgetop dwarf-tree forest, Spruce-fir rocky summit, Hemlock- beech forest, Ash-elm- red maple forest, Mountain floodplain forest, Riverside outcrop community, Bulder field, Talus slope, Sandstone pavement barrens, Acidic cliff

Wetland: Northern conifer swamp, Acidic shrub swamp, Black spruce - tamarack peatland forest, Boreal conifer swamp, Glacial bog, Graminoid swale, Hemlock palustrine forest, Highbush blueberry - sphagnum wetland, Inland acidic seep community, Nonglacial bog, Red maple-black gum swamp

Secured Status: 40 percent secured, 31 percent on above average sites.

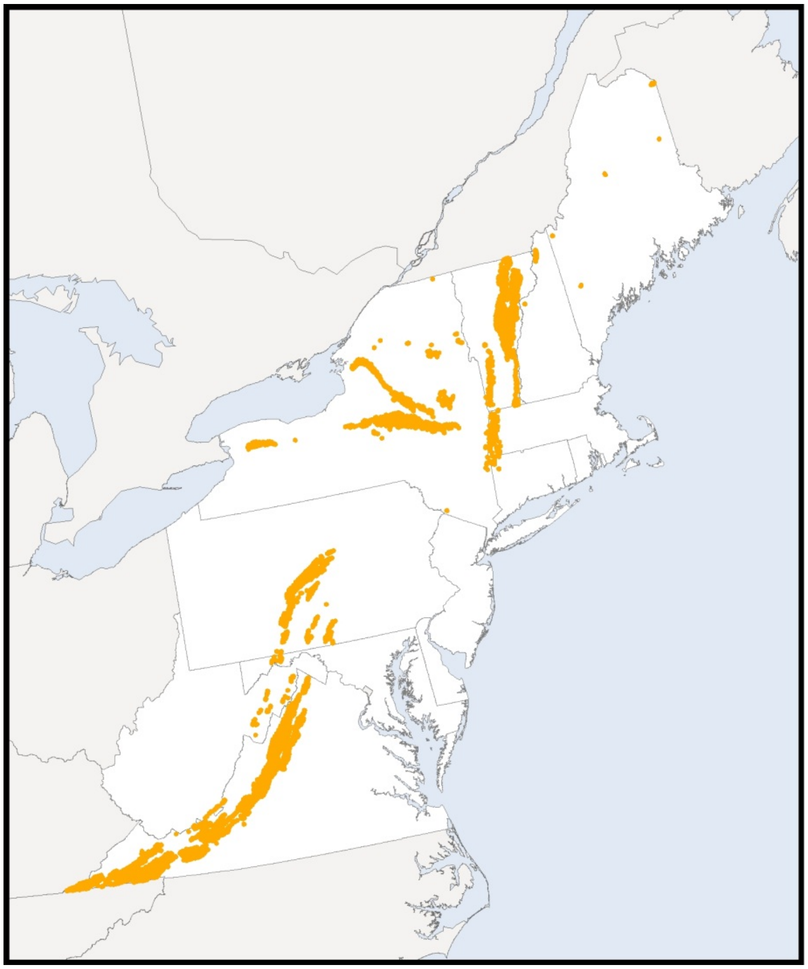
Resilience Score Category	Percents			Acres
	GAP1 or 2	GAP3	Unsecured	Total Acres
M:SED	4%	17%	79%	37,279,164
1: Far Below Average	0%	0%	16%	5,965,490
2: Below Average	0%	1%	15%	6,209,607
3: Average	1%	6%	29%	13,644,163
4: Above Average	1%	4%	8%	4,897,466
5: Far Above Average	2%	5%	11%	6,562,437

Map 5.18: Resilience scores for M-SED



Mid Elevation Calcareous Settings (M-CALC)

Description: Settings on limestone, dolomite, dolostone, marble, or other calcareous bedrocks at mid elevations between 800' and 2500'.



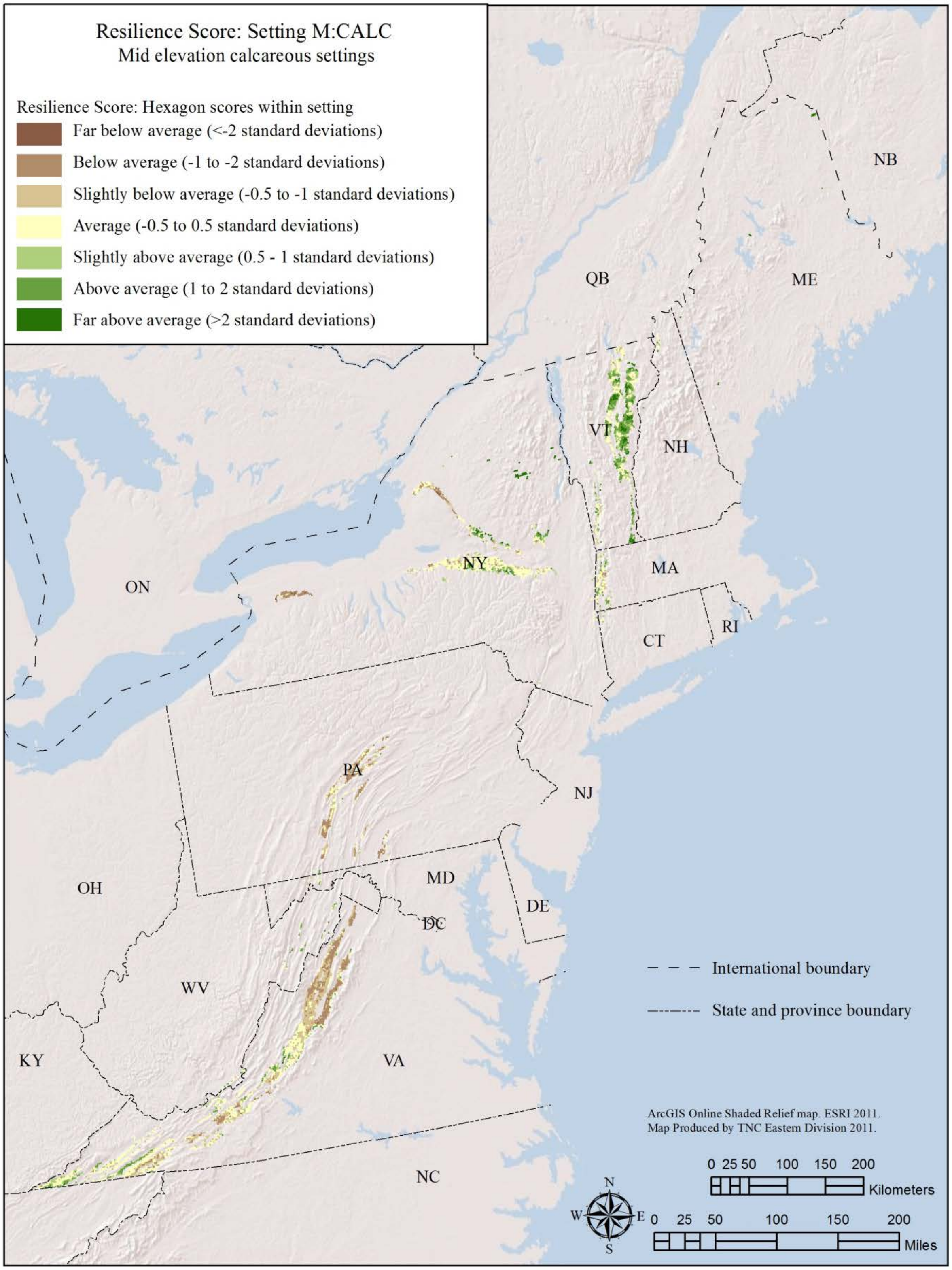
Example Communities
Upland: Limestone / dolomite barren, Chinquapin oak - red cedar woodland, Cave/mine, Limestone outcrops, Montane dry calcareous forest, Calcareous cliff, Northern hardwood talus woodland, Red cedar rocky summit, Boreal calcareous cliff, Temperate calcareous outcrop, Rich northern hardwood forest

Wetland: Circumneutral maple/ash basin swamp, Intermediate fen, Calcareous spring marsh / muck fen, Calcareous sloping fen, Calcareous basin fen, Riverside prairie, Shenandoah valley sinkhole pond, Calcareous seep, Spring, Fluctuating natural pool, Calcareous sloping fen, Seepage swamp, Rich sloping fen, Rich fen

Secured Status: 4 percent secured, 2 percent on above average sites.

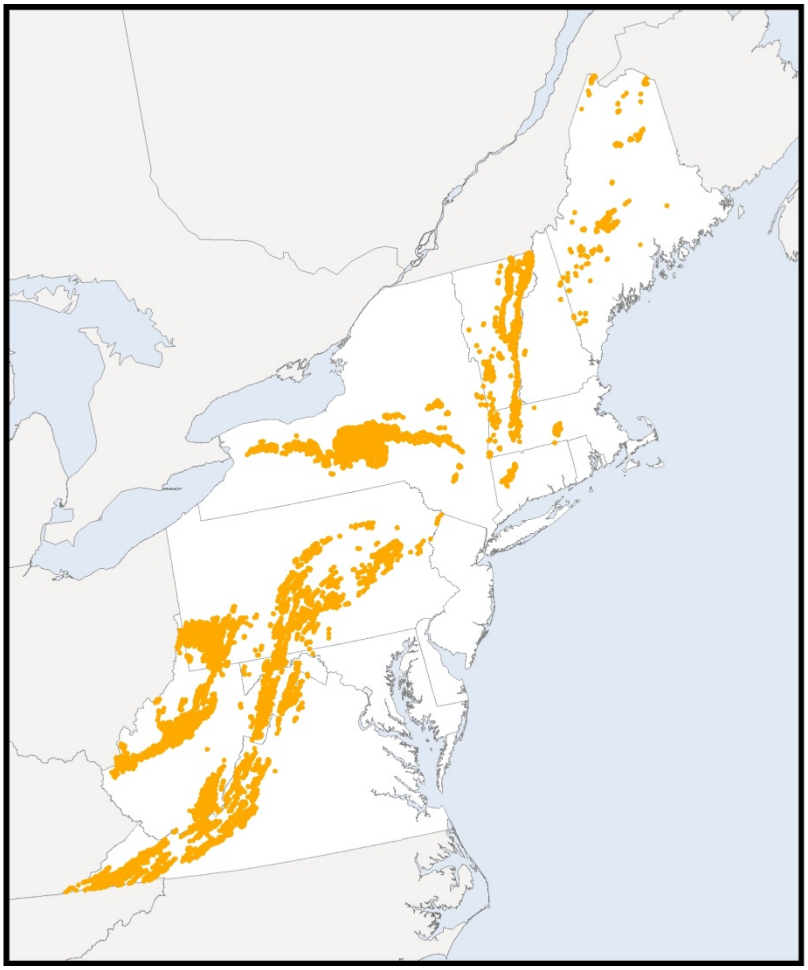
Reslience Score Category	Percents			Acres
	GAP1 or 2	GAP3	Unsecured	Total Acres
M:CALC	1%	3%	96%	4,450,372
1: Far Below Average	0%	0%	15%	652,057
2: Below Average	0%	0%	20%	914,065
3: Average	0%	1%	36%	1,659,121
4: Above Average	0%	0%	10%	484,032
5: Far Above Average	1%	1%	15%	741,097

Map 5.19: Resilience scores for M-CALC



Mid Elevation Moderately Calcareous Settings (M-MODCALC)

Description: Settings on calcareous sandstone, calcareous shales, mixed sedimentary rocks with limestone, or other moderately calcareous bedrocks at mid elevations between 800’ and 2500’.



Example Communities

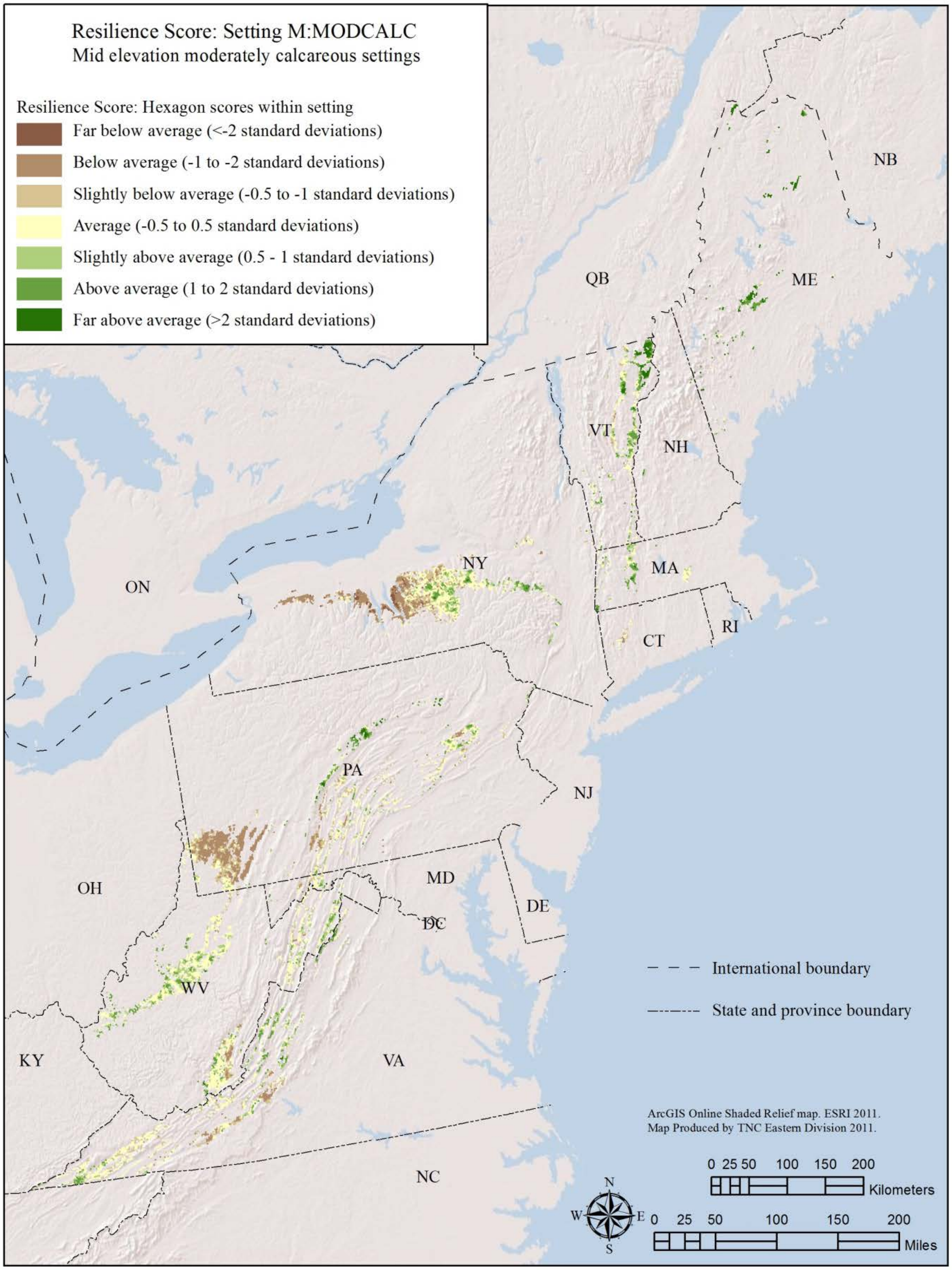
Upland: Eastern white pine - hardwood forest, Dry / mesic calcareous forest, Yellow oak - redbud woodland, Basic mesic forest, Calcareous forest or woodland, Beech-birch-maple forest, Northern Appalachian calcareous rocky summit, Mountain calcareous cliff, Temperate circumneutral outcrop, Rich cove / slope forest, Boreal calcareous cliff, Mountain / piedmont basic woodland, Temperate calcareous outcrop, Low-elevation basic outcrop barren

Wetland: Hemlock - mixed hardwood palustrine forest, Mountain / piedmont acidic seepage swamp, Red maple-tamarack peat swamp, Rich hemlock-hardwood peat swamp, Shenandoah valley sinkhole pond, Appalachian bog, Rich shrub fen, Black spruce-tamarack bog, Ephemeral/fluctuating natural pool, Inland poor fen, Rich sloping fen

Secured Status: 10 percent secured, 8 percent on above average sites.

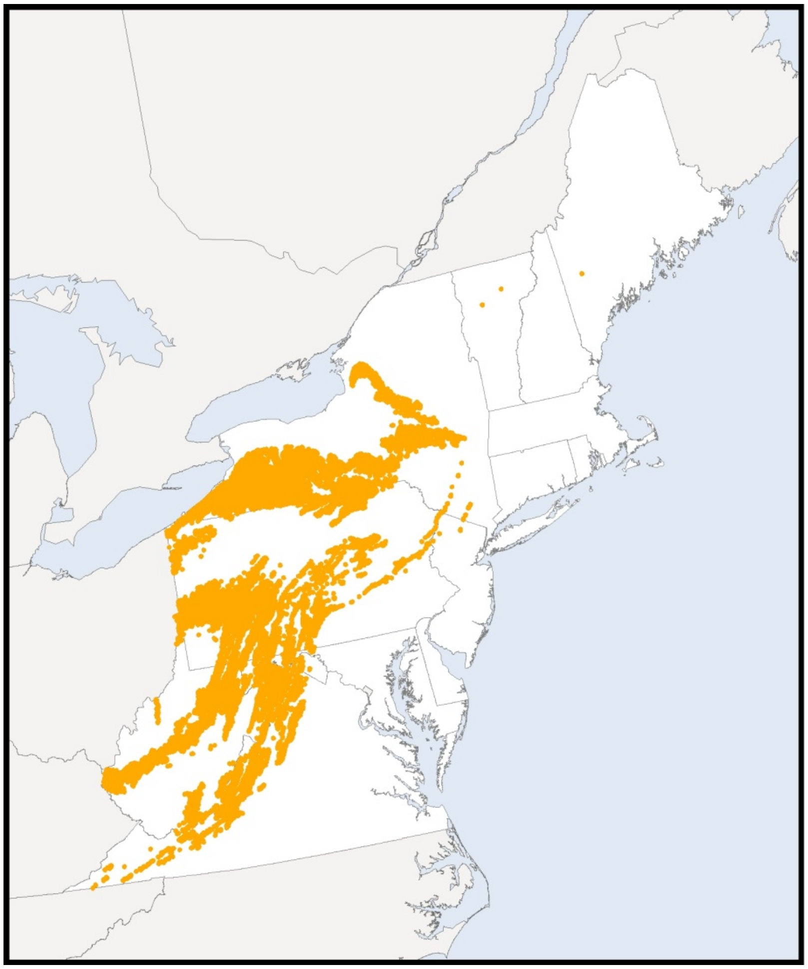
Resilience Score Category	Percents			Acres
	GAP1 or 2	GAP3	Unsecured	Total Acres
M:MODCALC	1%	9%	90%	7,504,763
1: Far Below Average	0%	0%	18%	1,327,118
2: Below Average	0%	0%	15%	1,155,154
3: Average	0%	2%	35%	2,807,316
4: Above Average	0%	2%	12%	1,079,070
5: Far Above Average	1%	5%	10%	1,136,105

Map 5.20: Resilience scores for M-MODCALC



Mid Elevation Shale Settings (M-SHALE)

Description: Settings on acidic fissile shale (shale that flakes into thin plats) at mid elevations between 800' and 2500'.



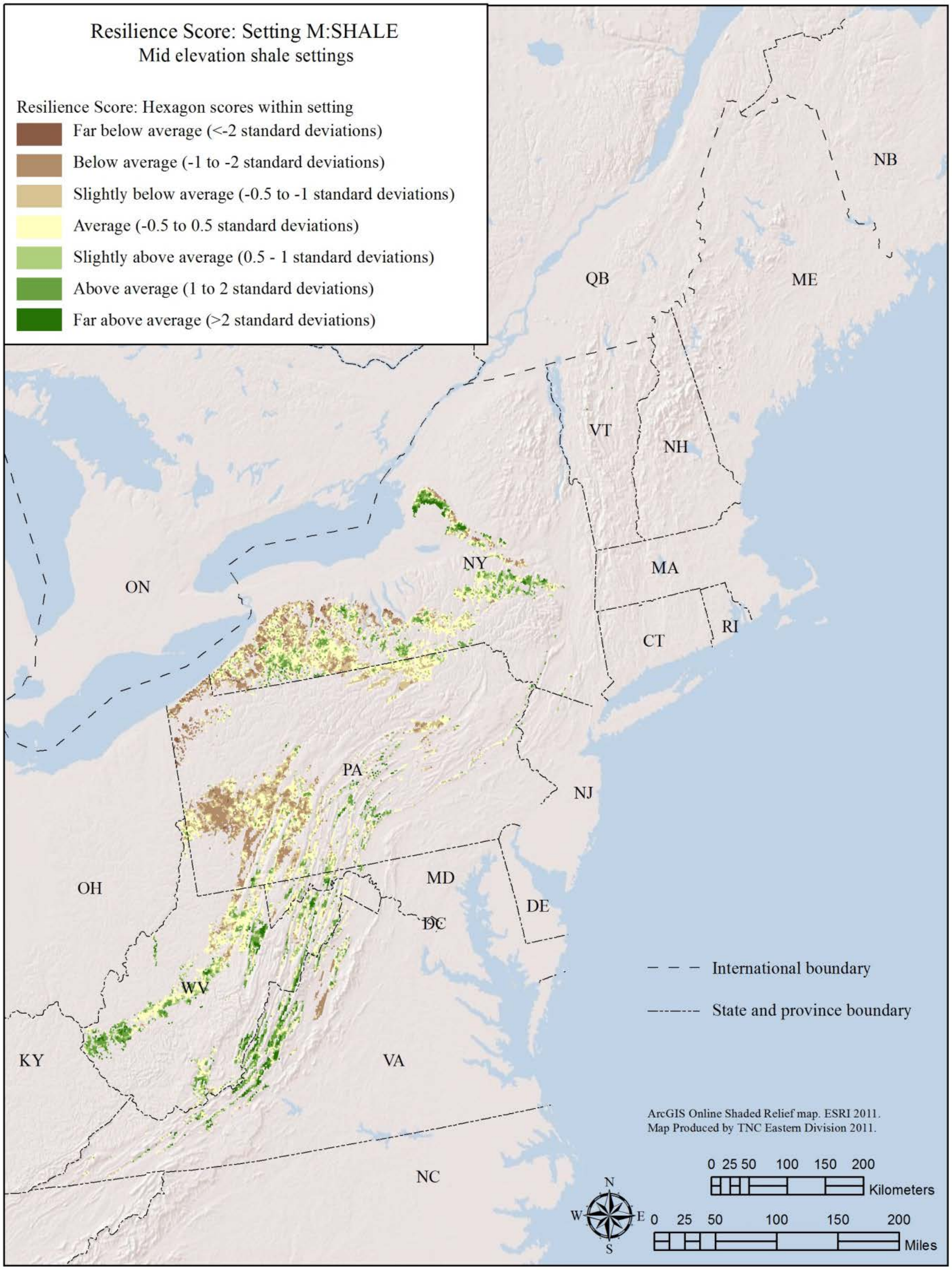
Example Communities
Upland: Red-cedar - mixed hardwood rich shale woodland, Shale talus slope woodland, Central Appalachian shale barren, Shale cliff and talus community, Shale barren, Low-elevation boulder field woodland, White pine-mixed hardwoods, Allegheny oak forest, Appalachian oak-hickory forest, Maple-basswood rich mesic forest, Mountain / piedmont acidic woodland

Wetland: Sedge meadow, Rich hemlock-hardwood peat swamp, Hemlock-hardwood swamp, Rich sloping fen, Highbush blueberry bog thicket, Calcareous spring marsh / muck fen.

Secured Status: 8 percent secured, 7 percent on above average sites.

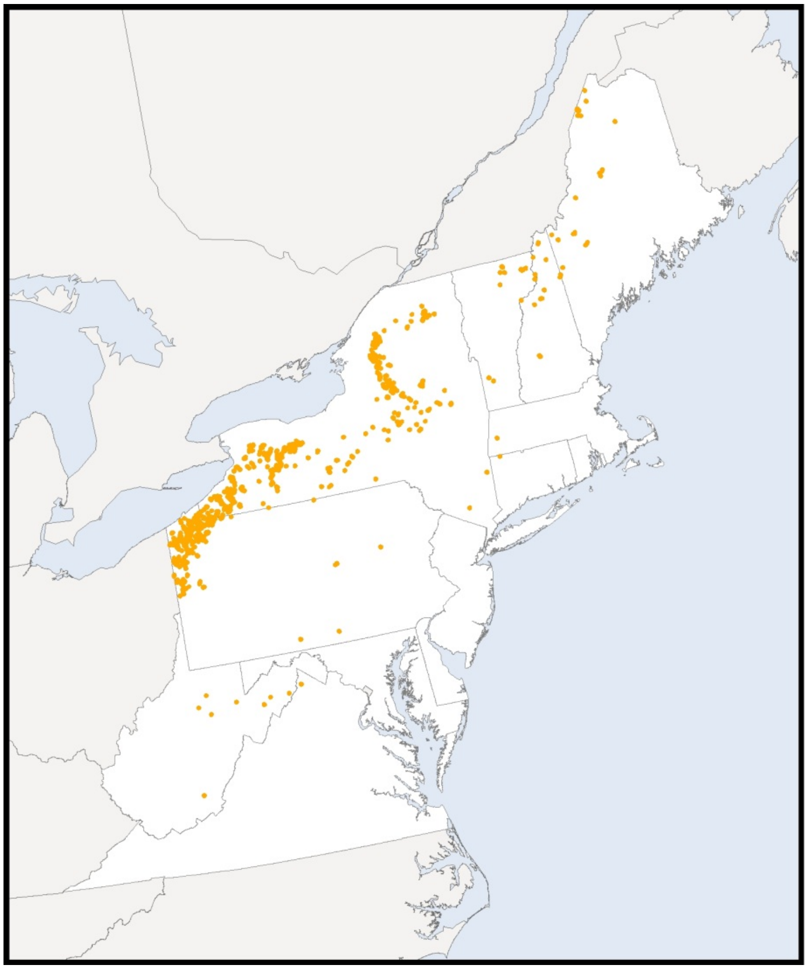
Resilienc Score Category	Percents			Acres
	GAP1 or 2	GAP3	Unsecured	Total Acres
M:SHALE	1%	7%	91%	13,898,142
1: Far Below Average	0%	0%	16%	2,236,208
2: Below Average	0%	0%	18%	2,564,199
3: Average	0%	1%	34%	5,005,420
4: Above Average	0%	1%	11%	1,756,117
5: Far Above Average	1%	5%	12%	2,336,199

Map 5.21: Resilience scores for M-SHALE



Mid Elevation Surficial Sediment Settings (M-SURF)

Description: Settings on surficial sediment of sand, silt and clay (often associated with river and lake plains) at mid elevations between 800' and 2500'.



Example Communities

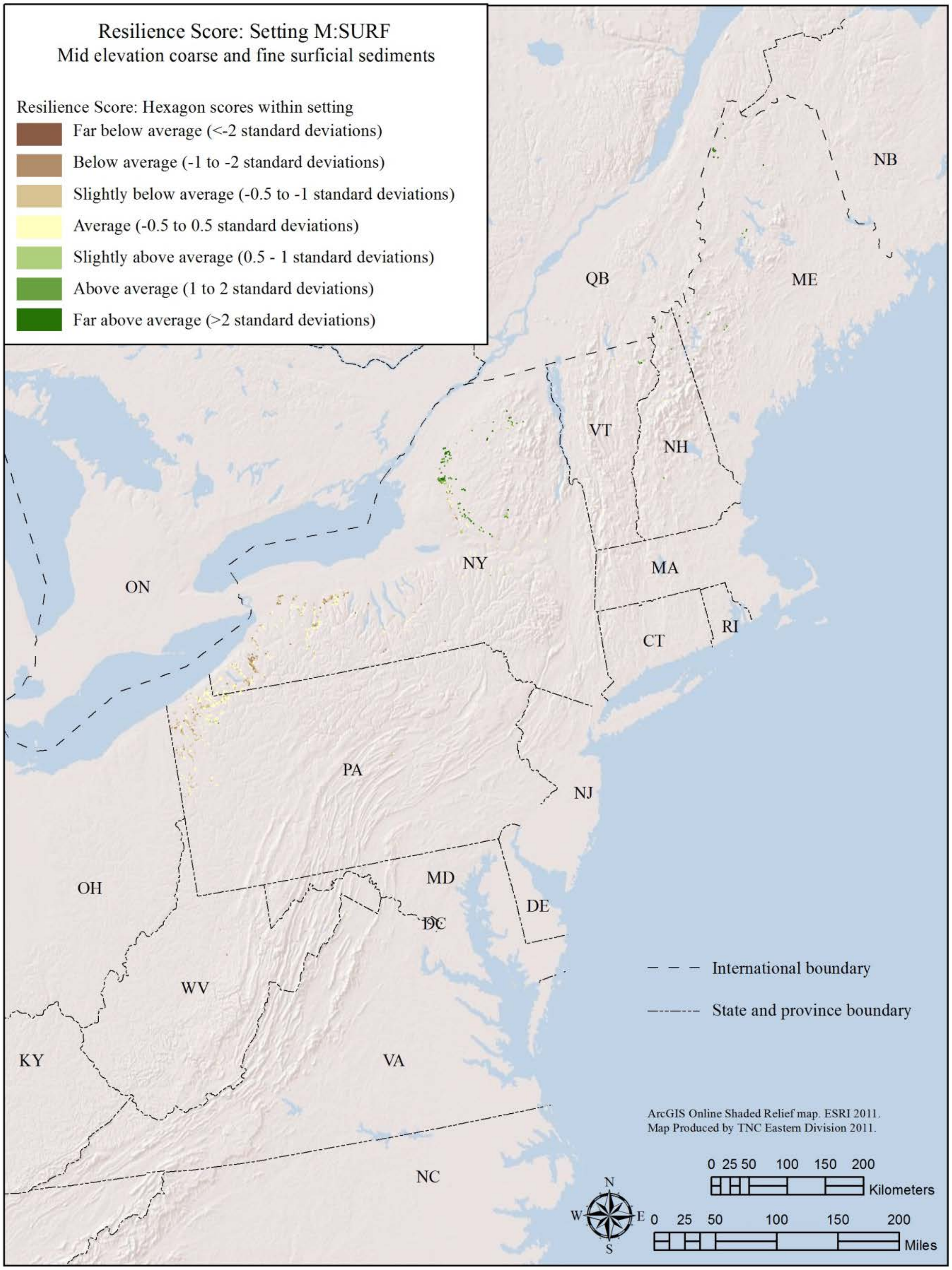
Upland: Boreal heath barrens, Larch Forest, Hemlock-mixed mesic hardwoods, Spruce flats

Wetland: Calcareous marsh, Leatherleaf thicket, Northern appalachian calcareous seep community, Hillside graminoid-forb fen, Sphagnum canopy, Basin graminoid-forb fen, Circumneutral seepage swamp, Shrub fen, Dwarf shrub bog.

Secured Status: 8 percent secured, 7 percent on above average sites.

Resilience Score Category	Percents			Acres
	GAP1 or 2	GAP3	Unsecured	Total Acres
M:SURF	2%	6%	92%	740,009
1: Far Below Average	0%	0%	8%	63,003
2: Below Average	0%	0%	27%	203,018
3: Average	1%	2%	40%	314,991
4: Above Average	0%	1%	5%	40,998
5: Far Above Average	1%	3%	11%	117,999

Map 5.22: Resilience scores for M-SURF



Mid Elevation Ultramafic Bedrock (M-Ultra)

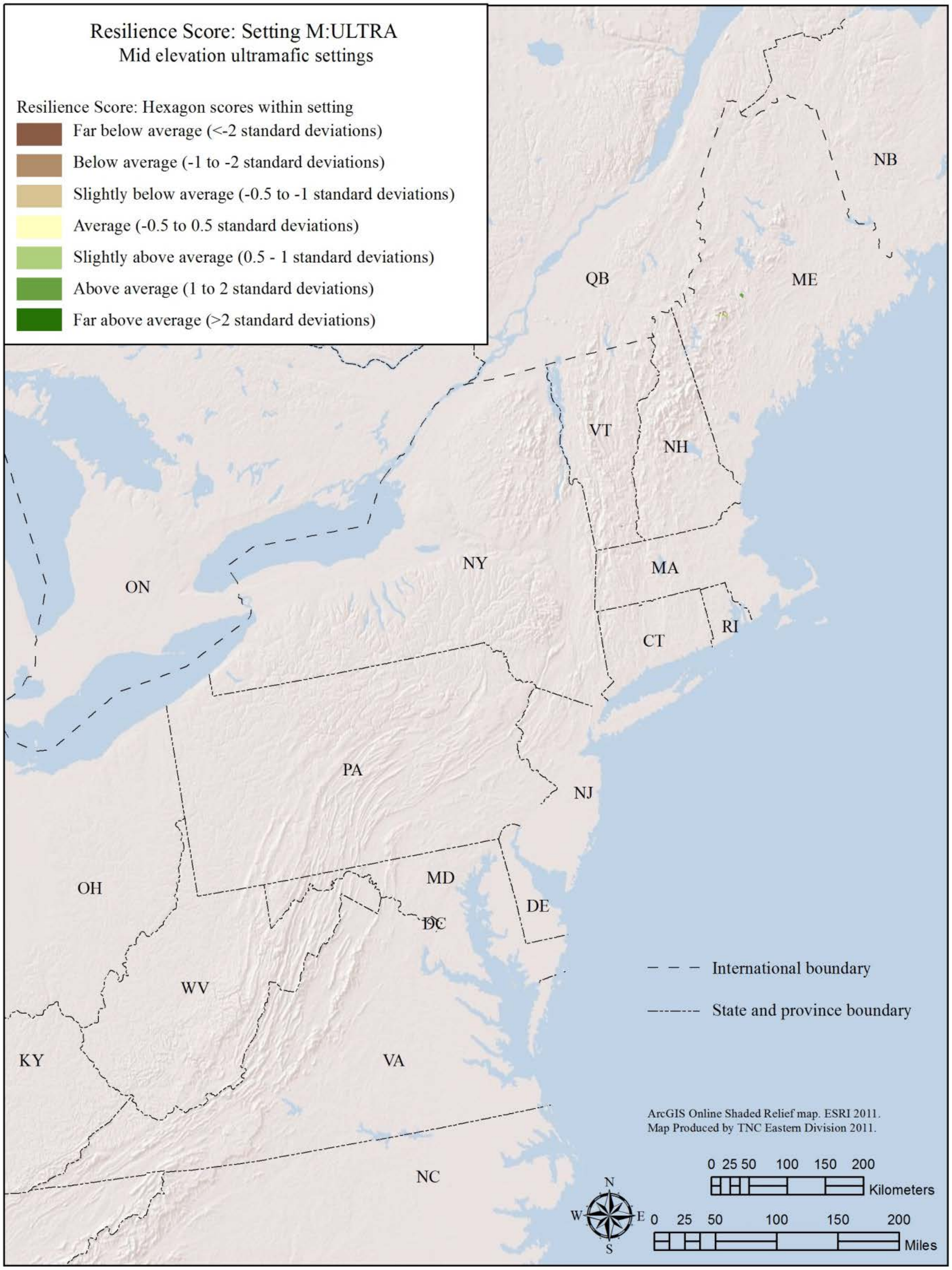
Description: Rare setting (22,298 acres) in serpentine and other ultra mafic bedrock at mid elevations above 800' and below 2500'. Ultra mafic soils are high in magnesium and low in calcium, and typically have elevated amounts of chromium and nickel. Because these soils are toxic to many plants a unique flora has developed that tolerate these conditions. This setting is limited to outcrops and bedrock exposures at this elevation. Large examples are present in Quebec.

Example Communities
No community occurrences overlay this setting

Securement status: 3 percent secured, 3 percent on above average sites

Resilience Score Category	Percent			Acres
M-Ultra	GAP1 or 2	GAP3	Unsecured	Total Acres
1: Far Below Average	1%	2%	97%	22,998
2: Below Average	0%	1%	21%	4,999
3: Average	0%	0%	13%	2,999
4: Above Average	1%	2%	41%	10,001
5: Far Above Average	0%	0%	22%	5,000

Map 5.23: Resilience scores for L- ULTRA



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HIGH ELEVATION SETTINGS

Settings, usually high mountain landscapes, above 2500 feet. Maps 5.24-5.29.

High Elevation Granite or Mafic (H:GRAN): Bedrock mountain setting of intrusive granitic rock, plutons of mafic rock or volcanic basalts. .

High Elevation Sedimentary (H-SED): Bedrock mountain setting of sandstone, quartzite, conglomerate or other resitent sedimentary rocks

High Elevation Mixed Sedimentary and Calcareous (H-SED/CALC): Mountains and ridges of resistant sandstone intermixed with valleys or lowlands of limetone or other calcareous bedrock.

High Elevation Calcareous and Moderately Calcareous (H-CALC/MOD): Mountainous landscape sof rich limestone or dolomite.

High Elevation Acidic Shale (L-SHALE): Settings on stable and unstable shale slopes.

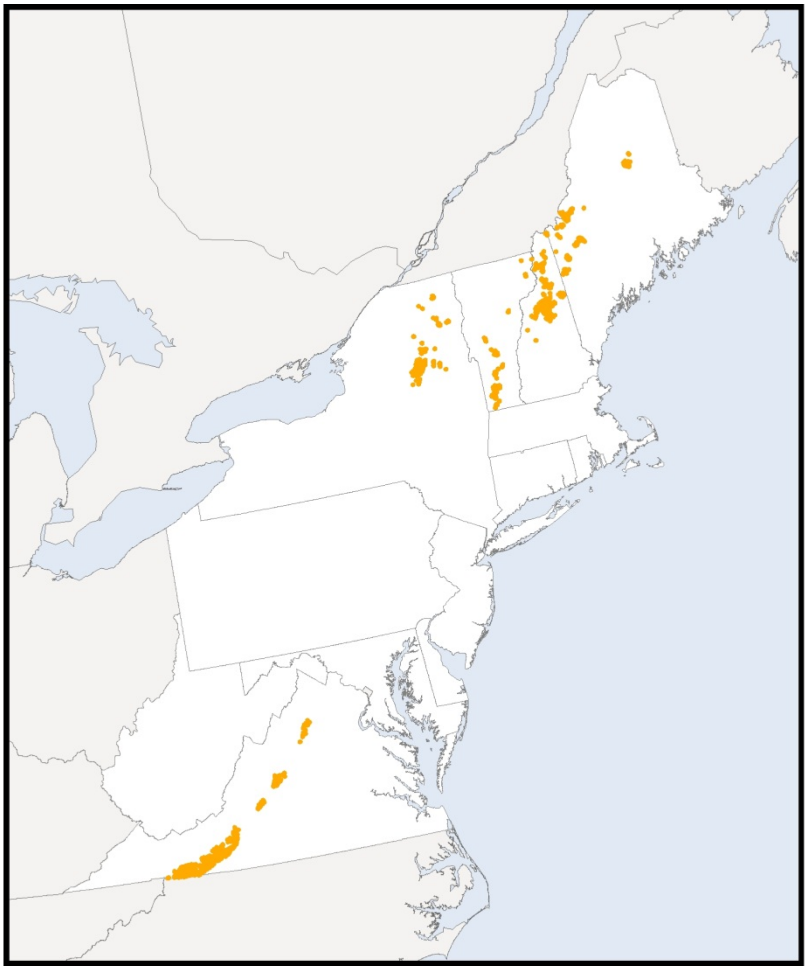
Alpine and Subalpine (ALP-ALL): Very high elevation settings over 2500' on any substrate with systems dominated by extreme wind and cold. Alpine areas often have stunted trees (krumholz) and unique floras.

MISCELLANEOUS SETTINGS

Steep Slopes on sedimentation (STEEP-SED): Very steep slopes mostly on sedimentary rock and found through out the region at any elevation. Map 5.30

High Elevation Granitic or Mafic Settings (H-GRAN)

Description: High mountain settings on granite, granidiorite, gneiss, anorthosite, basalt or other granitic or mafic bedrock at elevations over 2500'.



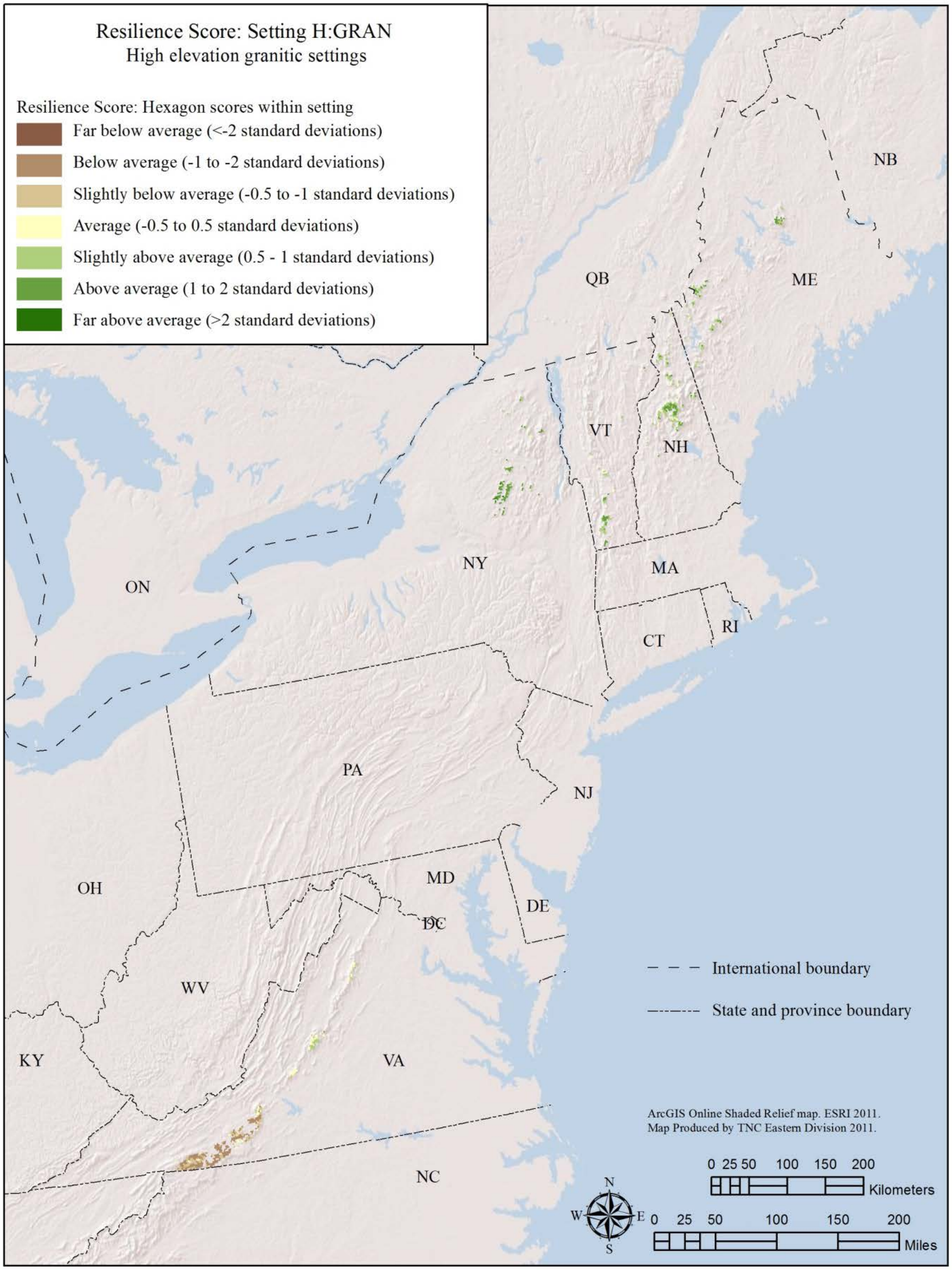
Example Communities
Upland: High elevation spruce/fir forest, Subalpine spruce-fir forest, Central Appalachian northern hardwood forest, Alpine ridge, Krummholz, NE boreal heathland, NE acidic rocky summit, Montane spruce-fir forest, Lichen / bryophyte boulderfield, NE alpine community, NNE acidic cliff community, NNE acidic talus woodland, NNE mesic hardwood forest on acidic bedrock, NNE cold-air talus forest, Northern red oak forest,
High-elevation outcrop barren, Eastern hemlock - hardwood forest, Montane mixed oak - hickory forest, High-elevation boulder field woodland.

Wetland: Forested bog, High-elevation seepage swamp, New England alpine/subalpine bog

Secured Status: 49 percent secured, 39 percent on above average sites.

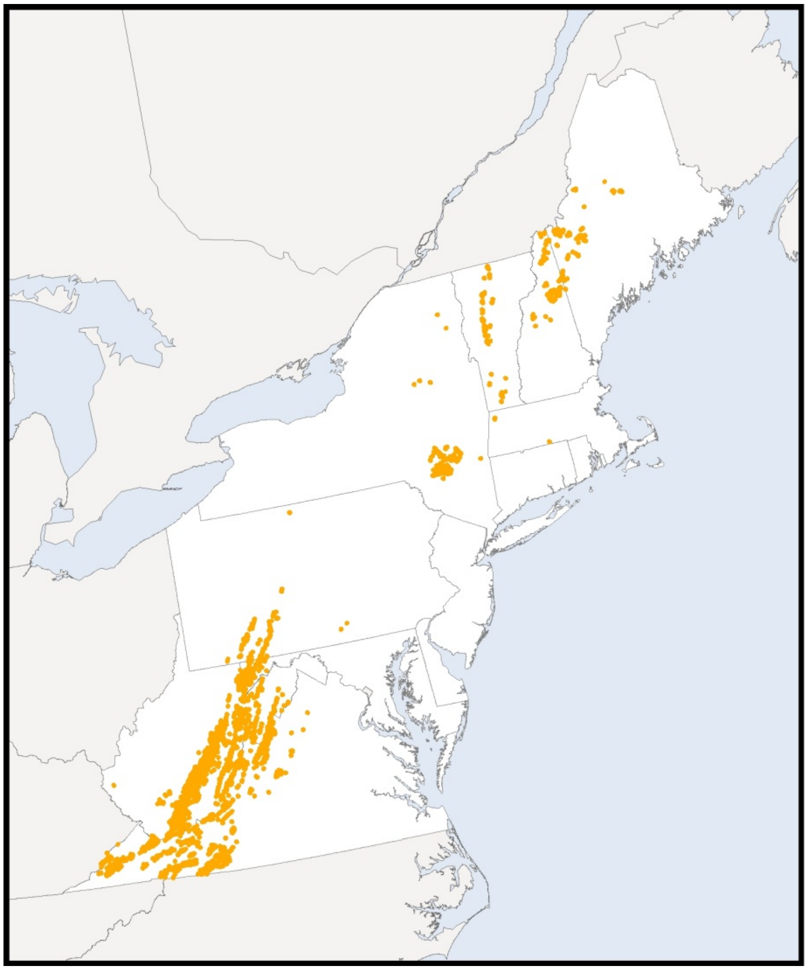
Resilience Score Category	Percents			Acres
	GAP1 or 2	GAP3	Unsecured	Total Acres
H:GRAN	36%	13%	51%	930,071
1: Far Below Average	0%	0%	23%	222,022
2: Below Average	1%	0%	14%	145,013
3: Average	4%	3%	5%	113,006
4: Above Average	14%	7%	6%	257,004
5: Far Above Average	16%	2%	2%	193,026

Map 5.24: Resilience scores for H-GRAN



High Elevation Sedimentary Settings (H-SED)

Description: High mountain settings on sandstone, quartzite, conglomerate or other sedimentary or metat sedimentary bedrock at elevations over 2500'.



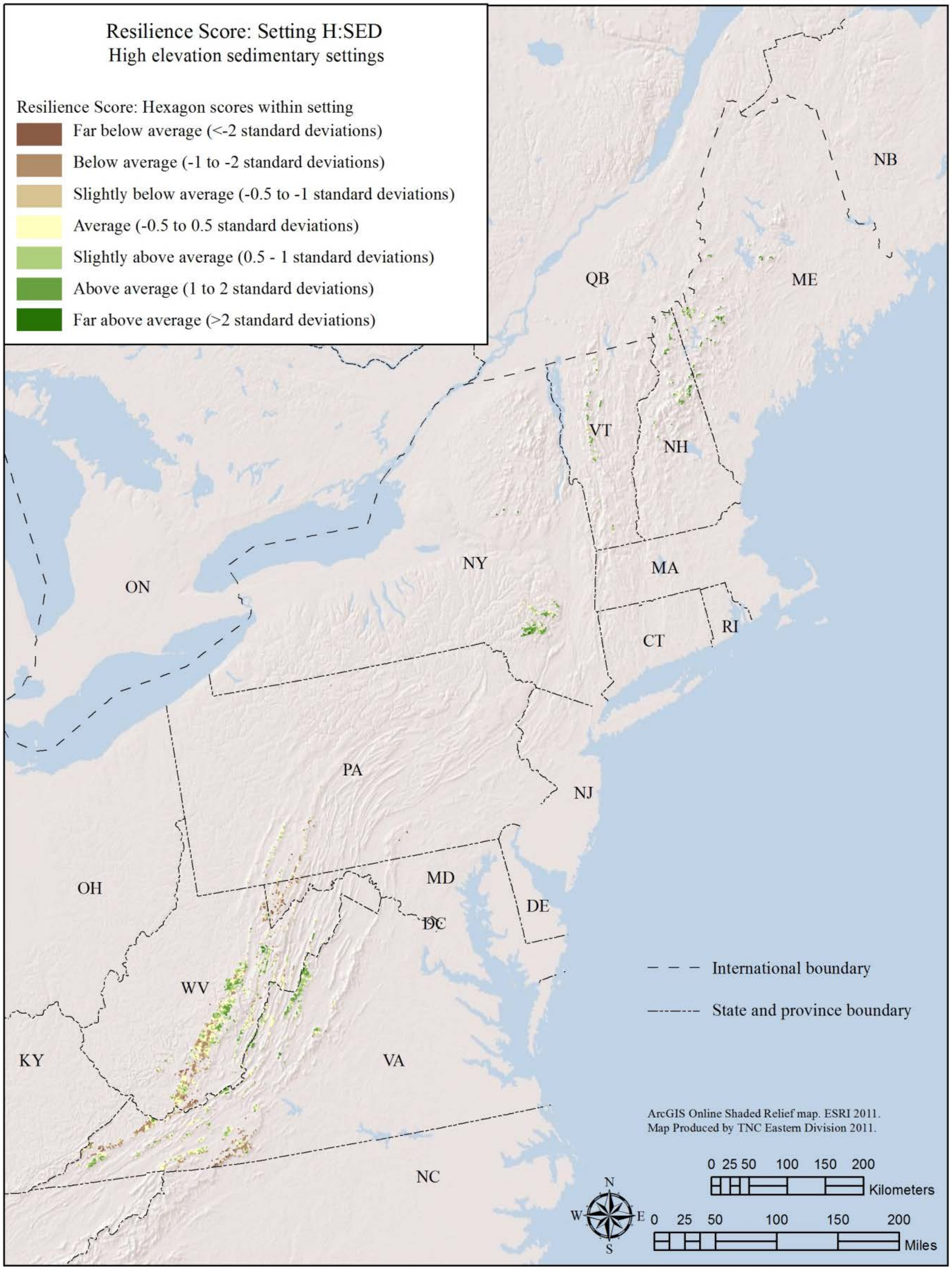
Example Communities
Upland: Montane yellow birch-red spruce forest, NE moist subalpine heathland, Subalpine krummholz, Boreal outcrop, Alpine ridge, NE boreal heathland, Spruce woodland, Alpine meadow, Montane spruce-fir forest, Lichen / bryophyte boulder field

Wetland: Alpine peatland, Mafic fen / seep, NNE basin swamp, High-elevation seepage swamp, Spring, Mountain peatland, New England alpine/subalpine bog

Secured Status: 40 percent secured, 25 percent on above average sites.

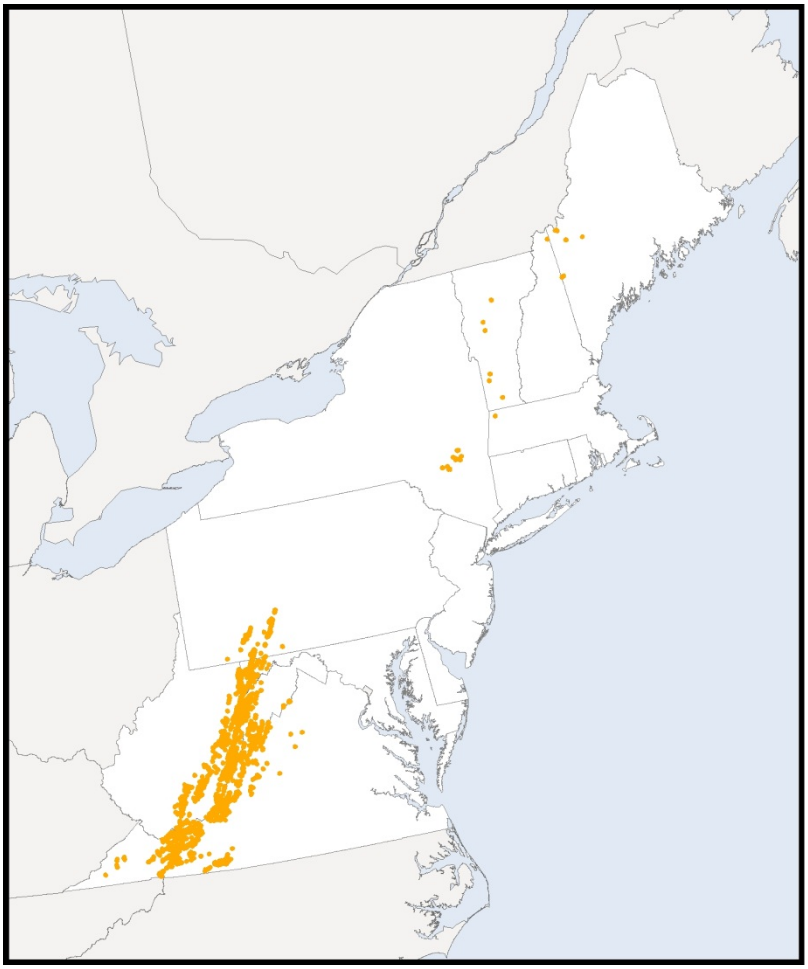
Resilience Score Category	Percents			Acres
	GAP1 or 2	GAP3	Unsecured	Total Acres
H:SED	18%	22%	60%	2,368,178
1: Far Below Average	0%	1%	16%	414,053
2: Below Average	1%	2%	12%	347,028
3: Average	3%	7%	17%	644,059
4: Above Average	6%	7%	10%	545,027
5: Far Above Average	7%	5%	6%	418,012

Map 5.25: Resilience scores for H-SED



High Elevation Mixed Sedimentary Settings (H-SED/CALC)

Description: High mountain settings on mixtures of limestone and sandstone, or other sedimentary or metasedimentary bedrock at elevations over 2500'.



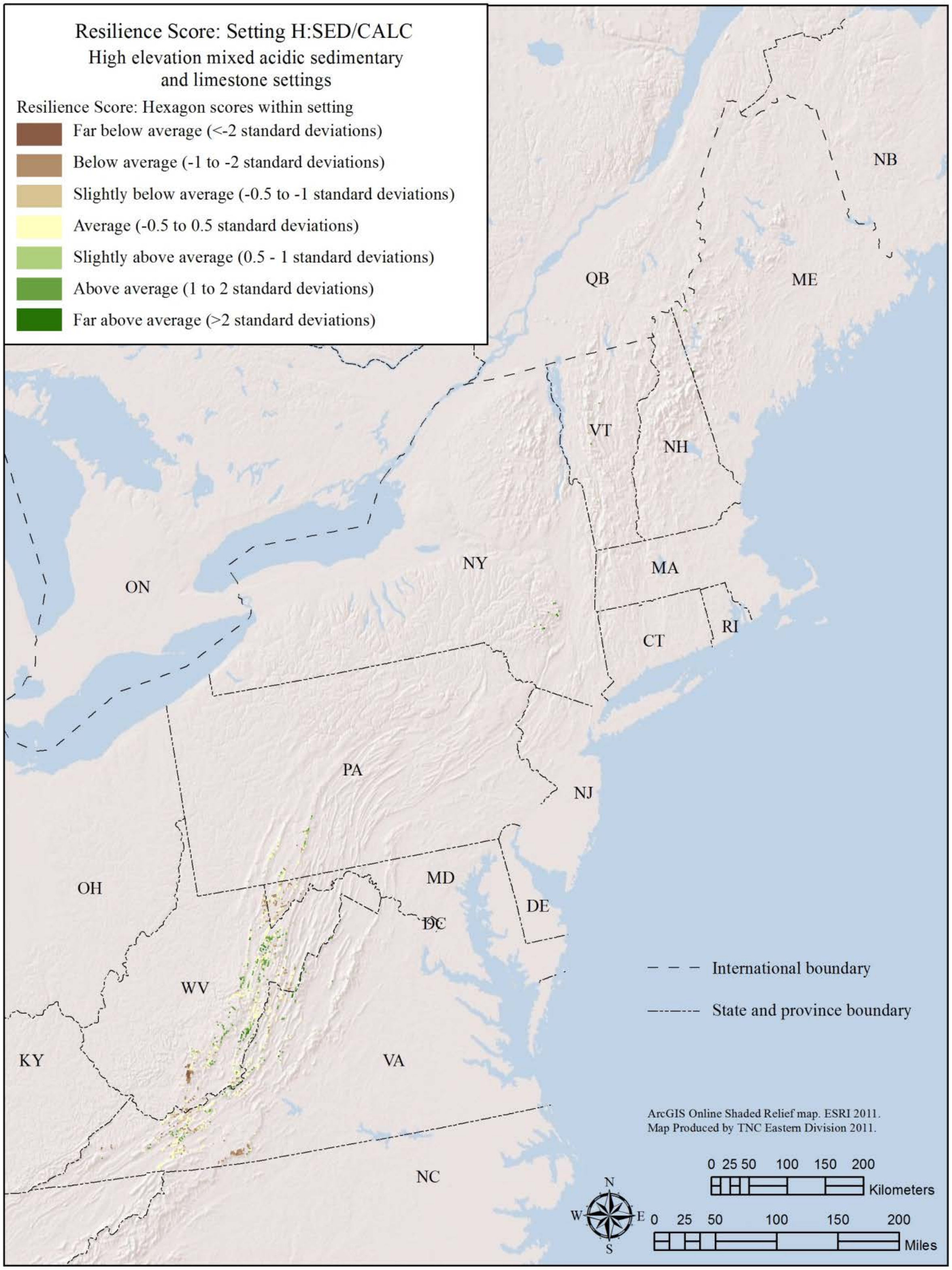
Example Communities
Upland: Maple-ash-basswod rich forest, Acidic cove forest
Cove hardwood forest, Montane spruce-fir forest, Oak / heath forest, Low-elevation acidic outcrop barren, Mountain fir forest, Pine - oak / heath woodland, Montane mixed oak / oak - hickory forest

Wetland: Black ash-balsam fir swamp , Sphagnum - beaked rush peatland, Mountain peatland, Marsh & river marsh, Bog

Secured Status: 36 percent secured, 19 percent on above average sites.

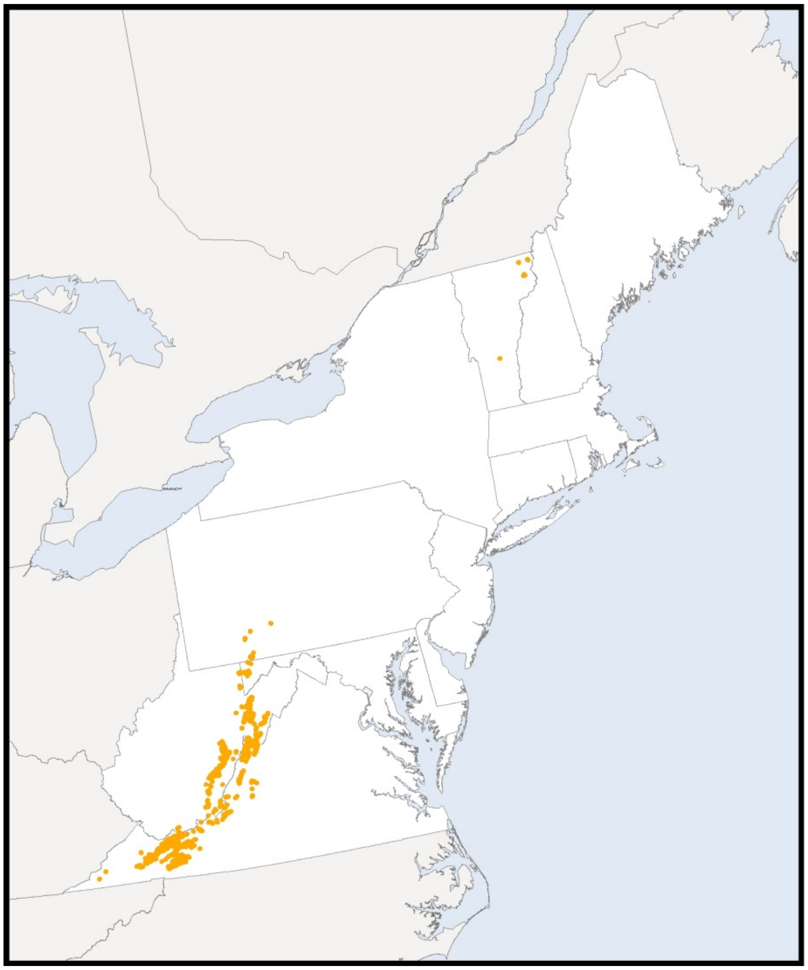
Resilience Score Category	Percents			Acres
	GAP1 or 2	GAP3	Unsecured	Total Acres
H:SED/CALC	6%	30%	64%	1,210,107
1: Far Below Average	0%	1%	15%	204,020
2: Below Average	0%	3%	12%	178,014
3: Average	2%	11%	25%	459,045
4: Above Average	1%	5%	6%	146,011
5: Far Above Average	3%	10%	6%	223,018

Map 5.26: Resilience scores for H-SED/CALC



High Elevation on Calcareous or Moderately Calcareous Settings (H-CALCMOD)

Description: High mountain settings on limestone, dolomite, marble or other calcareous bedrock at elevations over 2500'.



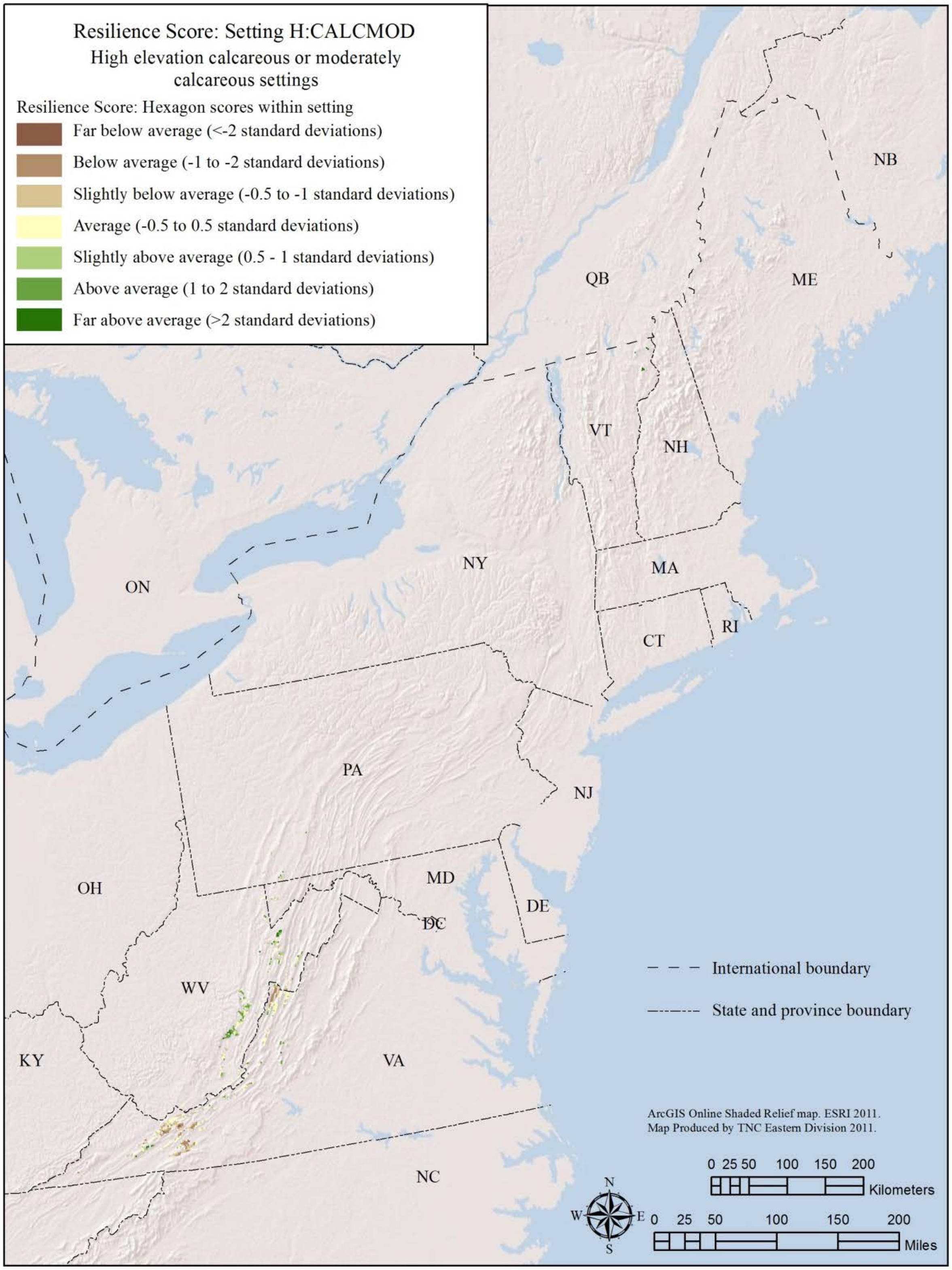
Example Communities
Upland: none recorded

Wetland: Balsam fir/ winterberry-grey alder swamp, Mountain peatland, Bog and wet meadow

Secured Status: 36 percent secured, 19 percent on above average sites.

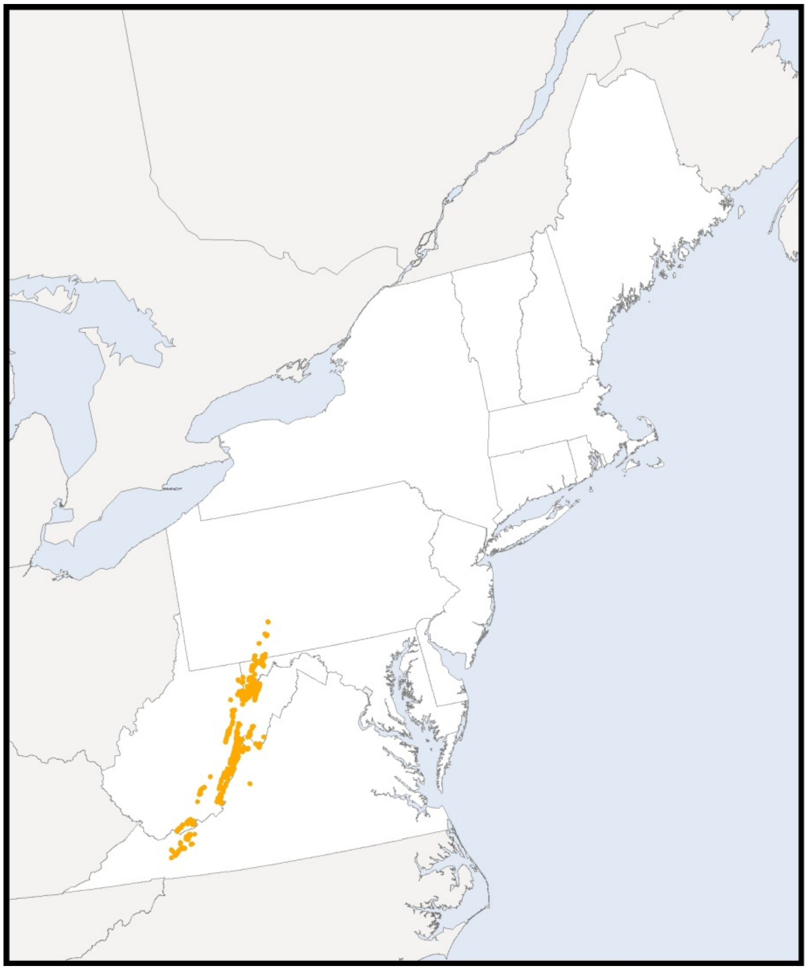
Resilience Score Category	Percents			Acres
	GAP1 or 2	GAP3	Unsecured	Total Acres
H:CALCMOD	2%	11%	88%	603,055
1: Far Below Average	0%	0%	15%	94,012
2: Below Average	0%	1%	19%	121,014
3: Average	0%	2%	30%	199,012
4: Above Average	0%	2%	12%	88,011
5: Far Above Average	1%	5%	12%	101,005

Map 5.27: Resilience scores for H-CALCMOD



High Elevation Shale Settings (H-SHALE)

Description: High mountain settings on fissile shale at elevations over 2500'.



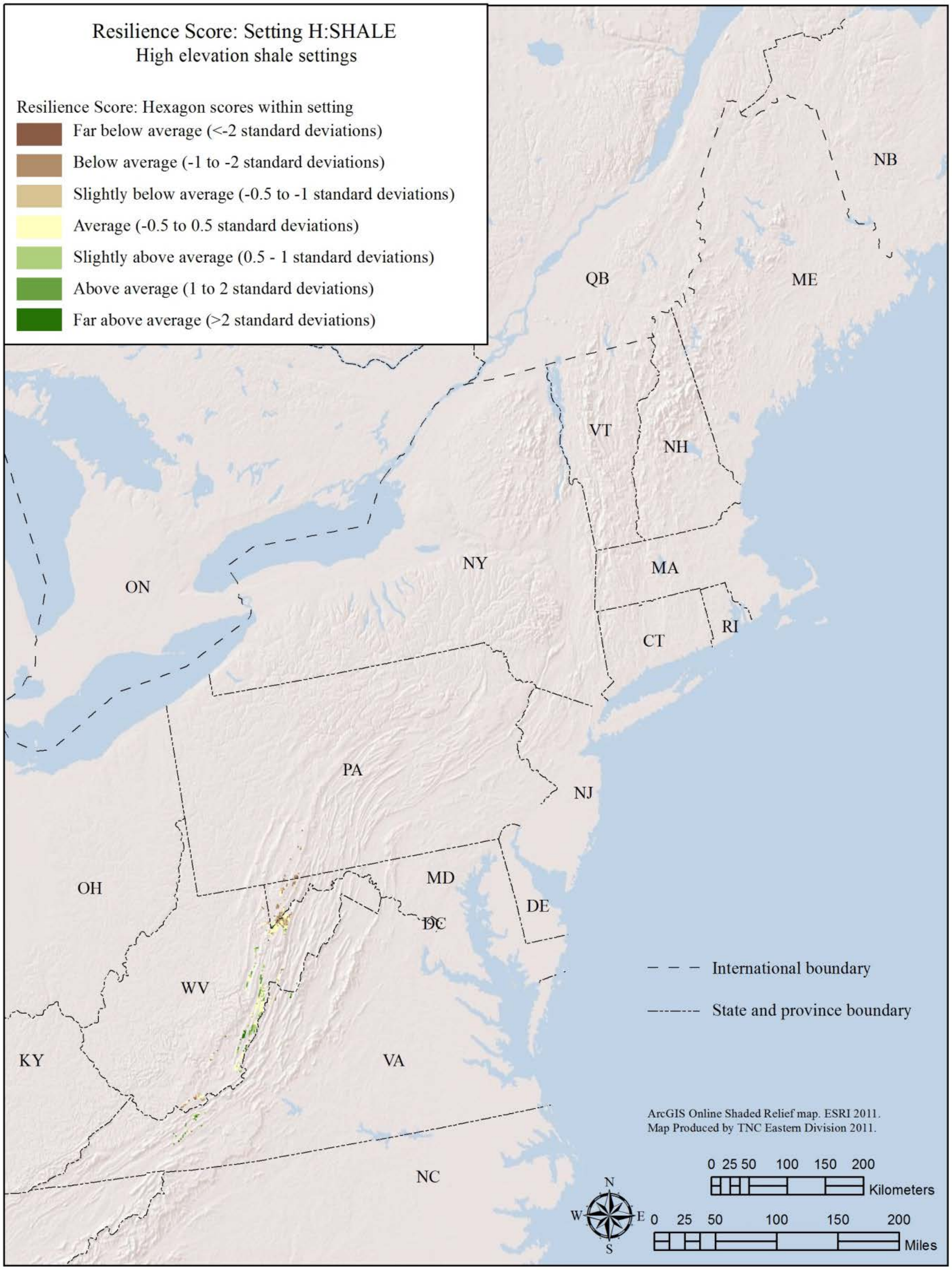
Example Communities
Upland: Eastern hemlock forest, Northern hardwood forest

Wetland: Bog, Mountain peatland

Secured Status: 31 percent secured, 20 percent on above average sites.

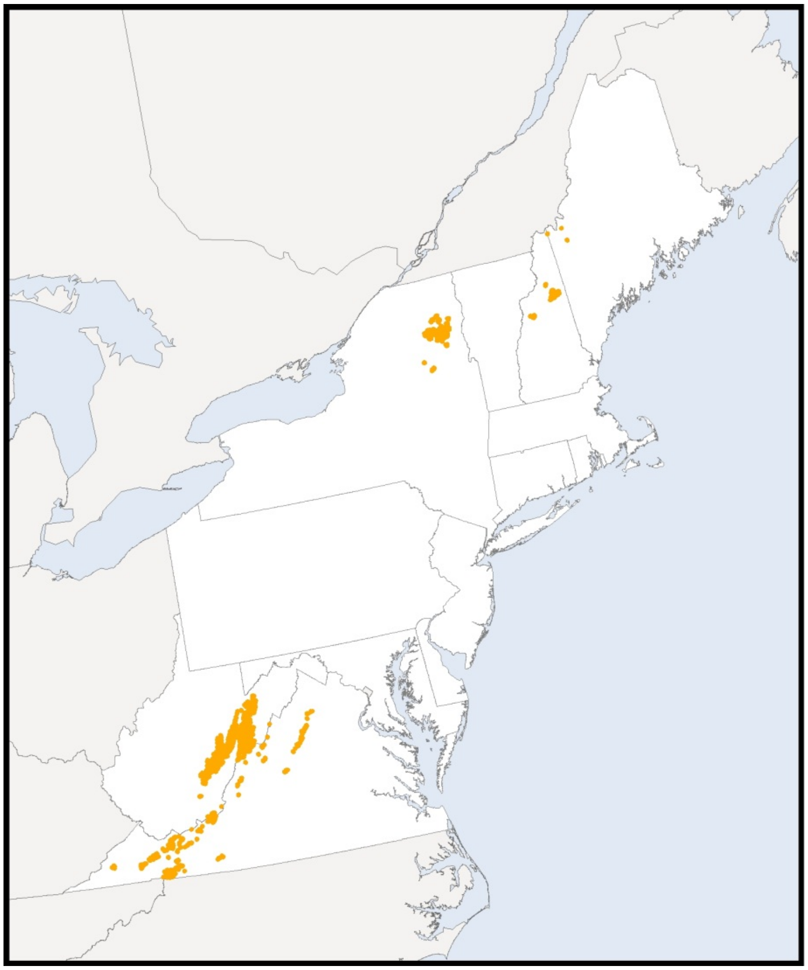
Resilience Score Category	Percents			Acres
	GAP1 or 2	GAP3	Unsecured	Total Acres
H:SHALE	3%	28%	69%	448,045
1: Far Below Average	0%	0%	18%	85,013
2: Below Average	0%	1%	13%	61,006
3: Average	0%	9%	27%	159,019
4: Above Average	0%	8%	8%	69,004
5: Far Above Average	2%	10%	4%	74,003

Map 5.28: Resilience scores for H-SHALE



Alpine Settings on any Bedrock (ALP-ALL)

Description: High mountain settings above 3600' on any type of substrate.



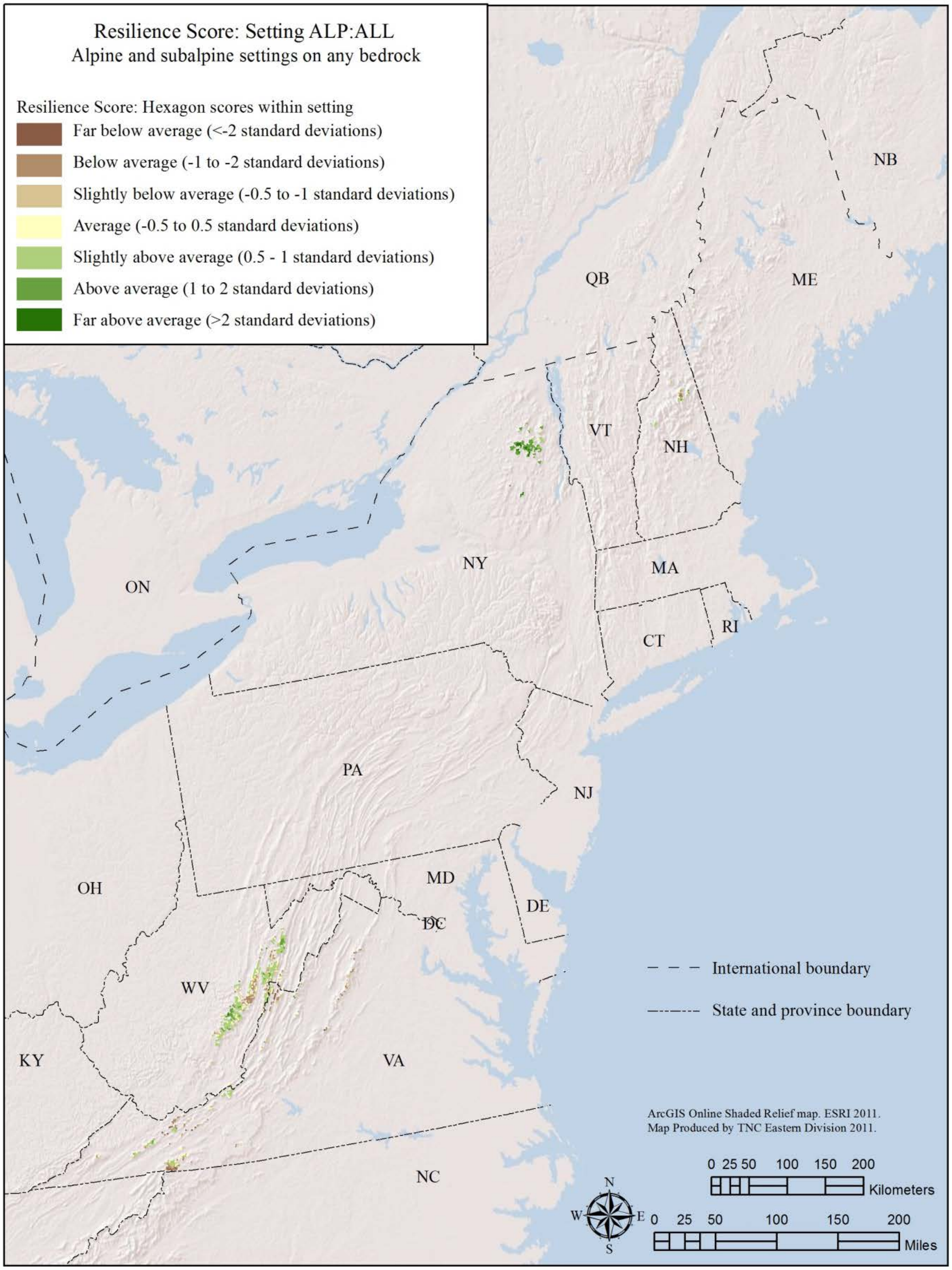
Example Communities
Upland: Alpine krummholz, Alpine meadow, Grass bald, High-elevation cove forest, Subalpine heath/krummolz , Red spruce-fraser fir /southern mt cranberry forest, Red spruce-hemlock/rhododendron, Red spruce / great laurel forest, Red pine/minniebush forest, Pitch pine/ black chokeberry woodland, Sandstone cliff and ledge, Mountain acidic cliff
Red spruce- balsam fir forest, NE alpine community, NNE cold-air talus forest/woodland, Mountain fir forest

Wetland: Balsam fir/melic manna grass seepage swamp, High-elevation seepage swamp, Appalachian bog, Spring, New England alpine/subalpine bog, Marsh & river marsh, Bog, Montane depression wetland

Secured Status: 31 percent secured, 20 percent on above average sites.

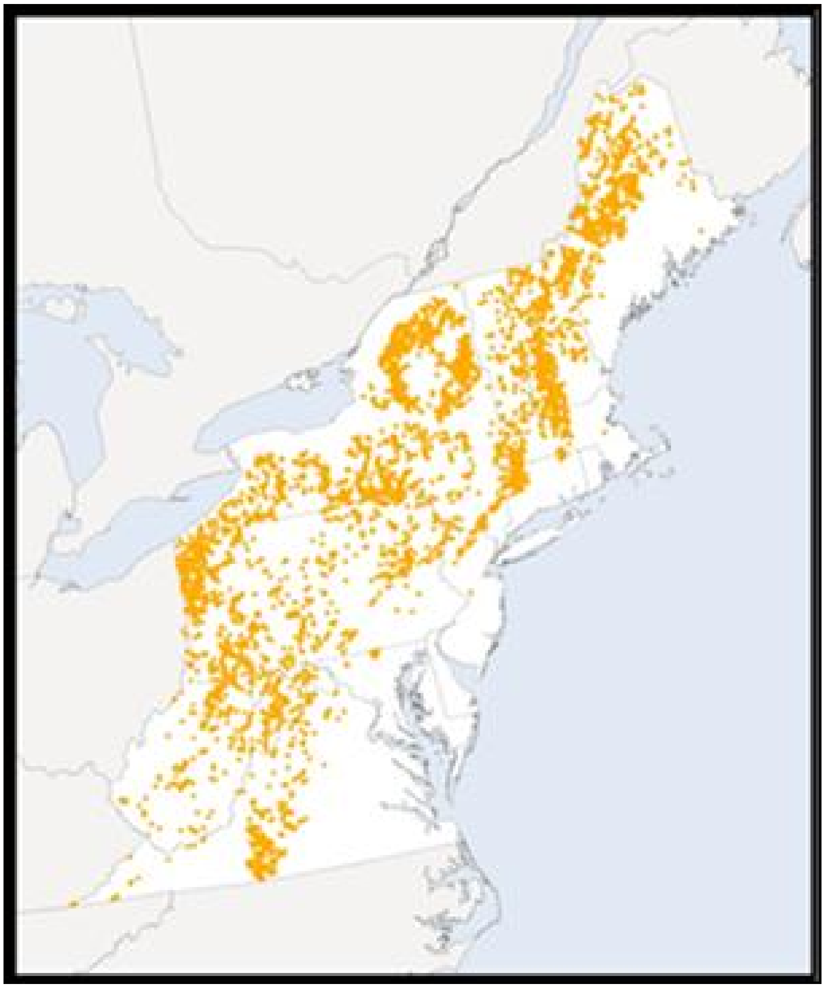
Resilience Score	Percents			Acres
	GAP1 or 2	GAP3	Unsecured	Total Acres
ALPINE: ALL	28%	38%	34%	986,088
1: Far Below Average	2%	4%	10%	164,022
2: Below Average	2%	7%	6%	149,013
3: Average	2%	6%	5%	127,012
4: Above Average	8%	19%	11%	384,030
5: Far Above Average	13%	2%	1%	162,012

Map 5.29: Resilience scores for ALPINE-ALL



Very Steep Slopes on Sedimentary Bedrock (STEEP-SED)

Description: Miscellaneous steep slopes through out the region at any elevation**.**

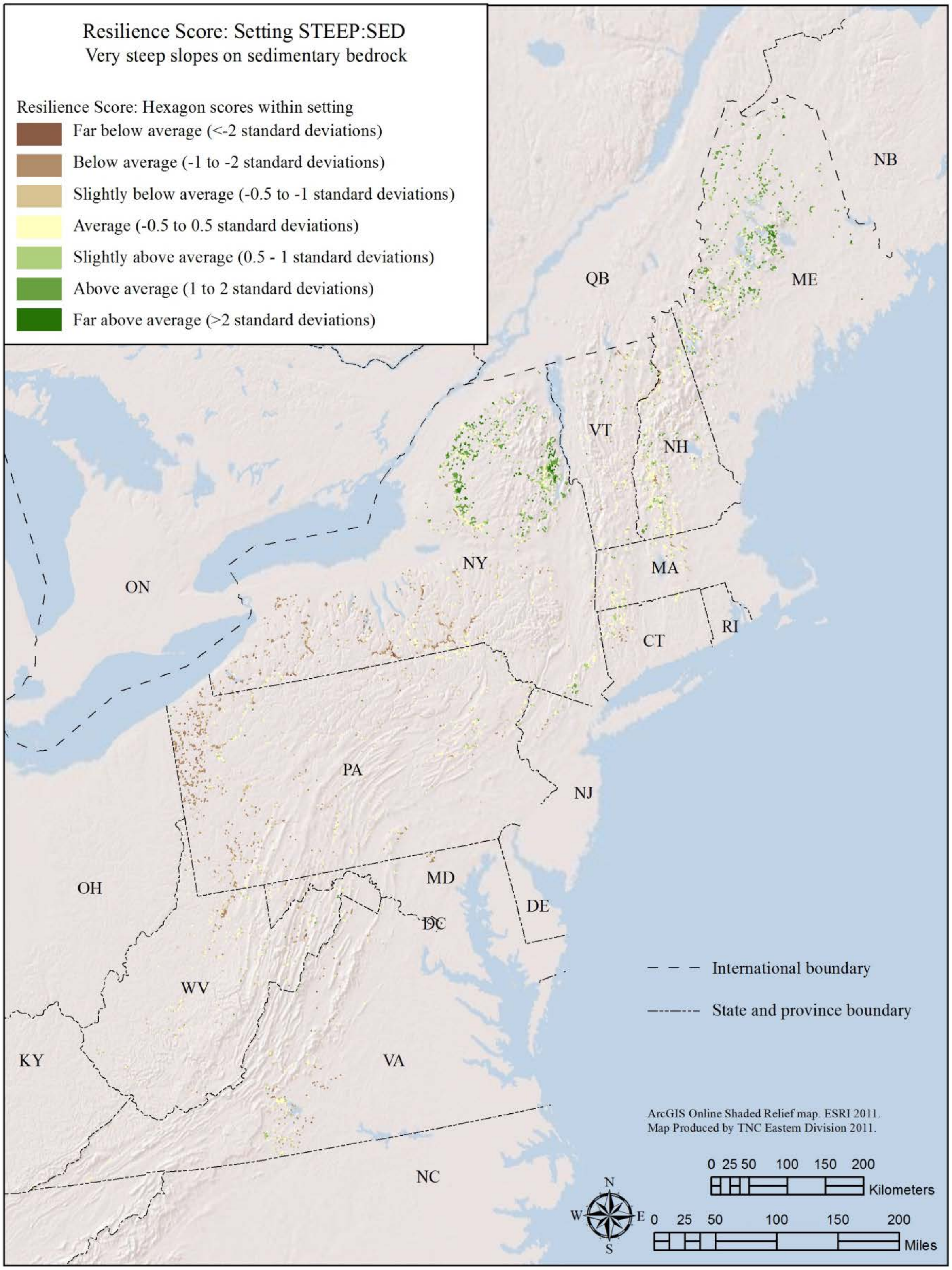


Example: Current Communities
Northern Appalachian acidic seep community, Oak-beech forest, Acidic cliff, Acidic talus slope woodland, Appalachian oak-hickory forest, Appalachian oak-pine forest, Boreal circumneutral outcrop.

Secured Status: 21 percent secured, 13 percent on above average sites.

Resilience Score Category	Percents			Acres
	GAP1 or 2	GAP3	Unsecured	Total Acres
STEEP:SED	8%	13%	79%	4,630,412
1: Far Below Average	0%	0%	17%	807,095
2: Below Average	0%	1%	16%	804,074
3: Average	1%	5%	26%	1,483,110
4: Above Average	1%	3%	10%	637,036
5: Far Above Average	5%	4%	10%	899,097

Map 5.30: STEEP- SED



CHAPTER

6

Results: Resilient Sites

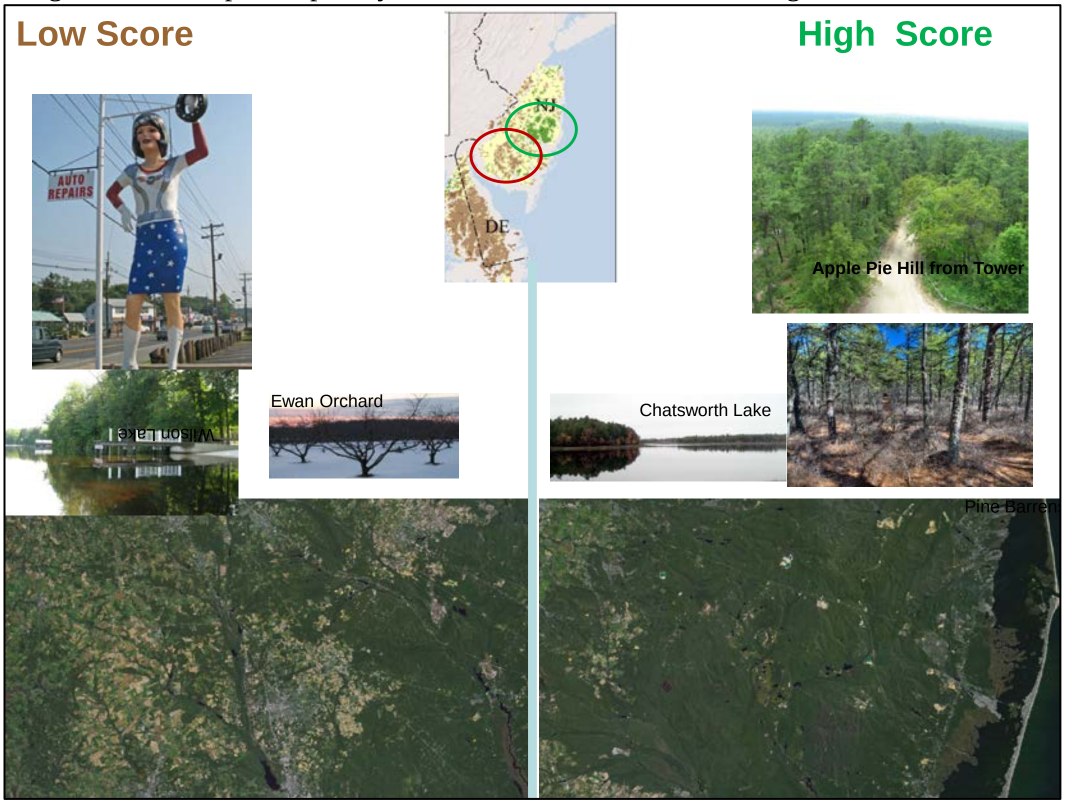
In this chapter, we examine the results derived by combining the geophysical settings, the estimated resilience scores, and the linking flow concentration areas into a single integrated picture. We map the places and networks revealed by this integration within ecological regions (ecoregions).

To guide conservation decisions we compare the results with The Nature Conservancy's portfolio of important biodiversity sites developed previously for each ecoregion and note areas that score high for both estimated resilience and current biodiversity. Further, we pinpoint settings that are underrepresented in the current secured lands network and identify resilient areas for conservation focus. Connected networks of sites with high estimated resilience are identified both within and across ecoregions

Resilience and Vulnerability

Resilience to climate change, and its opposite, **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 6.1).

Figure 6.1. **Estimated resilience and vulnerability.** This image shows air-photos for two areas in New Jersey. The one on the left is flat and fragmented, and scores low for resilience; the one on the right scores has greater landscape complexity and connectedness, and scores higher for resilience.



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. Our standard legend was:

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**

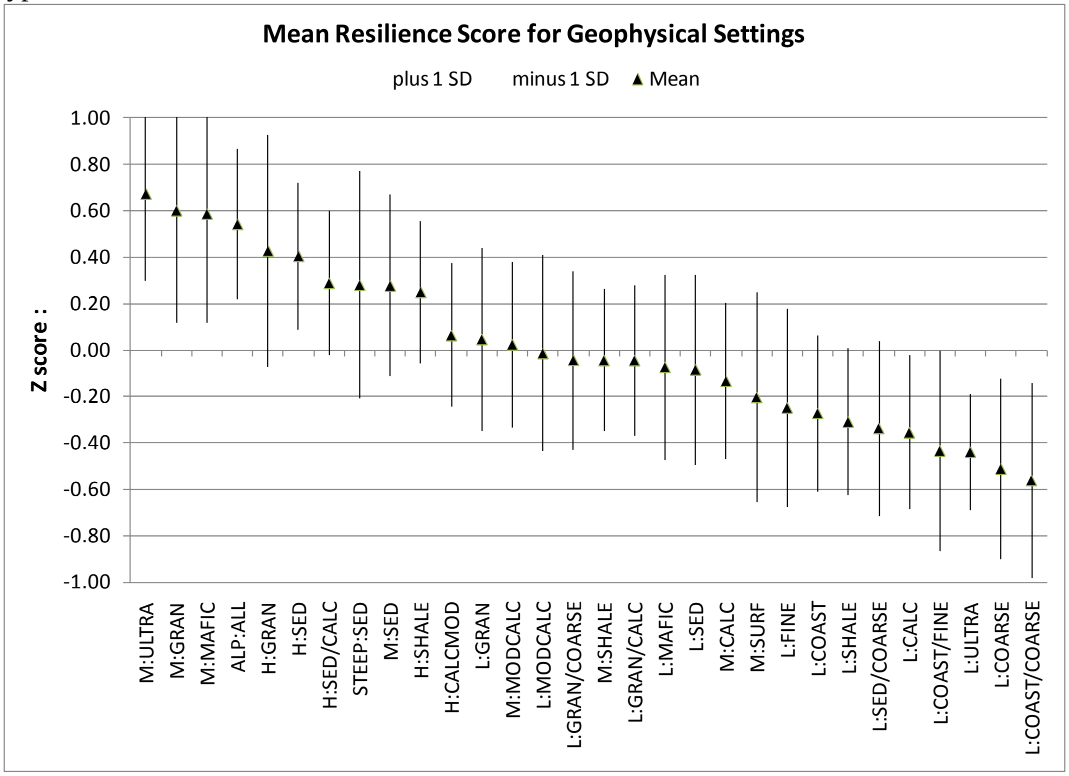
Use of this scheme assumed that the scores followed a normal distribution with a mean and standard deviation that accurately summarized the data. To ensure that this was true, we examined the distribution patterns and when necessary log transformed the data; this did not affect the actual relationships.

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. We measured the discrepancies between settings by summarizing the estimated resilience score for each one (Figure 6.2). Mid elevation granites, for example, represented topographically complex mountainous regions with poor soils. These were largely still intact, with scores averaging above the regional mean. In contrast, low elevation calcareous settings were mostly gentle valley bottoms with fertile soils, highly fragmented by agriculture and development. These settings scored below the regional mean (M-GRAN and L-CALC in Figure 6.2).

To account for the inherent differences between settings, each was evaluated individually within an ecoregion, and the results were combined into a single map that showed the highest scoring areas for each setting.

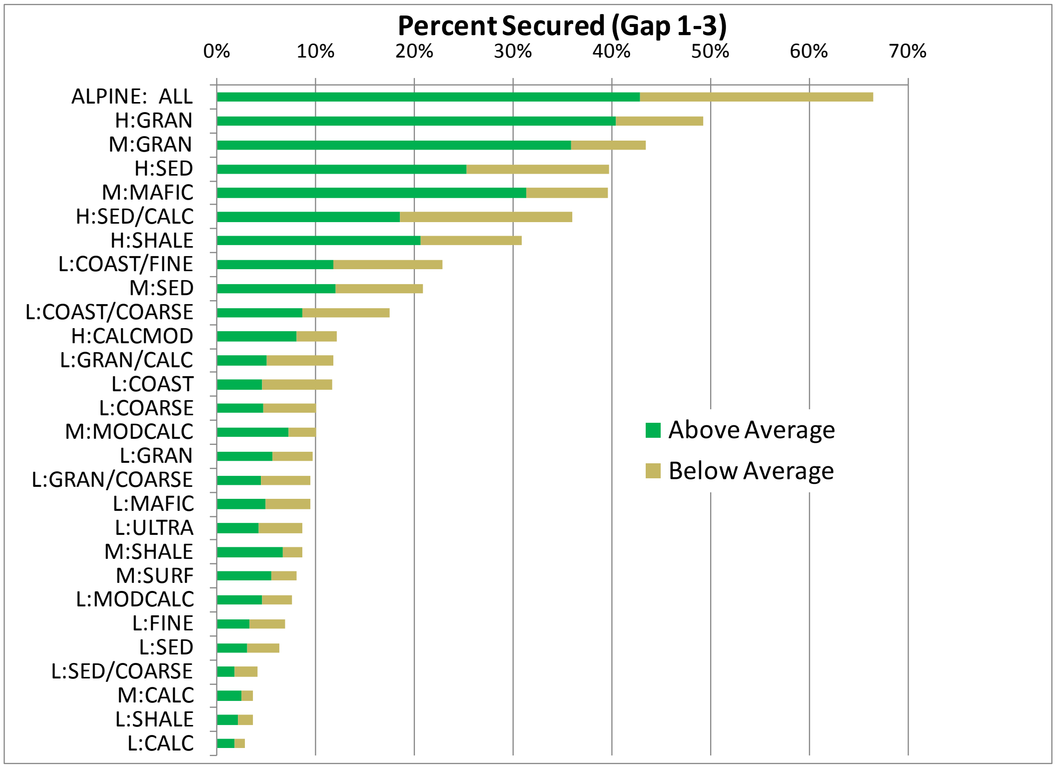
Figure 6.2. **Average resilience score for each geophysical setting**. Units are in z-scores with a mean of zero and standard deviation of one based on all cells in the region. Setting abbreviations match the codes described in Chapter Five. Low scoring settings on the right side are almost exclusively low elevation types with soils derived from surficial sediment, limestone or shale



To account for the inherent differences between settings, each was evaluated individually within an ecoregion, and the results were combined into a single map that showed the highest scoring areas for each setting.

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. Low elevation calcareous settings, that constitute the best agricultural and tree growing land in the region were less than five percent secured. In contrast, high elevation alpine environments – wonderful for hiking but difficult places in which to live or farm – were over 66 percent secured (Figure 6.3). Like the low scoring settings, the underrepresented settings were predominantly low elevation regions with soils derived from surficial sediments, or calcareous, moderately calcareous, or shale bedrock. Mid elevation calcareous and shale bedrocks were underrepresented as well.

Figure 6.3: Securement status of the geophysical settings. This chart shows the proportion of total securement for each setting, 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 Baily 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).

The ecoregions we used for this analysis were developed by The Nature Conservancy in conjunction with the U.S. Forest service. They are a modification of Baily (1995) that puts more emphasis on natural communities and less on climate. Six ecoregions were fully contained within the 13-state area of interest and it is within these that we have high confidence in the results of this analysis. Alphabetically, these were (Map 6.1):

Central Appalachians (CAP)
Mountainous regions of central PA, WV, MD, VA, and TN consisting of high plateaus (Allegheny mountains 1000-4861 ft.), folded and faulted parallel ridges (the ridge and valley 300-4000ft), a belt of folded limestone (the Great Valley) and uplifted mountains (northern Blue Ridge 1000-4000 ft.). Bedrock is mostly of sedimentary origin.

Chesapeake Bay (CBY)
This region consists 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.

High Allegheny Plateau (HAL)
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, and the unglaciated regions are mostly sandy clays.

Lower New England and Northern Piedmont (LNE)
An extensive low-relief plain 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. Well-drained coarse sandy soils are common in outwash areas. Farther south, in the un-glaciated piedmont, these features are less common.

North Atlantic Coast (NAC)
Glaciated irregular plains 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.

Northern Appalachian –Acadian (NAP)
Mountainous regions and boreal hills and lowlands in Northern New England and Maritime Canada. The ecoregion includes 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 and all of New Brunswick, Nova Scotia and Prince Edward Island.

Partial Ecoregions: Several other ecoregions had a small portion of their full extent included within this region. For these areas, the **results may be biased** because we only examined the portion occurring within the States and Provinces included in the study area. Because our evaluation methods were based on comparing scores for sites to the average score for the ecoregion, evaluating only a portion of an ecoregion will not give the same results as if we examined the whole ecoregion. This may have artificially inflated or decreased scores. The partial ecoregions included:

Cumberland Plateau (CUP)
This region consists of low mountains and dissected sedimentary uplands extending to WV and VA.

Great Lakes (GL)
An extensive glaciated lake plain, lowlands, morainal hills and till plains in PA and NY,

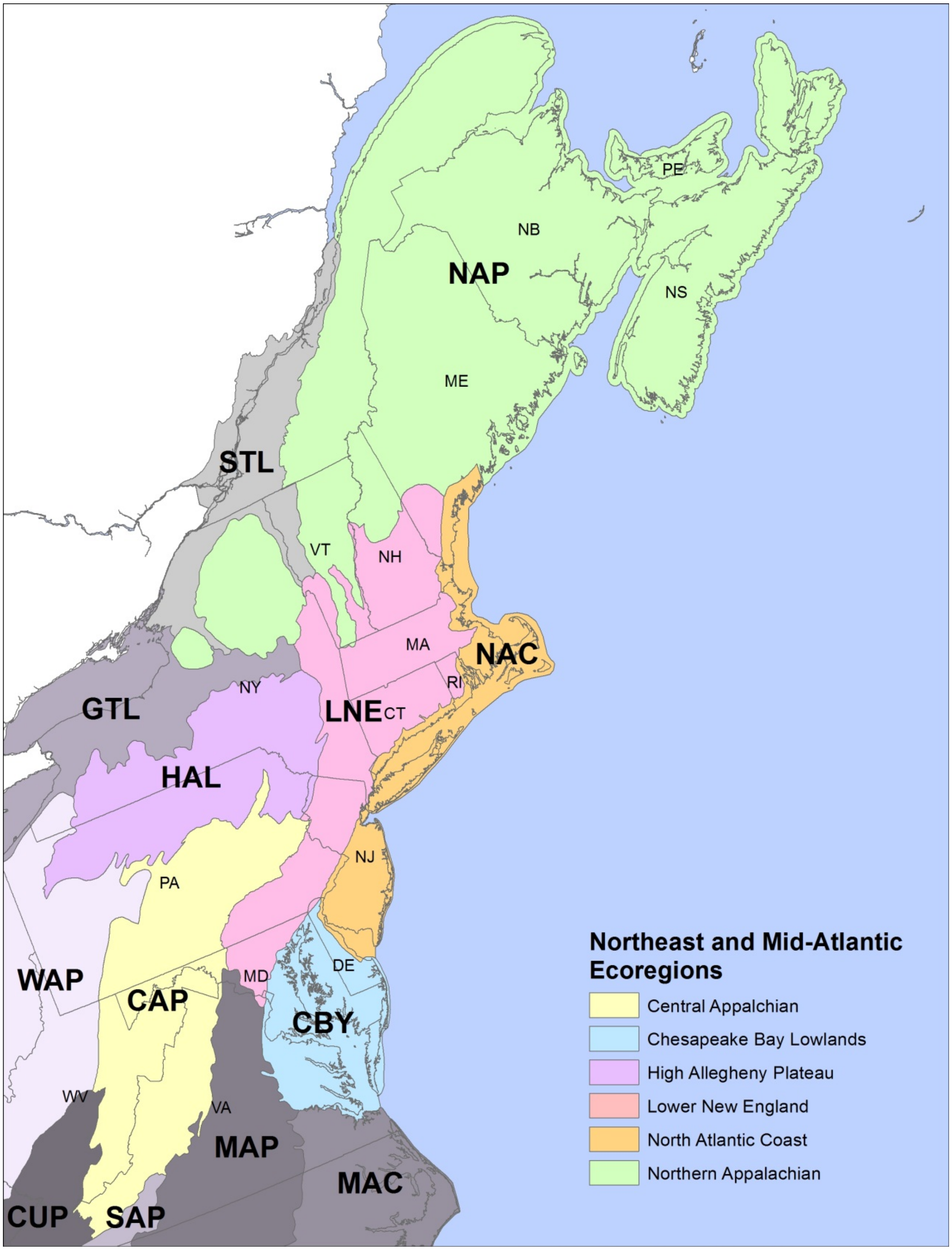
Piedmont (PIE)
This is a stream-dissected plain extending southward from central Virginia.

Southern Appalachians (SAP)
This is a mountainous region of southern VA, western NC and SC, northernmost GA and Eastern TN.

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

Western Allegheny Plateau (WAP)
This region is a mature, stream-dissected plateau in NY, PA, and WV.

Map 6.1: The Nature Conservancy's ecoregions of the Northeast and Mid-Atlantic regions.



Ecoregion Results

For each wholly contained ecoregion, we present our results maps as five key maps:

1) The highest scoring areas for estimated resilience,
2) The most resilient examples of each geophysical setting in the ecoregion,
3) Focal areas with high estimated resilience,
4) Key places of current and future biodiversity, and
5) Networks of resilient site based on linkages and focal areas.

Each result was calculated **relative to the ecoregion and to the setting**. Explanations, interpretation, and, in some cases, the method of mapping, are described below. The finals set of maps show the entire region, but these are composites of the individual ecoregion maps plus the results for the partial ecoregions. The latter areas are lightly blurred on the maps to remind users of the problems with the partial ecoregions.

<u>Highest Scoring Areas for Estimated Resilience.</u> These wall-to-wall 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). Specifically, the maps display the estimated resilience score for every individual 1000-acre hexagon, in relation to the average score for all hexagons of that setting in the ecoregion. Green colors indicate areas that scored above average for estimated resilience; these were the places with the highest landscape complexity 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.

A small, but logical, modification to these 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. The regional override corrected for this because all these sites were expected to be highly resilient.

<u>The Most Resilient Examples of each Geophysical Setting in the Ecoregion</u>. These maps show only the hexagons that scored above the mean (> 0.5 Z-score) 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. Several important patterns were revealed by this perspective. First, some resilient areas contain many types of settings in close proximity; an example of this was in the southern Central Appalachians where sedimentary ridges, shale slopes, calcareous valleys, and alpine mountains co-occur in a small area. These highly diverse landscapes would be excellent places for conservation action. Second, the maps reveal how the visual patterns of resilience were influenced by the amount of each setting in the ecoregion; an example of this is seen in the Northern Appalachians where mid-elevation sedimentary settings dominated the landscape. Because we identified the most resilient half of this setting, there is, by definition, a lot of this setting shown on the map. Lastly, these maps exposed settings have a number of small but high scoring sites scattered throughout the ecoregion as single 1000-acre hexagons.

Focal Areas with High Estimated Resilience: These maps display a simplified picture of the resilient sites created by grouping together hexagons that scored high for estimated resilience and occurred in close proximity to each other. The groupings smoothed out the map by clustering adjacent individual hexagons into larger identifiable sites and ignoring isolated hexagons. The new "sites," that we call "focal areas" could be easily overlaid with other pertinent information such as species and community locations, and secured lands, as we did below.

To create the focal areas we created polygons around areas with a high density of resilient hexagons. In order to do this, we extracted all hexagons with a resilience score one-half standard deviation above the mean or greater (>0.5), and created a point indicating the centroid of each hexagon. Next, we ran a point density analysis using a 10,000 acre circular neighborhood around every cell in the region. This resulted in a surface where each cell (90 meter) was coded with the density of high scoring hexagon centroids within its neighborhood. Cell values ranged from 0 to 12, with the number indicating the number of high scoring hexagons within the 10,000 acre radius, (as each hexagon is 1000 acres, a value of 12 indicates that 100 percent of the area plus the boundary regions scored high. After visual inspection, we chose a threshold of >= 5 as a cutoff to represent areas of high density. Contiguous grid cells with values >= 5 were grouped into polygons using the regiongroup and gridpoly ArcGIS functions. We used a size criterion of >= 1000 acres to filter out single hexagons.

Key Places for Current and Future Biodiversity.
These maps compare the areas that scored high for resilience with the areas that were identified as important places for current biodiversity in The Nature Conservancy's ecoregional assessments. The Conservancy's ecoregional portfolios were designed to identify the best occurrences of all rare species and natural communities that were characteristic of each ecoregion. The large number of ecological features assessed in the assessments included: rare vertebrates, invertebrates and plants; all types and scales of communities from large forests and wetlands to small isolated fens or cliff communities; streams and rivers of all sizes; and subterranean caves. Each occurrence had to meet a viability criteria based on its size, condition, and landscape context. Additionally, each portfolio was meant to encompass multiple examples of all target features in sufficient number, distribution, and quality to ensure their long-term persistence within the ecoregion.

The Conservancy spent over a decade completing ecoregional assessments, and each one took years to complete. In addition to including the best available data on the ecological features of the region, the assessments were performed by teams of ten to fifty scientists, including experts on each target of interest. The idea was to create a blueprint - a portfolio - of public and private conservation areas that, if conserved, would collectively protect the full biological diversity of an ecoregion. In the Northeast and Mid-Atlantic United States, the assessments focused first on terrestrial ecosystems and next on freshwater aquatic systems. These have now been integrated into one portfolio. Marine ecoregions were also completed in the Northwest Atlantic and are underway in the South Atlantic Bight. Full information on all of the Northeast and Mid-Atlantic ecoregional assessments, as well as the maps, reports and data for each ecoregion may be found at http://conserveonline.org/workspaces/ecs/plans

Ecosystem and community sites identified by the ecoregional assessments were done at multiple scales from large matrix-forming forest types to unique small patch communities such as limestone cliffs. Because the protection of viable examples of these representative ecosystems was intended to serve as a "coarse filter," to conserve both common and rare species, there is a direct relationship between the coarse-filter ecosystems and the geophysical settings. In one sense, the settings are just a coarser filter, where the emphasis is on the physical setting rather than the species composition – an ecosystem is defined as the intersection of both features.

Overlaying the ecoregional portfolio sites on the resilient sites identified **areas that have both significant current biodiversity and the potential for long term resilience**. Our expectation, however, was not that the biodiversity will stay the same at the site; rather the overlay provides confirmation that the site currently supports a diverse community of native species and maintains its ecological functions and processes. The combination of estimated resilience and confirmation of current biodiversity, suggested places where conservation practitioners have much to work with, and where they might succeed in sustaining a resilient system over the long term. Surprisingly, across the whole regional portfolio, at least one site that scored high for both resilience and biodiversity was apparent for every geophysical setting, the smallest amount being 5,000 acres of low elevation ultramafic.

The targets in the ecoregional portfolio varied in their inherent viability; even the best known examples of some rare species populations, for example, were only found in fragmented landscapes. Correspondingly, the overlay also identified sites that have significant current biodiversity but scored as vulnerable to changes driven, or exacerbated by, a changing climate. These sites are shown on the maps in brown colors. Additionally, the overlay highlighted places that scored high for estimated resilience but for which the assessments had not identified significant current biodiversity – many of the linkage areas met this criteria. We recommend that the latter areas be examined further before investing deeply in land conservation.

<u>Focal Areas, Linkages and Networks:</u> The final maps show the juxtaposition of the focal areas with the key linkages and flow concentration areas. To make the maps, we first used the results of the circuitscape regional flow pattern analysis to identify areas where, due to the patterns of human use, ecological flows and species movements potentially become concentrated or channelized. We mapped these pathways by selecting areas where "current density" was above the mean for the region. To identify potential key linkages we overlaid the focal areas that scored high for resilience on the flow concentration surface. The resulting maps illustrate the overlap between the hexagons and the high current density areas, as well as the areas between the sites that might merit attention for connectivity.

This analysis shows three prevalent patterns of flow in the region: 1) areas with low scores and low permeability, 2) areas with average scores indicating connected areas with diffuse flow patterns, and 3) areas with high scores where flows become concentrated.

Notes on creating the flow pattern maps: the areas of regional flow concentration were created from the Regional Flow Patterns grid. Grid cells were extracted that scored above average (>1000) for the concentrated flow and scored average (between -500 and 1000) and then converted these grids into points. Next, we ran a point density analysis using a 10,000 acre circular neighborhood at 90 meter resolution. The smaller polygons (less than 1000 acres) were filtered out in order to produce a clean map. In a few very developed spots (mainly northern New Jersey) the landscape was so developed, current has no choice but to be diffuse in developed landscapes. The developed land use classes from the input grid were removed from the regional flow concentration grid.

Central Appalachians

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.

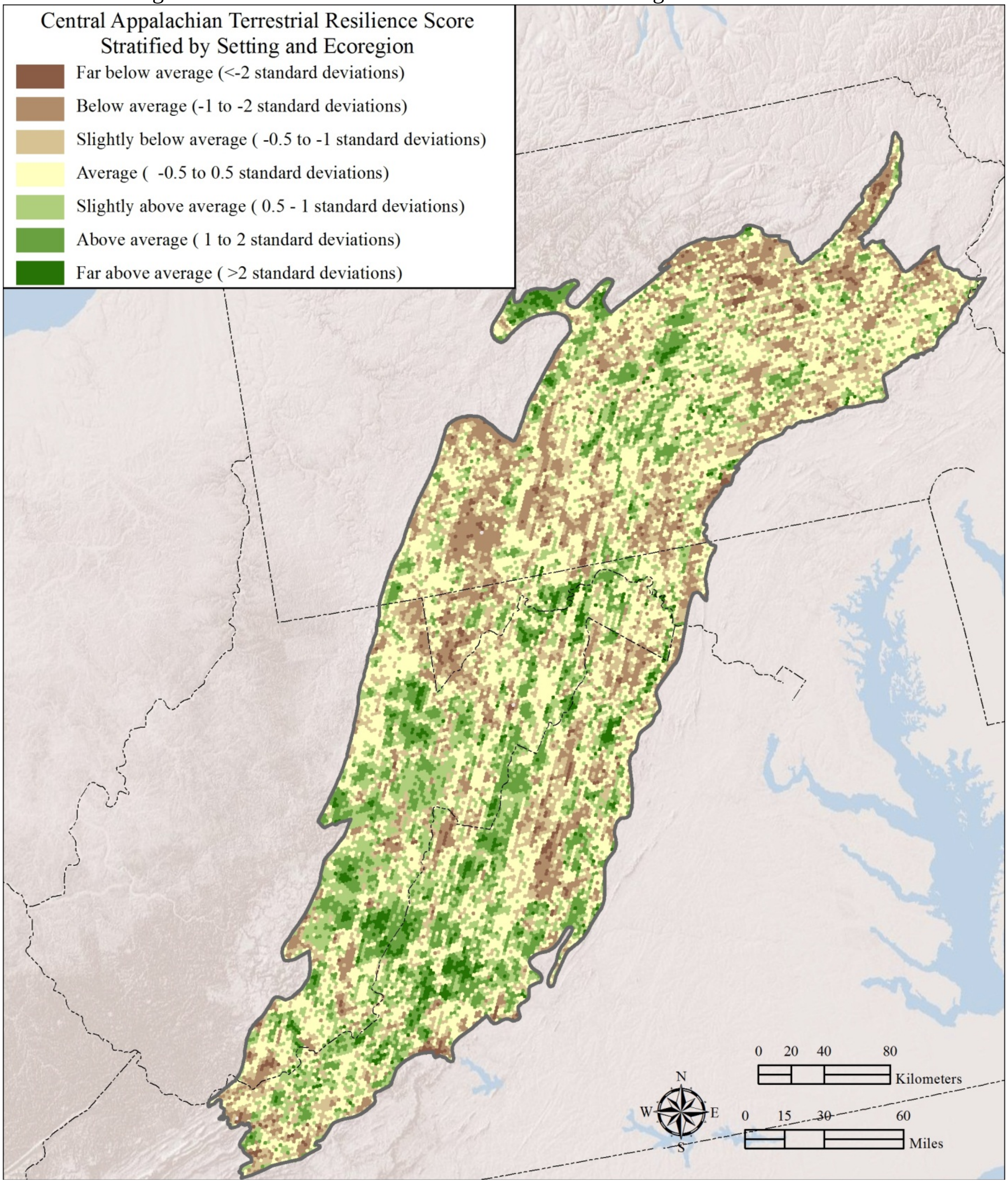
This region is primarily forested with oak-heath forest, mixed mesophytic forest and oak-hickory-ash forest forming the dominant matrix. High elevation areas contain red spruce rocky summits and swamps, talus slope woodlands, shale barrens, ridge top pitch pine barrens, and dwarf red oak communities. 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.

<u>Highest scoring areas for each setting</u> (Map 6.2 and 6.3)
Areas that scored high for resilience were concentrated in the mountainous regions of West Virginia, the Allegheny front, and the ridge and valley region of central Pennsylvania. The Great Valley and Clinch River watershed contained some of the top scoring limestone areas in the region.

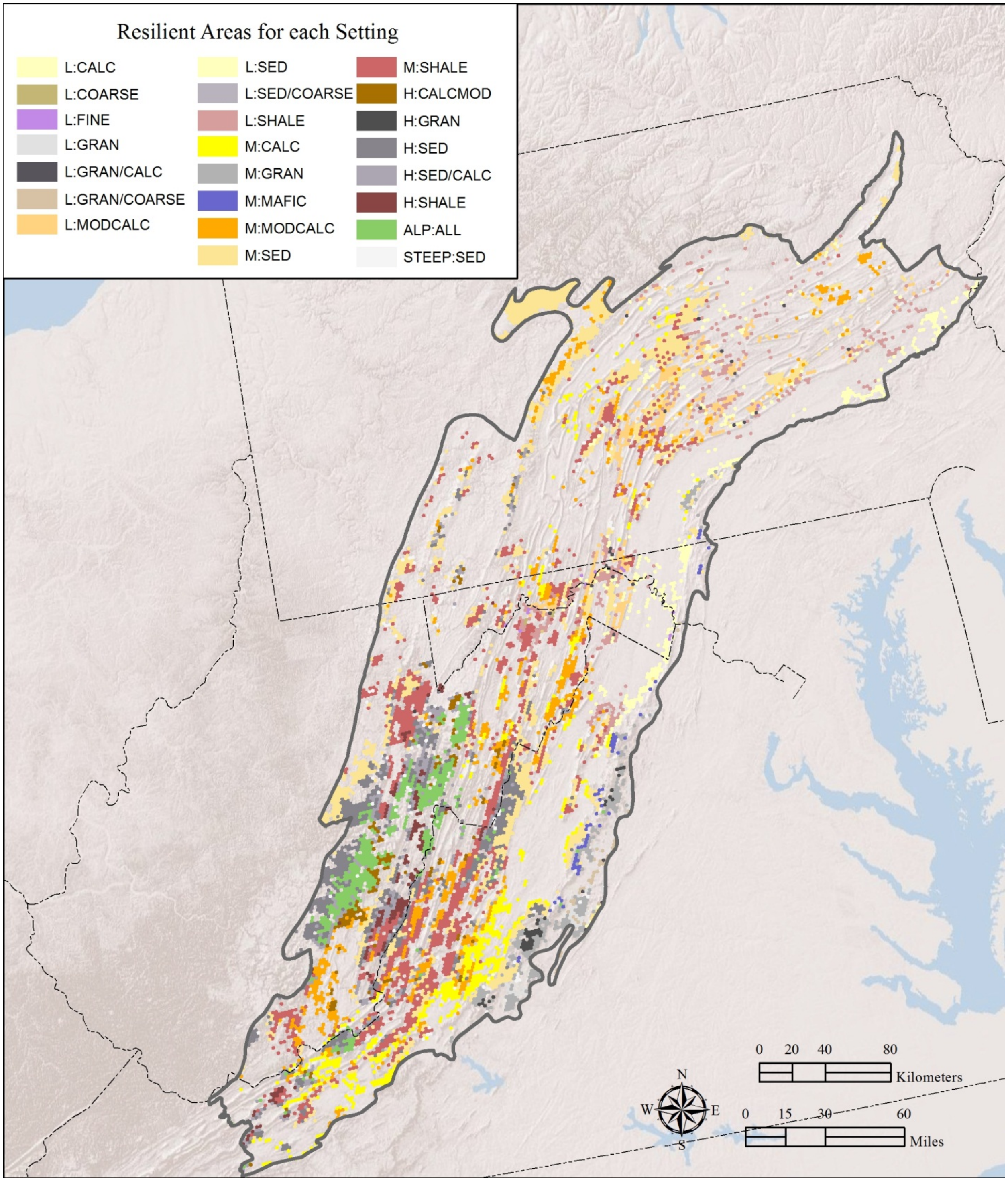
<u>Focal areas and key places for current and future diversity</u> (Map 6.4 and 6.5)
In this region there was strong correspondence between the portfolio and the resilient sites. Sites that did not score well, and are likely vulnerable to climate change, included many of the small patch wetland complexes in the northern section of the Great Valley, and some of the forest blocks in central Pennsylvania.

<u>Linkages and networks of resilient sites</u> (Map 6.6)
The Central Appalachians ecoregion had the highest concentrated current flow of any ecoregion in the study area. It is uniquely positioned to intercept north-south movements and the natural ridgelines connecting forest areas appeared to be important linkages to maintain.

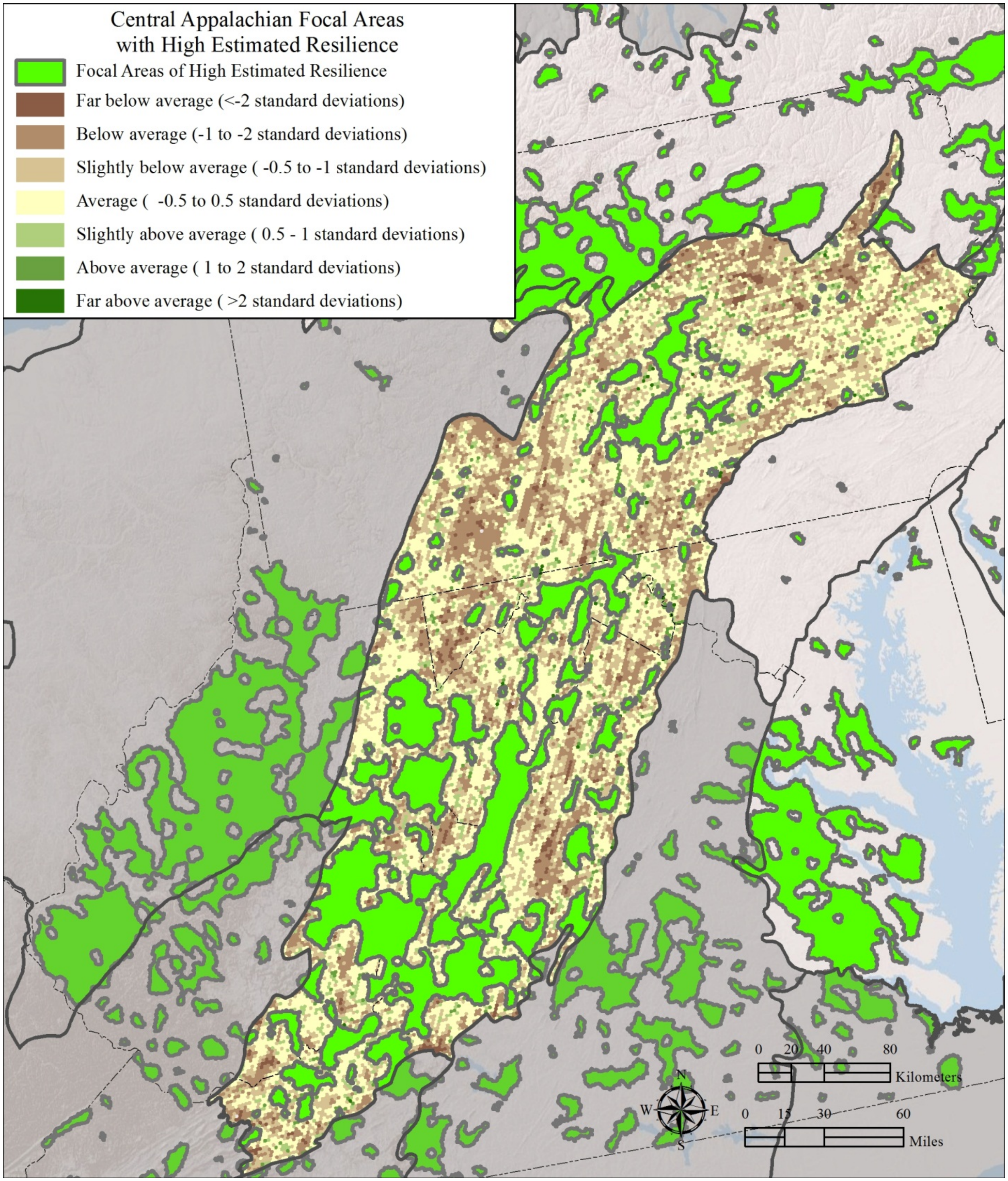
Map 6.2: Central Appalachians: Resilience Estimates. Areas in yellow are comprised of cells with an average estimated resilience score based on their geophysical setting, landscape complexity and local connectedness. Areas in green score above average and are estimated to be more resilient. Areas in brown are below average and are estimated to be vulnerable to climate change and other factors.



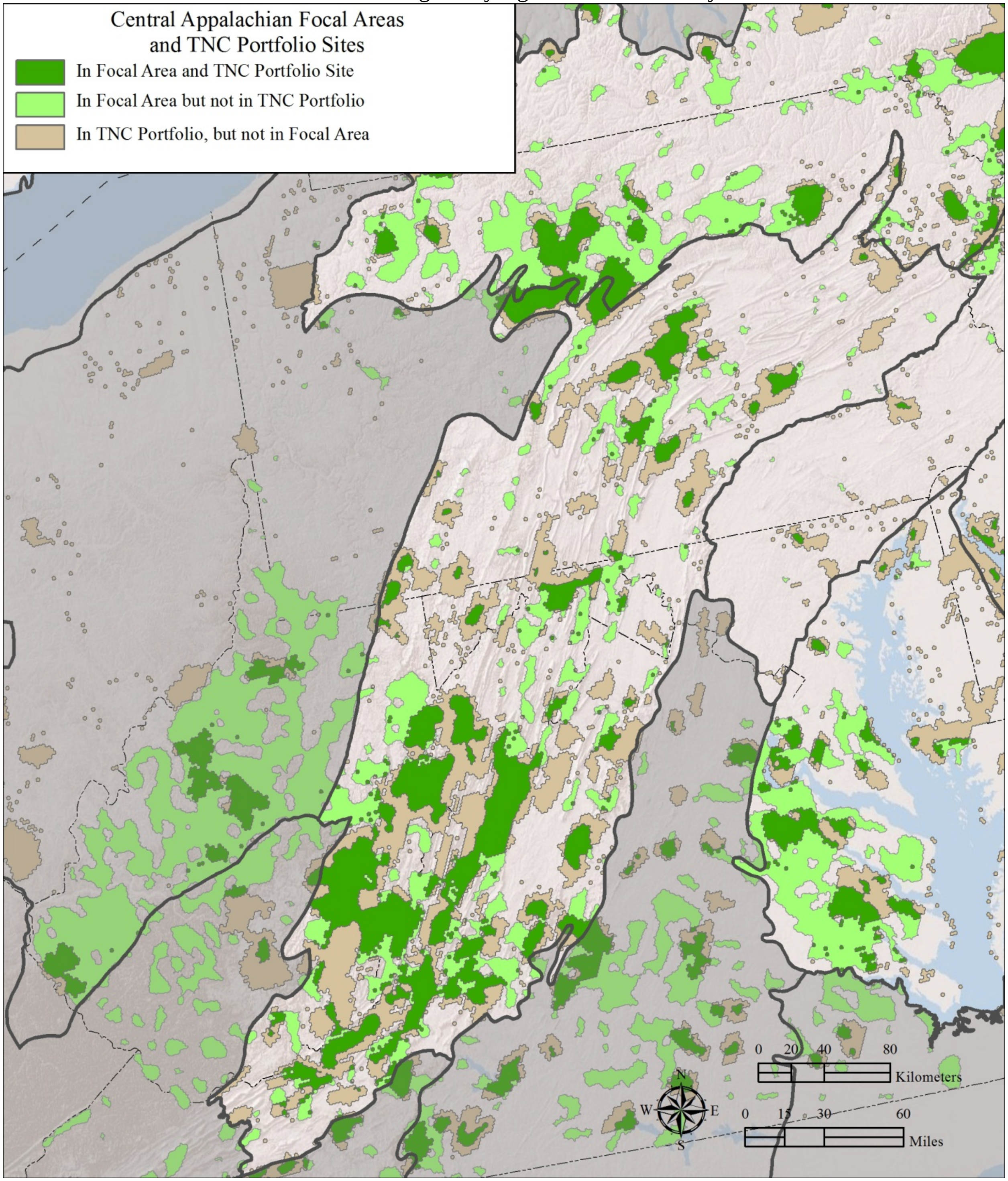
Map 6.3: Central Appalachians: Resilient Areas for each Setting. This map shows only the 1000-acre hexagons that score above the mean for estimated resilience; each high scoring hexagon is colored based on its corresponding geophysical setting. This map reveals how the settings are reflected in the resilience scores.



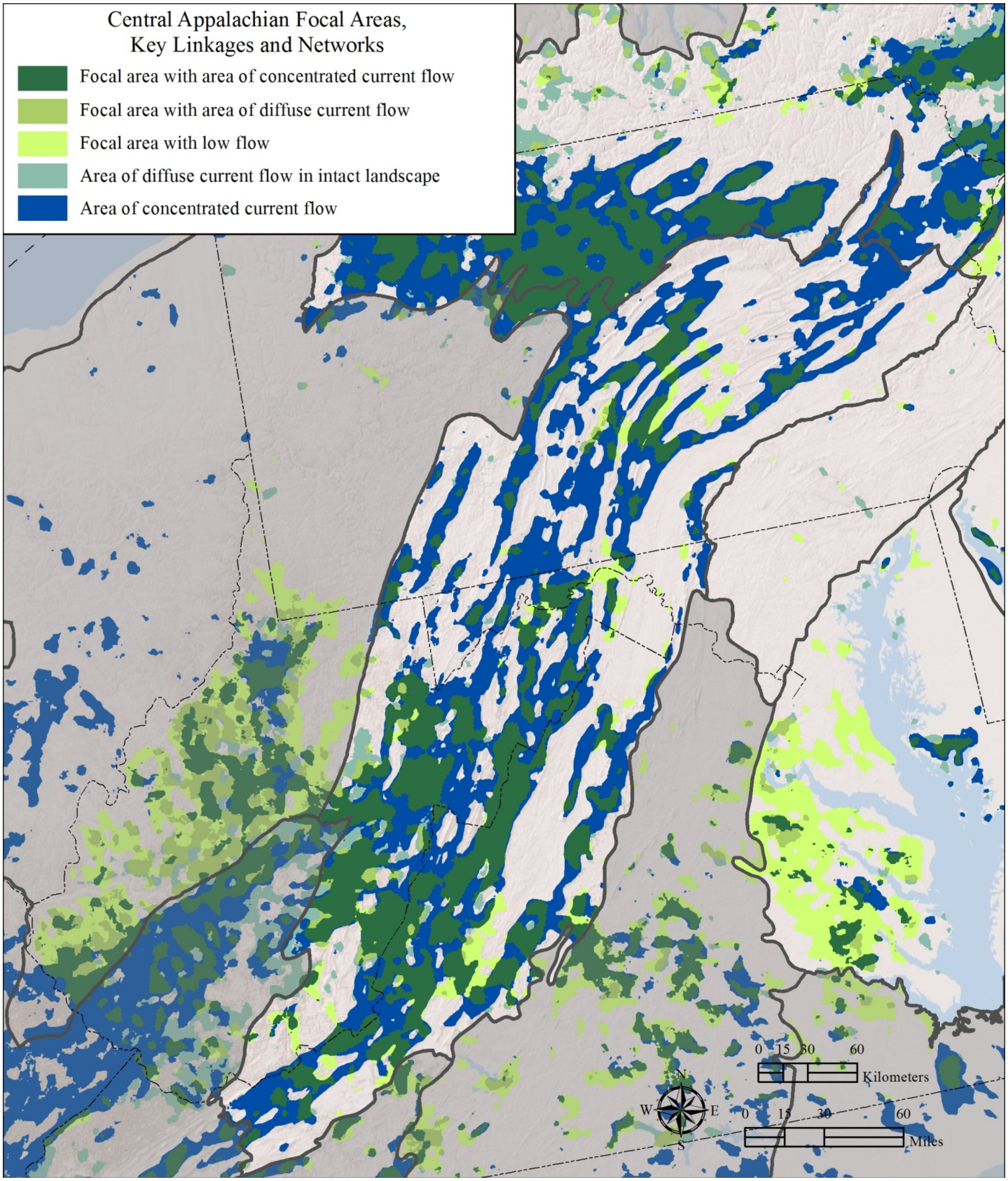
Map 6.4: Central Appalachians: Focal Areas with High Estimated Resilience. This map simplifies the estimated resilience map by clustering adjacent areas of high resilience into larger sites and ignoring single small isolated sites. Although the map relinquishes some detail, it is designed to identify large and small landscapes appropriate for conservation focus.



Map 6.5: Central Appalachians: Focal Areas and TNC Portfolio sites. This map identifies the focal areas that correspond with The Nature Conservancy's ecoregional portfolio of sites with significant biodiversity. The portfolio sites contain the best known occurrences of a forest, wetland or unique natural community, a rare species, a cave or stream system, or all of the above. Sites in dark green meet the criteria for high estimated resilience and for significant biodiversity. Sites in brown have significant biodiversity but are estimated to be vulnerable to climate change. Sites in pale green have high estimated resilience but were not known to have ecoregionally significant biodiversity features.



Map 6.6: Central Appalachians: Focal Areas, Key Linkages and Networks. This map integrates the focal areas with the regional flow concentrations. In the map, focal areas located in areas of high flow concentrations area shown in olive green. Focal areas that are large and highly intact have diffuse flow and are shown in pale green. Key linkages are shown in areas with no focal area but high amounts of concentrated flow, and these are shown in dark blue. Blue-green areas are fairly intact regions with diffuse flow but no identified focal area.



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.

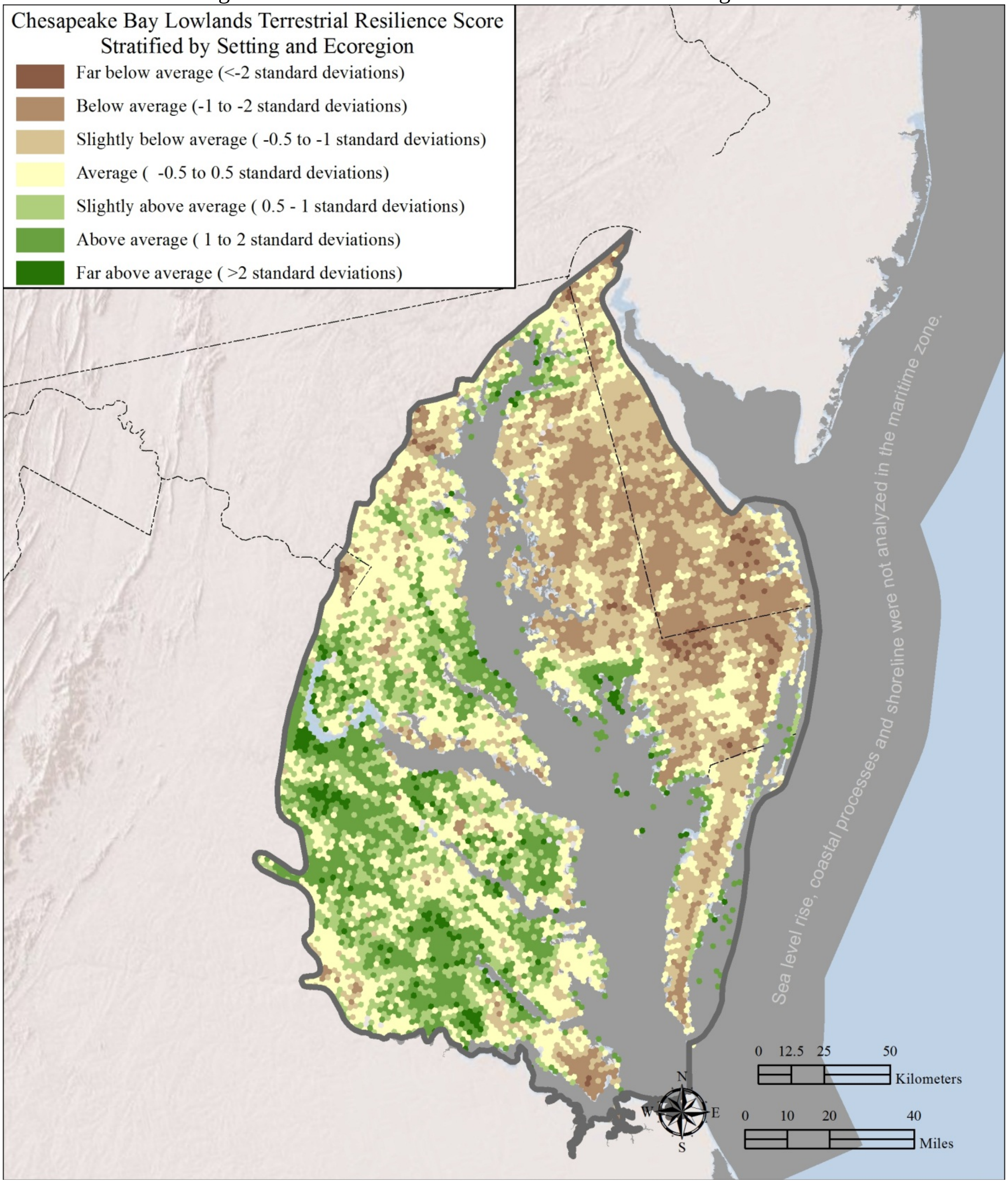
Highest scoring areas for each setting (Map 6.7 and 6.8)
Areas that scored high for resilience included much of the entire southwestern section – the Atlantic Southern Loam Hills - of the ecoregion.

This region included coastal shoreline where the analysis may be inaccurate due to incomplete or faulty data along the oceanic border of the region (see discussion in Chapter 2*), or because we did not account for sea-level rise.*

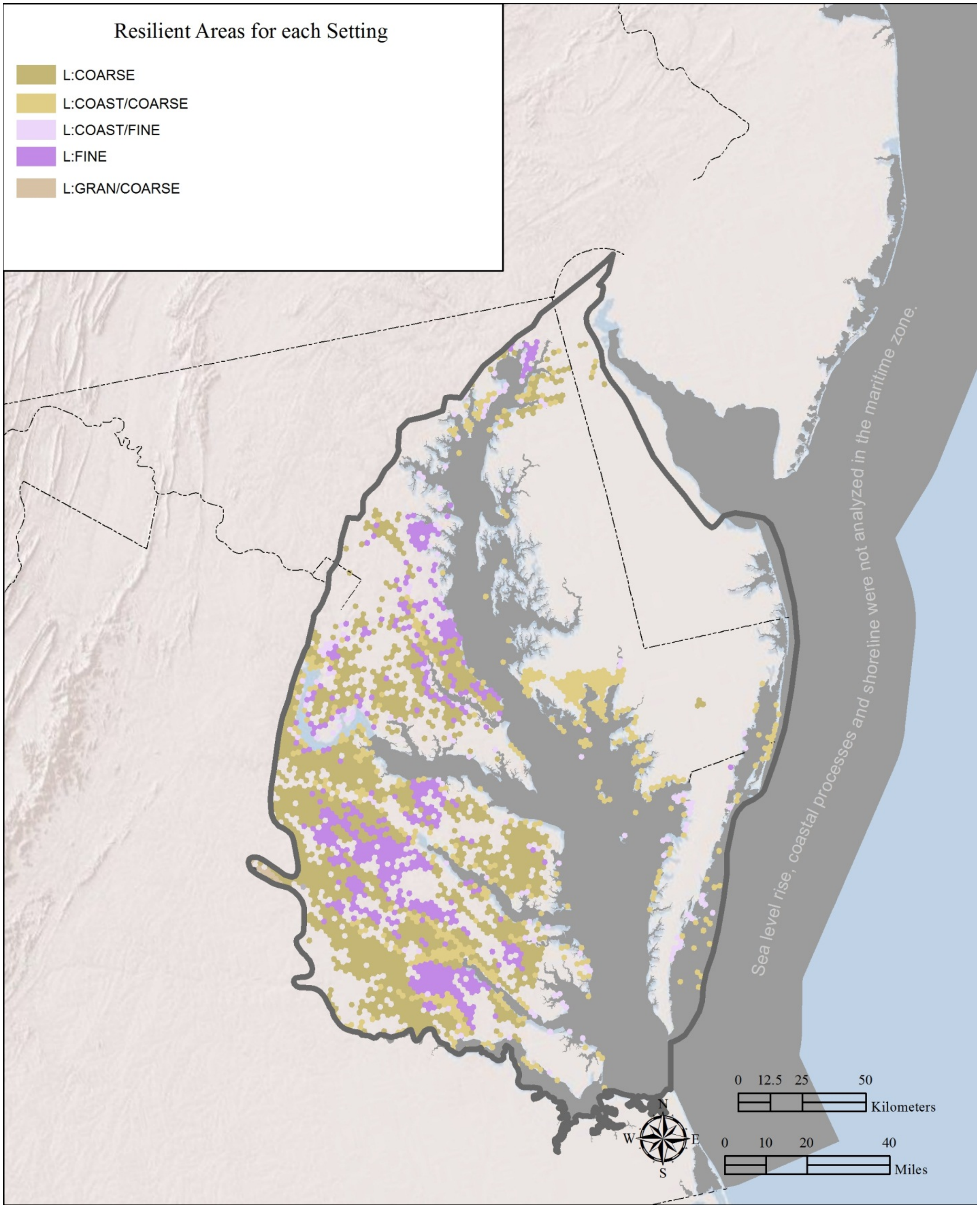
Focal areas and key places for current and future diversity (Map 6.9 and 6.10)
In this region the west side of the Bay had a strong correspondence between the portfolio and the resilient sites, but the opposite was true on the east side of the bay, especially the Delmarva Upland, which scored as vulnerable or highly vulnerable to climate change.

Linkages and networks of resilient sites (Map 6.11)
The Chesapeake Bay Lowlands ecoregion had few flow concentration areas, but small ones are scattered throughout the southern end of the ecoregion.

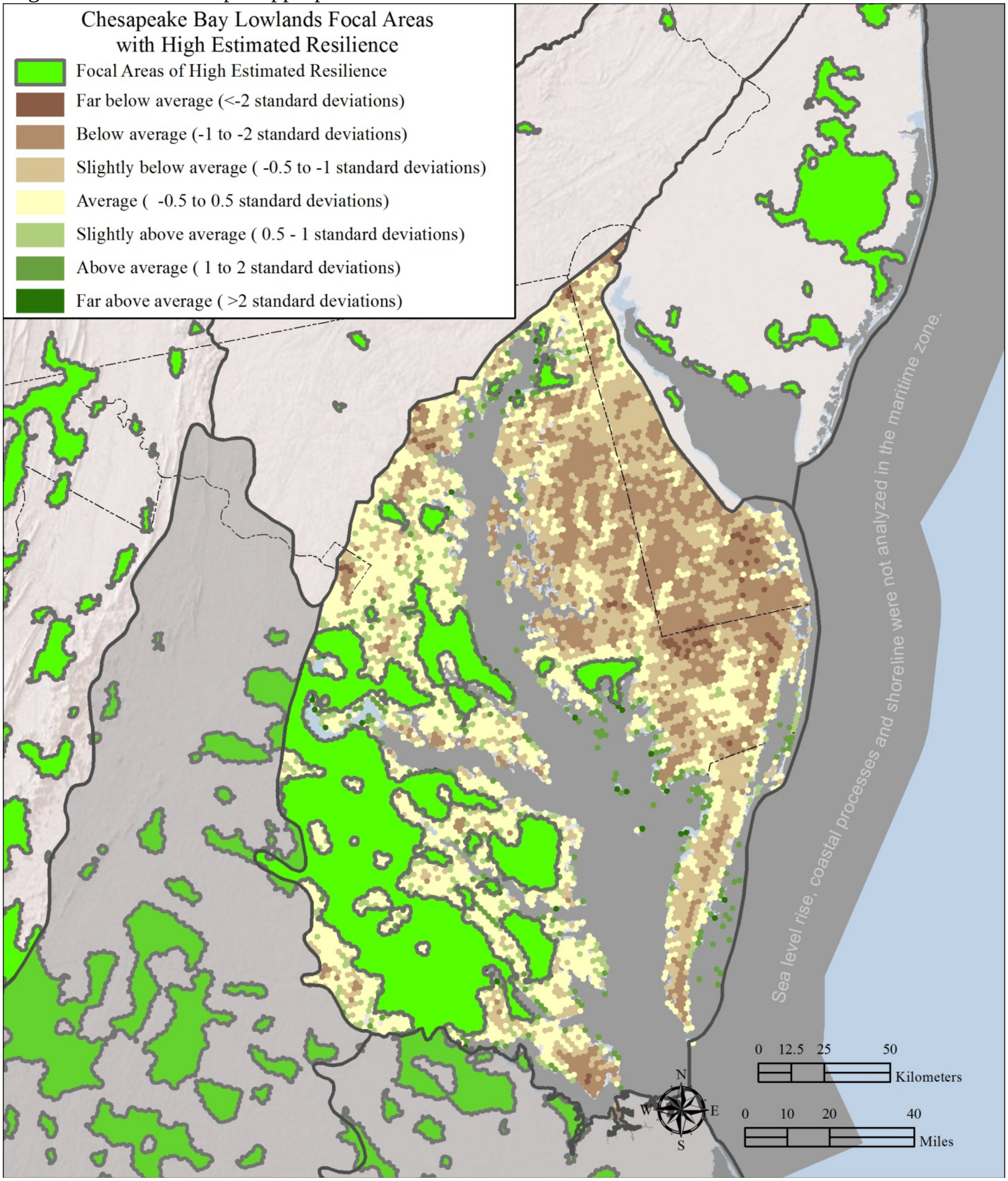
Map 6.7: Chesapeake Bay Lowlands: Resilience Estimates. Areas in yellow are comprised of cells with an average estimated resilience score based on their geophysical setting, landscape complexity and local connectedness. Areas in green score above average and are estimated to be more resilient. Areas in brown are below average and are estimated to be vulnerable to climate change and other factors.



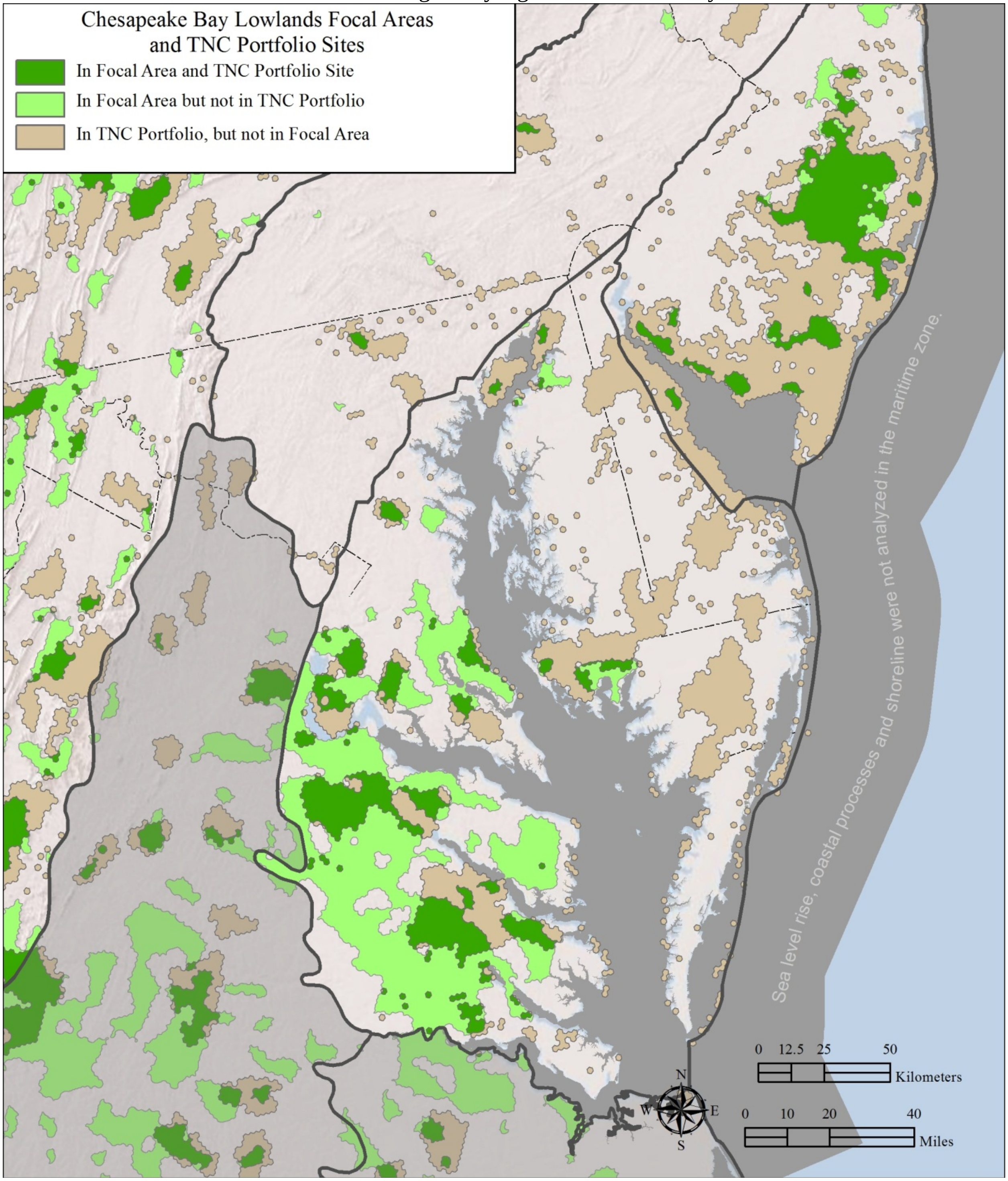
Map 6.8: Chesapeake Bay Lowlands: Resilient Areas for each Setting. This map shows only the thousand-acre hexagons that score above the mean for estimated resilience; each high scoring hexagon is colored based on its corresponding geophysical setting. This map reveals how the settings are reflected in the resilience scores.



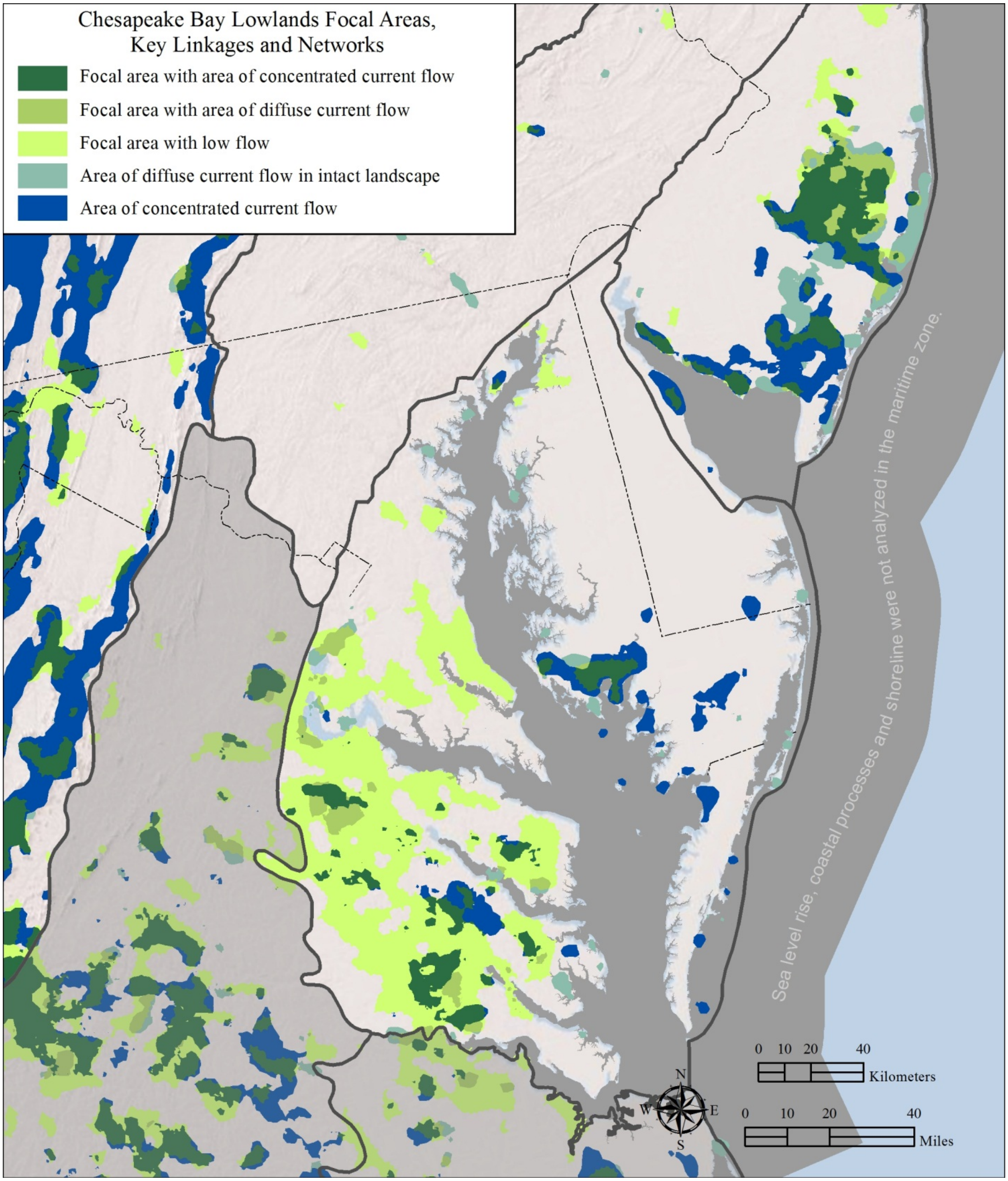
Map 6.9: Chesapeake Bay Lowlands: Focal Areas with High Estimated Resilience. This map simplifies the estimated resilience map by clustering adjacent areas of high resilience into larger sites and ignoring single small isolated sites. Although the map relinquishes some detail, it is designed to identify large and small landscapes appropriate for conservation focus.



Map 6.10: Chesapeake Bay Lowlands: Focal Areas and TNC Portfolio sites. This map identifies the focal areas that correspond with The Nature Conservancy's ecoregional portfolio of sites with significant biodiversity. The portfolio sites contain the best known occurrences of a forest, wetland or unique natural community, a rare species, a cave or stream system, or all of the above. Sites in dark green meet the criteria for high estimated resilience and for significant biodiversity. Sites in brown have significant biodiversity but are estimated to be vulnerable to climate change. Sites in pale green have high estimated resilience but were not known to have ecoregionally significant biodiversity features.



Map 6.11: Chesapeake Bay Lowlands: Focal Areas, Key Linkages and Networks. This map integrates the focal areas with the regional flow concentrations. In the map, focal areas located in areas of high flow concentrations area shown in olive green. Focal areas that are large and highly intact have diffuse flow and are shown in pale green. Key linkages are shown in areas with no focal area but high amounts of concentrated flow, and these are shown in dark blue. Blue-green areas are fairly intact regions with diffuse flow but no identified focal area.



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 East-West flow patterns in the region.

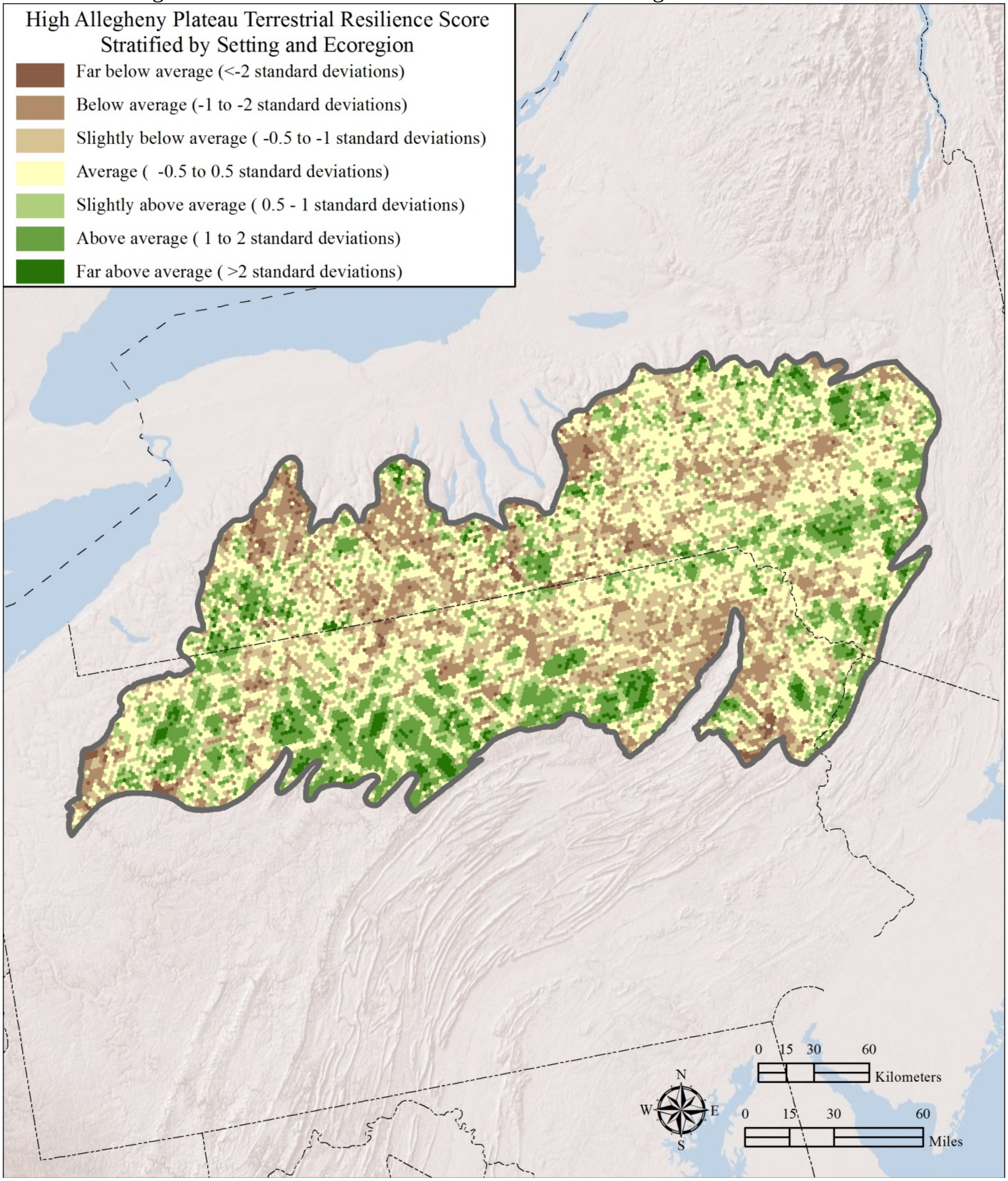
This ecoregion is primarily forested with oak-heath forests, maple-beech-birch northern hardwoods, hemlock-white pine and oak-hickory-ash forest forming the dominant matrix type. Other typical communities include hemlock swamps, leather leaf bogs and blueberry bogs.

<u>Highest scoring areas for each setting</u> (Map 6.12 and 6.13)
Areas that scored high for resilience included the Allegheny High Plateau and Deep Valley regions, parts of the Catskill Mountains and some shale and limestone areas that flank the Mohawk Valley.

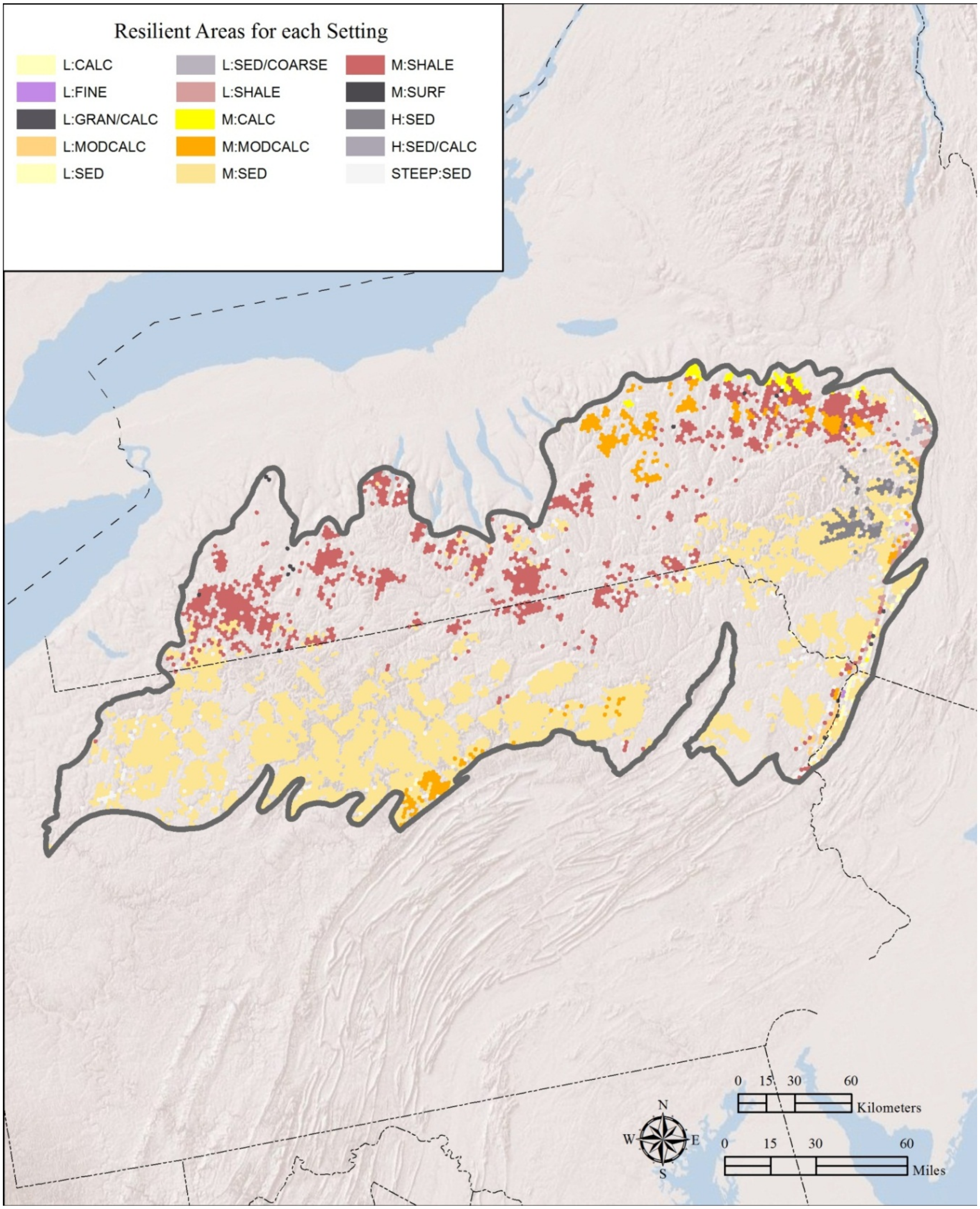
<u>Focal areas and key places for current and future diversity</u> (Map 6.14 and 6.15)
In this region there was strong correspondence between the portfolio and the resilient sites, both of which occurred mostly around the perimeter of the ecoregion

<u>Linkages and networks of resilient sites</u> (Map 6.16)
The High Allegheny Plateau ecoregion had the highest concentrated East-West current flow in the region with the Allegheny forest region and the Catskill-Central Appalachian linkage being the points of highest concentration.

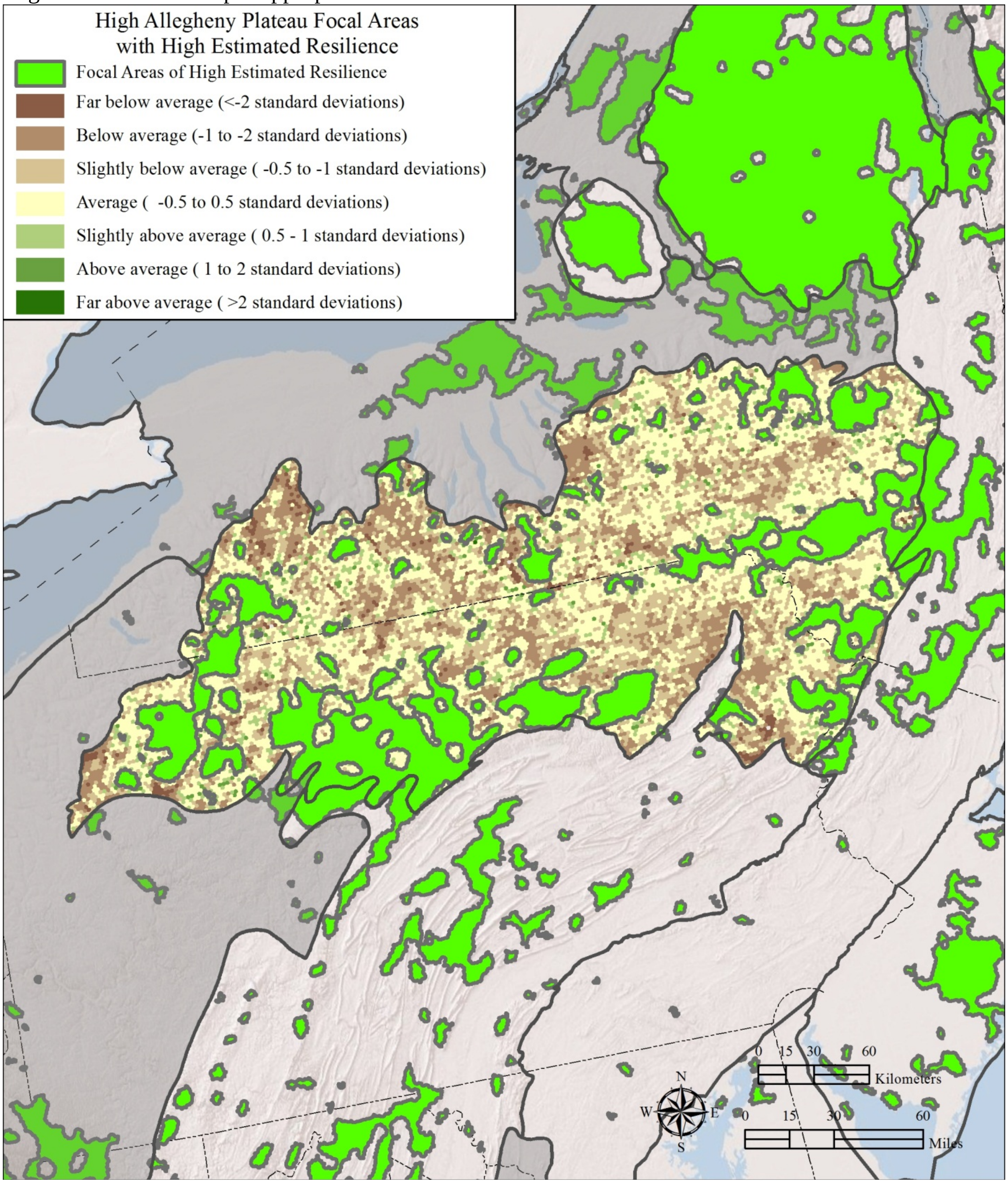
Map 6.12: High Allegheny Plateau: Resilience Estimates. Areas in yellow are comprised of cells with an average estimated resilience score based on their geophysical setting, landscape complexity and local connectedness. Areas in green score above average and are estimated to be more resilient. Areas in brown are below average and are estimated to be vulnerable to climate change and other factors.



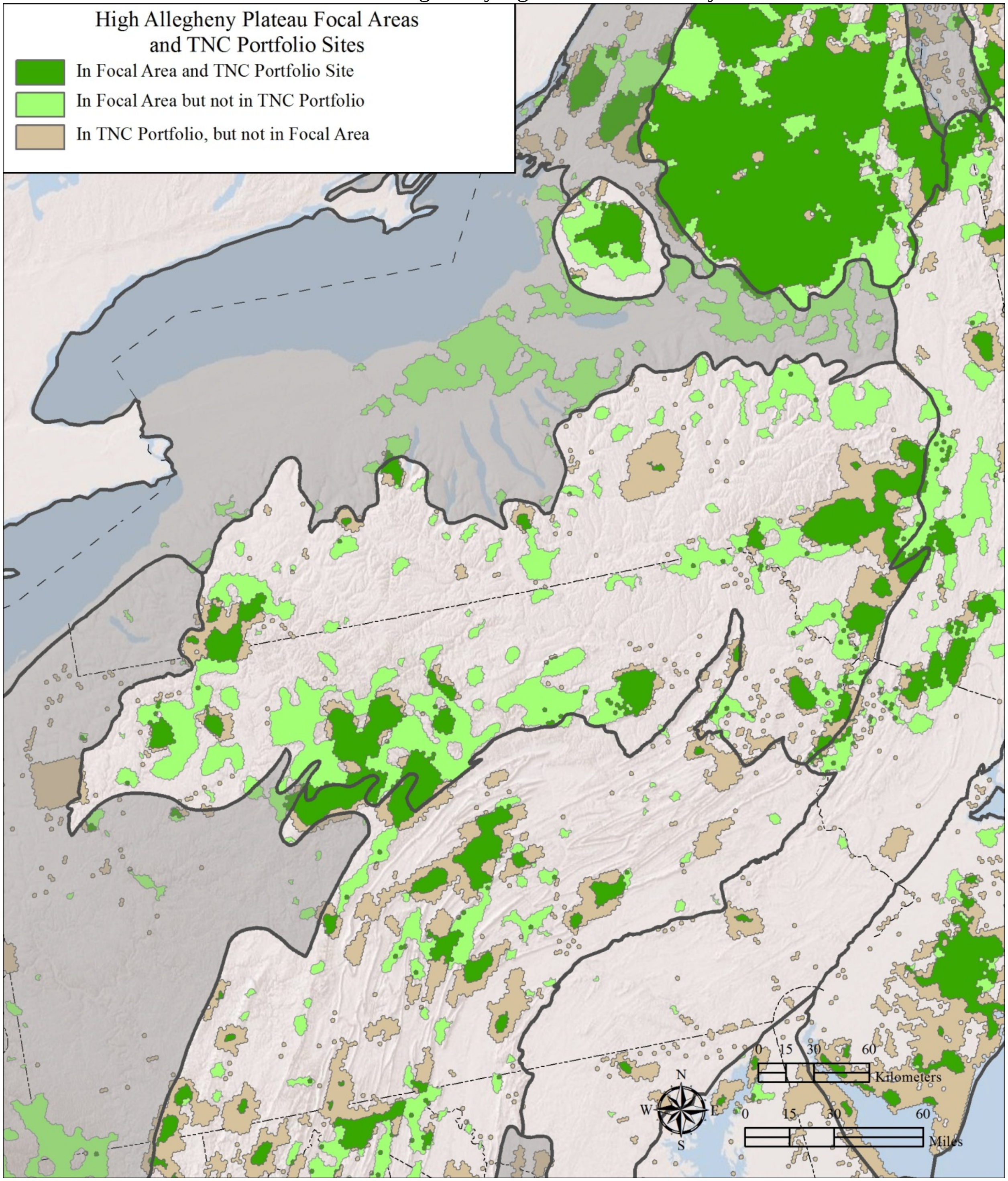
Map 6.13: High Allegheny Plateau: Resilient Areas for each Setting. This map shows only the 1000-acre hexagons that score above the mean for estimated resilience; each high scoring hexagon is colored based on its corresponding geophysical setting. This map reveals how the settings are reflected in the resilience scores.



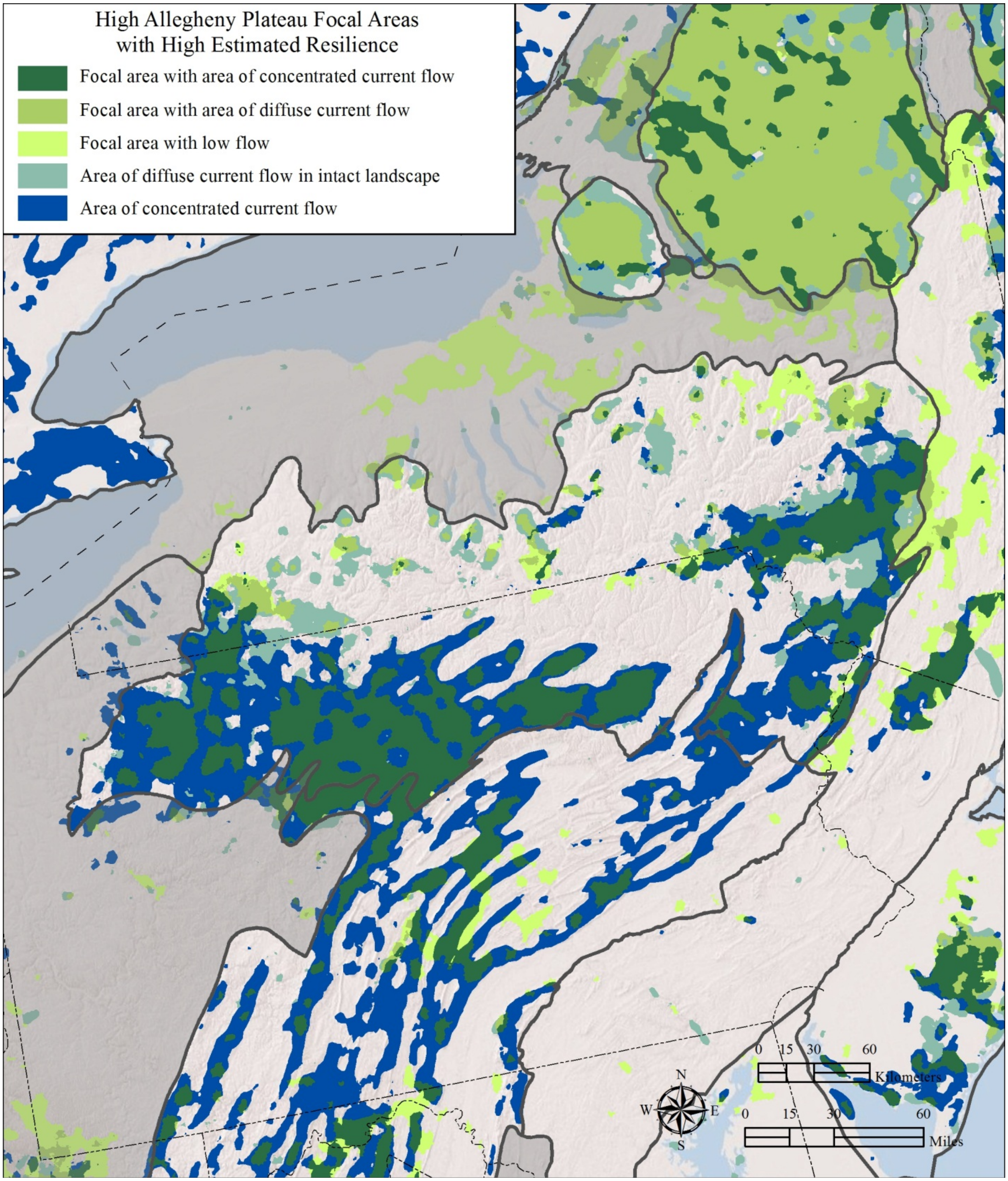
Map 6.14: High Allegheny Plateau: Focal Areas with High Estimated Resilience. This map simplifies the estimated resilience map by clustering adjacent areas of high resilience into larger sites and ignoring single small isolated sites. Although the map relinquishes some detail, it is designed to identify large and small landscapes appropriate for conservation focus.



Map 6.15: High Allegheny Plateau: Focal Areas and TNC Portfolio sites. This map identifies the focal areas that correspond with The Nature Conservancy's ecoregional portfolio of sites with significant biodiversity. The portfolio sites contain the best known occurrences of a forest, wetland or unique natural community, a rare species, a cave or stream system, or all of the above. Sites in dark green meet the criteria for high estimated resilience and for significant biodiversity. Sites in brown have significant biodiversity but are estimated to be vulnerable to climate change. Sites in pale green have high estimated resilience but were not known to have ecoregionally significant biodiversity features.



Map 6.16: High Allegheny Plateau: Focal Areas, Key Linkages and Networks. This map integrates the focal areas with the regional flow concentrations. In the map, focal areas located in areas of high flow concentrations area shown in olive green. Focal areas that are large and highly intact have diffuse flow and are shown in pale green. Key linkages are shown in areas with no focal area but high amounts of concentrated flow, and these are shown in dark blue. Blue-green areas are fairly intact regions with diffuse flow but no identified focal area.



Lower New England

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. Well-drained 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.

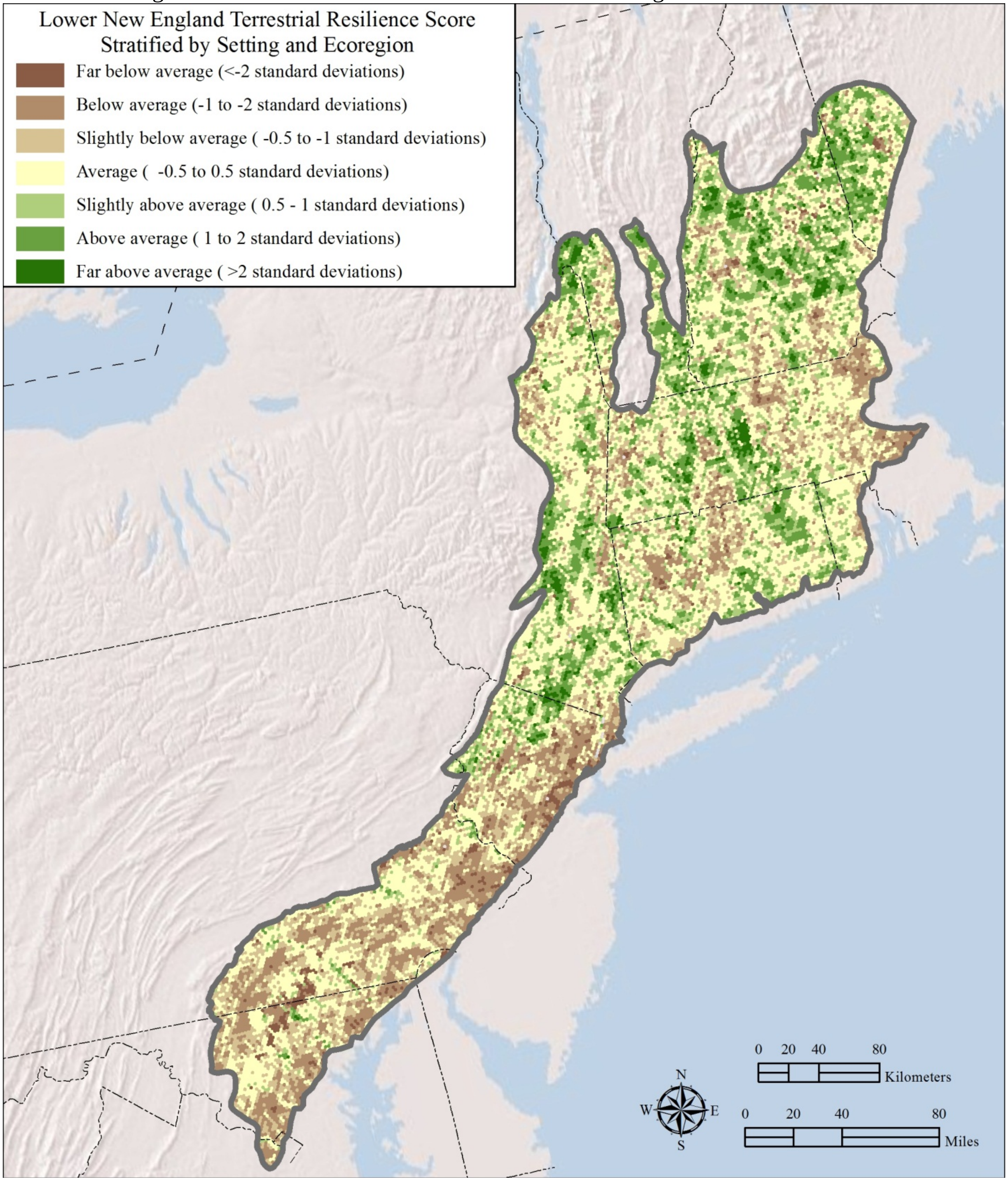
The region is 60-70 percent forested with red oak-sugar maple forest, hemlock-white pine forest, maple-beech-birch northern hardwoods, and northern white pine-red oak forests forming the dominant matrix. A variety of fire-related communities, such as pitch pine-scrub oak barrens or serpentine barrens are typical, and forested swamps are widespread. Limestone regions contain calcareous swamps, fens and seeps.

<u>Highest scoring areas for each setting</u> (Map 6.17 and 6.18)
Areas that scored high for resilience were concentrated in the Sebago –Ossipee hills of ME and NH, the Monadnock Plateau of central MA, the Southern Piedmont of VT, the CT-RI borderlands, the three-state Berkshire region, the southernmost section of the Hudson Highlands and the northernmost section of the Hudson glacial plain. The northern piedmont region of PA and MD, for the most part, scored as vulnerable.

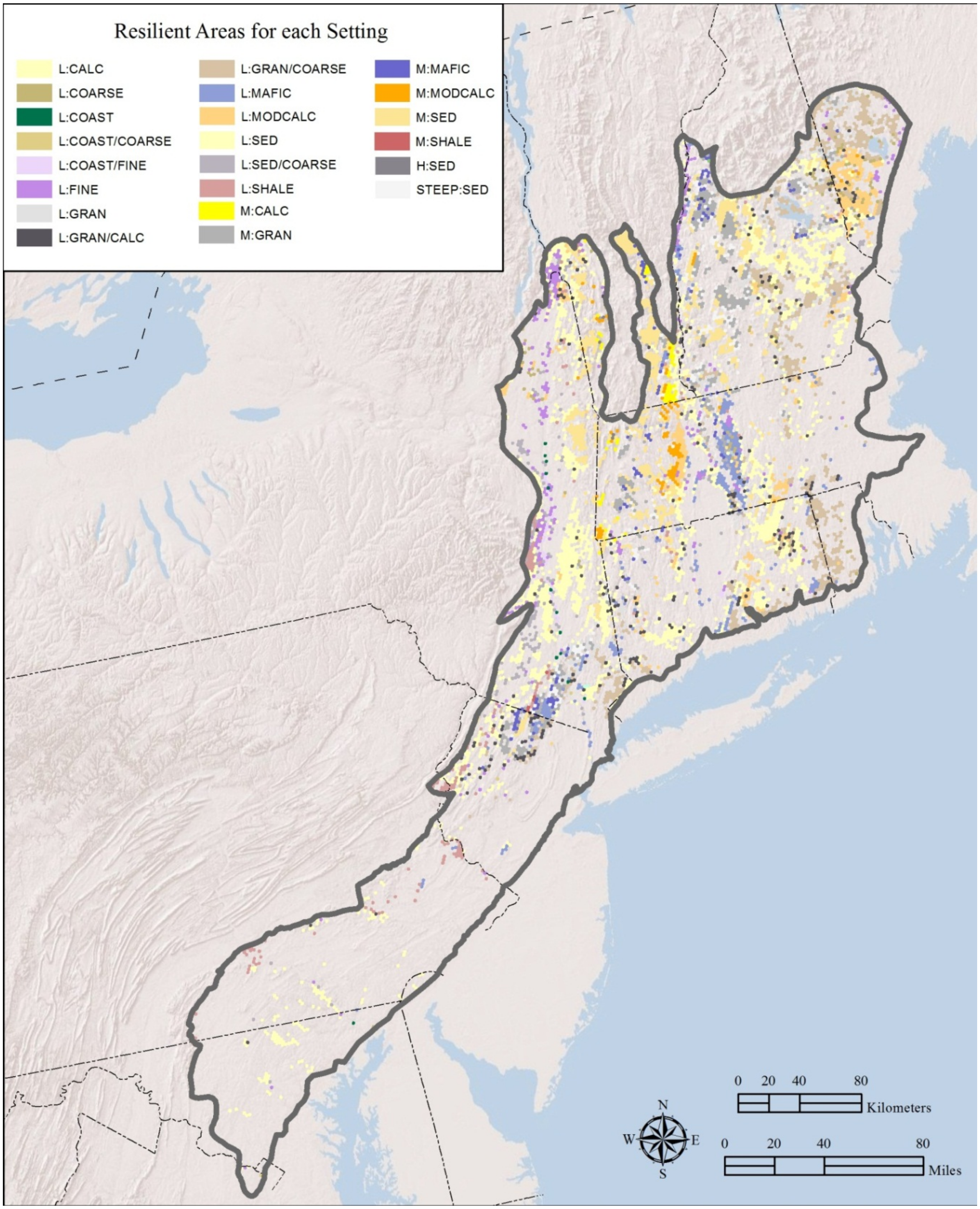
<u>Focal areas and key places for current and future diversity</u> (Map 6.19 and 6.20)
In this region there was strong correspondence between the portfolio and the resilient sites. Sites that did not score well included the forest blocks in the northern Piedmont.

<u>Linkages and networks of resilient sites</u> (Map 6.21)
The Lower New England ecoregion had high concentrated current flow in the two north-south hill complexes that flank the Connecticut River valley.

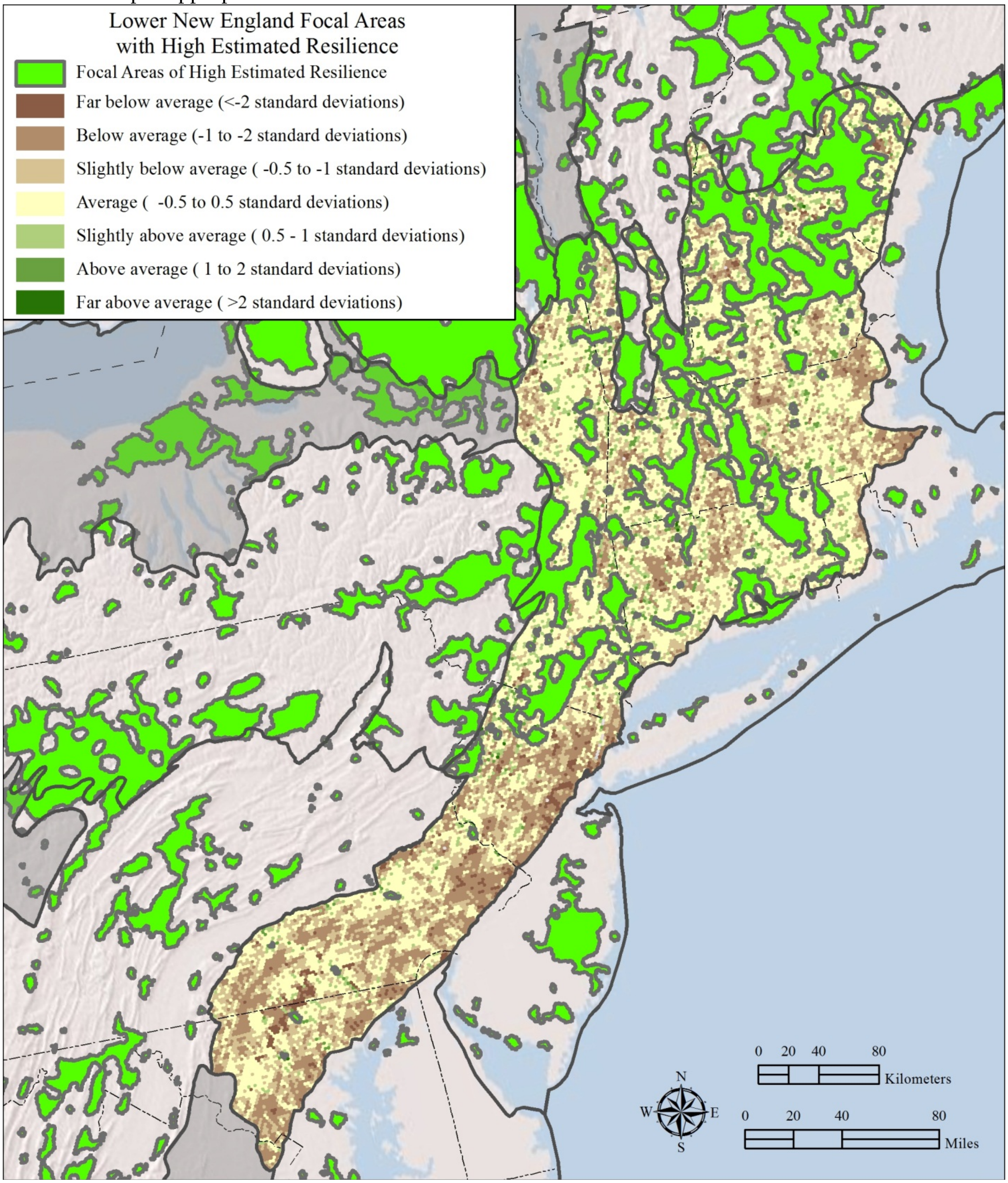
Map 6.17: Lower New England: Resilience Estimates. Areas in yellow are comprised of cells with an average estimated resilience score based on their geophysical setting, landscape complexity and local connectedness. Areas in green score above average and are estimated to be more resilient. Areas in brown are below average and are estimated to be vulnerable to climate change and other factors.



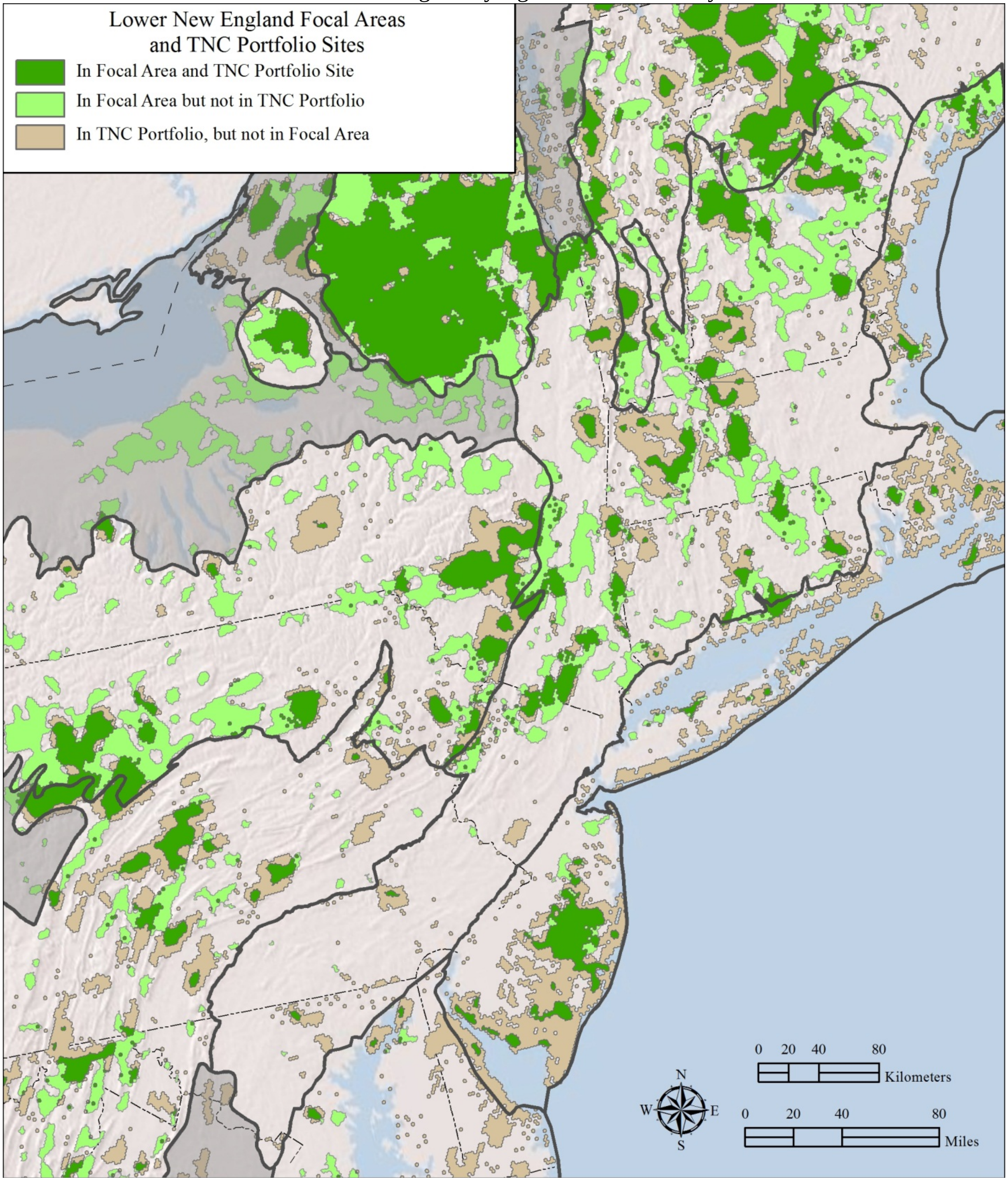
Map 6.18: Lower New England: Resilient Areas for each Setting. This map shows only the 1000-acre hexagons that score above the mean for estimated resilience; each high scoring hexagon is colored based on its corresponding geophysical setting. This map reveals how the settings are reflected in the resilience scores.



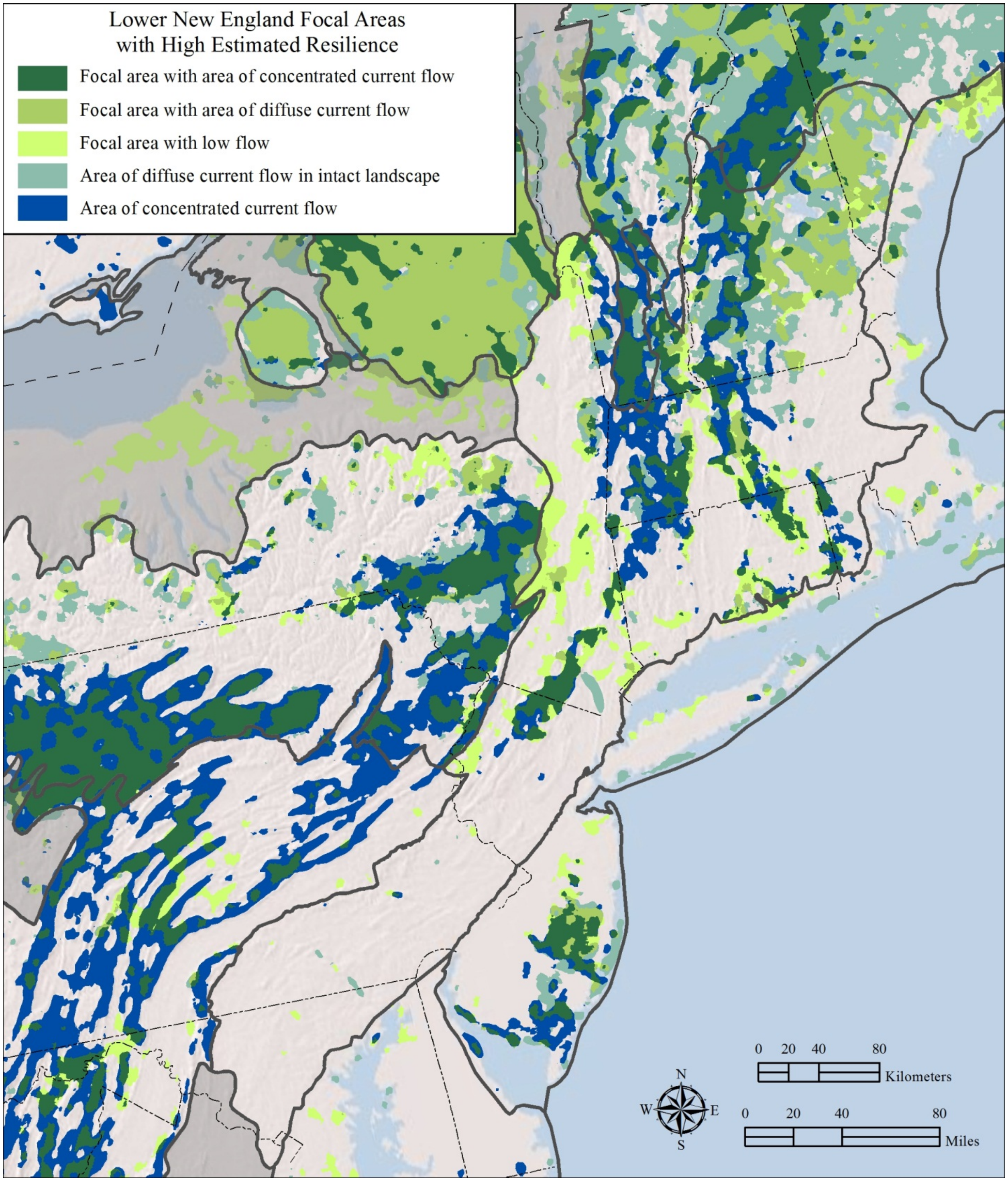
Map 6.19: Lower New England: Focal Areas with High Estimated Resilience. This map simplifies the estimated resilience map by clustering adjacent areas of high resilience into larger sites and ignoring single small isolated sites. Although the map relinquishes some detail, it is designed to identify large and small landscapes appropriate for conservation focus.



Map 6.20: Lower New England: Focal Areas and TNC Portfolio sites. This map identifies the focal areas that correspond with The Nature Conservancy's ecoregional portfolio of sites with significant biodiversity. The portfolio sites contain the best known occurrences of a forest, wetland or unique natural community, a rare species, a cave or stream system, or all of the above. Sites in dark green meet the criteria for high estimated resilience and for significant biodiversity. Sites in brown have significant biodiversity but are estimated to be vulnerable to climate change. Sites in pale green have high estimated resilience but were not known to have ecoregionally significant biodiversity features.



Map 6.21: Lower New England: Focal Areas, Key Linkages and Networks. This map integrates the focal areas with the regional flow concentrations. In the map, focal areas located in areas of high flow concentrations area shown in olive green. Focal areas that are large and highly intact have diffuse flow and are shown in pale green. Key linkages are shown in areas with no focal area but high amounts of concentrated flow, and these are shown in dark blue. Blue-green areas are fairly intact regions with diffuse flow but no identified focal area.



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.

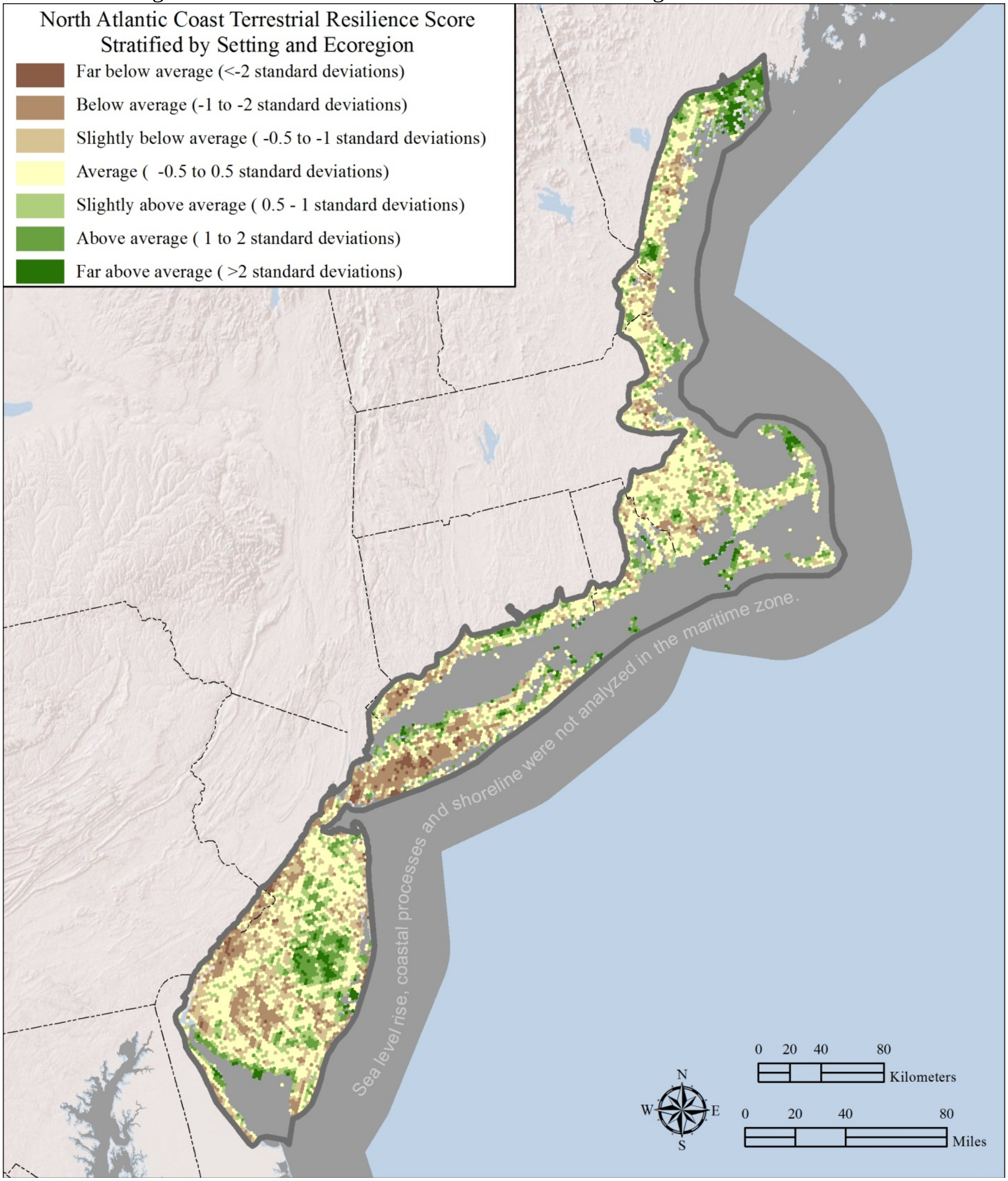
<u>Highest scoring areas for each setting</u> (Map 6.22 and 6.23)
Areas that scored high for resilience include the Casco Bay Coast in ME, the Great Bay region of NH, the Great Marsh and Cape Cod region of MA, the Pawcatuck Borderland in RI, small sections of easternmost Long Island, and a large portion of the NJ Pine Barrens.

This region included coastal shoreline where the analysis may be inaccurate due to incomplete or faulty data along the oceanic border of the region (see discussion in Chapter 2), *or because we did not account for the effects of sea level rise.*

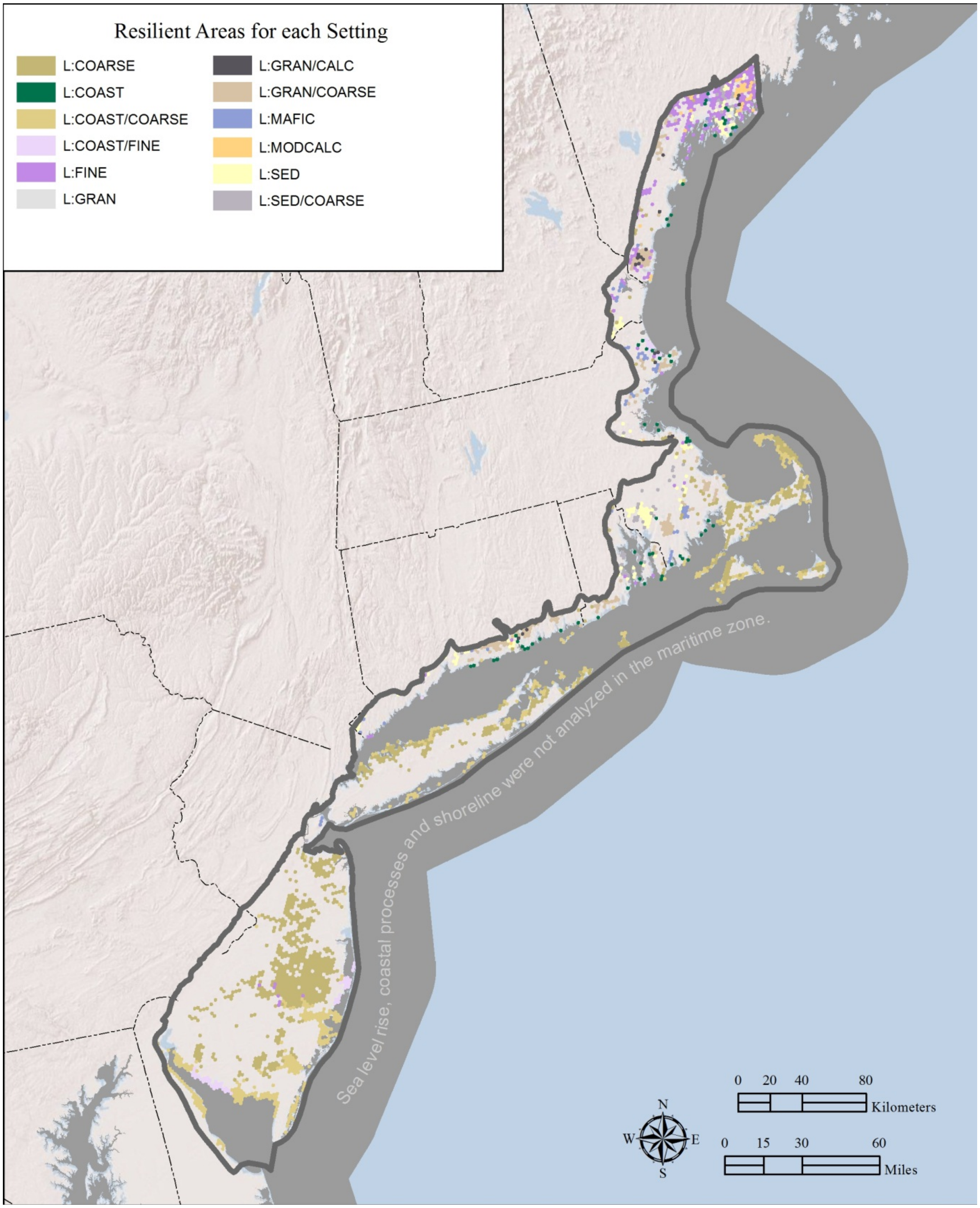
<u>Focal areas and key places for current and future diversity</u> (Map 6.24 and 6.25)
In this region there was strong correspondence between the portfolio and the resilient sites.

<u>Linkages and networks of resilient sites</u> (Map 6.26)
The North Atlantic Coast ecoregion had very few areas of concentrated current flow, the most notable being south of the NJ Pinelands.

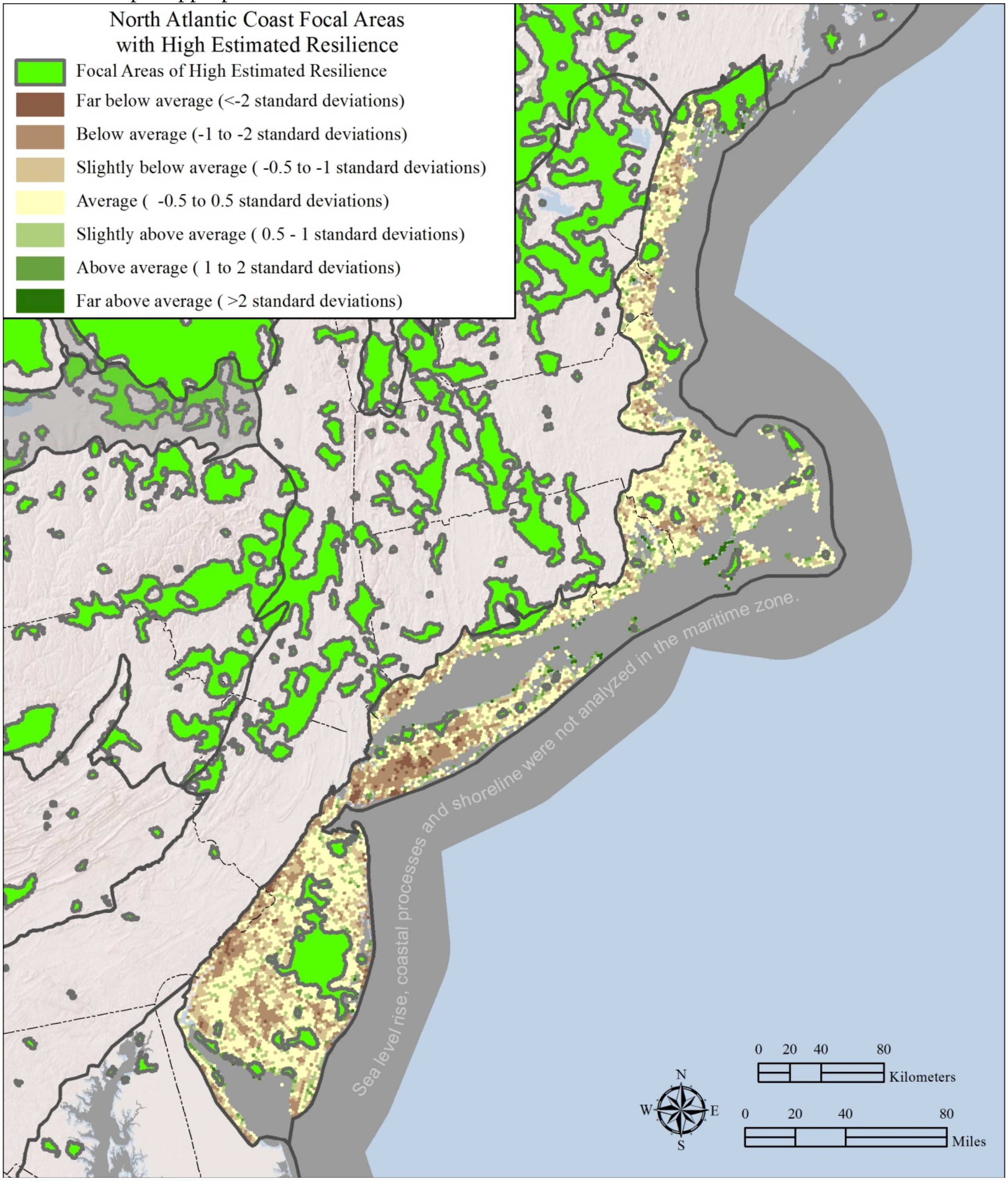
Map 6.22: North Atlantic Coast: Resilience Estimates. Areas in yellow are comprised of cells with an average estimated resilience score based on their geophysical setting, landscape complexity and local connectedness. Areas in green score above average and are estimated to be more resilient. Areas in brown are below average and are estimated to be vulnerable to climate change and other factors.



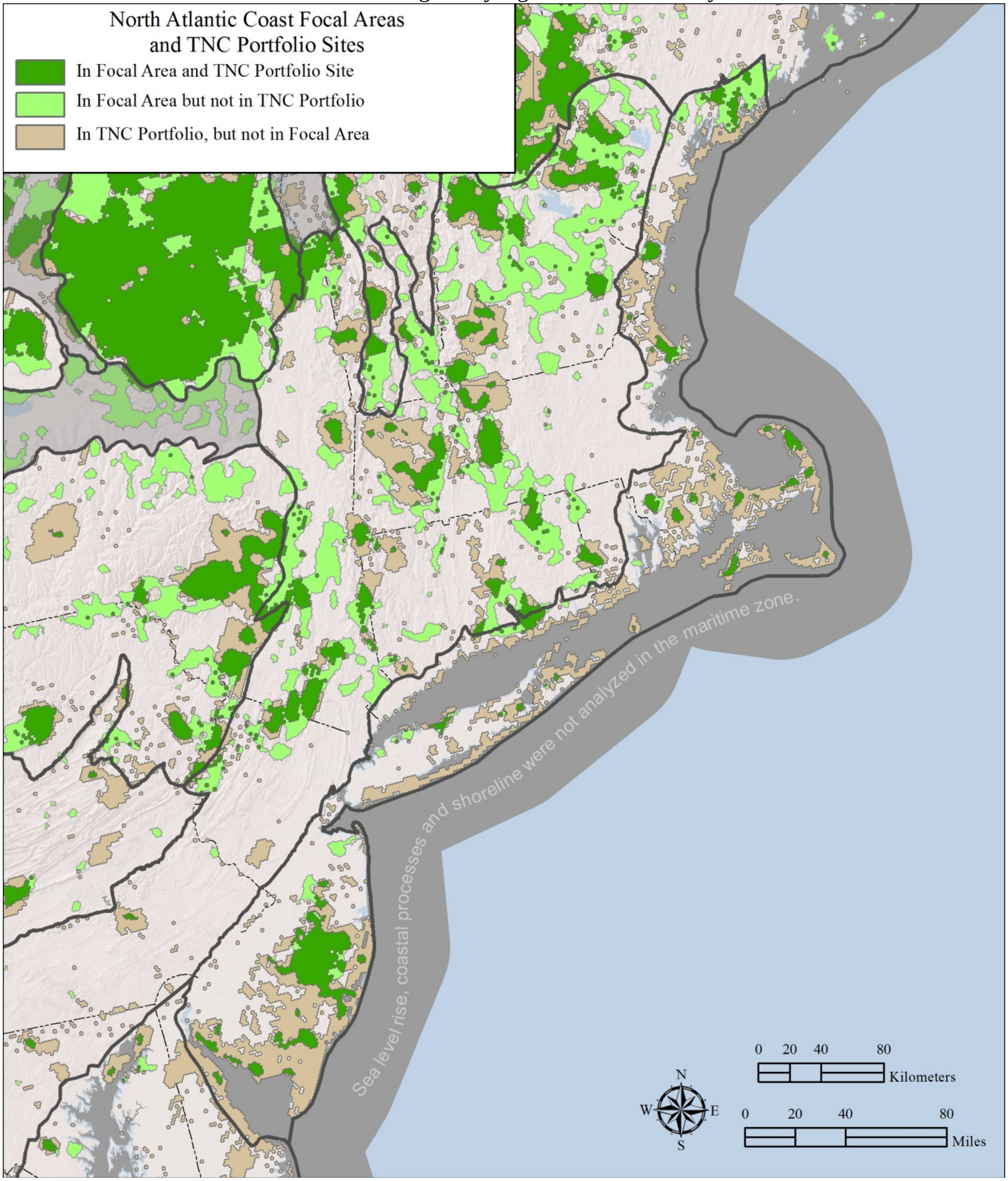
Map 6.23: North Atlantic Coast: Resilient Areas for each Setting. This map shows only the 1000-acre hexagons that score above the mean for estimated resilience; each high scoring hexagon is colored based on its corresponding geophysical setting. This map reveals how the settings are reflected in the resilience scores.



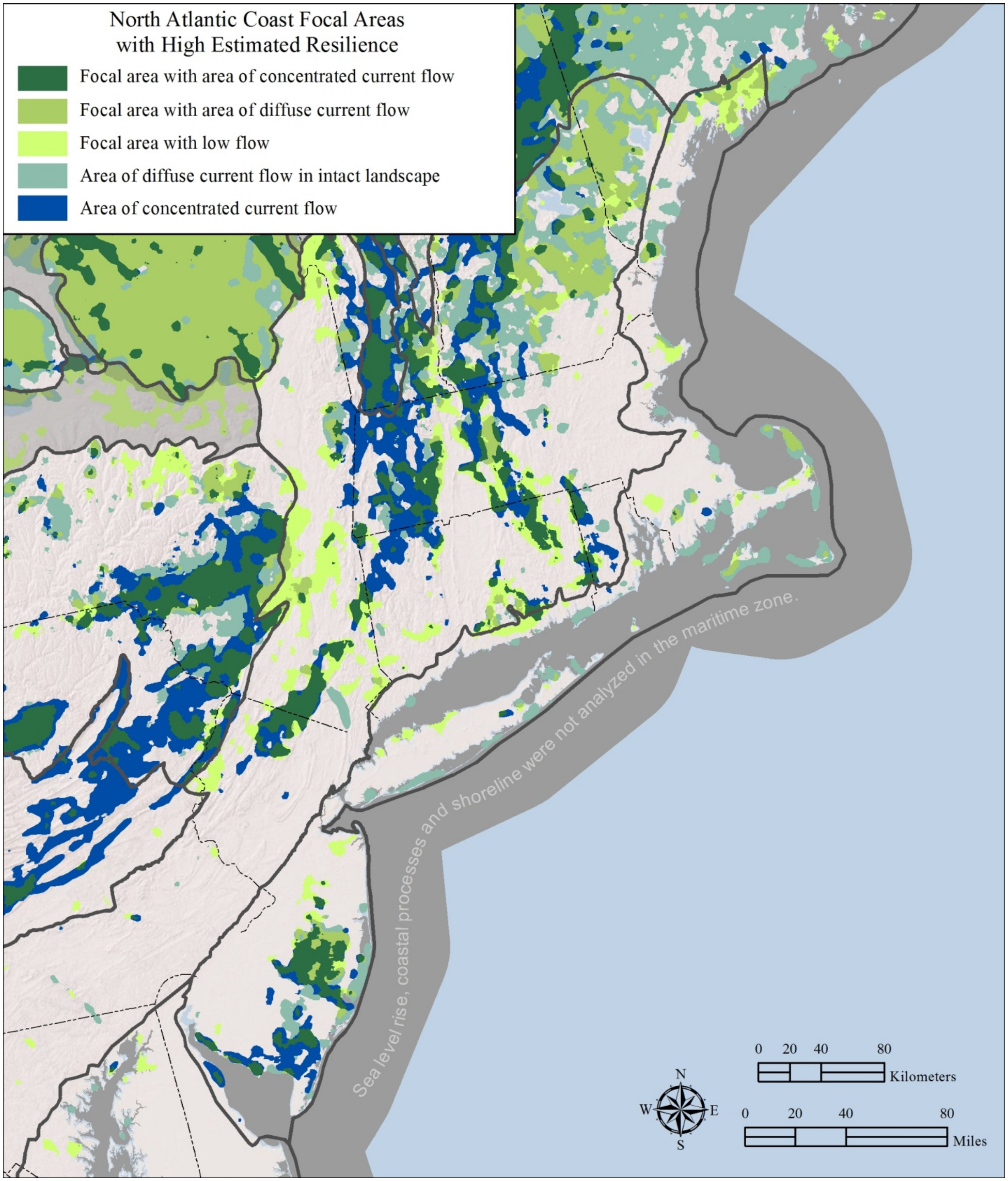
Map 6.24: North Atlantic Coast: Focal Areas with High Estimated Resilience. This map simplifies the estimated resilience map by clustering adjacent areas of high resilience into larger sites and ignoring single small isolated sites. Although the map relinquishes some detail, it is designed to identify large and small landscapes appropriate for conservation focus.



Map 6.25: North Atlantic Coast: Focal Areas and TNC Portfolio sites. This map identifies the focal areas that correspond with The Nature Conservancy's ecoregional portfolio of sites with significant biodiversity. The portfolio sites contain the best known occurrences of a forest, wetland or unique natural community, a rare species, a cave or stream system, or all of the above. Sites in dark green meet the criteria for high estimated resilience and for significant biodiversity. Sites in brown have significant biodiversity but are estimated to be vulnerable to climate change. Sites in pale green have high estimated resilience but were not known to have ecoregionally significant biodiversity features.



Map 6.26: North Atlantic Coast: Focal Areas, Key Linkages and Networks. This map integrates the focal areas with the regional flow concentrations. In the map, focal areas located in areas of high flow concentrations area shown in olive green. Focal areas that are large and highly intact have diffuse flow and are shown in pale green. Key linkages are shown in areas with no focal area but high amounts of concentrated flow, and these are shown in dark blue. Blue-green areas are fairly intact regions with diffuse flow but no identified focal area.



Northern Appalachian – Acadian

Note: Maps showing landscape complexity and landscape permeability for the whole Northern Appalachian-Acadian ecoregion including the Canada Maritimes are in Appendix III.

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.

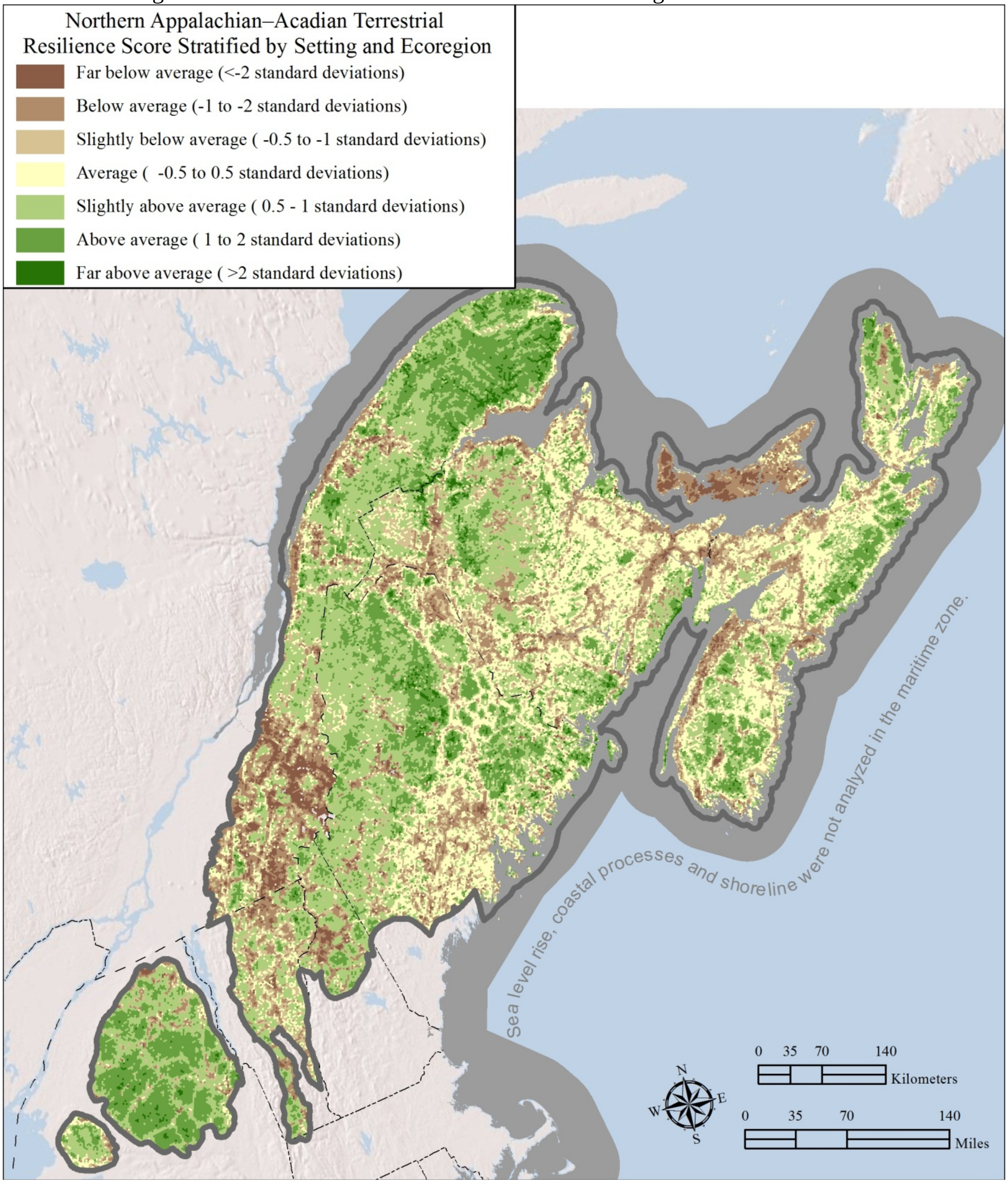
<u>Highest scoring areas for each setting</u> (Map 6.27 and 6.28)
Areas that scored high for resilience include a huge area of the Gaspe Peninsula and the St John Uplands of northern ME, although these largely reflected only one setting type: mid elevation sedimentary. The Adirondacks of NY, which were primarily composed of granite and mafic rock, also scored high. More geologically complex, high-scoring regions included the ME central mountains and foothills, the New Brunswick Acadian Highlands, and the ME-New Brunswick lowlands, all the way to the coast. The southern end of the Nova Scotia hills and drumlins, and parts of the rock Gulf of ME coast also scored high.

This region included coastal shoreline where the analysis may be inaccurate due to incomplete or faulty data along the oceanic border of the region (see discussion in Chapter 2), *or because we did not account for the effects of sea level rise.*

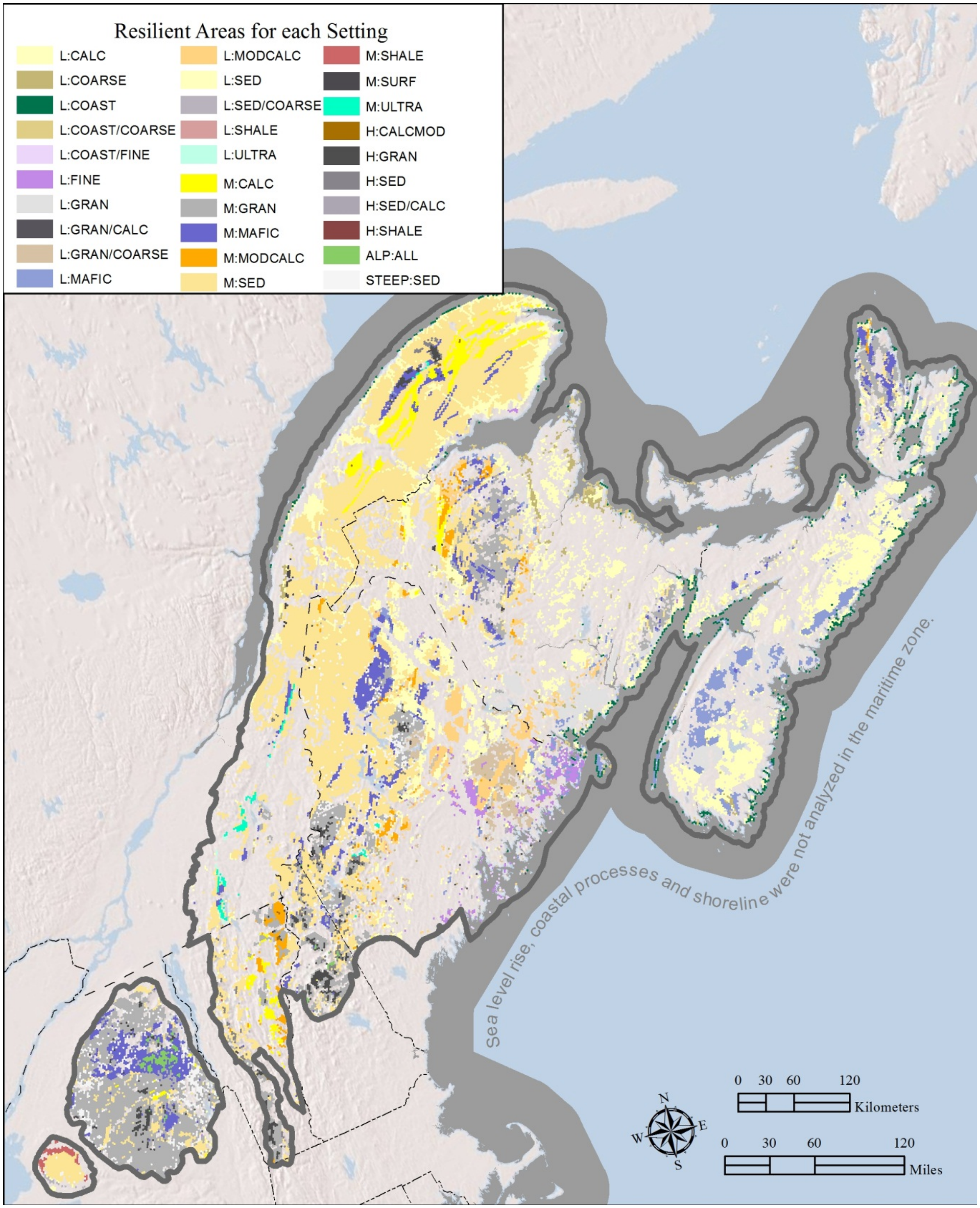
<u>Focal areas and key places for current and future diversity</u> (Map 6.29 and 6.30)
In this region there was strong correspondence between the portfolio and the resilient sites except in the central ME Embayment region and the Estrie – Beauce plateaus and hills region.

<u>Linkages and networks of resilient sites</u> (Map 6.31)
The Northern Appalachian ecoregion was remarkable in having high levels of diffuse current flow throughout most of the region. High concentrated current flow was found in the Connecticut lakes region and the Western ME Foothills regions, both of which overlap with resilient focal areas. Important linkages into the Adirondack region also overlapped, to a large extent, with focal areas.

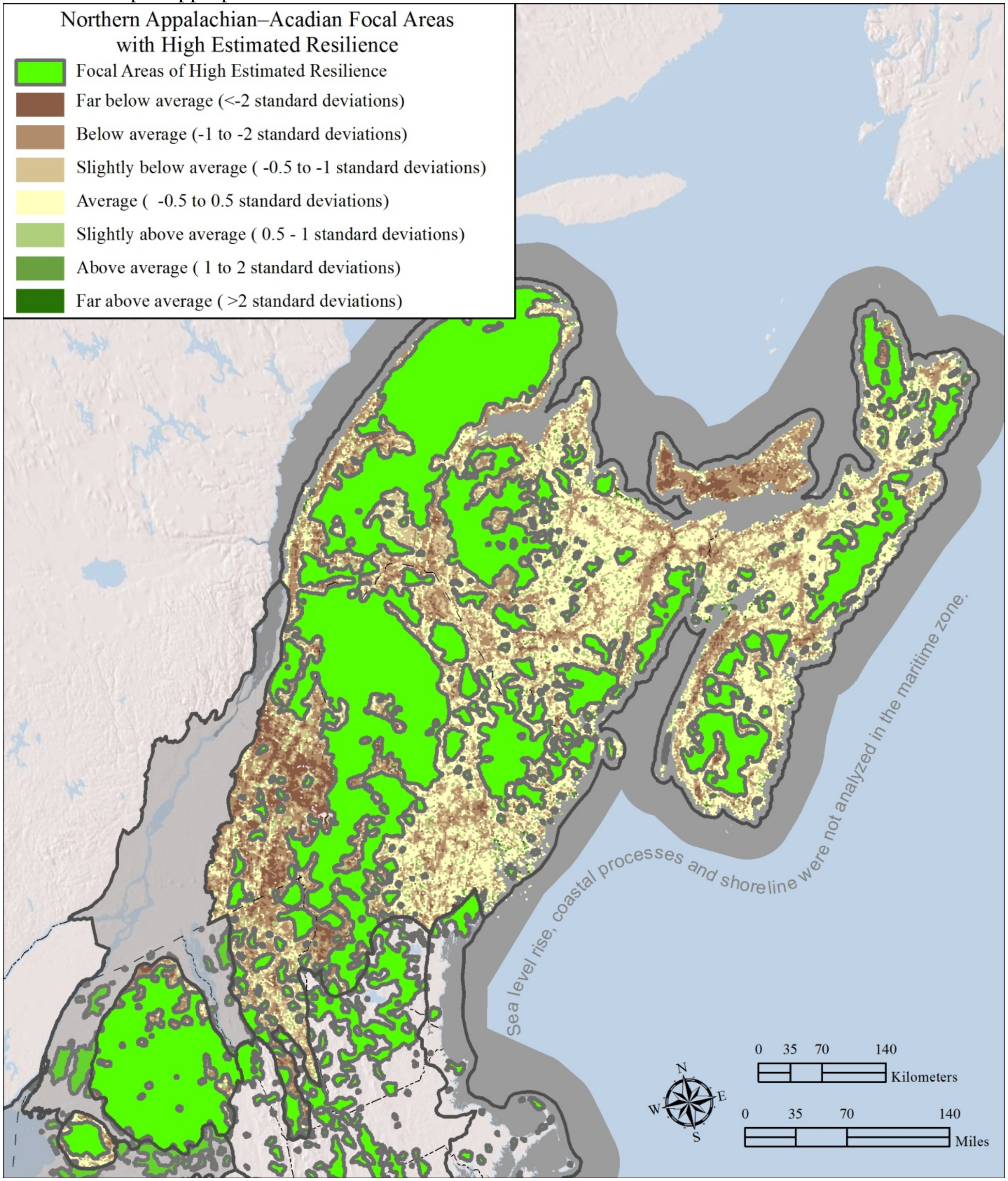
Map 6.27: Northern Appalachian: Resilience Estimates. Areas in yellow are comprised of cells with an average estimated resilience score based on their geophysical setting, landscape complexity and local connectedness. Areas in green score above average and are estimated to be more resilient. Areas in brown are below average and are estimated to be vulnerable to climate change and other factors.



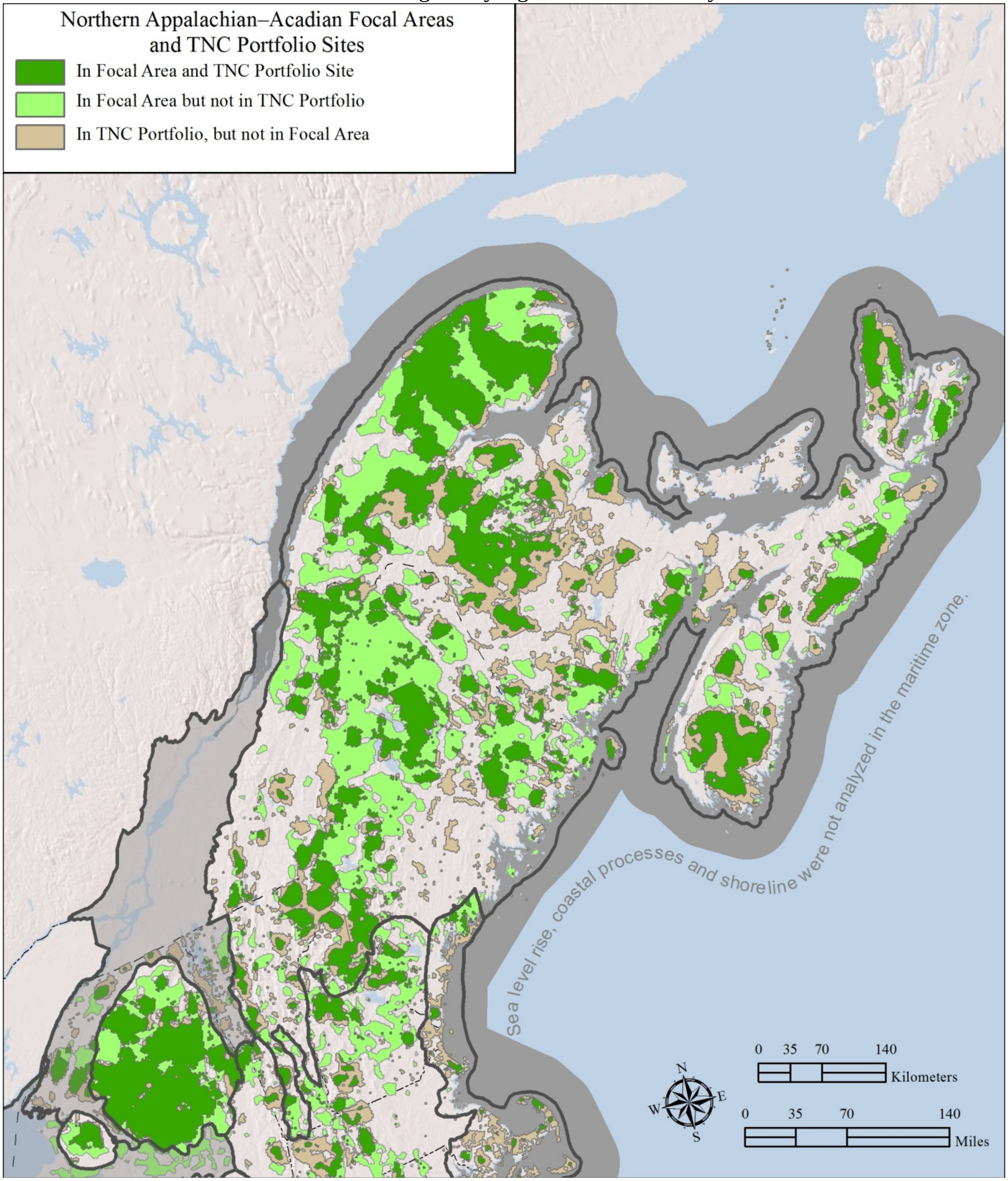
Map 6.28: Northern Appalachian: Resilient Areas for each Setting. This map shows only the 1000-acre hexagons that score above the mean for estimated resilience; each high scoring hexagon is colored based on its corresponding geophysical setting. This map reveals how the settings are reflected in the resilience scores.



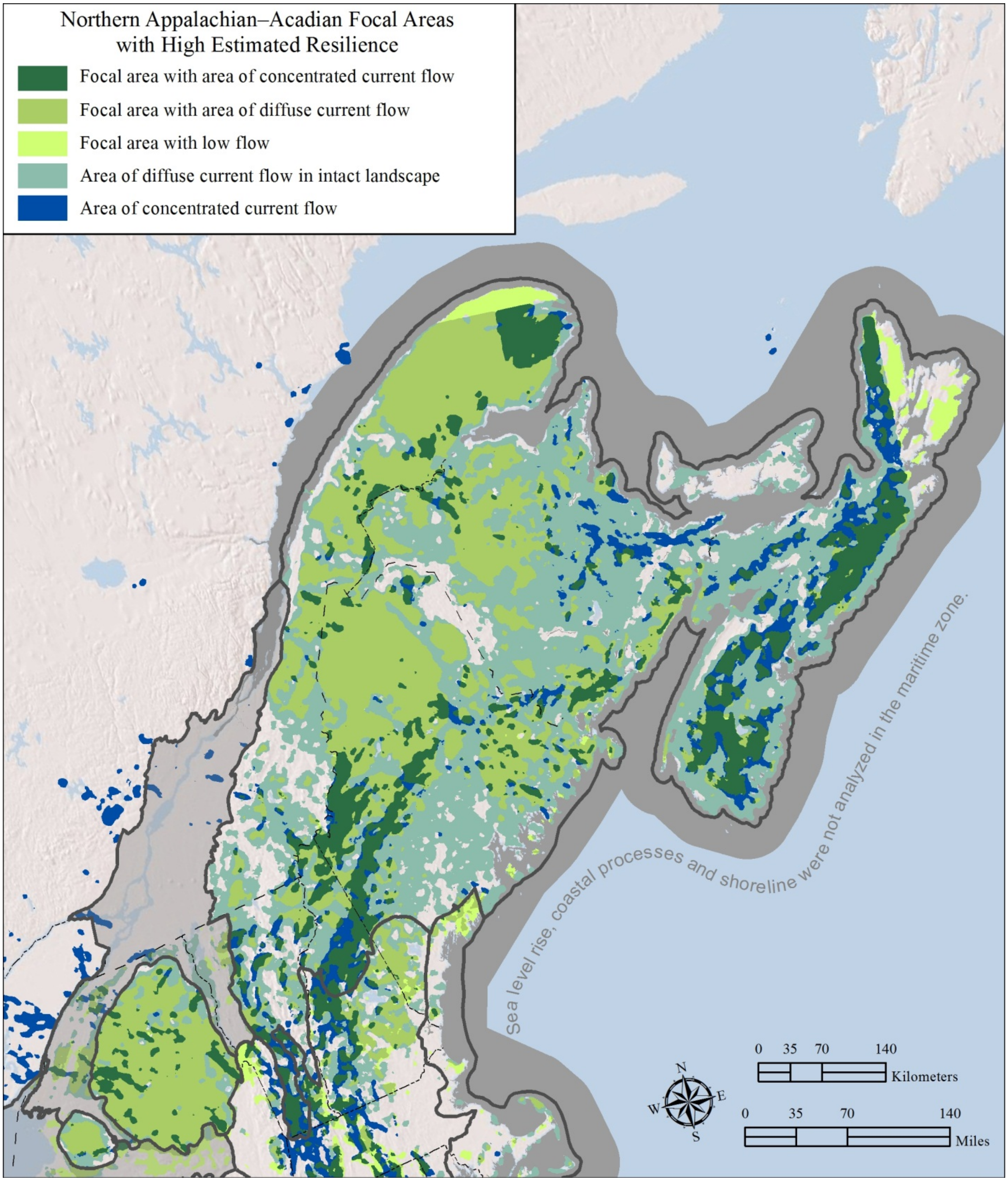
Map 6.29: Northern Appalachian: Focal Areas with High Estimated Resilience. This map simplifies the estimated resilience map by clustering adjacent areas of high resilience into larger sites and ignoring single small isolated sites. Although the map relinquishes some detail, it is designed to identify large and small landscapes appropriate for conservation focus.



Map 6.30: Northern Appalachian: Focal Areas and TNC Portfolio sites. This map identifies the focal areas that correspond with The Nature Conservancy's ecoregional portfolio of sites with significant biodiversity. The portfolio sites contain the best known occurrences of a forest, wetland or unique natural community, a rare species, a cave or stream system, or all of the above. Sites in dark green meet the criteria for high estimated resilience and for significant biodiversity. Sites in brown have significant biodiversity but are estimated to be vulnerable to climate change. Sites in pale green have high estimated resilience but were not known to have ecoregionally significant biodiversity features.



Map 6.31: Northern Appalachian: Focal Areas, Key Linkages and Networks. This map integrates the focal areas with the regional flow concentrations. In the map, focal areas located in areas of high flow concentrations area shown in olive green. Focal areas that are large and highly intact have diffuse flow and are shown in pale green. Key linkages are shown in areas with no focal area but high amounts of concentrated flow, and these are shown in dark blue. Blue-green areas are fairly intact regions with diffuse flow but no identified focal area.

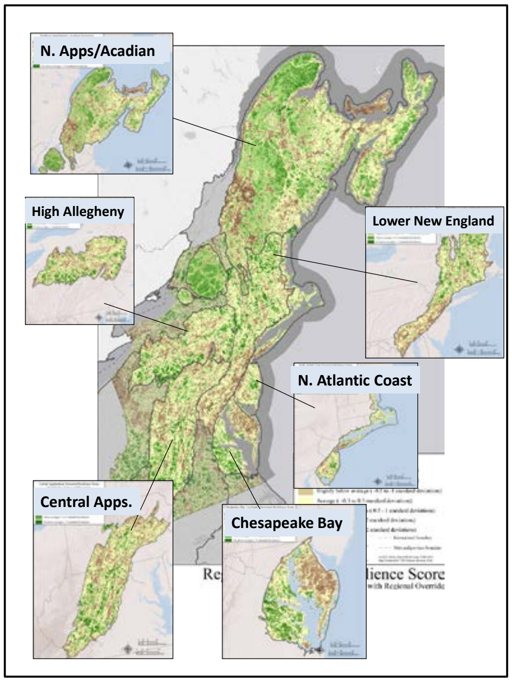


Thirteen-State Region

Composite Map of all Ecoregions

The composite maps were made be joining the ecoregion analyses together into a single map, with the partial ecoregions greyed-out slightly to reflect that fact that these sections may be incomplete. The results include the same five maps as for the individual ecoregions plus two new maps:

1) The highest scoring areas for estimated resilience by setting within ecoregions (Map 6.32),
2) The most resilient examples of each geophysical setting in the ecoregion (Map 6.33),
3) Focal areas with high estimated resilience based on settings within ecoregion (Map 6.34),
4) Key places of current and future biodiversity (Map 6.35),
5) Networks of resilient site based on linkages and focal areas (Map 6.36), and,
6) Securement status of the focal areas (Map 6.37).



Regional Maps without the Ecoregions

These maps show the estimated resilience scores for each individual setting across the 13-state region. Because there are differences in the flora and fauna among different ecoregions and across latitude, these maps do not show a comprehensive picture for conserving all biodiversity, instead they highlight those places that score the highest for a particular setting across the Northeast and Mid-Atlantic.

7) Highest scoring areas for estimated resilience by setting across the region (Map 6.38), and,
8) Comparison of scores across perspectives: region, settings within the region, settings within ecoregion, and ecoregion only (Map 6.39).

Discussion

Areas that scored high for resilience occur throughout the region, reflecting the patterns of the geophysical landscape (Maps 6.32 and 6.34). Although this analysis was done cell by cell on 1000-acre hexagons, when the results are viewed in aggregate the high scoring cells cluster to create larger patterns; these range in size from large regions like the Adirondacks or the northern Gaspe Peninsula to small sites of a few thousand acres in the northern Piedmont region. Patterns of resilience are also consistent *across* many of the ecoregion boundaries, such as between the High Allegheny and Lower New England ecoregions where high scoring areas in adjacent regions fuse to form a single focal area (Map 6.34). Further, the patterns often cross geologic types. For example, the large resilient area in the southern Central Appalachians encompasses a dense concentration of different settings (Map 6.33).

The amount of resilient area (the green) shown on the map simply 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. As discussed earlier, some settings like mid elevation granite have an average score that is relatively high, where other settings like low elevation limestone have an average score that is relatively low (Figure 6.2). For the results to be understood in meaningful context, conservationists using these datasets for planning will need to keep in mind what geophysical setting, or cluster of settings, they are aiming to conserve and realize that all of these valuations are comparative – no absolute thresholds for resiliency have been identified.

The visual patterns on these maps also reflect the geographic extent of different settings. Acidic sedimentary environments make up 40 percent of the 13-state region, and thus they also make up 40 percent of the resilient area (Map 6.33). In these sedimentary settings then, conservationists have more choices available for investment, although the region’s sedimentary settings already enjoy a high degree of securement (Map 6.37). Most other settings have smaller geographic extents - 5 percent or less - so options are more limited on where conservation activities could best be employed.

We emphasize again that although we have gone to some lengths to make this analysis as transparent and rigorous as possible, the analysis is essentially a hypothesis based on those attributes thought to be predictive of resilience and that could be mapped at a regional scale; the results are estimates. Current research is reinforcing the importance of landscape complexity that allows species to persist through a changing climate, and the value of connectivity in this function has strong historical evidence and widespread agreement among the scientific community. Still, there is a much uncertainty about how the effects of climate change will play out on the landscape. 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 The Nature Conservancy’s portfolio sites.

Many Conservancy portfolio sites scored high for resilience (Map 6.35). Using both current evidence and future forecasts these are great places for conservation action such as land protection. The fact that they currently contain good examples of common forest ecosystems and best populations of rare species or viable examples of unique communities confirms that these are places where the important characteristics of the setting are expressed. Further, we can cautiously assume that because the system is currently functioning in a close to natural state, this feature should enhance the system’s ability to adapt to changes, and continue support a diverse array of species. The assumption that we cannot make is that the species currently present at the site will be the same in the future.

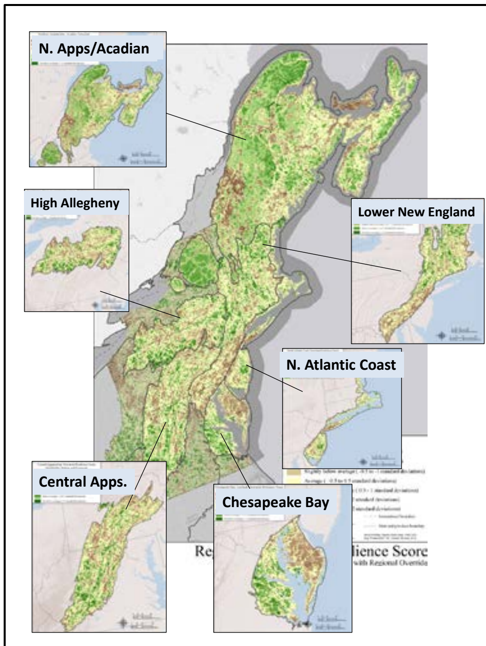
We recommend that areas scoring high for resilience but not confirmed by a portfolio site be explored further before taking conservation action. It may well be that these areas have excellent current biodiversity features even if they did not show up in the Conservancy’s portfolios (those were admittedly focused on the best of the best), or they may be critical linkage areas. It is also possible that, due to historical events or past management practices, these places may not be appropriate for conservation even if they were predicted to be resilient by these measures. Site visits, or overlays of Natural Heritage information, can help substantiate the value of these sites. In the reverse case, portfolio sites that scored low for resilience, we suggest that appropriate action depends on why it scored low and whether there is anything to be done about that. It will be important to look at what type of feature drove its inclusion in the portfolio (a rare species? a large patch system?), whether that feature’s viability is closely tied to these attributes of resilience, and whether the site is located in a key place for connectivity

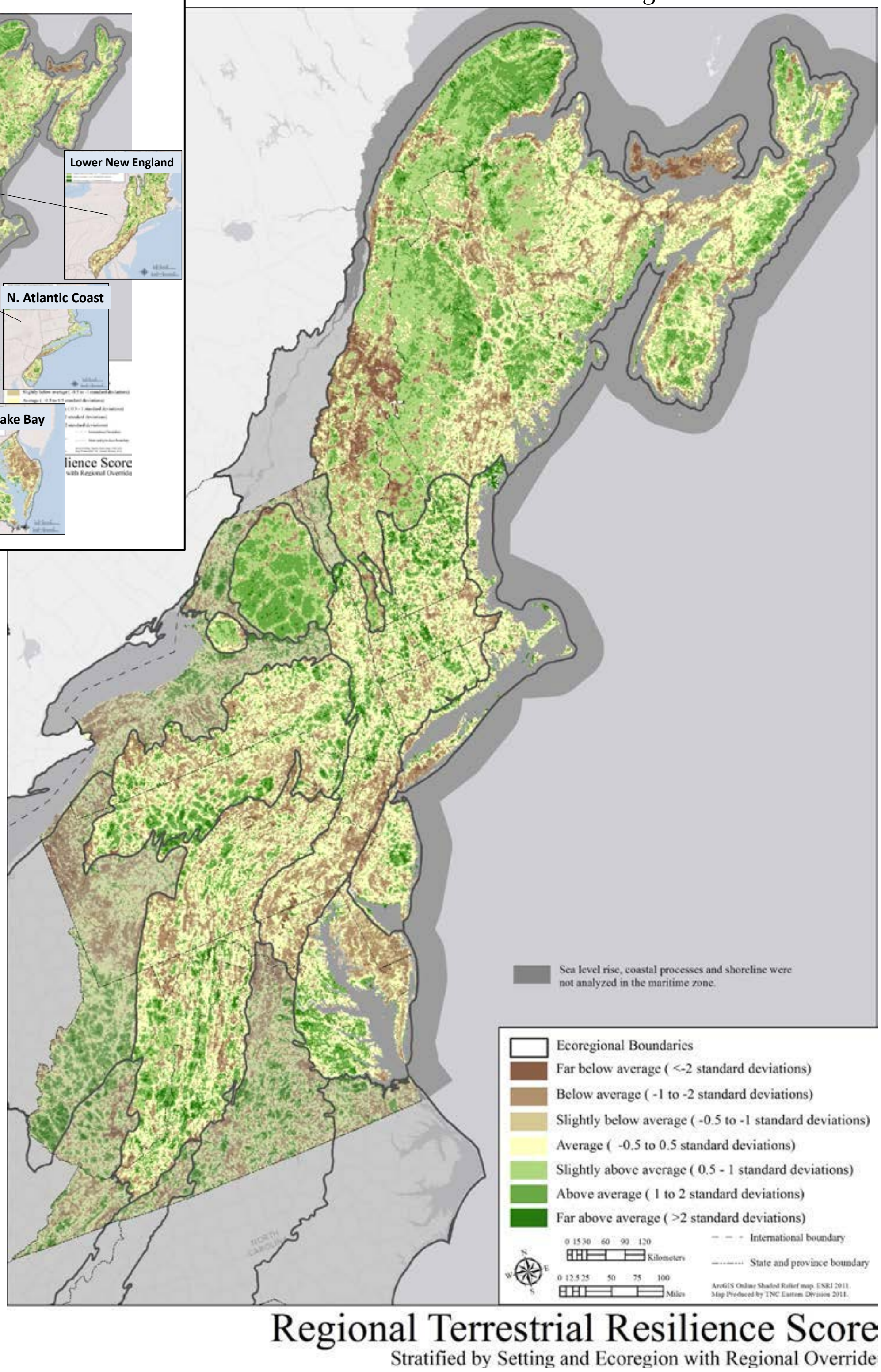
Areas that are secured from development tended to score high for resilience (Map 6.37) at least in part because securement maintains or sometimes improves the local connectedness of the area. This is important because, of the two metrics we used to estimate resilience (landscape complexity and local connectedness), only connectedness can reasonably be improved through conservation action. Secured areas tend to be higher in complexity also; this is likely because the original intent of many protected areas in the U.S. was upper watershed protection, so they often encompass steep slopes and mountains. The challenge ahead is to bring securement (in some form or another) to the resilient portions of low elevation and simpler landscapes that currently represent many of the settings richest in biodiversity.

Organizing our results by ecoregion ensured that we identified an appropriate geographic spread for each setting and gave geographic stability to the results. However, we were curious as to where the highest scoring areas were for each setting across the 13-states (this boundary was admittedly arbitrary from an ecological perspective, but politically it encompassed all of New England and the Mid-Atlantic). The results (Map 6.38) can be thought of as a composite of the individual setting maps presented in Chapter 5. Some places scored high no matter what perspective they were examined from (Map 6.39). This map shows the places that scored high from several perspectives: region, setting within region, setting within ecoregion, or ecoregion. This map, like the overlay of TNC portfolio sites, may provide confidence that the site is a good choice for conservation action.

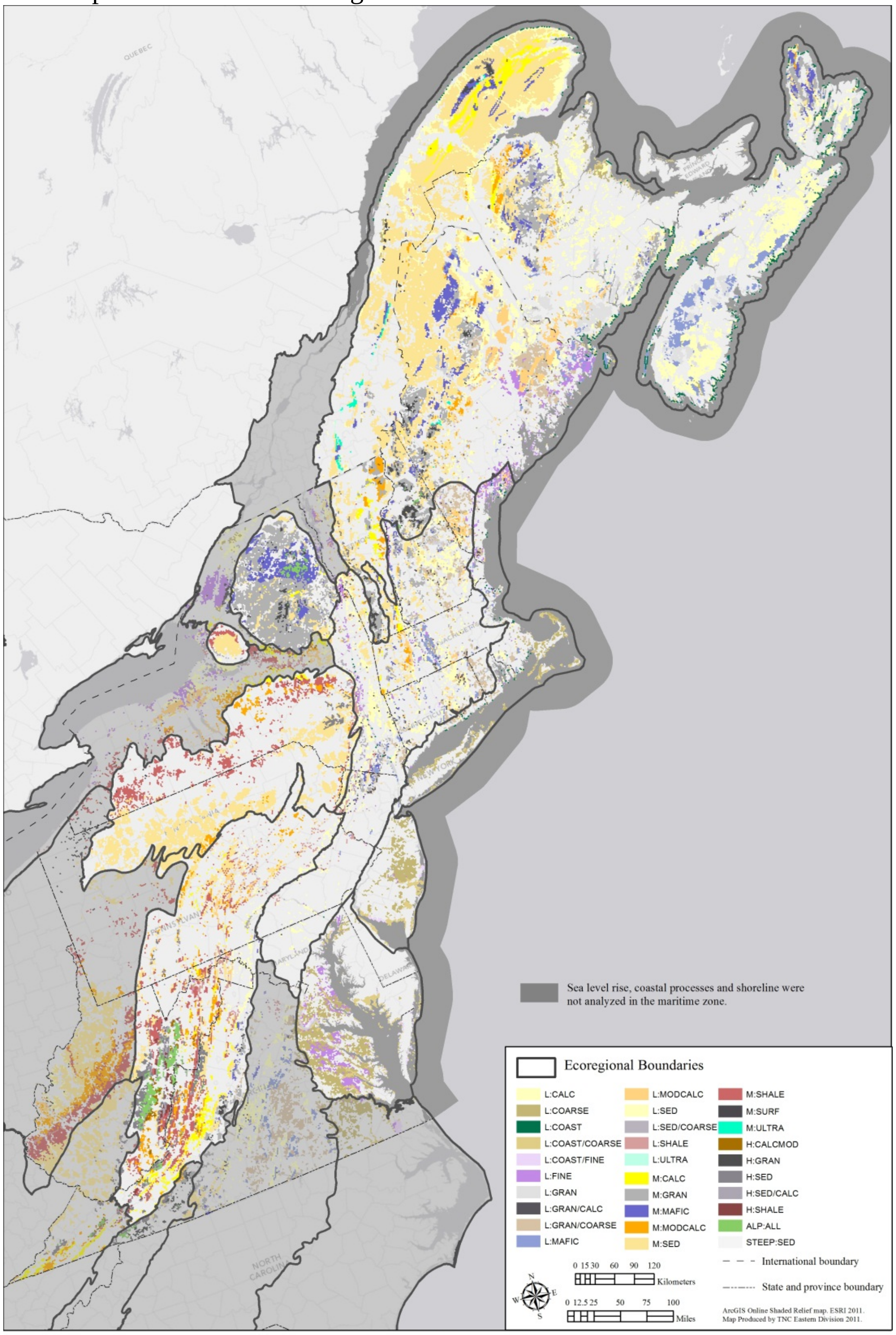
When viewed regionally, the flow concentration areas reveal interesting and potentially important linkages across the region. For instance, the position and context of the Central Appalachians and High Allegheny ecoregions give them significance with respect to maintaining connections and movements that we previously did not recognize. Throughout the region, large and small linkages are apparent, but not all coincide with above average resilient areas (Map 6.36). However, because areas that support movement and process can be of lower quality than areas intended to support breeding source populations or set aside to develop structurally complex forest, the large linkage areas may well be appropriate places for some kind of conservation action. We suggest that these be explored further, as is being done in the Northern Appalachians' Staying Connected project. It is essential under a rapidly changing climate that conservation activities not become just a collection of good places, but that they develop a connected network of resilient areas. We hope that this analysis of linkages, in conjunction with the resilience estimates across the full spectrum of geophysical settings, provides the basic tools for conservationists to create such a network.

Map 6.32: The highest scoring areas for estimated resilience. Areas in yellow are comprised of cells with an average estimated resilience score based on their geophysical setting, landscape complexity and local connectedness as compared to others in their geophysical setting and ecoregion. Areas in green score above average and are estimated to be more resilient. Areas in brown are below average and are estimated to be vulnerable to climate change and other factors.





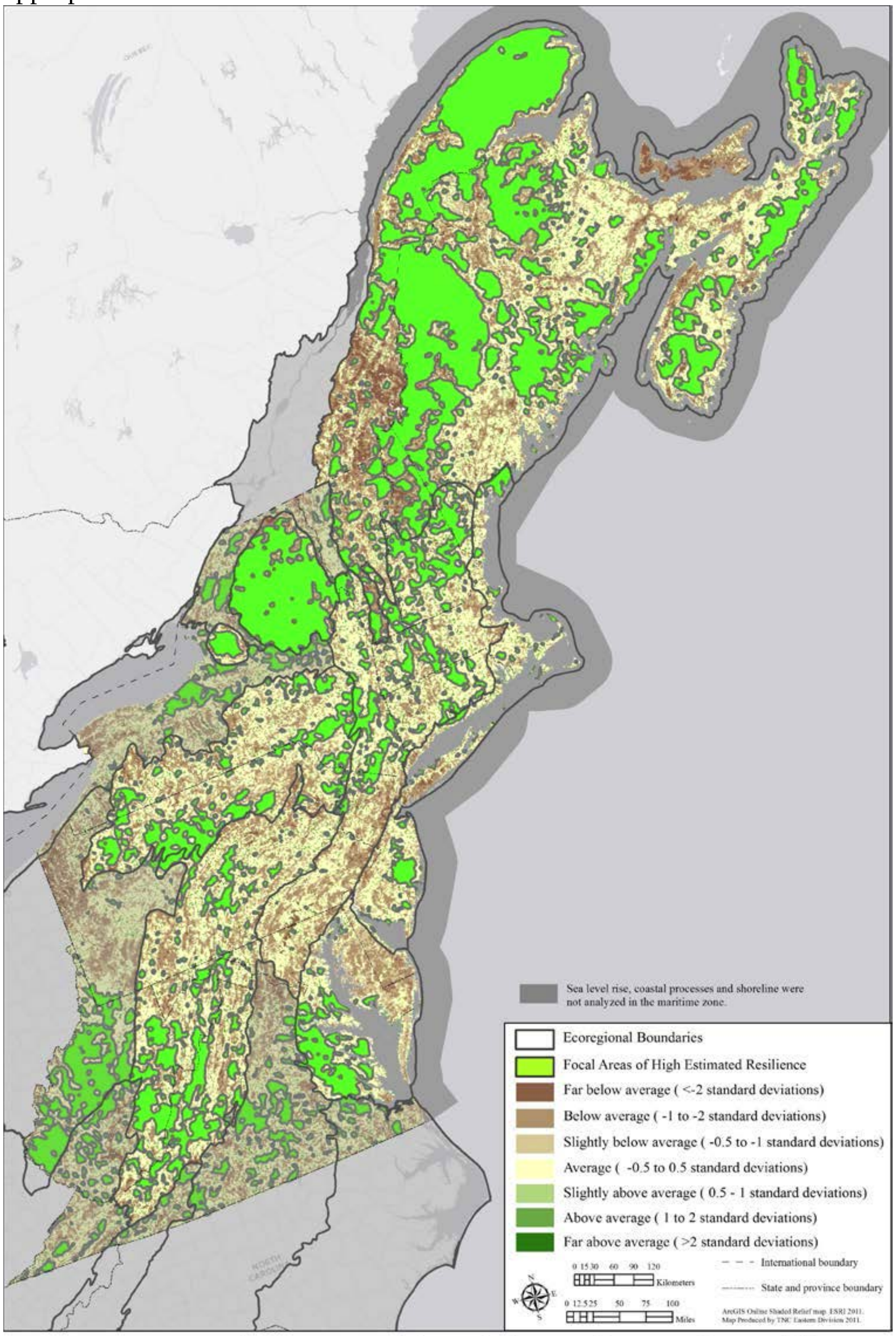
Map 6.33: The most resilient examples of each geophysical setting in the region. This map shows only the 1000-acre hexagons that score above the mean for estimated resilience as compared to others in their ecoregion; each high scoring hexagon is colored based on its corresponding geophysical setting. This map reveals how the settings are reflected in the resilience scores.



Resilient Areas for each Setting

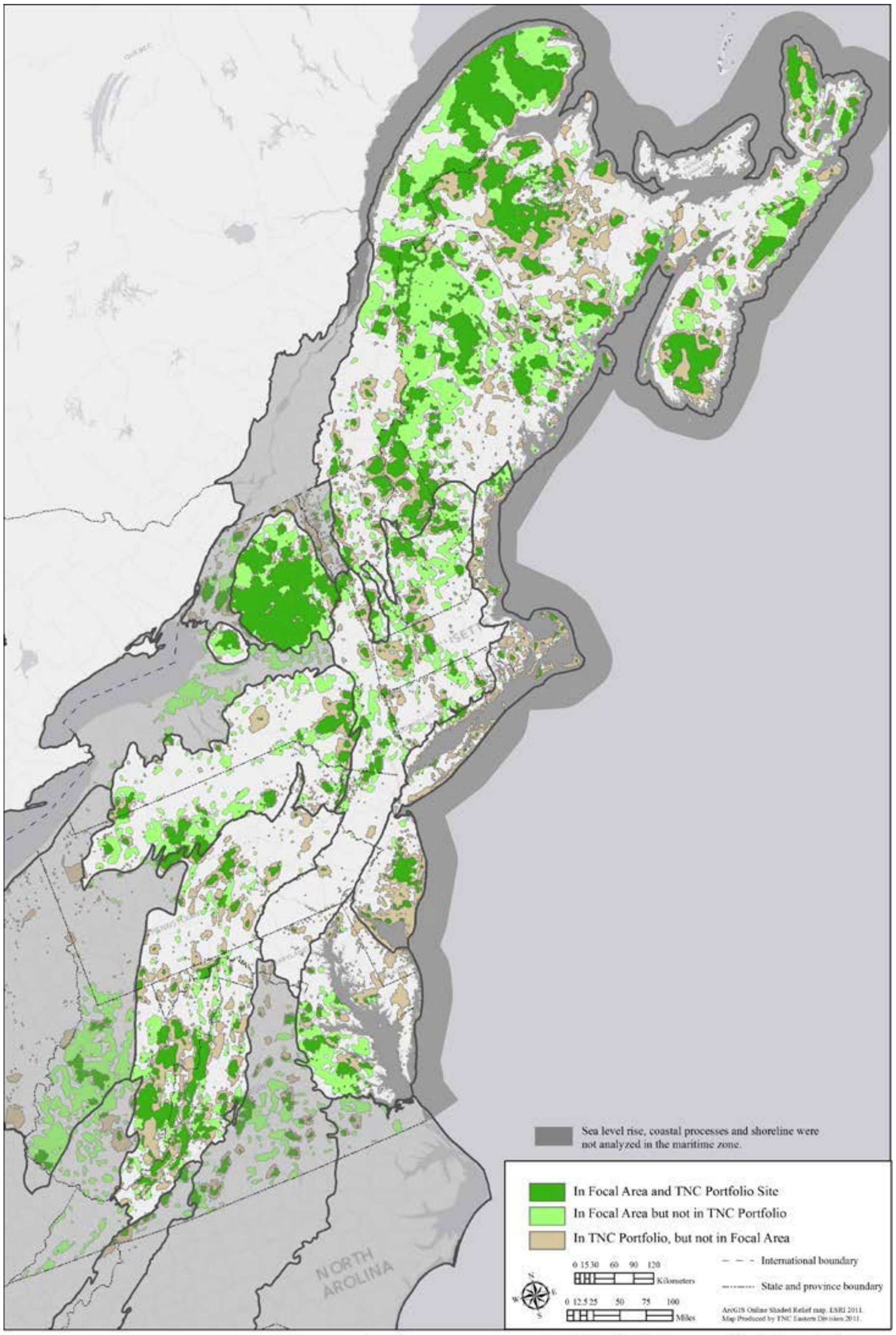
Stratified by Setting and Ecoregion with Regional Override

Map 6.34: Focal areas with high estimated resilience. This map simplifies the estimated resilience map by clustering adjacent areas of high resilience into larger sites and ignoring single small isolated sites. Although the map relinquishes some detail, it is designed to identify large and small landscapes appropriate for conservation focus.



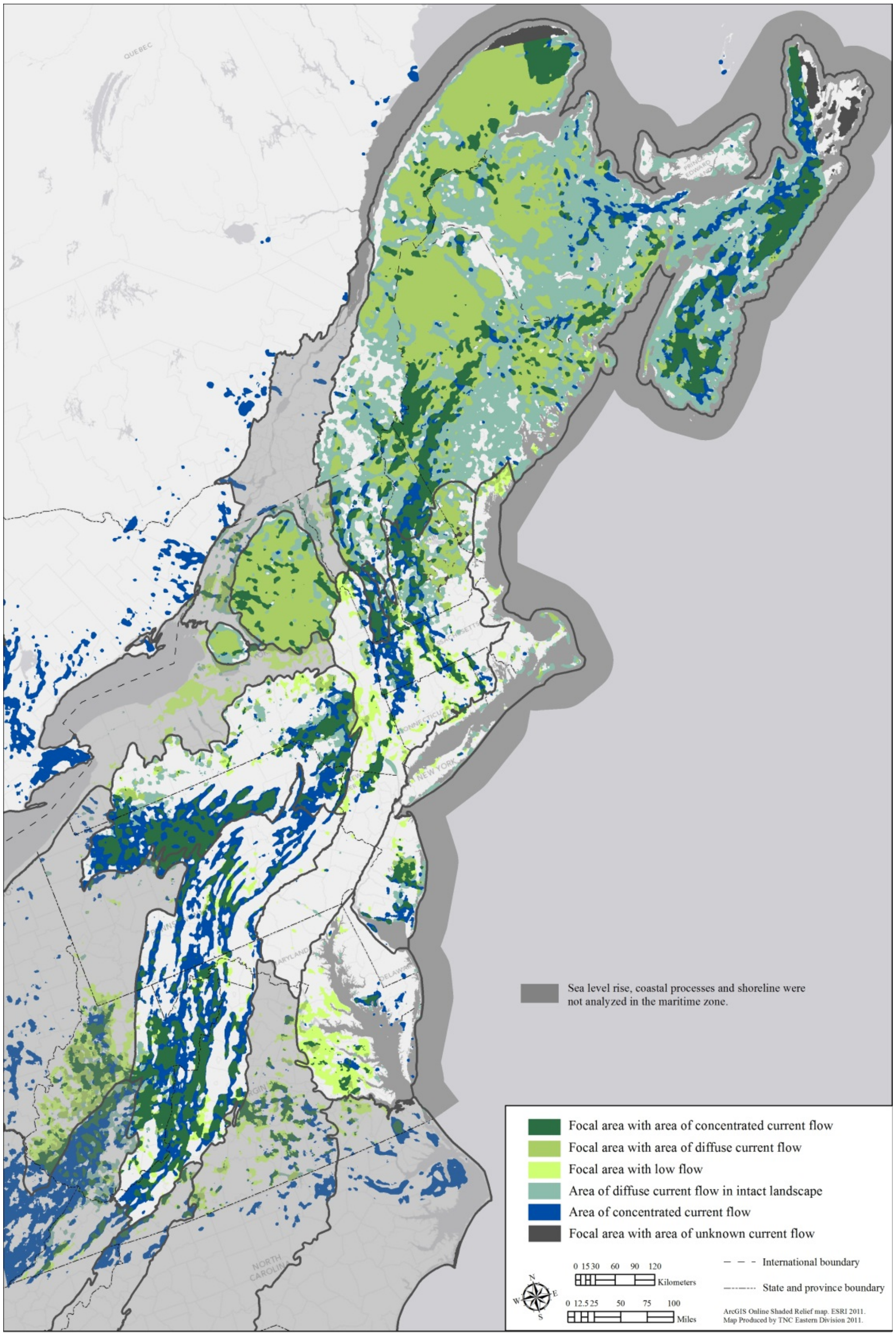
Focal Areas with High Estimated Resilience

Map 6.35: Key places of current and future biodiversity. This map identifies the focal areas that correspond with The Nature Conservancy's ecoregional portfolio of sites with significant biodiversity. The portfolio sites contain the best known occurrences of a forest, wetland or unique natural community, a rare species, a cave or stream system, or all of the above. Sites in dark green meet the criteria for high estimated resilience and for significant biodiversity. Sites in brown have significant biodiversity but are estimated to be vulnerable to climate change. Sites in pale green have high estimated resilience but were not known to have ecoregionally significant biodiversity features.



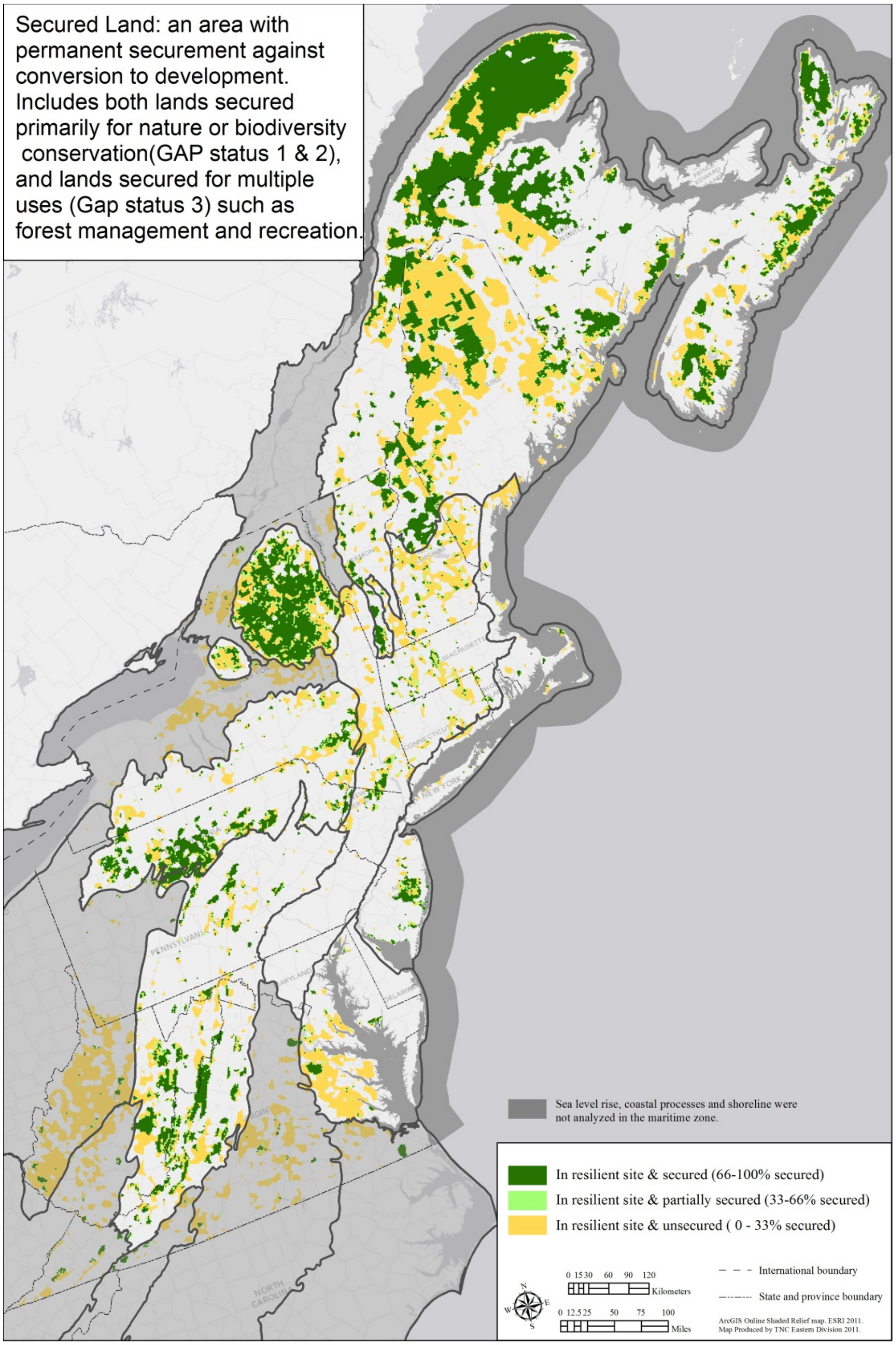
Focal Areas and TNC Portfolio Sites

Map 6.36: Networks of resilient sites based on linkages and focal areas. This map integrates the focal areas with the regional flow concentrations. In the map, focal areas located in areas of high flow concentrations area shown in olive green. Focal areas that are large and highly intact have diffuse flow and are shown in pale green. Key linkages are shown in areas with no focal area but high amounts of concentrated flow, and these are shown in dark blue. Blue-green areas are fairly intact regions with diffuse flow but no identified focal area.



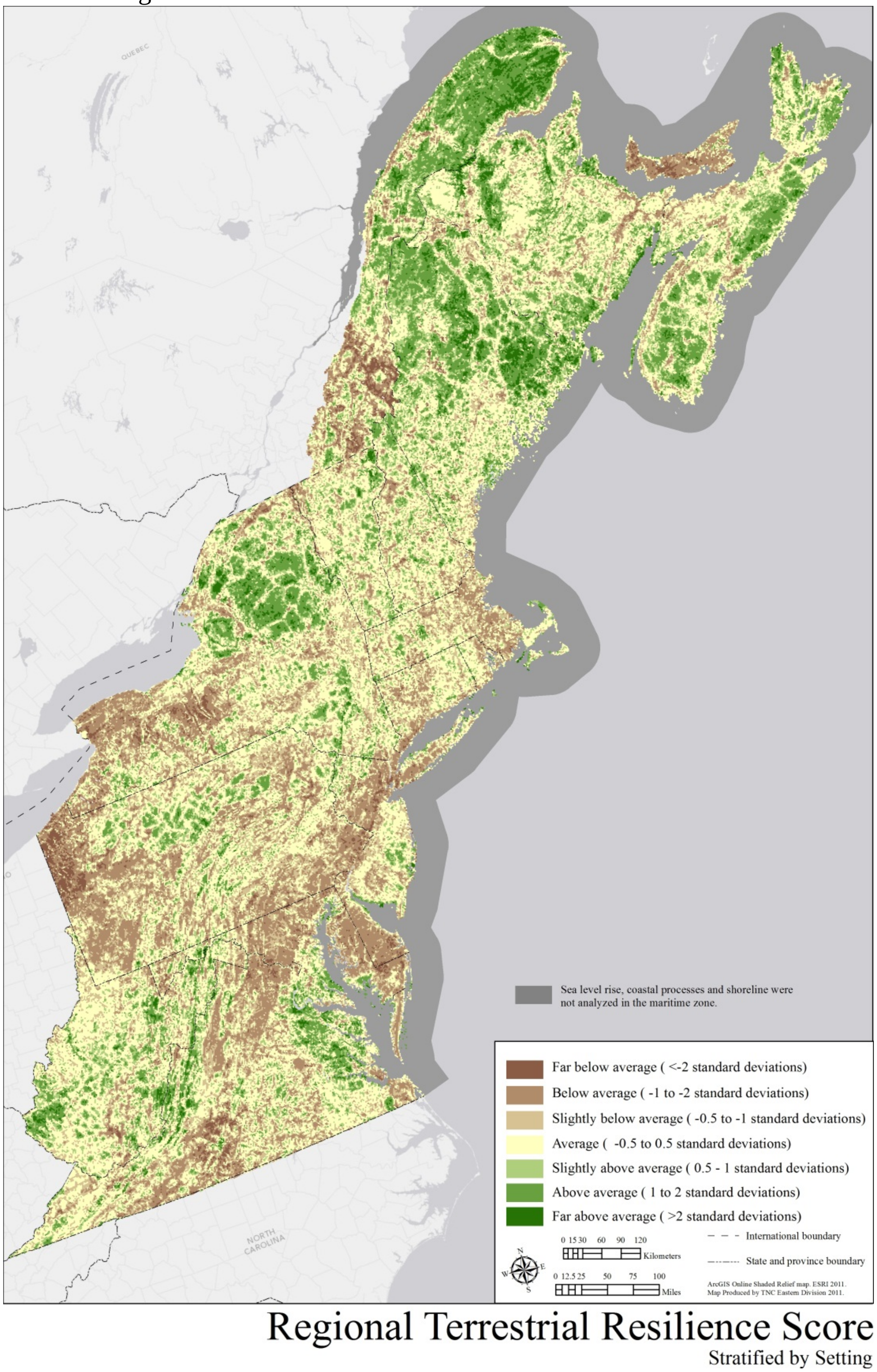
Focal Areas and Key Linkages

Map 6.37: Securement Status of the Focal Areas. This map shows the percent of secured land (GAP 1, 2 or 3) within the focal areas

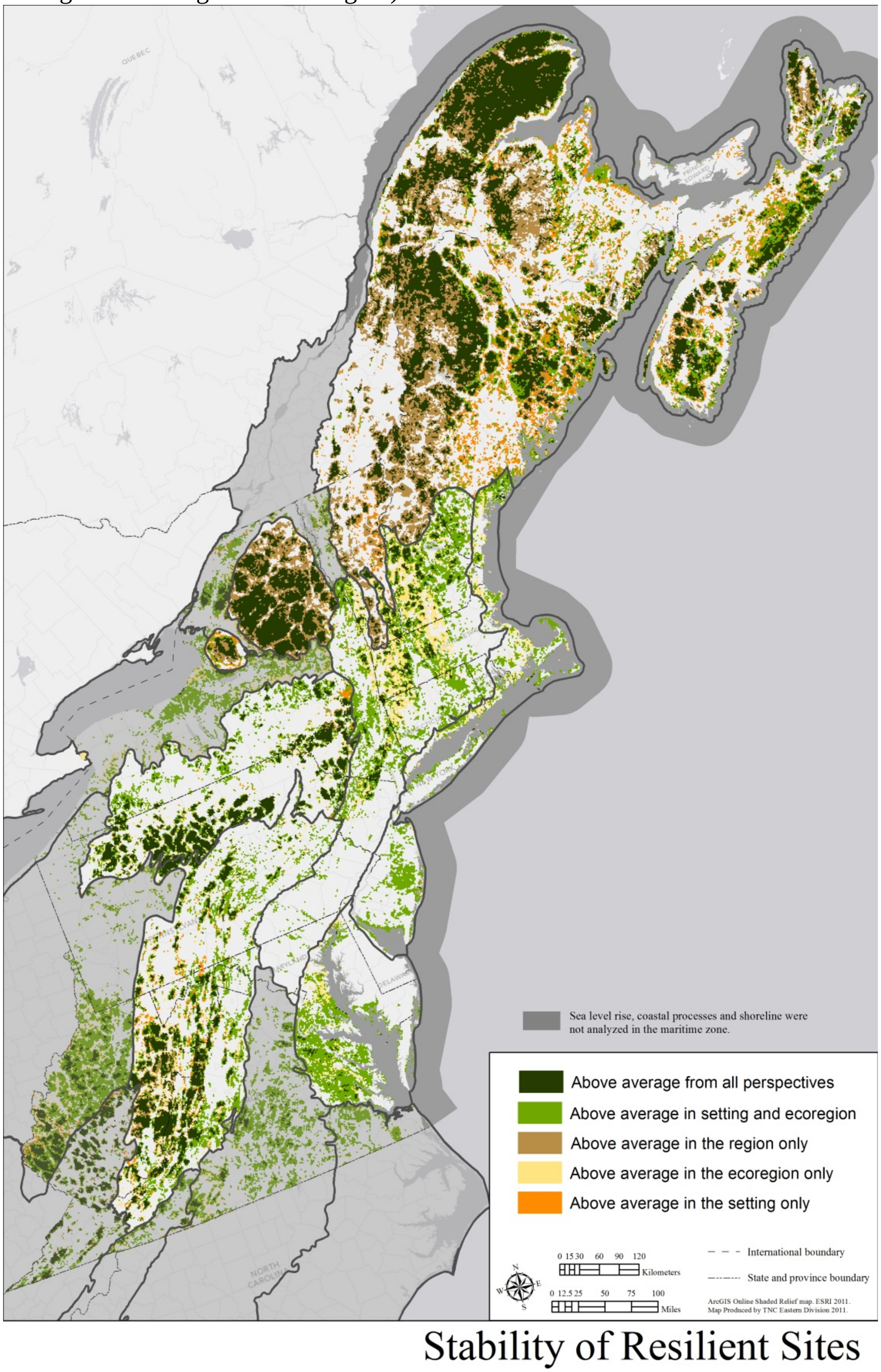


Focus Areas and Secured Areas

Map 6.38: The highest scoring areas for estimated resilience by setting across the region. Areas in yellow are comprised of cells with an average estimated resilience score based on their geophysical setting, landscape complexity and local connectedness. Areas in green score above average and are estimated to be more resilient. Areas in brown are below average and are estimated to be vulnerable to climate change and other factors



Map 6.39: Comparison of scores for full region, individual settings and settings within ecoregion. This map shows areas that score above average from every perspective that we examined (region, setting, ecoregion or setting within ecoregion) or for various combinations.



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The Northern Appalachian-Acadian Ecoregion:

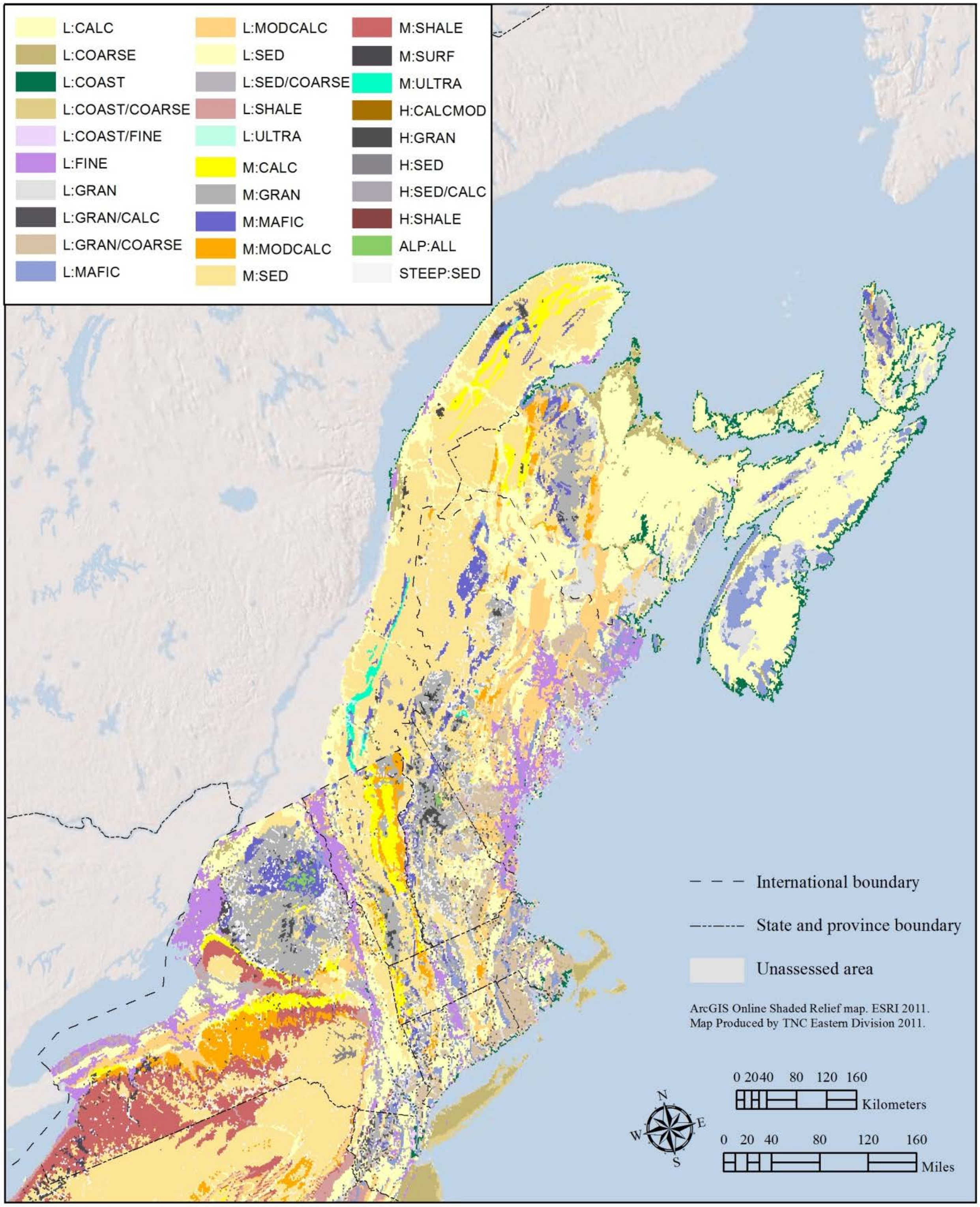
Foundation Maps

We finished our analysis of Quebec and Maritime Canada after the methods section of this report had already been completed. Consequently the maps in chapters 1-5 are focused on the US only. Here we present the foundational maps for entire Northen Appalachian-Acadian ecoregion so users can understand the development of the resilience estimates for this region. The maps include:

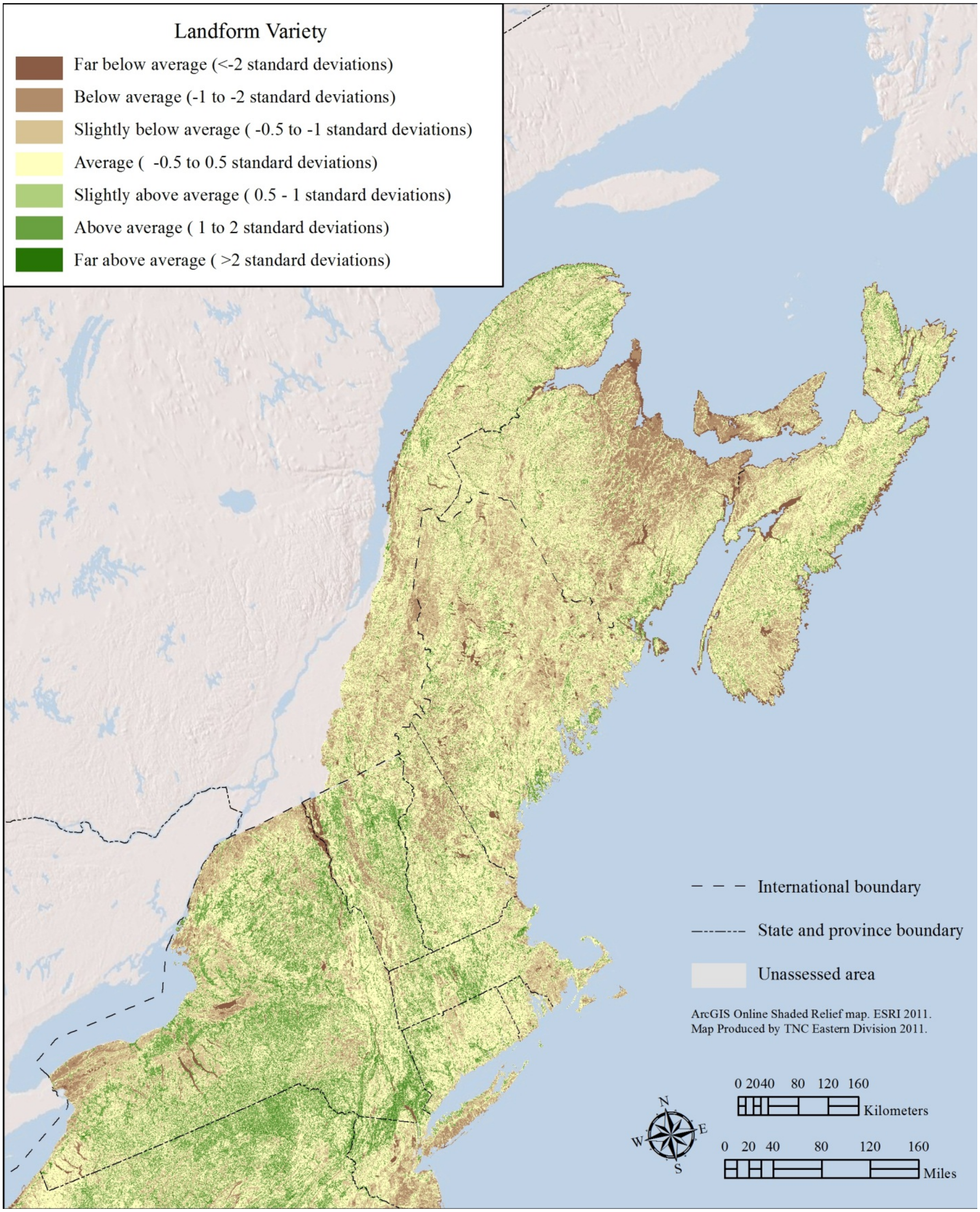
Map I1.1 Geophysical Settings
Map I1.2 Landform Variety
Map I1.3 Elevation Range
Map I1.4 Wetland Density
Map I1.5 Landscape Complexity
Map I1.6 Local Connectedness
Map I1.7 Regional Flow

Creation of each map followed the same methods described in chapter 2 for the geophysical settings and 3 for the measure of landscape complexiy and local connectedness. The integrated results with respect to estimating resilience, examining resilience by setting and ecoregion, and looking at regional linkages and networks are presented in Chapter 6.

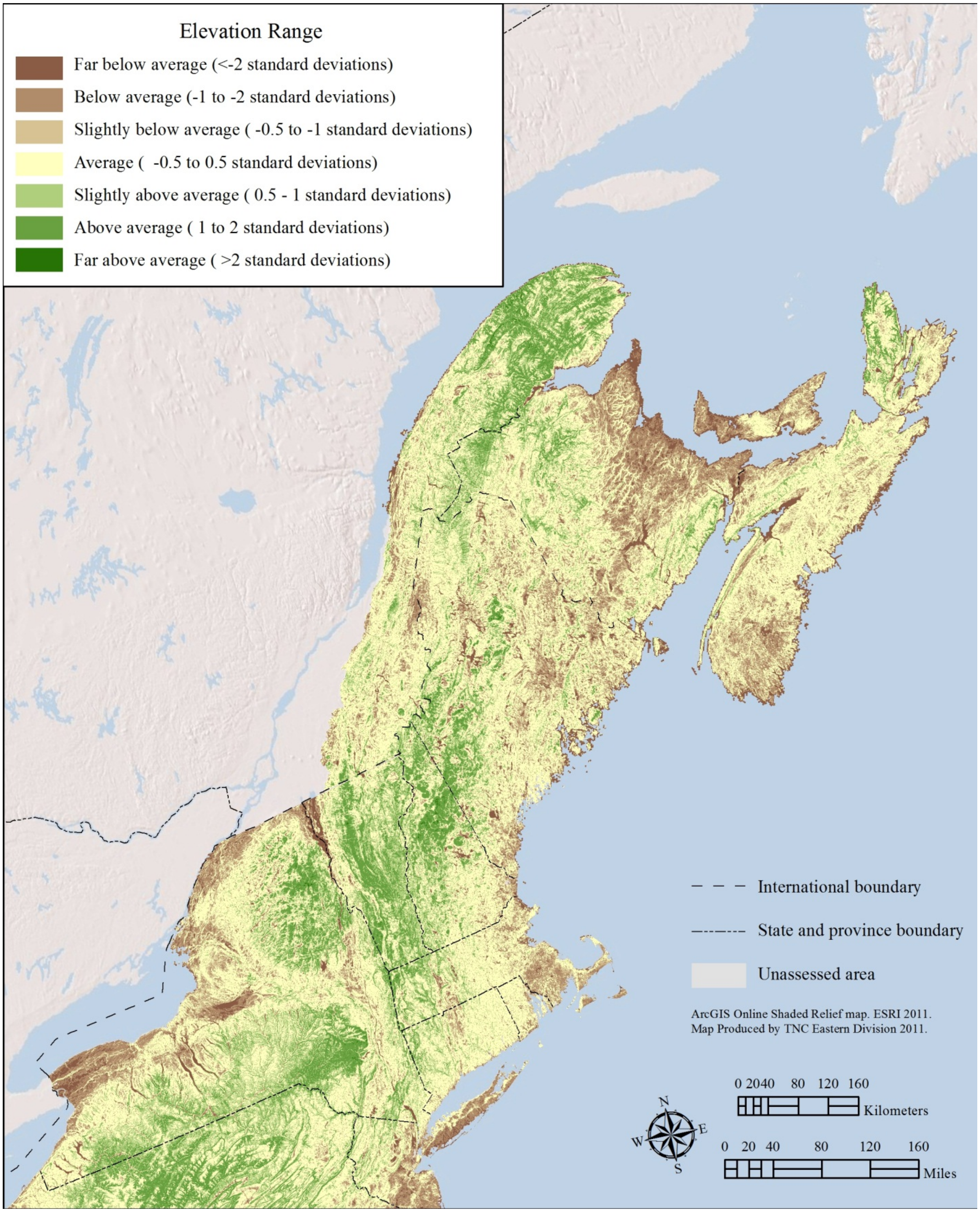
Map I1.1: Geophysical Settings of the Northern Appalachian- Acadian Ecoregion. The settings used in this report are combinations of an elevation zone and a geology class such as "low elevation calcareous" (L:CALC)



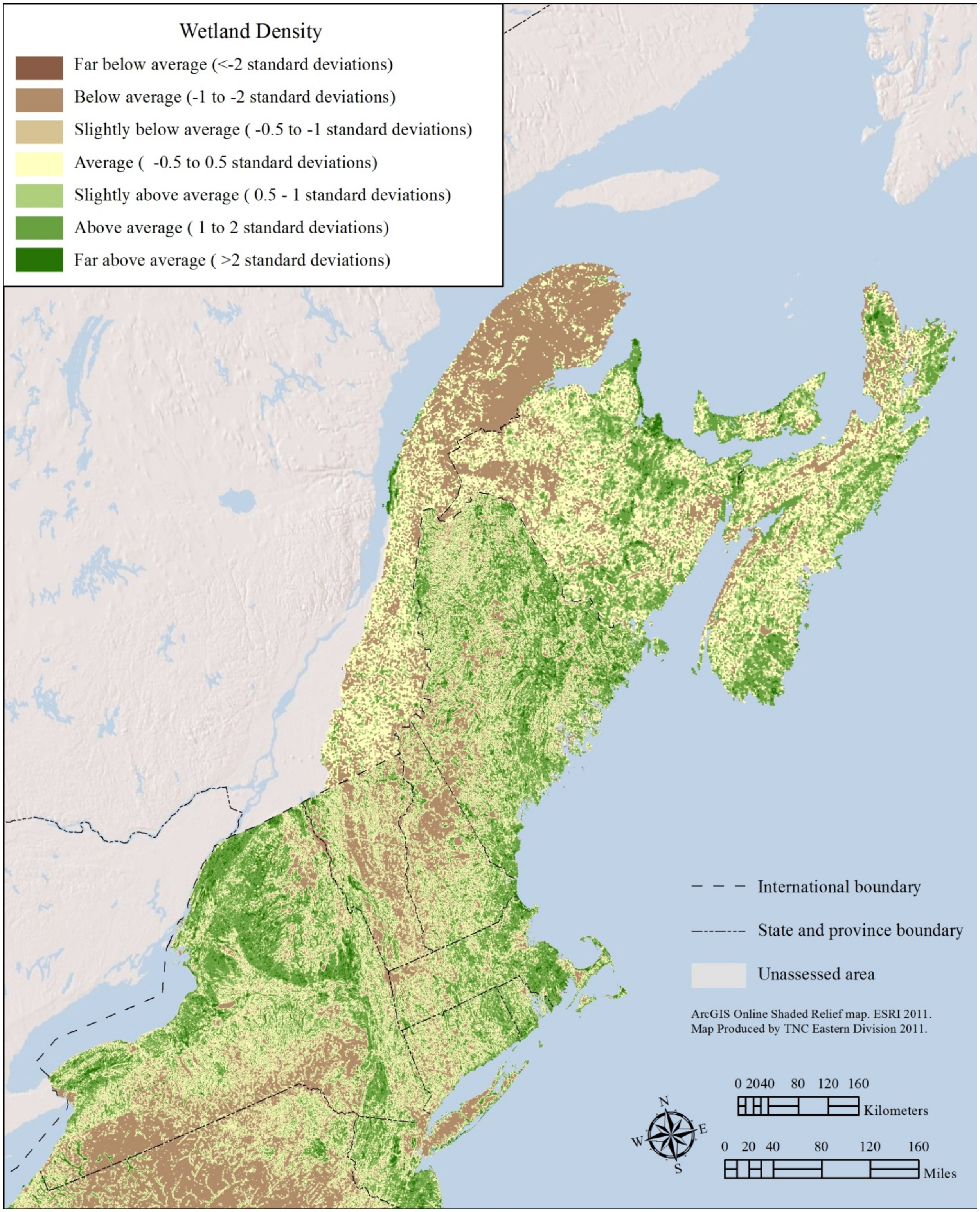
Map I1.2: Landform Variety in the Northern Appalachian-Acadian Ecoregion. This map counts the number of landforms (11 possible) in a 100 acre circle around a central cell, and compares it to the ecoegional average.



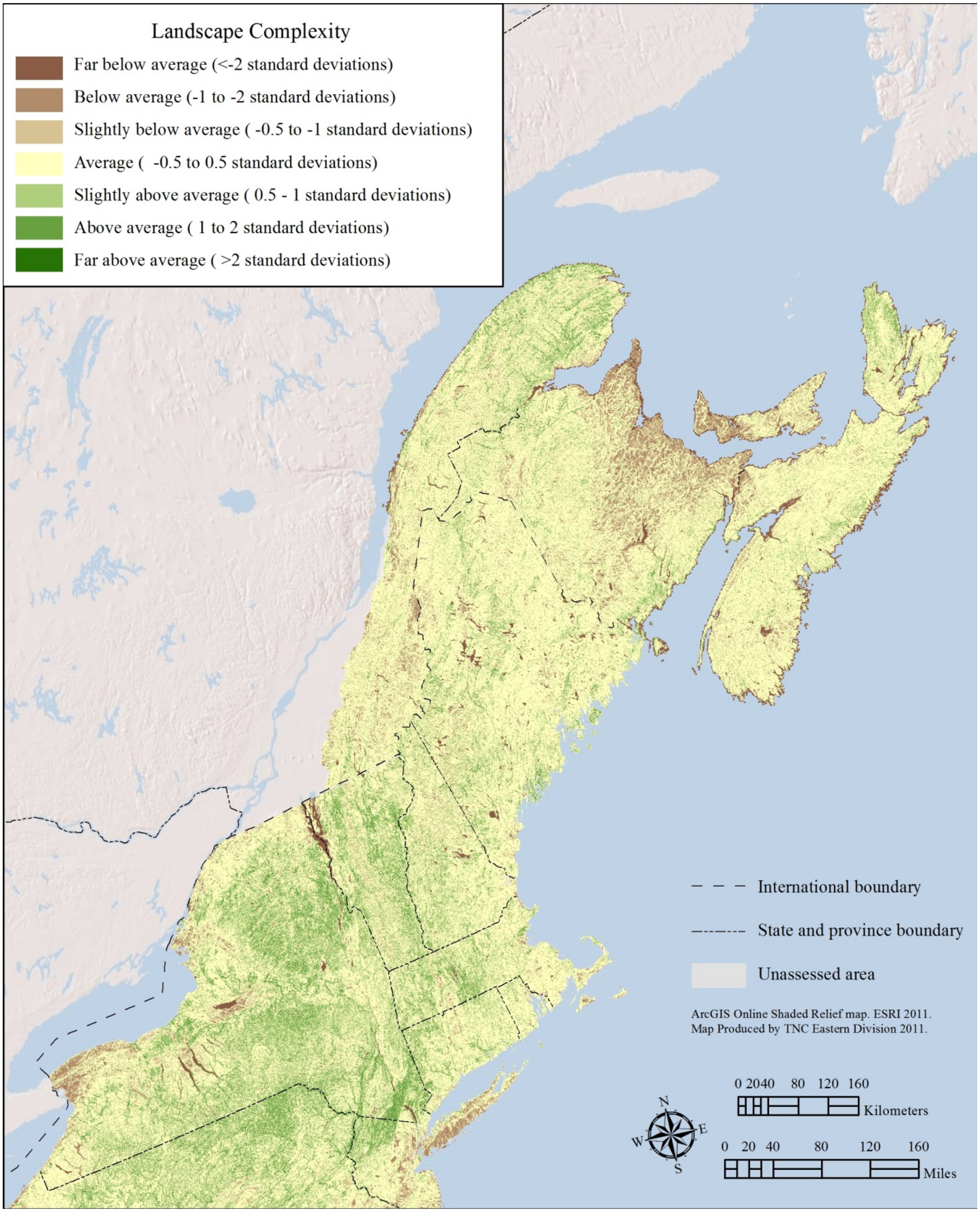
Map I1.3: Elevation Range in the Northern Appalachian-Acadian Ecoregion. This map measures the elevation range in a 100 acre circle around a central cell and compares it to the ecoregion average.



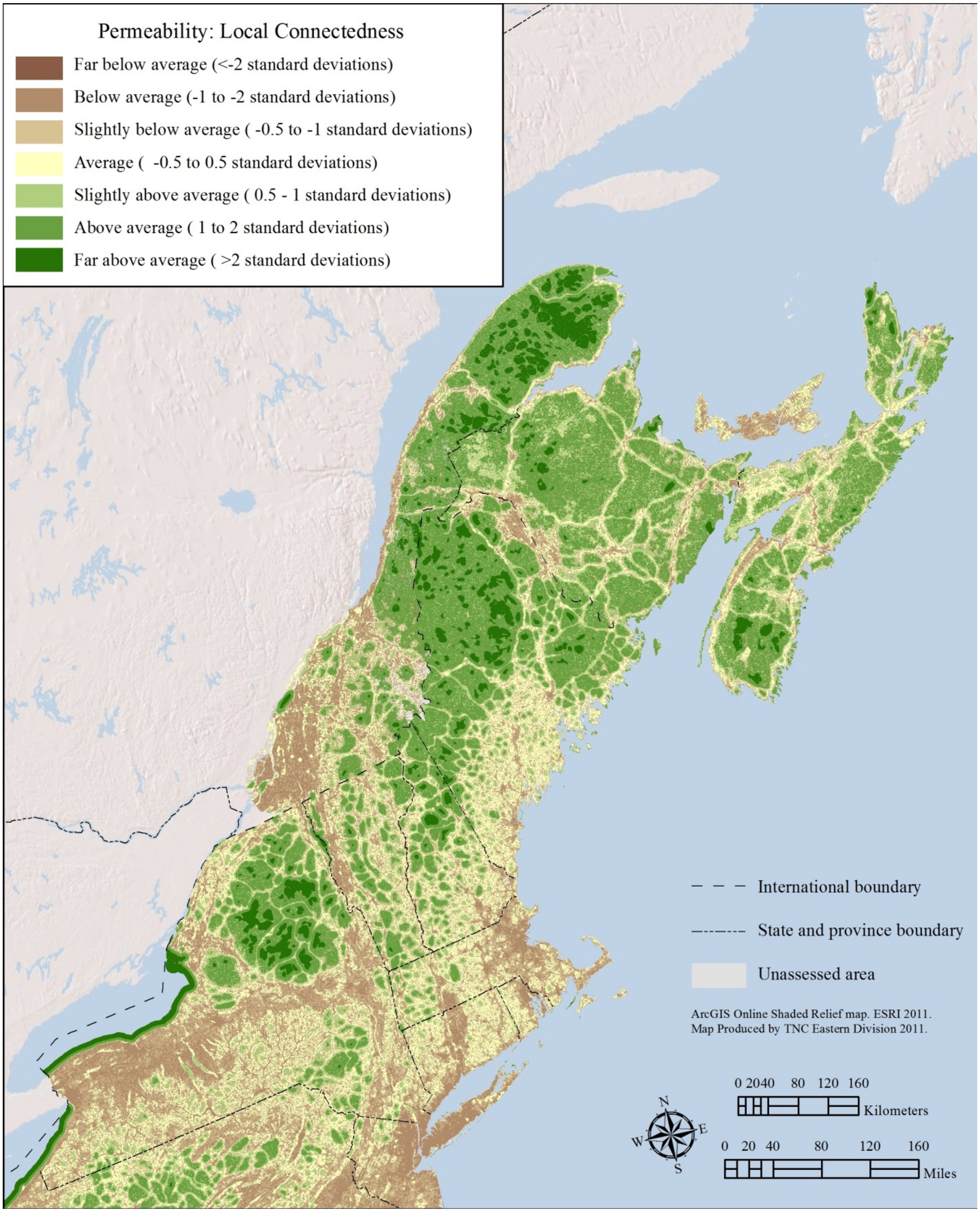
Map I1.4: Wetland Density in the Northern Appalachian- Acadian Ecoregion. This map measures the weighted density of wetlands in a 100 and 1000 acre circle around a central cell and compares it to the ecoregional average.



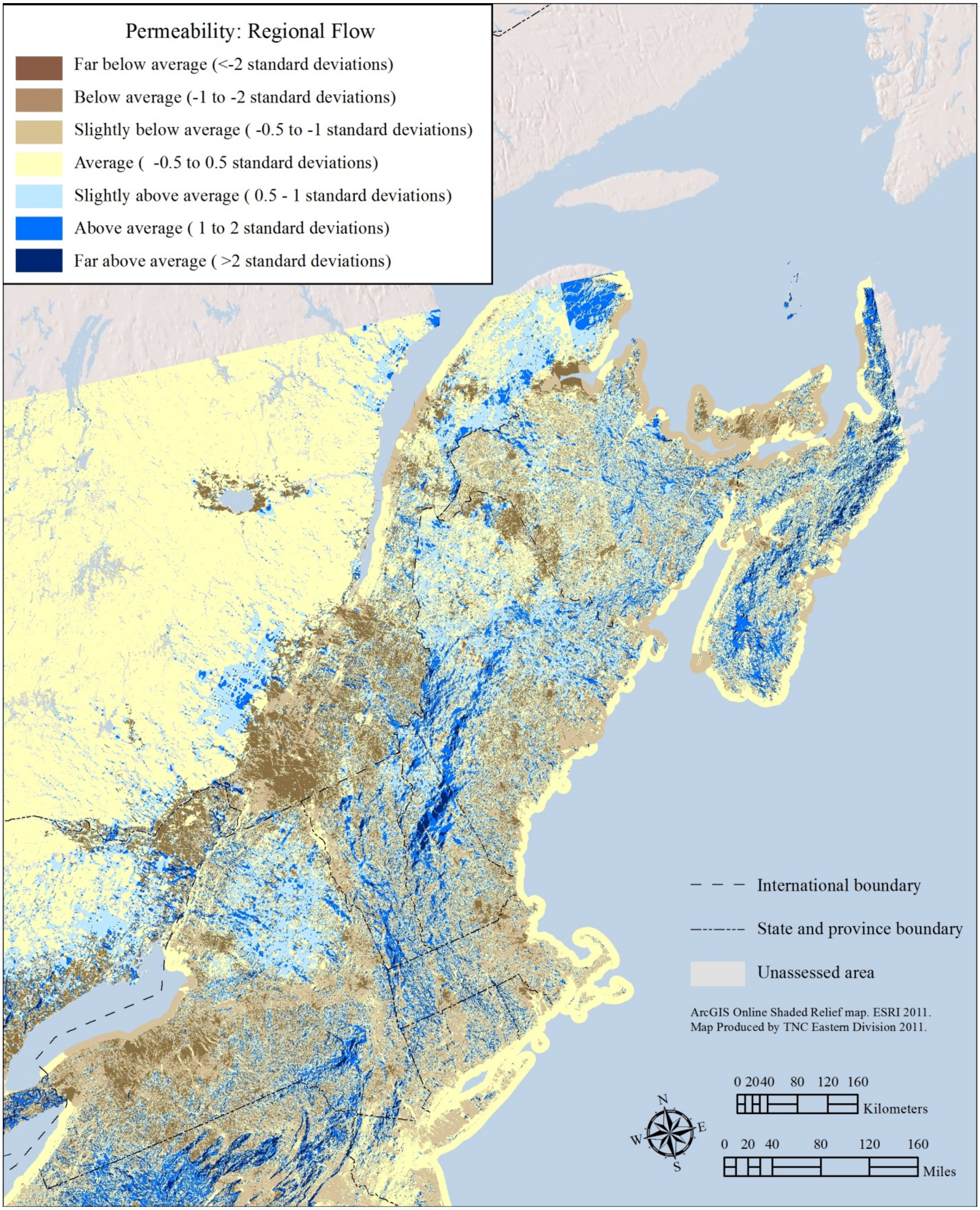
Map I1.5: Landscape Complexity of the Northern Appalachian-Acadian Ecoregion. This map estimates the degree of landscape complexity of a cell based on the combined values of landform variety, elevation range and wetland density, and compares if to the regional average.



Map I1.6: Local Connectedness of the Northern Appalachian-Acadian Ecoregion. This map estimates the degree of connectness of a cell with its suroundings within a three kilometer radius, and compares it to the ecoregional average.



Map I1.7: Regional flow patterns of the Northern Appalachian-Acadian Ecoregion. This map shows areas of concentrated flow (above average), diffuse or dispersed flow (average) and low or blocked flow (below average).



Detail on Ecological Land Units

Adapted from Ecological Land Units: Elevation Zones, Geology, and Landforms, Ferree, C. and Anderson, M.A. 2008. Ecological Land Units. Version 11/2008. The Nature Conservancy Eastern Conservation Science Office. Boston, MA.

The Ecological Land Unit (ELU) dataset is a composite of several layers of abiotic information that critically influence the form, function, and distribution of ecosystems - elevation zone, bedrock geology, and landforms. Each 30m grid cell is assigned a given elevation, bedrock or surficial geology, and landform class. The three components can be viewed or queried separately or in combination. Elevation has been shown to be a powerful predictor of the distribution of forest communities in the Northeast. Temperature, precipitation, and exposure commonly vary with changing altitude. Bedrock geology strongly influences area soil and water chemistry. Bedrock types also differ in how they weather and in the physical characteristics of the residual soil type. Rowe (1998) contends that landform is "the anchor and control of terrestrial ecosystems." Landforms are largely responsible for local variation in solar radiation, moisture availability, soil development, and susceptibility to wind and other disturbance. We adopted the Fels and Matson (1997) system for landform modeling, in which combinations of slope and landscape position are used to define topographic units such as ridges, sideslopes, coves, and flats on the landscape. Six ecologically relevant elevation zones were defined; over 250 bedrock and surficial geology classes were collapsed into 9 ecologically distinct geology classes; and GIS modeling gave us 13 ecologically significant landform classes. Combination of these resource grids resulted in over 700 unique ELUs in the region.

Elevation classes

Elevation has been shown to be a powerful predictor of the distribution of forest communities in the Northeast. Temperature, precipitation, and exposure commonly vary with changing altitude. We broke continuous elevation data from the National Elevation Dataset of the USGS into discrete elevation classes with relevance to the distribution of forest types region-wide. Meaningful biotic zones would be defined with quite different elevation cut-offs in the northern and southern parts of the region, so class ranges necessarily approximate critical ecological values.

Table 1. Ranges for elevation classes.

Elevzone	*(feet)*	*Characteristic forest type in Lower New England*
1000/2000	0-20ft & 20-800ft	Oak, pine-oak, pine-hemlock, maritime spruce, floodplain forest
3000	800-1700ft	Hemlock-N. hardwoods, N. hardwoods, lowland spruce-fir
4000	1700-2500ft	Northern hardwoods, spruce-hardwoods
5000, 6000	2500-3600ft, >3600ft	Krummholz, montane spruce-fir, alpine communities

Bedrock geology and deep sediments

Bedrock geology strongly influences area soil and water chemistry. Even in glaciated landscapes, studies suggest that soil parent material is commonly of local origin, rarely being ice-transported more that a few miles from its source. Bedrock types also differ in how they weather and in the physical characteristics of the residual soil type. Because of this, local lithology is usually the principle determinant of soil chemistry, texture, and nutrient availability. Many ecological community types are closely related to the chemistry and drainage of the soils or are associated with particular bedrock exposures.

We grouped bedrock units on the bedrock geology maps of the northeast 14 states into five bedrock classes (Table 2). We based our scheme on broad classification schemes developed by other investigators which emphasize chemistry and texture, and on bedrock settings that are important to many ecological communities, particularly to herbaceous associations.

In some settings deep sediments of glacial origin mantle the bedrock. The consolidated bedrock of valleys of pro-glacial lakes, for example, may lie under many meters of fine lacustrine sediments, and deep coarse deltaic or outwash deposits often overlay the bedrock in pine barrens and sand plains in the northeast. In these settings it is the nature of the sediments—their texture, compactness, and moisture-holding capacity, their nutrient availability, their ability to anchor overstory trees in a wind disturbance--that is ecologically relevant, and not the nature of the underlying bedrock. We used a USGS dataset of sediments of the glaciated northeast to identify such places. The USGS map was compiled at a coarse scale (1:1,000,000), but we made the data a little “smarter” by informing it with our landform map (please see landforms development section that accompanies this metadata). Our landform layer was compiled at a much finer scale (the scale of the digital elevation models from which they were shaped, 1:24,000), and we allowed the deep coarse or fine sediments of the USGS dataset to be mapped only on those landforms on which they would naturally be expected to occur. In the case of sandy, coarse sediments, this would be in broad basin and valley/toe slope settings; in the case of fine clayey lacustrine or marine sediments, in these same settings, plus low hills and lower sideslopes. The seven bedrock classes were numbered 100 through 700 (Table 2), and the coarse and fine sediments classes were numbered 800 and 900, respectively.

Table 2. Bedrock geology classes.

Geology Class	Lithologies (including metamorphic equivalents)
Ultramafic: magnesium rich alkaline rock	Serpentine, soapstone, pyroxenite, dunite, peridotite, talc schist
Mafic: quartz poor alkaline to slightly acidic rock	Ultrabasic: anorthosite, Basic: gabbro, diabase, basalt, Intermediate: diorite, andesite, syenite, trachyte, Metamorphic equivalents : Greenstone, amphibolites, epidiorite, granulite, bostonite, essexite
Acidic Granitic: quartz rich, resistant acidic igneous rock	Granite, granodiorite, rhyolite, felsite, pegmatite, Metamorphic equivalents : Granitic gneiss, charnocktites, migmatites
Acidic Sedimentary: fine to coarse grained, acidic sedimentary rock	Mudstone, claystone, siltstone, Non-fissile shale, sandstone, breccia, conglomerate, greywake, arenites, Metamorphic equivalents: slate, phyllite, pelite, schist, pelitic schist, granofel, quartzite
Acidic Shale: fine grained acidic sedimentary rock with fissile texture	Fissile shales only
Calcareous Sedimentary: basic/alkaline, soft sedimentary rock with high calcium content	Limestone, dolomite, dolostone, other carbonate-rich clastic rocks, Metamorphic equivalents : Marble
Moderately Calcareous Sedimentary: neutral to basic, moderately soft sedimentary rock with some calcium	Calcareous shale and sandstone, calc-silicate granofel, Metamorphic equivalents: calcareous schists and phyllite
Fine Sediment: fine-grained surficial sediments	Unconsolidated mud, clay, drift, ancient lake deposits
Coarse Sediment: coarse-grained surficial sediments.	Unconsolidated sand, gravel, pebble, till.

Landforms

Stanley Rowe called landform "the anchor and control of terrestrial ecosystems." It breaks up broad landscapes into local topographic units, and in doing so provides for meso- and microclimatic expression of broader climatic character. It is largely responsible for local variation in solar radiation, soil development, moisture availability, and susceptibility to wind and other disturbance. As one of the five "genetic influences" in the process of soil formation, it is tightly tied to rates of erosion and deposition, and therefore to soil depth, texture, and nutrient availability. These are, with moisture, the primary edaphic controllers of plant productivity and species distributions. If the other four influences on soil formation (climate, time, parent material, and biota) are constant over a given space, it is variation in landform that drives variation in the distribution and composition of natural communities.

Of the environmental variables discussed here, it is landform that most resists quantification. Landform is a compound measure, which can be decomposed into the primary terrain attributes of elevation, slope, aspect, surface curvature, and upslope catchment area. The wide availability and improving quality of digital elevation data has made the quantification of primary terrain attributes a simple matter. Compound topographic indices have been derived from these primary attributes to model various ecological processes. We adopted the Fels and Matson (1997) approach to landform modeling. They described a metric that combines information on slope and landscape position to define topographic units such as ridges, sideslopes, coves, and flats on the landscape. That approach is described here: feel free to skip over the details, to the set of defined landforms that emerges from the process (Figure 1 and Table 3 below).

The parent dataset for the two grids used to construct the landforms is the 30 meter National Elevation Dataset digital elevation model (DEM) of the USGS. Step one was to derive a grid of discrete slope classes relevant to the Northern Appalachian landscape. We remapped slopes to create classes of 0-2˚ (0.0-3.5%), 2-6˚ (3.5–10.5%), 6-24˚ (10.5–44.5%), 24-35˚ (44.5-70.0%), and >35˚ (>70.0%) (vertical axes of Figure1). Ground checks have shown that, because the NED dataset averages slopes over 30 meter intervals, raster cells in the 2 steepest elevation classes contain actual terrain slopes of from about 35 to 60 degrees (in the 24-35˚ class) and 60 to 90 degrees (in the steepest class).

The next step was the calculation of a landscape position index (LPI), a unitless measure of the position of a point on the landscape surface in relation to its surroundings. It is calculated, for each elevation model point, as a distance-weighted mean of the elevation differences between that point and all other elevation model points within a user-specified radius:

$$LPI_o = [\sum_{1,n} (z_i - z_o) / d_i] / n,$$

where: z_o = elevation of the focal point whose LPI is being calculated,

z_i = elevation of point i of n model points within the search radius of the focal point

d_i = horizontal distance between the focal point and point i

n = the total number of model points within the specified search distance

If the point being evaluated is in a valley, surrounding model points will be mostly higher than the focal point and the index will have a positive value. Negative values indicate that the focal point is close to a ridge top or summit, and values approaching zero indicate low relief or a mid-slope position (Fig. 1).

The specified search distance, sometimes referred to as the "fractal dimension" of the landscape, is half of the average ridge-to-stream distance. We used two methods to fix this distance for each subsection within the region, one digital and one analog. The "curvature" function of the ArcInfo Grid module uses the DEM to calculate change in slope ("slope of the slope") in the landscape. This grid, when displayed as a stretched grayscale image, highlights valley and ridge structure, the "bones" of the landscape, and ridge-to-stream distances can be sampled on-screen. For our analog approach we used 7.5' USGS topographic quadsheets. In each case, we averaged several measurements of ridge-to-stream distances, in landscapes representative of the subsection, to obtain the fractal dimension. This dimension can vary considerably from one subsection to another.

[There is a third approach to fixing the landscape fractal dimension that is intriguing. A semivariogram of a clip of the DEM for a typical portion of the regional landscape can be constructed— it quantifies the spatial autocorrelation of the digital elevation points by calculating the squared difference in elevation between each and every pair of points in the landscape, then plotting half that squared difference (the “semivariance”) against the distance of separation. A model is then fitted to the empirical semiovariogram “cloud of points.” (This model is used to guide the prediction of unknown points in a kriging interpolation.) The form of the model is typically an asymptotic curve that rises fairly steeply and evenly near the origin (high spatial autocorrelation for points near one another) and flattens out at a semivariance “sill” value, beyond which distance there is little or no correlation between points. Though the sill distance, in the subsections where we tried this approach, was 2 or 3 times the “fractal distance” as measured with the first 2 methods, the relationship between the two was fairly consistent. With a little more experimentation, the DEM semivariogram could prove to be a useful landscape analysis tool.]

The next step was to divide the grid of continuous LPI values into discrete classes of high, moderately high, moderately low, and low landscape position. Histograms of the landscape position grid values were examined, a first set of break values selected, and the resulting classes visualized and evaluated. We did this for several different types of landscapes (rolling hills, steeply cut mountainsides, kame complexes in a primarily wet landscape, broad valleys), in areas of familiar geomorphology. The process was repeated many times, until we felt that the class breaks accurately caught the structure of the land, in each of the different landscape types. Success was measured by how well the four index classes represented the following landscape features:

- High landscape position (very convex): sharp ridges, summits, knobs
- Moderately high landscape position: upper side slopes, rounded summits and ridges, low hills and kamic convexities
- Moderately low landscape position: lower sideslopes and toe slopes, gentle valleys and draws, broad flats
- Low landscape position (very concave): steeply cut stream beds and coves, and flats at the foot of steep slopes

We assigned values 1-5 to the five slope classes, and 10, 20, 30, and 40 to the four LPI classes. Following Fels and Matson (1997), we summed the grids to produce a matrix of values (Fig. 1), and gave descriptive names to landforms that corresponded to matrix values. We collapsed all units in slope classes 4 and 5 into "steep" and "cliff" units, respectively. The ecological significance of these units, which are generally small and thinly distributed, lies in their very steepness, regardless of where they occur on the landscape.

Recognizing the ecological importance of separating occurrences of "flats" (0-2˚) into primarily dry areas and areas of high moisture availability, we calculated a simple moisture index that maps variation in moisture accumulation and soil residence time. We used National Wetlands Inventory datasets to calibrate the index and set a wet/dry threshold, then applied it to the flats landform to make the split. The formula for the moisture index is:

Moist_index = ln [(flow_accumulation + 1) /(slope + 1)]

Grids for both flow accumulation and slope were derived from the DEM by ArcInfo Grid functions of the same names.

For the ecoregional ELU dataset, upper and lower sideslopes are combined, and a simple ecologically relevant aspect split is embedded in the sideslope and cove slope landforms (Figure 2 and Table 3).

Last, waterbodies from the National Hydrography Dataset (NHD), which was compiled at a scale of 1:100,000 and is available for the whole region, were incorporated into the landform layer with codes 51 (broader river reaches represented as polygons) and 52 (lakes, ponds, and reservoirs). Single-line stream and river arcs from the NHD were not burned into the landforms--only those river reaches that are mapped as polygons.

Landform units for an area of varied topography in the southeastern New Hampshire are shown in map view in Figure 2.

<u>The Ecological Land Unit Grid</u>

With the elevation, substrate, and landform layers, all the elements for assembling ecological land units, or ELUs, are in place. ELU code values for each cell in the region-wide grid are simply the summed class values for elevation zone, substrate, and landform for that cell. For example, a cell in a wet flat (landform 31) at 1400 feet (elevation class 2000) on granitic bedrock (substrate class 500) would be coded 2531.

ELU_code = Elev class (ft) + Substrate class + Landform

Elev class (ft)	Substrate class	Landform
1000 (0-20)	100 Acidic sed/metased	4 Steep slope
2000 (20-800)	200 Acidic shale	5 Cliff
3000 (800-1700)	300 Calc sed/metased	11 Flat summit/ridgetop
4000 (1700-2500)	400 Mod. calc sed/metased	13 Slope crest
5000 (2500-3600)	500 Acidic granitic	21 Hilltop (flat)
600 (3600+)	600 Mafic/intermed granitic	22 Hill (gentle slope)
	700 Ultramafic	23 N-facing sideslope
	800 Coarse sediments	24 S-facing sideslope
	900 Fine sediments	30 Dry flat
		31 Wet flat
		32 Valley/toe slope
		41 Flat at bottom of steep slope
		43 N-facing cove/draw
		44 S-facing cove/draw
		51 River
		52 Lake/pond/reservoir

Fig. 1: Formulation of landform models from land position and slope classes.

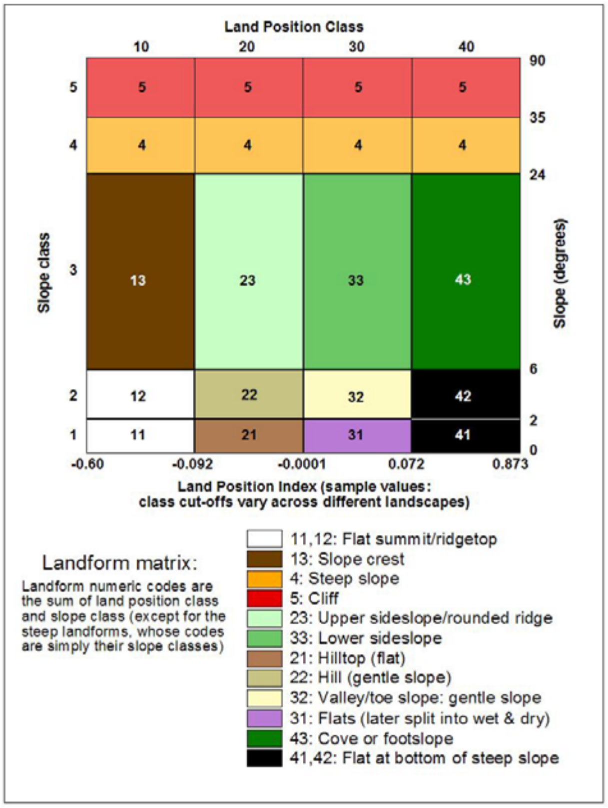
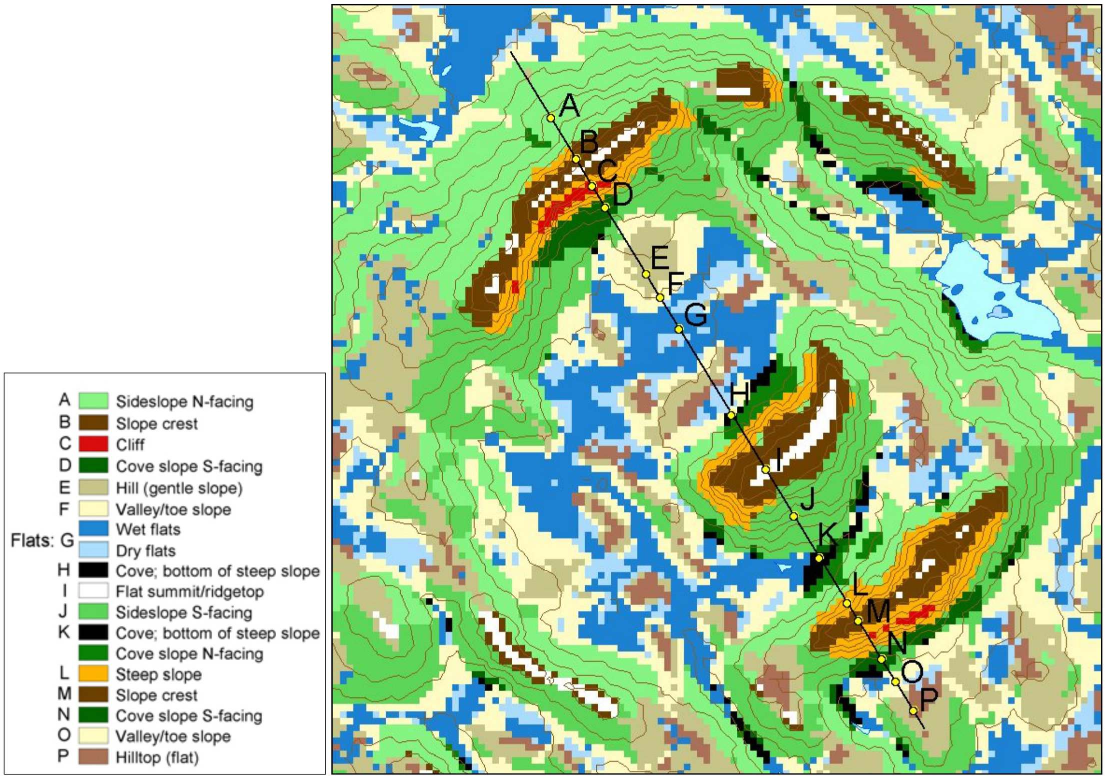


Fig. 2: Landforms in Pawtuckaway State Park, NH



For more information on landform development, please consult the full article “Fels, J, and K.C. Matson. 1997. A cognitively-based approach for hydrogeomorphic land classification using digital terrain models.” which is available on the internet at:
www.ncgia.ucsb.edu/conf/SANTA_FE_CD-ROM/sf_papers/fels_john/fels_and_matson.html

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.

Regionally Significant Species of Greatest Conservation Need

A. **NatureServe 2011 NatureServe Central Databases. Arlington, Virginia. U.S.A. Precise locational (Element Occurrence) data polygons for all species in the following states: Connecticut, Delaware, District of Columbia, Maryland, Maine, New Hampshire, New Jersey, New York, Rhode Island, Virginia, Vermont, and West Virginia. Data Source: NatureServe (www.natureserve.org) and its Natural Heritage member programs.** NatureServe and its Natural Heritage member programs have developed a Multi-Jurisdictional Dataset (MJD). The creation of the MJD is aimed at improving conservation planning and actions by providing access to a comprehensive dataset of U.S. and Canadian species and ecological communities. These data are dependent on the research and observations of many scientists and institutions, and reflect our current state of knowledge. Many areas have never been thoroughly surveyed, however, and the absence of data in any particular geographic area does not necessarily mean that species or ecological communities of concern are not present. The data was exported from NatureServe 2/2011.
B. **Pennsylvania Natural Heritage Program, Pittsburg, PA. U.S.A.** The Pennsylvania Natural Heritage Program (PNHP) is a partnership of the Department of Conservation and Natural Resources, the Western Pennsylvania Conservancy, the Pennsylvania Fish and Boat Commission, and the Pennsylvania Game Commission. The Pennsylvania Natural Heritage Program (PNHP) provided The Nature Conservancy (TNC) with GIS shapefiles and tabular data for Element Occurrences for non-Federally listed tracked birds, mammals, terrestrial invertebrates, plants, and natural communities contained in the PNHP database for the entire state of Pennsylvania. For amphibians, reptiles, fish, aquatic invertebrates (e.g., mussels, odonates) and species listed under the US Endangered Species Act, PNHP was only able to provide Environmental Review polygons. The data was exported from the Pennsylvania Natural Herigate Program 2/2011.
C. **Massachusetts Natural Heritage & Endangered Species Program. Westborough, Massachusetts. U.S.A.** The Massachusetts Natural Heritage & Endangered Species Program is part of the Massachusetts Division of Fisheries and Wildlife. The Massachusetts Natural Heritage and Endangered Species Program provided The Nature Conservancy with GIS shapefiles and tabular data for all Element Occurrences contained in the NHESP database for species and natural communities

within the state. The data was exported from the Massachusetts Natural Heritage & Endangered Species Program 1/2011.

D. **Delaware Natural Heritage and Endangered Species Program. Smyrna, Delaware. U.S.A.** The Delaware Natural Heritage and Endangered Species Program is part of the Delaware Division of Fish and Wildlife. The Delaware Natural Heritage and Endangered Species Program provided The Nature Conservancy with GIS shapefiles and tabular data for all Element Occurrences contained in the NHESP database for species and natural communities within the state. The data was exported from the Delaware Natural Heritage and Endangered Species Program 2005.

How did we consistently map species occurrences and do the hexagon overlay? All source species occurrence datasets were converted to point features if they were not already in point format for this intersection. Centroids were created by The Nature Conservancy from the following sources using the XTools extension (ver. 6.0) for ArcGIS:

- Massachusetts Natural Heritage & Endangered Species Program Element Occurrence Record Source polygons
- Massachusetts Natural Heritage & Endangered Species Program Element Occurrence Record Source lines
- NatureServe Multi-Jurisdictional Dataset polygons
- Pennsylvania Natural Heritage Program Environmental Review polygons

These were combined with data already in point format from:

- Delaware Natural Heritage and Endangered Species Program Element Occurrence Record
- Massachusetts Natural Heritage & Endangered Species Program Element Occurrence Record source points
- Pennsylvania Natural Heritage Program Element Occurrence Record point representations of polygon records

The following types of centroids were classified as precise enough for the overlay with 1000 acre hexagons:

1) The NatureServe MJD most precise available polygon occurrences where the representational accuracy was listed as very high, high, or medium.
2) The NatureServe MJD most precise available polygon occurrences where the representational accuracy was listed as unknown or blank but the polygon was < 125 acres in size, the minimum size allowable for a procedural feature to be classified as of medium representational accuracy
3) All occurrences obtained from Massachusetts Natural Heritage Program
4) All occurrences obtained from Delaware Natural Heritage Program
5) Pennsylvania Natural Heritage Program Element Occurrence Records for non-Federally listed tracked birds, mammals, terrestrial invertebrates, plants, and natural communities

The following types of occurrences were classified as not precise enough for the centroid overlay with 1000 acre hexagons:

1. The NatureServe MJD most precise available polygon occurrences where the representational accuracy was listed as low or very low
2. The NatureServe MJD most precise available polygon occurrences where the representational accuracy was listed as unknown or blank and the polygon was >= 125 acres in size
3. Pennsylvania amphibians, reptiles, fish, aquatic invertebrates (e.g., mussels, odonates) and species listed under the US Endangered Species Act for which PNHP could only provide Environmental Review polygons.

<u>Roads and Railroads</u>

Roads: Tele Atlas North America, Inc., 2009. U.S. and Canada Streets Cartographic. 1:100,000 Tele Atlas StreetMap Premium v. 7.2 ESRI® Data & Maps: StreetMap. 2009 Data Update: North America. Redlands, California, USA. U.S. and Canada Streets Cartographic represents streets, highways, interstate highways, roads with and without limited access, secondary and connecting roads, local and rural roads, roads with special characteristics, access ramps, and ferries within the United States and Canada.

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.

How did we create Road/Railroad Density? We calculated a wall-to-wall dataset of the road and railroad density (meters/hectare) within a 1,000 meter radius of each 30m pixel for the New England and Mid-Atlantic States. We compiled roads from the following sources: 1) Roads: Tele Atlas North America, Inc., 2009. U.S. and Canada Streets Cartographic. 1:100,000 Tele Atlas StreetMap Premium v. 7.2 ESRI® Data & Maps: StreetMap. 2009 Data Update: North America. Redlands, California, USA. U.S. 2) 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. From this dataset we excluded 4-wheel drive trails, walking trails, and ferry lines because these features were not consistently mapped across states. Using the remaining class 1-8 roads and all railroads, we calculated the density of line features using the ESRI ArcGIS 9.3 Workstation GRID command LINEDENSITY (<lines>, {item}, {cellsize}, <SIMPLE | KERNEL>,{unit_scale_factor}, {radius}) with the parameters linedensity (mrg_rd18rr.shp, none, 30, simple, 10000, 1000). We had to divide the region into 8 tiles for analysis and create integer outputs due to the large file sizes involved. Each of the 8 tile areas was also buffered out by 10km prior to running through the linedensity command to make sure the border section of each tile was accurately calculated. These 10km buffer area results were then clipped off before combining the 8 tiles into a resultant regional dataset. The final dataset was also clipped to the state boundaries.

<u>Land Cover</u>

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

NLCD 2006 quantifies land cover and land cover change between the years 2001 to 2006 and provides an updated version of NLCD 2001. These products represent the first time this type of 30-meter cell land cover change has been produced for the conterminous United States. Products were generated by comparing spectral characteristics of Landsat imagery between 2001 and 2006, on an individual path/row basis, using protocols to identify and label change based on the trajectory from NLCD 2001 products. A formal accuracy assessment of the NLCD 2006 land cover change product is planned for 2011.

NLCD 2006 Product Descriptions:

NLCD 2006 Land Cover - An updated circa 2006 land cover layer (raster) for the conterminous United States for all pixels. The resultant product for the northeast 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.

NLCD 2006 Land Cover Change – A land cover layer (raster) containing only those pixels identified as changed between NLCD 2001 Land Cover Version 2.0 and NLCD 2006 Land Cover products for the conterminous United States.

NLCD 2006 Percent Developed Imperviousness - An updated circa 2006 continuous imperviousness estimate layer (raster) for the conterminous United States for all pixels. The impervious surface data classifies each 30m pixel into 101 possible values (0% - 100%).

NLCD 2001/2006 Percent Developed Imperviousness Change – A raster layer containing the difference of those imperviousness values that changed between NLCD 2001 Percent Developed Imperviousness Version 2.0 and NLCD 2006 Percent Developed Imperviousness.

Species Names

Species Names

Common Name	Scientific Name	Group
Acadian Quillwort	*Isoetes acadiensis*	Pteridophyte
Addison'S Leatherflower	*Clematis addisonii*	Dicot
Alewife Floater	*Anodonta implicata*	Mollusk
Algae-Like Pondweed	*Potamogeton confervoides*	Monocot
Allegheny Woodrat	*Neotoma magister*	Mammal
Alpine Goldenrod	*Solidago arctica*	Dicot
American Burying Beetle	*Nicrophorus americanus*	Insect
American Ginseng	*Panax quinquefolius*	Dicot
American Larch	*Larix laricina*	Gymnosperm
American Peregrine Falcon	*Falco anatum*	Bird
An Amphipod	*Stygobromus redactus*	Arthropod
Anticosti Aster	*Symphyotrichum anticostense*	Dicot
Appalachian Blue Violet	*Viola appalachiensis*	Dicot
Appalachian Grizzled Skipper	*Pyrgus wyandot*	Insect
Appalachian Oak Fern	*Gymnocarpium appalachianum*	Pteridophyte
Appalachian Springsnail	*Fontigens bottimeri*	Mollusk
Appalachian Tiger Beetle	*Cicindela ancocisconensis*	Insect
Arctic Bentgrass	*Agrostis mertensii*	Monocot
Arnica	*Arnica lanceolata*	Dicot
Arogos Skipper	*Atrytone arogos*	Insect
Atlantic Pigtoe	*Fusconaia masoni*	Mollusk
Atlantic Salmon	*Salmo salar*	Fish
Atlantic Sturgeon	*Acipenser oxyrinchus*	Fish
Atlantic White Cedar	*Chamaecyparis thyoides*	Gymnosperm
Atlantic Whitefish	*Coregonus huntsmani*	Fish
Auricled Twayblade	*Listera auriculata*	Monocot
Avernus Cave Beetle	*Pseudanophthalmus avernus*	Insect
Awned Meadowbeauty	*Rhexia aristosa*	Dicot
Awned Mountain-Mint	*Pycnanthemum setosum*	Dicot
Bachman'S Sparrow	*Aimophila aestivalis*	Bird
Balsam Fir	*Abies balsamea*	Gymnosperm
Barbed-Bristle Bulrush	*Scirpus ancistrochaetus*	Monocot
Barratt'S Sedge	*Carex barrattii*	Monocot
Barrens Dagger Moth	*Acronicta albarufa*	Insect
Barrens Itame	*Itame inextricata*	Insect
Barrens Metarranthis Moth	*Metarranthis apiciaria*	Insect
Barrow'S Goldeneye (Eastern Population)	*Bucephala islandica*	Bird
Barton'S St. John'S-Wort	*Hypericum adpressum*	Dicot
Bartram Shadbush	*Amelanchier bartramiana*	Dicot
Basil Mountain-Mint	*Pycnanthemum clinopodioides*	Dicot
Bayard'S Adder'S-Mouth Orchid	*Malaxis bayardii*	Monocot
Bayonet Rush	*Juncus militaris*	Monocot
Beach Pinweed	*Lechea subcylindrica*	Dicot
Beach-Dune Tiger Beetle	*Cicindela hirticollis*	Insect
Bicknell'S Thrush	*Catharus bicknelli*	Bird

Biggers' Cave Amphipod	*Stygobromus biggersi*	Arthropod
Black Lordithon Rove Beetle	*Lordithon niger*	Insect
Blackberry	*Rubus orarius*	Dicot
Blackpoll Warbler	*Dendroica striata*	Bird
Blake'S Milk-Vetch	*Astragalus minor*	Dicot
Blanding'S Turtle	*Emydoidea blandingii*	Reptile
Blanding'S Turtle	*Emys blandingii*	Reptile
Blue Backed Trout	*Salvelinus oquassa*	Fish
Blue Ridge Bittercress	*Cardamine flagellifera*	Dicot
Blue Ridge St. John'S-Wort	*Hypericum mitchellianum*	Dicot
Blue Scorpion-Weed	*Phacelia covillei*	Dicot
Blue Sucker	*Cycleptus elongatus*	Fish
Blueberry Gray	*Glena cognataria*	Insect
Bluebreast Darter	*Etheostoma camurum*	Fish
Blunt Manna-Grass	*Glyceria obtusa*	Monocot
Bog Asphodel	*Narthecium americanum*	Monocot
Bog Bluegrass	*Poa paludigena*	Monocot
Bog Copper	*Lycaena epixanthe*	Insect
Bog Jacob'S-Ladder	*Polemonium vanbruntiae*	Dicot
Bog Rosemary	*Andromeda glaucophylla*	Dicot
Bog Turtle	*Clemmys muhlenbergii*	Reptile
Bog Turtle	*Glyptemys muhlenbergii*	Reptile
Boott'S Rattlesnake Root	*Prenanthes boottii*	Dicot
Box Huckleberry	*Gaylussacia brachycera*	Dicot
Boykin'S Lobelia	*Lobelia boykinii*	Dicot
Braun'S Holly-Fern	*Polystichum braunii*	Pteridophyte
Bridle Shiner	*Notropis bifrenatus*	Fish
Bristly Black Currant	*Ribes lacustre*	Dicot
Brook Floater	*Alasmidonta varicosa*	Mollusk
Brook Snaketail	*Ophiogomphus aspersus*	Insect
Broom Crowberry	*Corema conradii*	Dicot
Buchholz'S Dart Moth	*Agrotis buchholzi*	Insect
Burnsville Cove Cave Amphipod	*Stygobromus conradi*	Arthropod
Bushy Rockrose	*Helianthemum dumosum*	Dicot
Butternut	*Juglans cinerea*	Dicot
Canada Mountain Ricegrass	*Piptatherum canadense*	Monocot
Canadian Yew	*Taxus canadensis*	Gymnosperm
Canby Bulrush	*Scirpus etuberculatus*	Monocot
Canby'S Dropwort	*Oxypolis canbyi*	Dicot
Canby'S Mountain-Lover	*Paxistima canbyi*	Dicot
Candy Darter	*Etheostoma osburni*	Fish
Cape Fear Spatterdock	*Nuphar sagittifolia*	Monocot
Catspaw	*Epioblasma obliquata*	Mollusk
Cave Beetle	*Pseudanophthalmus lallemanti*	Insect
Cedar Sedge	*Carex juniperorum*	Monocot
Chamisso'S Miner'S-Lettuce	*Montia chamissoi*	Dicot
Champlain Beachgrass	*Ammophila champlainensis*	Monocot
Cheat Minnow	*Pararhinichthys bowersi*	Fish
Cheat Minnow	*Rhinichthys bowersi*	Fish
Cheat Mountain Salamander	*Plethodon nettingi*	Amphibian
Cheat Threetooth	*Triodopsis platysayoides*	Mollusk
Chermock'S Mulberry Wing	*Poanes chermocki*	Insect
Clasping Twisted-Stalk	*Streptopus amplexifolius*	Monocot

Clayton'S Copper	*Lycaena claytoni*	Insect
Clingman'S Hedge-Nettle	*Stachys clingmanii*	Dicot
Clubshell	*Pleurobema clava*	Mollusk
Coastal Barrens Buckmoth	*Hemileuca maia*	Insect
Coastal Swamp Metarranthis	*Metarranthis pilosaria*	Insect
Cobblestone Tiger Beetle	*Cicindela marginipennis*	Insect
Collins' Sedge	*Carex collinsii*	Monocot
Comet Darner	*Anax longipes*	Insect
Coppery Emerald	*Somatochlora georgiana*	Insect
Cow Knob Salamander	*Plethodon punctatus*	Amphibian
Craig County Cave Amphipod	*Stygobromus estesi*	Arthropod
Creamflower Tick-Trefoil	*Desmodium ochroleucum*	Dicot
Curly Grass Fern	*Schizaea pusilla*	Pteridophyte
Cuthbert Turtlehead	*Chelone cuthbertii*	Dicot
Cut-Leaved Coneflower	*Rudbeckia gaspereauensis*	Dicot
Daecke'S Pyralid Moth	*Crambus daeckellus*	Insect
Darlington'S Glade Spurge	*Euphorbia purpurea*	Dicot
Decodon Stem Borer Moth	*Papaipema sulphurata*	Insect
Delmarva Beggar-Ticks	*Bidens bidentoides*	Dicot
Delmarva Fox Squirrel	*Sciurus cinereus*	Mammal
Diana Fritillary	*Speyeria diana*	Insect
Drooping Bluegrass	*Poa languida*	Monocot
Drooping Bluegrass	*Poa saltuensis*	Monocot
Drowned Hornedrush	*Rhynchospora inundata*	Monocot
Dwarf Wedge Mussel	*Alasmidonta heterodon*	Mollusk
Dwarf White Birch	*Betula minor*	Dicot
Dwarf White Birch	*Betula minor*	Dicot
Earleaf Foxglove	*Agalinis auriculata*	Dicot
Eastern Massasauga	*Sistrurus catenatus*	Reptile
Eastern Prairie White-Fringed Orchid	*Platanthera leucophaea*	Monocot
Eastern Ribbon Snake	*Thamnophis sauritus*	Reptile
Eastern Sand Darter	*Ammocrypta pellucida*	Fish
Eastern Sand Darter	*Etheostoma pellucidum*	Fish
Eastern Small-Footed Myotis	*Myotis leibii*	Mammal
Eaton'S Beggar-Ticks	*Bidens eatonii*	Dicot
Eaton'S Lipfern	*Cheilanthes eatonii*	Pteridophyte
Ebony Boghaunter	*Williamsonia fletcheri*	Insect
Elk River Crayfish	*Cambarus elkensis*	Arthropod
Ensiform Rush	*Juncus ensifolius*	Monocot
Estuary Pipewort	*Eriocaulon parkeri*	Monocot
Extra-Striped Snaketail	*Ophiogomphus anomalus*	Insect
Fairy Wand	*Chamaelirium luteum*	Monocot
False Hop Sedge	*Carex lupuliformis*	Monocot
Fanshell	*Cyprogenia stegaria*	Mollusk
Fernald'S Bluegrass	*Poa fernaldiana*	Monocot
Few-Flower Sedge	*Carex pauciflora*	Monocot
Filmy Fissidens	*Fissidens hyalinus*	Bryophyte
Fire-Pink	*Silene robusta*	Dicot
Five-Lined Skink	*Eumeces fasciatus*	Reptile
Flypoison Borer Moth	*Papaipema 1*	Insect
Footpath Sallow Moth	*Metaxaglaea semitaria*	Insect
Forcipate Emerald	*Somatochlora forcipata*	Insect
Fragile Papershell	*Leptodea fragilis*	Mollusk

Fragile Rockbrake	*Cryptogramma stelleri*	Pteridophyte
Fragrant Cliff Fern	*Dryopteris fragrans*	Pteridophyte
Franz'S Cave Amphipod	*Stygobromus franzi*	Arthropod
Franz'S Cave Isopod	*Caecidotea franzi*	Arthropod
Frosted Elfin	*Callophrys irus*	Insect
Furbish'S Lousewort	*Pedicularis furbishiae*	Dicot
Gasp? Shrew	*Sorex gaspensis*	Mammal
Gaspe Arrow-Grass	*Triglochin gaspensis*	Monocot
Goat Hill Chickweed	*Cerastium villosissimum*	Dicot
Golden Crest	*Lophiola aurea*	Monocot
Golden Eagle	*Aquila chrysaetos*	Bird
Gordian Sphinx	*Sphinx gordius*	Insect
Grand Caverns Blind Cave Millipede	*Trichopetalum weyeriensis*	Arthropod
Green Floater	*Lasmigona subviridis*	Mollusk
Green Gentian	*Frasera caroliniensis*	Dicot
Green Mountain Maidenhair-Fern	*Adiantum viridimontanum*	Pteridophyte
Greenbrier Cave Amphipod	*Stygobromus emarginatus*	Arthropod
Greenbrier Valley Cave Millipede	*Pseudotremia fulgida*	Arthropod
Greenbrier Valley Cave Pseudoscorpion	*Kleptochthonius henroti*	Arthropod
Green-Faced Clubtail	*Gomphus viridifrons*	Insect
Hammond'S Yellow Spring Beauty	*Claytonia hammondiae*	Dicot
Harlequin Duck	*Histrionicus histrionicus*	Bird
Harlequin Duck - E. Pop - Grand Manan Archipelago	*Histrionicus 1*	Bird
Harned'S Clintonia	*Clintonia alleghaniensis*	Monocot
Harperella	*Ptilimnium nodosum*	Dicot
Harper'S Fimbristylis	*Fimbristylis perpusilla*	(blank)
Harris'S Checkerspot	*Chlosyne harrisii*	Insect
Hay'S Spring Amphipod	*Stygobromus hayi*	Arthropod
Helma'S Net-Spinning Caddisfly	*Cheumatopsyche helma*	Insect
Henrot'S Cave Isopod	*Caecidotea henroti*	Arthropod
Hessel'S Hairstreak	*Callophrys hesseli*	Insect
Highland Rush	*Juncus trifidus*	Monocot
Hill'S Pondweed	*Potamogeton hillii*	Monocot
Hirst Brothers' Panic Grass	*Panicum hirstii*	Monocot
Hoffmaster'S Cave Planarian	*Macrocotyla hoffmasteri*	Vermiform
Holsinger'S Cave Isopod	*Caecidotea holsingeri*	Arthropod
Houghton'S Umbrella-Sedge	*Cyperus houghtonii*	Monocot
Hudsonian Whiteface	*Leucorrhinia hudsonica*	Insect
Incurvate Emerald	*Somatochlora incurvata*	Insect
Indiana Bat	*Myotis sodalis*	Mammal
Indiana Bat Maternity Colony Site	*Indiana site*	Mammal
Inland Barrens Buckmoth	*Hemileuca 3*	Insect
Ipswich Sparrow	*Passerculus princeps*	Bird
Ironcolor Shiner	*Notropis chalybaeus*	Fish
James Cave Amphipod	*Stygobromus abditus*	Arthropod
James Spinymussel	*Pleurobema collina*	Mollusk
Jesup'S Milk-Vetch	*Astragalus jesupii*	Dicot
John Friend'S Cave Isopod (Md)	*Caecidotea 3*	Arthropod
Kankakee Globemallow	*Iliamna remota*	Dicot
Karner Blue	*Lycaeides samuelis*	Insect
Katahdin Arctic	*Oeneis katahdin*	Insect
Kate'S Mountain Clover	*Trifolium virginicum*	Dicot
King'S Hairstreak	*Satyrium kingi*	Insect

Kirtland'S Snake	*Clonophis kirtlandii*	Reptile
Knieskern'S Beaked-Rush	*Rhynchospora knieskernii*	Monocot
Lake Sturgeon	*Acipenser fulvescens*	Fish
Lake Utopia Dwarf Smelt	*Osmerus 1*	Fish
Large-Flowered Barbara'S-Buttons	*Marshallia grandiflora*	Dicot
Largeleaf Grass-Of-Parnassus	*Parnassia grandifolia*	Dicot
Large-Leaved Sandwort	*Moehringia macrophylla*	Dicot
Least Tern	*Sterna antillarum*	Bird
Lillydale Onion	*Allium oxyphilum*	Monocot
Little Bluet	*Enallagma minusculum*	Insect
Loggerhead	*Caretta caretta*	Reptile
Longhead Darter	*Percina macrocephala*	Fish
Long'S Bittercress	*Cardamine longii*	Dicot
Long'S Bulrush	*Scirpus longii*	Monocot
Longsolid	*Fusconaia subrotunda*	Mollusk
Long-Stalked Holly	*Ilex collina*	Dicot
Long-Tailed Or Rock Shrew	*Sorex dispar*	Mammal
Lurking Leskea	*Plagiothecium latebricola*	Bryophyte
Madison Cave Amphipod	*Stygobromus stegerorum*	Arthropod
Madison Cave Isopod	*Antrolana lira*	Arthropod
Many Forms Sedge	*Carex polymorpha*	Monocot
Marcescent Sandwort	*Minuartia marcescens*	Dicot
Maritime Ringlet	*Coenonympha nipisiquit*	Insect
Maritime Shrew	*Sorex maritimensis?*	Mammal
Maryland Cave Beetle	*Pseudanophthalmus 15*	Insect
Massasauga	*Sistrurus catenatus*	Reptile
Millboro Leatherflower	*Clematis viticaulis*	Dicot
Minute Cave Amphipod	*Stygobromus parvus*	Arthropod
Mitchell'S Sedge	*Carex mitchelliana*	Monocot
Monkeyface	*Quadrula metanevra*	Mollusk
Mottled Duskywing	*Erynnis martialis*	Insect
Mountain Avens	*Geum peckii*	Dicot
Mountain Bellwort	*Uvularia nitida*	Monocot
Mountain Brook Lamprey	*Ichthyomyzon greeleyi*	Fish
Musk Root	*Adoxa moschatellina*	Dicot
New England Bluet	*Enallagma laterale*	Insect
New England Boneset	*Eupatorium novae-an*	Dicot
New England Cottontail	*Sylvilagus transitionalis*	Mammal
New Jersey Rush	*Juncus caesariensis*	Monocot
Nodding Mandarin	*Prosartes maculata*	Monocot
Nodding Pogonia	*Triphora trianthophora*	Monocot
North American Dwarf Burhead	*Echinodorus tenellus*	Monocot
Northeastern Beach Tiger Beetle	*Cicindela dorsalis*	Insect
Northern Barrens Tiger Beetle	*Cicindela patruela*	Insect
Northern Blazing-Star	*Liatris novae-angliae*	Dicot
Northern Bog Lemming	*Synaptomys borealis*	Mammal
Northern Madtom	*Noturus stigmosus*	Fish
Northern Meadow-Sweet	*Spiraea septentrionalis*	Dicot
Northern Metalmark	*Calephelis borealis*	Insect
Northern Monk'S-Hood	*Aconitum noveboracense*	Dicot
Northern Prostrate Clubmoss	*Lycopodiella margueritiae*	Pteridophyte
Northern Riffleshell	*Epioblasma rangiana*	Mollusk
Northern Spleenwort	*Asplenium septentrionale*	Pteridophyte

Northern Virginia Well Amphipod	*Stygobromus phreaticus*	Arthropod
Northern Wild Comfrey	*Cynoglossum boreal*	Dicot
Nottoway Brome Grass	*Bromus nottowayanus*	Monocot
Nova Scotia False-Foxglove	*Agalinis neoscotica*	Dicot
Ogden'S Pondweed	*Potamogeton ogdenii*	Monocot
Ohio Lamprey	*Ichthyomyzon bdellium*	Fish
Orangefin Madtom	*Noturus gilberti*	Fish
Organ Cavesnail	*Fontigens tartarea*	Mollusk
Ozark Milk-Vetch	*Astragalus distortus*	Dicot
Packard'S Blind Cave Millipede	*Trichopetalum packardi*	Arthropod
Pale Beaked-Rush	*Rhynchospora pallida*	Monocot
Pale False Foxglove	*Agalinis skinneriana*	Dicot
Peaks Of Otter Salamander	*Plethodon hubrichti*	Amphibian
Pennsylvania Cave Amphipod	*Crangonyx dearolfi*	Arthropod
Peregrine Falcon	*Falco peregrinus*	Bird
Persius Dusky Wing	*Erynnis persius*	Insect
Peters Mountain Mallow	*Iliamna corei*	Dicot
Piedmont Groundwater Amphipod	*Stygobromus tenuis*	Arthropod
Pine Barren Boneset	*Eupatorium resinosum*	Dicot
Pine Barren Gentian	*Gentiana autumnalis*	Dicot
Pine Barren Smoke Grass	*Muhlenbergia torreyana*	Monocot
Pine Barrens Bluet	*Enallagma recurvatum*	Insect
Pine Barrens Zale	*Zale lunifera*	Insect
Pine Barrens Zanclognatha	*Zanclognatha martha*	Insect
Pink Heelsplitter	*Potamilus alatus*	Mollusk
Pink Sallow	*Psectraglaea carnosa*	Insect
Pinnate-Lobe Black-Eyed-Susan	*Rudbeckia pinnatiloba*	Dicot
Piping Plover	*Charadrius melodus*	Bird
Piratebush	*Buckleya distichophylla*	Dicot
Pitcher Plant Borer Moth	*Papaipema appassionata*	Insect
Pizzini'S Cave Amphipod	*Stygobromus pizzinii*	Arthropod
Plymouth Gentian	*Sabatia kennedyana*	Dicot
Pondspice	*Litsea aestivalis*	
Popeye Shiner	*Notropis ariommus*	Fish
Precious Underwing	*Catocala pretiosa*	Insect
Price'S Cave Isopod	*Caecidotea pricei*	Arthropod
Prototype Quillwort	*Isoetes prototypus*	Pteridophyte
Puritan Tiger Beetle	*Cicindela puritana*	Insect
Pygmy Snaketail	*Ophiogomphus howei*	Insect
Quebec Emerald	*Somatochlora brevicincta*	Insect
Quillback	*Carpiodes cyprinus*	Fish
Quill-Leaf Arrowhead	*Sagittaria teres*	Monocot
Rabbitsfoot	*Quadrula cylindrica*	Mollusk
Rabbitsfoot	*Quadrula cylindrica*	Mollusk
Racovitza'S Terrestrial Cave Isopod	*Miktoniscus racovitzai*	Arthropod
Ram'S Head Lady'S-Slipper	*Cypripedium arietinum*	Monocot
Rapids Clubtail	*Gomphus quadricolor*	Insect
Rare Skipper	*Problema bulenta*	Insect
Rayed Bean	*Villosa fabalis*	Mollusk
Razorbill	*Alca torda*	Bird
Red Knot	*Calidris canutus*	Bird
Regal Fritillary	*Speyeria idalia*	Insect
Reticulated Nutrush	*Scleria reticularis*	Monocot

Ringed Bog Haunter	*Williamsonia lintneri*	Insect
Roanoke Logperch	*Percina rex*	Fish
Robbins' Cinquefoil	*Potentilla robbinsiana*	Dicot
Robinson'S Hawkweed	*Hieracium robinsonii*	Dicot
Robust Baskettail	*Epitheca spinosa*	(blank)
Rock Creek Groundwater Amphipod	*Stygobromus kenki*	Arthropod
Rock Grape	*Vitis rupestris*	Dicot
Rock Skullcap	*Scutellaria saxatilis*	Dicot
Rock Springs Cave Isopod	*Caecidotea 1*	Arthropod
Rock Vole	*Microtus chrotorrhinus*	Mammal
Roland'S Sea-Blite	*Suaeda rolandii*	Dicot
Rose Coreopsis	*Coreopsis rosea*	Dicot
Roseate Tern	*Sterna dougallii*	Bird
Roseate Tern	*Sterna dougallii*	Bird
Roseroot	*Rhodiola rosea*	Dicot
Roughhead Shiner	*Notropis semperasper*	Fish
Round Pigtoe	*Pleurobema sintoxia*	Mollusk
Rubifera Dart	*Diarsia rubifera*	Insect
Rugulose Grape Fern	*Botrychium rugulosum*	Pteridophyte
Running Buffalo Clover	*Trifolium stoloniferum*	Dicot
Salamander Mussel	*Simpsonaias ambigua*	Mollusk
Sand-Heather	*Hudsonia tomentosa*	Dicot
Sandplain Gerardia	*Agalinis acuta*	Dicot
Scarlet Bluet	*Enallagma pictum*	Insect
Schweinitz' Sedge	*Carex schweinitzii*	Monocot
Seabeach Amaranth	*Amaranthus pumilus*	Dicot
Seabeach Knotweed	*Polygonum glaucum*	Dicot
Sedge Wren	*Cistothorus platensis*	Bird
Semipalmated Sandpiper	*Calidris pusilla*	Bird
Sensitive Joint-Vetch	*Aeschynomene virginica*	Dicot
Serpentine Aster	*Aster depauperatus*	Dicot
Serpentine Aster	*Symphyotrichum depauperatum*	Dicot
Seth Forest Water Scavenger Beetle	*Hydrochus 1*	Insect
Shale Barren Rockcress	*Arabis serotina*	Dicot
Shenandoah Salamander	*Plethodon shenandoah*	Amphibian
Shenandoah Valley Cave Amphipod	*Stygobromus gracilipes*	Arthropod
Sherando Spinosid Amphipod	*Stygobromus 7*	Arthropod
Shortnose Sturgeon	*Acipenser brevirostrum*	Fish
Small Cranberry	*Vaccinium oxycoccos*	Dicot
Small White Lady'S-Slipper	*Cypripedium candidum*	Monocot
Small Whorled Pogonia	*Isotria medeoloides*	Monocot
Smoke Hole Bergamot	*Monarda 1*	Dicot
Smoke Hole Bergamot	*Monarda 1*	Dicot
Smooth Coneflower	*Echinacea laevigata*	Dicot
Snuffbox	*Epioblasma triquetra*	Mollusk
South Branch Valley Cave Millipede	*Pseudotremia princeps*	Arthropod
Southern Lady'S-Slipper	*Cypripedium kentuckiense*	Monocot
Southern Rock Vole	*Microtus carolinensis*	Mammal
Southern Water Shrew	*Sorex punctulatus*	Mammal
Spatterdock Darner	*Aeshna mutata*	Insect
Spatterdock Darner	*Rhionaeschna mutata*	Insect
Sphagnum	*Sphagnum andersonianum*	Bryophyte
Sphagnum	*Sphagnum angermanicum*	Bryophyte

Spine-Crowned Clubtail	*Gomphus abbreviatus*	Insect
Spiny Softshell Turtle	*Apolone spinera*	Reptile
Spotted Cave Beetle	*Pseudanophthalmus punctatus*	Insect
Spotted Darter	*Etheostoma maculatum*	Fish
Spreading Globe Flower	*Trollius laxus*	Dicot
Spreading Globeflower	*Trollius laxus*	Dicot
Spreading Pogonia	*Cleistes bifaria*	Monocot
Spreading Rockcress	*Arabis patens*	Dicot
Spring Cave Amphipod	*Stygobromus spinatus*	Arthropod
Spruce Knob Threetooth	*Triodopsis picea*	Mollusk
St. Lawrence Aster	*Symphyotrichum laurentianum*	Dicot
Steinmetz'S Bulrush	*Schoenoplectus steinmetzii*	Monocot
Stellmack'S Cave Amphipod	*Stygobromus stellmacki*	Arthropod
Swamp-Pink	*Arethusa bulbosa*	Monocot
Swamp-Pink	*Helonias bullata*	Monocot
Sweet Pinesap	*Monotropsis odorata*	Dicot
Sweet-Scented Indian-Plantain	*Hasteola suaveolens*	Dicot
Sword-Leaved Phlox	*Phlox buckleyi*	Dicot
Tall Larkspur	*Delphinium exaltatum*	Dicot
Tennessee Pondweed	*Potamogeton tennesseensis*	Monocot
The Buckmoth	*Hemileuca maia*	Insect
Thread Rush	*Juncus filiformis*	Monocot
Tidewater Amphipod	*Stygobromus indentatus*	Arthropod
Tidewater Interstitial Amphipod	*Stygobromus araeus*	Arthropod
Tidewater Mucket	*Leptodea ochracea*	Mollusk
Timber Rattlesnake	*Crotalus horridus*	Reptile
Tippecanoe Darter	*Etheostoma tippecanoe*	Fish
Tomah Mayfly	*Siphlonisca aerodromia*	Insect
Torrey'S Mountain Mint	*Pycnanthemum torrei*	Dicot
Treetop Emerald	*Somatochlora provocans*	Insect
Turgid Gayfeather	*Liatris turgida*	Dicot
Twilight Moth	*Lycia rachelae*	Insect
Upland Sandpiper	*Bartramia longicauda*	Bird
Upland Sandpiper	*Bartramia 1*	Bird
Upland Sandpiper	*Bartramia population2*	Bird
Upland Sandpiper	*Bartramia population3*	Bird
Virginia Big-Eared Bat	*Corynorhinus virginianus*	Mammal
Virginia Least Trillium	*Trillium virginianum*	Monocot
Virginia Least Trillium	*Trillium virginianum*	Monocot
Virginia Mallow	*Sida hermaphrodita*	Dicot
Virginia Northern Flying Squirrel	*Glaucomys fuscus*	Mammal
Virginia Sneezeweed	*Helenium virginicum*	Dicot
Virginia Spiraea	*Spiraea virginiana*	Dicot
Virginia Thistle	*Cirsium virginianum*	Dicot
Wavy Bluegrass	*Poa fernaldiana*	Monocot
West Virginia Spring Salamander	*Gyrinophilus subterraneus*	Amphibian
Western Wallflower	*Erysimum capitatum*	Dicot
White Alumroot	*Heuchera alba*	Dicot
White Monkshood	*Aconitum reclinatum*	Dicot
White Mountain Butterfly	*Oeneis semidea*	Insect
White Mountain Fritillary	*Boloria montinus*	Insect
Whorled Horse-Balm	*Collinsonia verticillata*	Dicot
Wiegand Sedge	*Carex wiegandii*	Monocot

Wild Calla	*Calla palustris*	Monocot
Wolf'S Spikerush	*Eleocharis wolfii*	Monocot
Wood Reedgrass	*Calamagrostis perplexa*	Monocot
Yellow Lampmussel	*Lampsilis cariosa*	Mollusk
Yellow Lance	*Elliptio lanceolata*	Mollusk
Yellow Nailwort	*Paronychia virginica*	Dicot
Yellow Nailwort	*Paronychia virginica*	Dicot
Yellow-Bellied Flycatcher	*Empidonax flaviventris*	Bird