Resilient Sites for Terrestrial Conservation

In the Southeast Region

The Nature Conservancy Eastern Conservation Science

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Acknowledgements

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CHAPTER

Introduction

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

A climate-resilient conservation portfolio includes sites representative of all geophysical settings selected for their landscape diversity and local connectedness. We developed methods to identify such a portfolio. First, we mapped geophysical settings across the entire study area. Second, within each geophysical setting we located sites with diverse topography that were highly connected by natural cover. Third, we compared the identified sites with the current network of conservation lands and with The Nature Conservancy's (TNC's) portfolio of important biodiversity sites identified based on rare species and natural community locations. Using this information we noted geophysical settings that were underrepresented in current conservation and identified places for each setting that could serve as strongholds for diversity both now and into the future.

Our approach to developing the network of resilient sites is based on several key observations. The first is that species diversity is highly correlated with geophysical diversity in the Eastern US (Anderson and Ferree 2010). Second, species take advantage of the micro-climates available in topographically complex landscapes (Weiss et al. 1988). Third, species can move to adjust to climatic changes if the area is permeable and connected. The characteristics of geophysical representation, landscape complexity, and landscape permeability are primary concepts in this research. And, the application of the approach to all types of geophysical settings, including sandy outwash plains and gentle limestone valleys, is essential to ensure that the the results are not biased towards mountainous terrain (Tingley et al. 2013) but cover the full spectrum of diversity in the region.

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

This report has four basic parts: In Chapter 2, we use mapping and classification to identify all the distinct geophysical settings in the region. In Chapter 3, we develop methods to identify sites that have high landscape diversity and local connectedness, factors that increase resilience. In Chapter 4 we examine the north-south and east-west connections between sites. Finally, in Chapters 5 and 6 we identify networks of resilient sites representing all the geophysical settings within seven ecoregions. Chapter 3 and 4 introduce new methods to quantify the physical and structural aspects of the landscape and explain how we identified important linkages between sites. These include models that measure a site's physical complexity (landform variety, elevation range, and wetland density) and permeability (local connectedness and regional flow patterns). The metrics were calculated for a nine-state region in the Southeast US, and as part of the results, we compare the resilient sites identified in the report with sites previously identified by TNC for their significant biodiversity.

The value of conserving a spectrum of physical settings is based on empirical evidence (Anderson and Ferree 2010), but there are many choices to make as to how this is accomplished. For example, out of all the possible limestone valleys that could be conserved, which one is the most likely to remain functional and sustain its biological diversity? We address this question in Chapter 3 which focuses specifically on prioritizing among examples of the same setting using physical characteristics that increase resilience. These characteristics fall into two categories. The first, **landscape diversity**, refers to the number of microhabitats and climatic gradients available within a given area. Landcape diversity is measured by counting the variety of landforms, the elevation range, and the density and configuration of wetlands present in a small area. 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). **Local connectedness**, the second factor, is defined as the number of barriers and the 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 the permeability. Maintaining a connected landscape is the most widely cited strategy in the scientific literature for building resilience (Heller and Zavaleta 2009) and has been suggested as an explanation for why there were few extinctions during the last period of comparable rapid climate change (Botkin et al. 2007).

The report is structured around the following key steps in the resilience analysis: 1) identify all geophysical settings, 2) estimate site resilience, and 3) link sites into networks. The results section presents the estimated resilience scores at two scales: **30 meter cells and 1000 acre (404-ha) sites.** All results are presented within **ecological regions** or "ecoregions" as defined by TNC based on the subsections delineated by the US Forest Service (USDA FS 2007) and Canadian Provinces (Anderson 1999). Because each region represents an area of similar physiography and landscape features, it is an appropriate natural unit in which to evaluate geophysical representation and to compare and contrast sites.

The study area includes the seven states of NC, SC, GA, FL, AL, TN, and KY in their entirety as well as large portions of VA and WV, and a tiny portion of MD. Scientists and conservation planners from those states helped with the development of these methods, the evaluation of datasets, and review of the results. Please see the acknowledgements for a list of all contributors. This report is a counterpart to **Resilient Sites for Terrestrial Conservation in the Northeast and Mid-Atlantic** (Anderson et al. 2011). More background on the approach and detail on how the results relate to current biodiversity patterns can be found in Anderson and Ferree (2010) and Anderson et al. (2014).

CHAPTER

2

Defining the Geophysical Settings

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

Ecoregions

We assessed the geophysical settings within the larger context of natural ecoregions. Ecoregions are large units of land with similar environmental conditions, especially landforms, geology and soils, which share a distinct assemblage of natural communities and species. The term “ecoregion" was coined by J.M. Crowley (1967) and later popularized by Robert Bailey of the 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). We used the TNC ecoregions with a slight modification to one boundary (See Appendix)

The ecoregions we used for this analysis were developed by TNC in conjunction with the USFS. They are a modification of Bailey (1995) that puts more emphasis on physical characteristics and natural communities and less on climatic patterns. Six ecoregions were fully contained within the nine-state area of interest and parts of four others were encompassed by this study. The ecoregions nest within three well recognized subregions: the Coastal Plain (MACP, SACP, FLP, TFL, UEGCP, EGCP), the Piedmont (PIED), and the Mountains (SBR, CSRV, ILP) (Figure 2.1). In the descriptions below and in some of the later analyses we separate the Coastal Plain from the Mountains and Piedmont.

Geophysical Settings

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

Bedrock geology classes and elevations zones follow those described in Anderson and Ferree (2010), with further divisions of the surficial substrate classes as described below. We compiled spatially explicit digital information on the physical characteristics of the regions including:

Bedrock geology: from state and national geology maps (see Appendix I)
Soils: spatial representations of county-level USDA soil surveys from the Soil Survey Geographic (SSURGO, NRCS 2009) database.
Elevation: from a 30 m digital elevation model (DEM, Gesch 2007)
Landforms: derived from the 30 m DEM (see Appendix II)

Specific definitions and thresholds are defined below.

Elevation Zones (Figure 2.4)

These zones correspond to major changes in vegetation and community patterns (Schafale and Weakley 1990, Williams 2010).

Coastal	0' to 20' includes coastal and very low oak-pine zones
Low	20' to 1700' includes most of coastal plain and piedmont
Mid	1700'to 2500' includes hills and tables of the Cumberland Plateau and Blue Ridge
High	2500' to 4500' includes the mountainous Blue Ridge and related forest types.
Very High	4500'+ includes spruce-fir and northern hardwood zones of the highest Blue Ridge

Geology Classes (Figure 2.5)

We created a regional map of bedrock geology by compiling the individual state geological maps newly crosswalked to a national taxonomy by the US Geologic Society (USGS) (http://mrdata.usgs.gov/geology/state/), and synthesizing these datasets into one seamless map for the region. The large array of individual bedrock types were grouped into one of seven major classes based on the chemical and physical properties of the soils derived from them, following the scheme presented in Anderson and Ferree (2010). Details and data sources are listed in Appendix I.

For the Mountains and Piedmont, the seven bedrock types were as follows:

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

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

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

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

Acidic 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.

Deep Surficial.
Deep deposits of unconsolidated sand or silt such as are found in old lake plains or large floodplains.

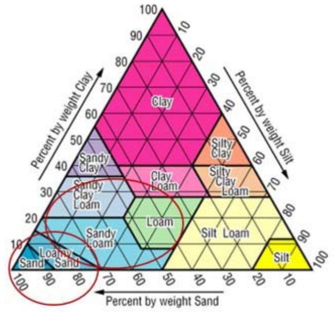


Figure 2.1: Soil Triangle. Area of sand and loam shown with circles.

For the Coastal Plain, we created a regional map of surficial sediments by compiling the SSURGO soil units and grouping them by soil texture. We used a non-heirarchical cluster analysis to group the map units into three broad groups based on their proportional content of sand, silt, and clay. All cluster analyses were conducted in PC-ORD vX (McCune and Grace 2002). The clusters were then crosswalked to their texture types using the USDA soil texture triangle (Figure 2.4). The groups defined were:

Sand: Sand, Loamy Sand
Loam: Loam, Sandy Loam, Sandy Clay Loam
Fine Sediment (Silt/Clay): Silt, Silt Loam, Silty Clay Loam, Clay Loam, Sandy Clay, Silty Clay, Clay

In karst and sinkhole regions, where surficial sediment occurred over limestone bedrock, we recognized three more categories:

Sand over Limestone: sand over limetsone
Loam over Limestone: loam and sandy loam over limestone
Fine Sediment over Limestone: silt, silt loam or clay over limestone

Additionally areas of exposed or only slightly buried sedimentary bedrock were mapped as:

Acidic Sedimentary- Coastal Plain: settings on sandstone, siltstone, conglomerate may show bedrock outcops overlain with sandy surficial soils.

Large wetlands over 300,000 acres in size on the coastal plain region were mapped based on their estimated underlying surficial soil type. Although we discussed the idea of treating these as a separate organic soil class, we decided against this because comparing and ranking them against each other would fail to acknowledge their fundamental importance in structuring the landscape (see page 113).

In total, the set of geological settings used in the analysis were:

Mountains and Piedmont
Acidic Sedimentary
Acidic Shale
Calcareous
Moderately Calcareous
Acidic Granitic
Mafic
Ultramafic
Deep Surficial Sediment

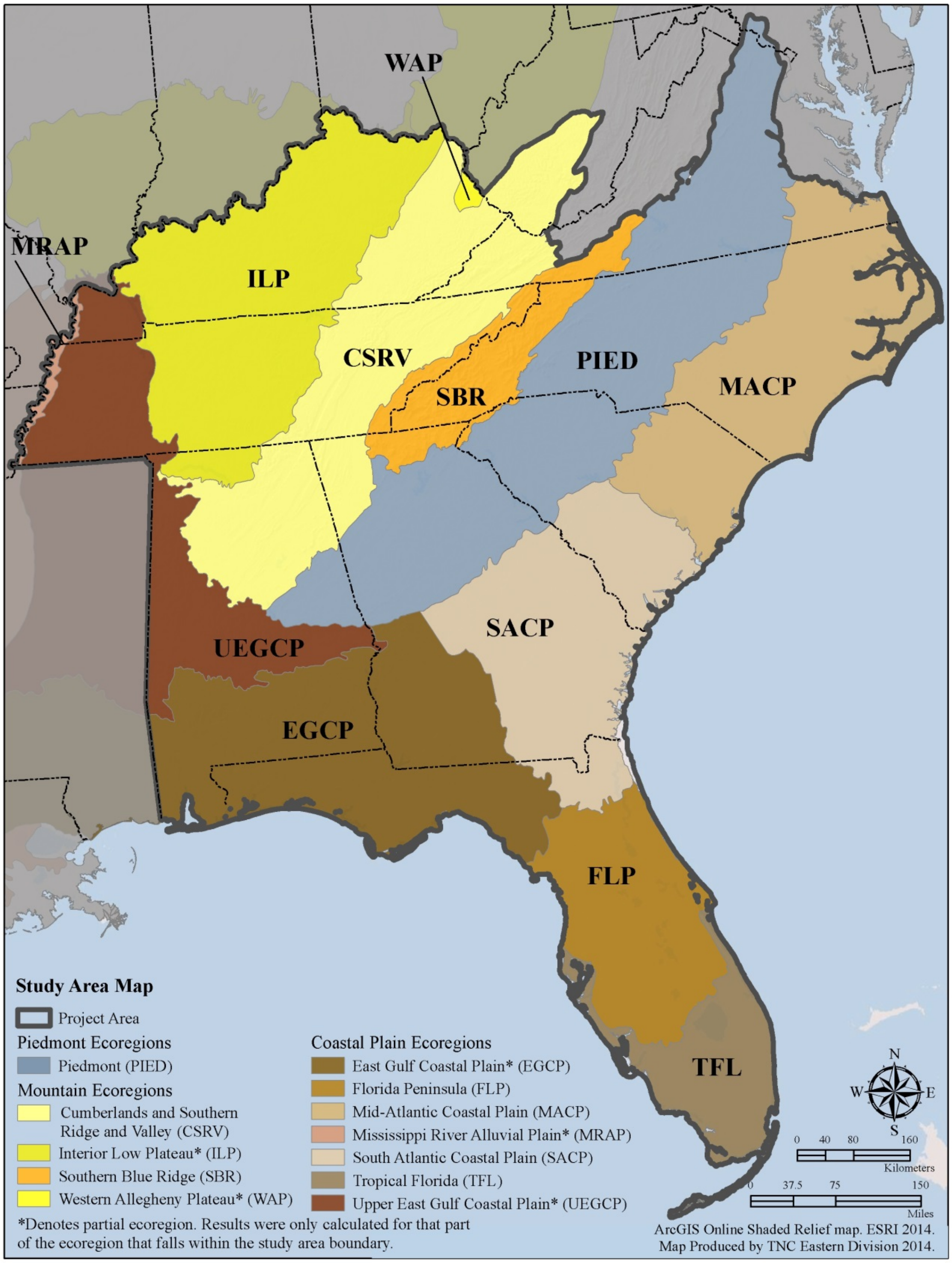
Coastal Plain
Sand
Loam
Fine sediments
Sand over Limestone
Loam over Limestone
Fine Sediments over Limestone
Acidic Sedimentary

Landform Types (Figure 2.6)

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

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

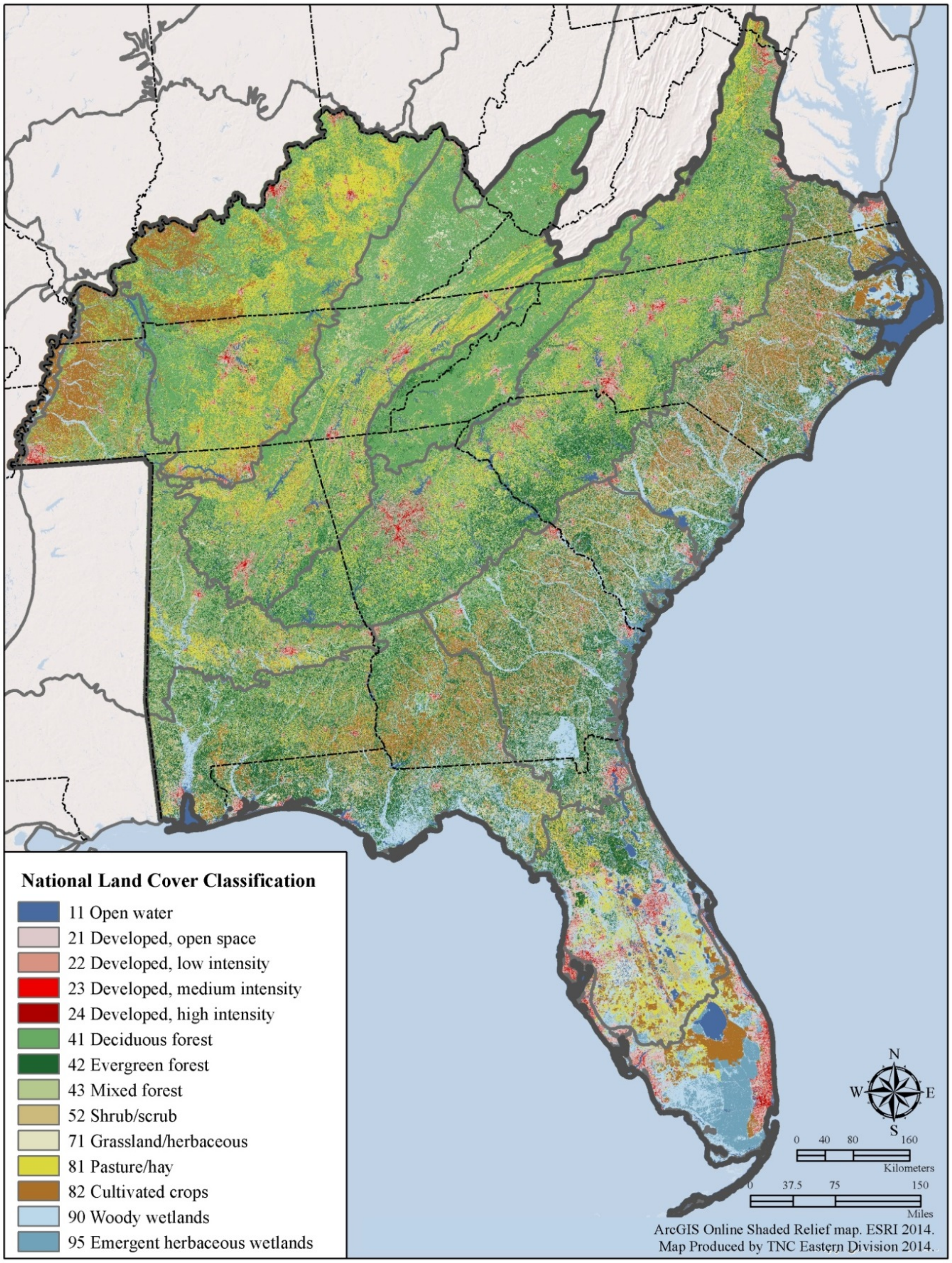
Figure 2.2: The Nauture Conservancy's Ecoregions comprising the study area. Seven ecoregions were completely included in this study (CRSV,SBR, PIED, MACP, SACP, FLP, TFL), as well as parts of four others (WAP, ILP, UEGCP, EGCP). The three subregions are shown with color: Coastal Plain (browns), Piedmont (blue), Mountains (yellow-orange)



*Denotes partial ecoregion. Results were only calculated for that part of the ecoregion that falls within the study area boundary.

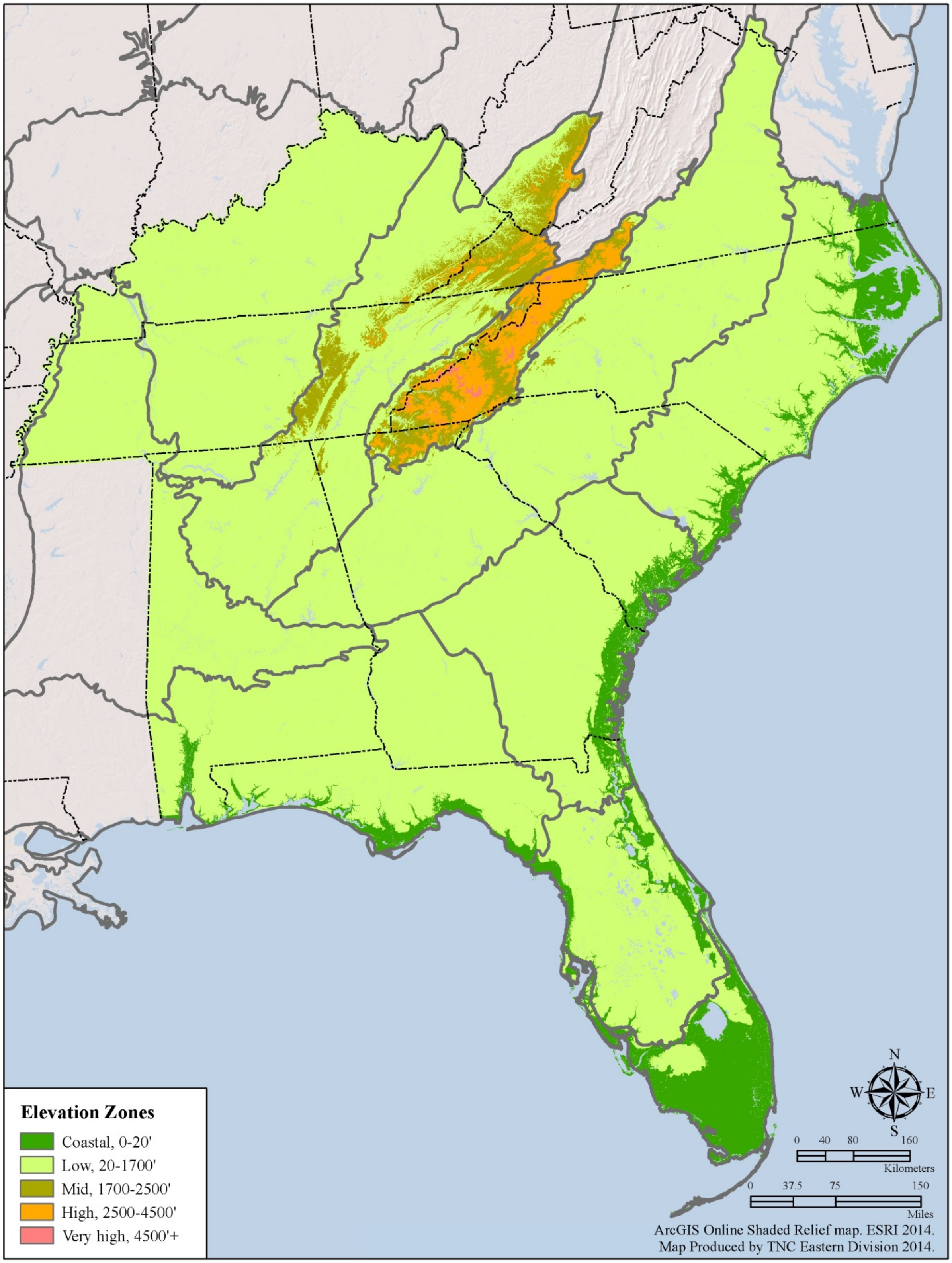
ArcGIS Online Shaded Relief map. ESRI 2014.
Map Produced by TNC Eastern Division 2014.

Figure 2.3: Land cover map of the southeastern United States. Ecoregion boundaries are shown in gray.



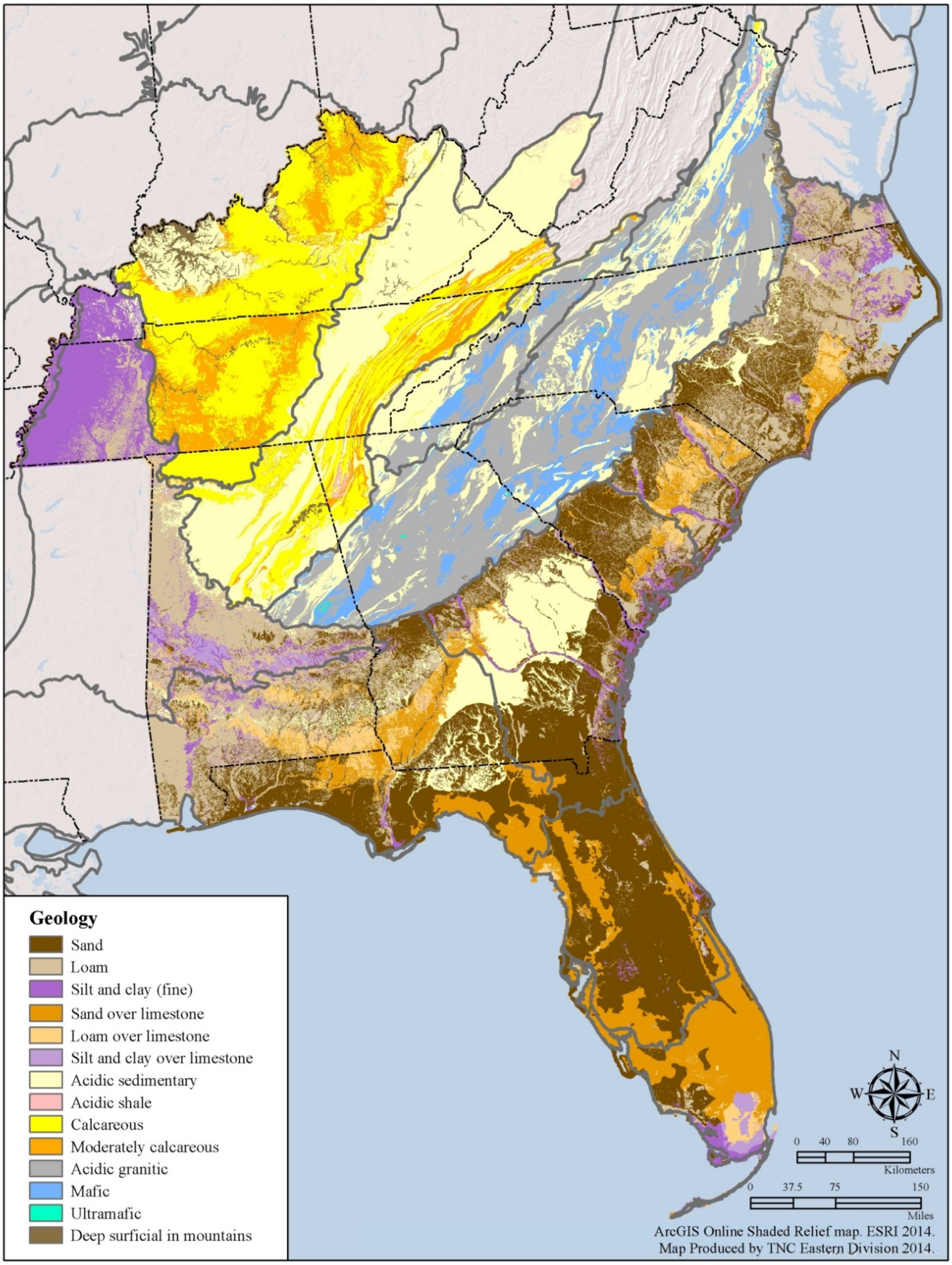
ArcGIS Online Shaded Relief map. ESRI 2014.
Map Produced by TNC Eastern Division 2014.

Figure 2.4: Elevation zones. The five elevation zones used in this study**.**



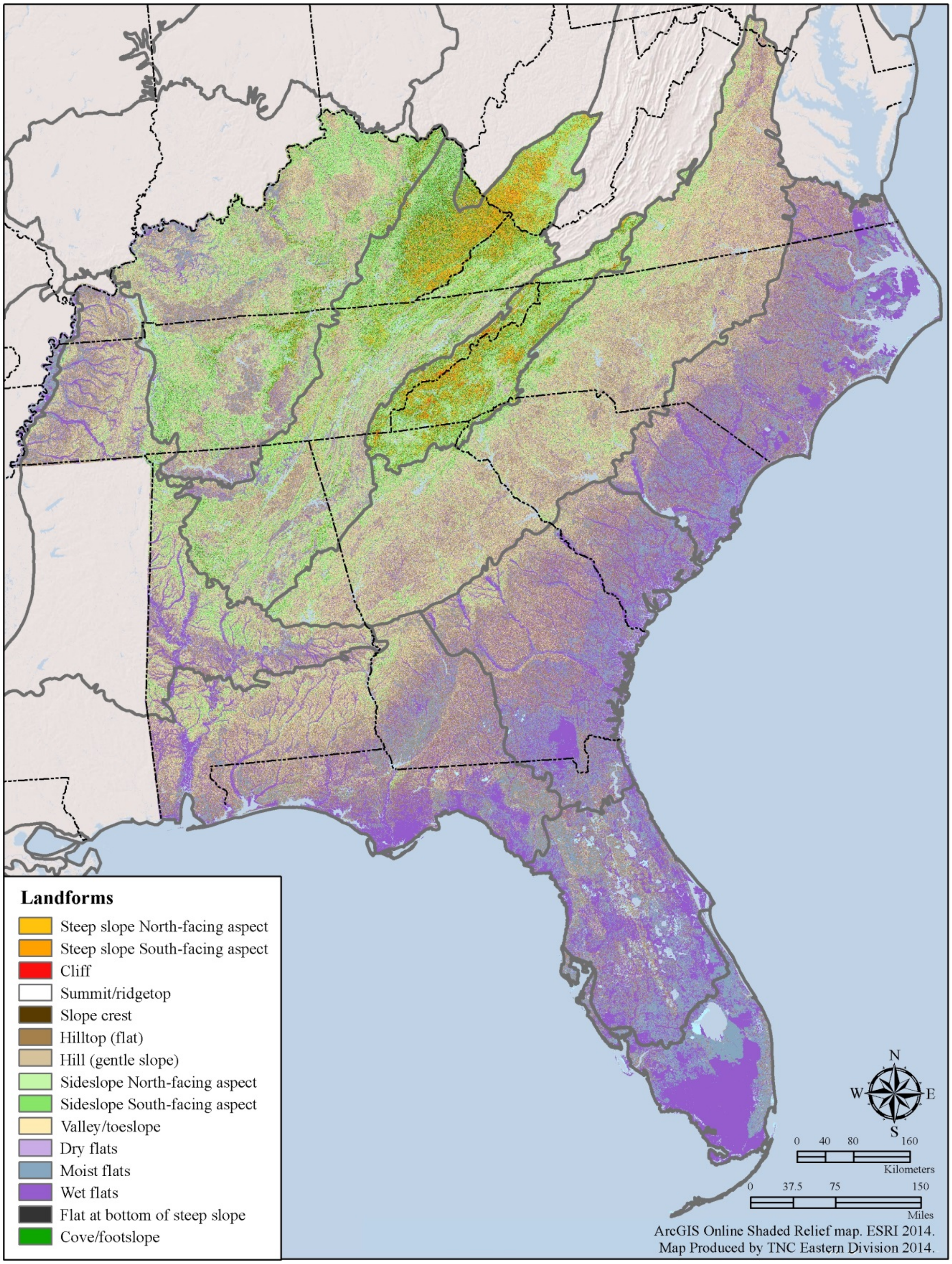
ArcGIS Online Shaded Relief map. ESRI 2014.
Map Produced by TNC Eastern Division 2014.

Figure 2.5: Geology classes. The 14 geology classes used in this report. Seven were bedrock-based and seven were based on surficial substrates.



ArcGIS Online Shaded Relief map. ESRI 2014.
Map Produced by TNC Eastern Division 2014.

Figure 2.6: Landform types. This map shows the 15 landforms used for characterizing the region and calculating the landfrom variety metric.



ArcGIS Online Shaded Relief map. ESRI 2014.
Map Produced by TNC Eastern Division 2014.

Figure 2.7: Geophysical settings used in this report. The 35 geophysical settings are combinations of an elevation zone and a geology class such as "low elevation calcareous" (L:CALC).

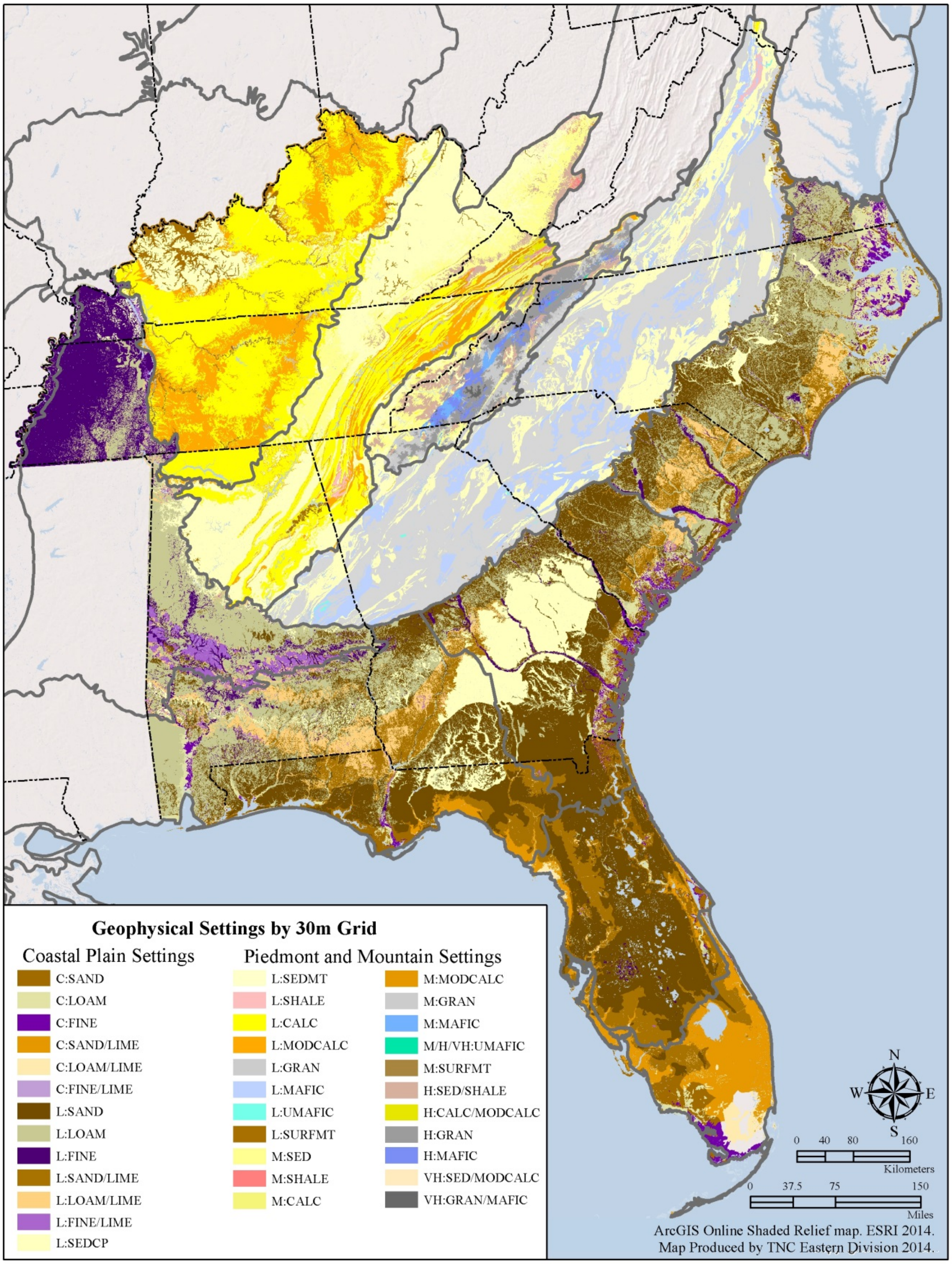


Figure 2.8: Geological settings: Examples of eight bedrock or surficial settings.

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

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

Granite: Pisgah State Forest, © Jeff Gunn

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

Mafic: Amphibolite mountains, © Jenny Bennet.

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

Limestone: Lost Spring TNC Preserve, © TN TNC.

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

Describing Geophysical Settings

We defined 35 geophysical settings with each being a combination of a geologic substrate and an elevation zone (Figure 2.6). The descriptions below describe each geological setting and are organized by the five elevation zones.

Subregions: Coastal Plain, Piedmont, and Mountains

The three mains subregions (Figure 2.1) differ greatly in their elevation ranges. The entire Coastal Plain (MACP, SACP, FLP, TFL, EGCP, UEGCP) is less than 800' in elevation and the vast majority is less than 460' feet. For this region we recognized two elevation zones: a very distinct coastal zone (0-20') and the remaining low elevation zone (20-1700'). The Piedmont (PIED) is almost entirely in the low elevation zone (20-1700') with a few very small inclusions of mid-elevation hills just over 1700 feet. The majority of the Mountain region (SBR, CSRV, ILP) also falls within the low elevation range (20-1700') but contains mid (1700-2500') and, high (2500-4500') elevations in the Cumberlands, and very high (>4500') elevations in the Blue Ridge. The higher elevation regions ranges have a distinct flora and fauna.

Species and Community Information

The elevation zone and variety of landforms present often influences the variety of communities and species' habitats. Information given here on the species and communities found in the settings are based on Natural Heritage Element Occurrences and represent species of concern or characteristic communities. These are provided to give users an indication of the type of biodiversity that this setting favors. We expect the future species composition to be of a similar ecological character (e.g. cave adapted and alkaline-tolerant species in limestone, sand adapted and fire-tolerant species in coarse sand), but perhaps not the same taxa. Many of the ecosystem and community types will likely be present in some future form but but their exact compositon and structure may vary widely from the current expression.
Coastal settings: *Although we present the information on the coastal zone for completeness and interest, the methods and data we used to measure resilience have numerous problems in the coastal zone. The various datasets are inconsistent in their coastal boundaries and most of the coastal hexagons extend into the "ocean" outside of this analysis. Thus, the calculations for the coastal settings are not trustworthy and the results in this elevation zone may be misleading. On the final result maps we "grey out" the 0-3 meter elevation zone because sealevel rise is expected to inundate this zone over the next century and we did not assess changes in coastal processes in this study.*

Coastal Sand (C-SAND): Maritime settings under 20' elevation on coarse sand. Beaches, dunes, swales and sandplains

Coastal Loam (C-LOAM): Maritime settings under 20' elevation on loam and sandy loam. Maritime forests and grasslands

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

Coastal (< 20’)

Communities in this elevation zone include: beach and dune communities, maritime woodland, salt and brackish marsh, non-alluvial swamp forest, river mouths and deltas, coastal shorelines, and other coastal or maritime settings.

Rare or Uncommon species found in this elevation zone include:

Vertebrates: **Amphibians:** dwarf siren, flatwoods salamander, Florida bog frog, four-toed salamander, frosted flatwoods salamander, gopher frog, Gulf Coast mud salamander, many-lined salamander, Neuse River waterdog, one-toed amphiuma, striped newt, **Reptiles** Alabama red-bellied turtle, alligator snapping turtle, american alligator, black swamp snake, Carolina watersnake, chicken turtle, delta map turtle, diamondback terrapin, eastern indigo snake, Florida keys mole skink, Florida pine snake, Florida scrub lizard, glossy crayfish snake, gopher tortoise, gulf salt marsh snake, leatherback, loggerhead, Mississippi green water snake, red rat snake, rim rock crowned snake, southern hognose snake, striped mud turtle, Suwannee cooter. **Birds** american oystercatcher, bald eagle, black rail, black skimmer, black-crowned night-heron, black-necked stilt, black-whiskered vireo, brown pelican, caspian tern, common tern, crested caracara, glossy ibis, great egret, great white heron, gull-billed tern, least bittern, least tern, limpkin, little blue heron, mangrove cuckoo, merlin, osprey, piping plover, reddish egret, roseate spoonbill, roseate tern, royal tern, sandwich tern, scott's seaside sparrow, snail kite, snowy egret, snowy plover, tricolored heron, white ibis, white-crowned pigeon, wilson's plover, wood stork, yellow-crowned night-heron. **Mammals** Florida black bear, Key Largo woodrat, Key West raccoon, Lower Keys rabbit, Sherman's fox squirrel, Key Largo cotton mouse, Florida long-tailed weasel, southeastern myotis, Florida mouse, Key deer, Southeastern beach mouse

Plants:Hundereds of species including: bahama brake, beaked spikerush, brittle thatch palm, chapman's crownbeard, christmas berry, coastal goldenrod, coastal vervain, corkwood, Cruise's goldenaster, Curtiss' sandgrass, dune bluecurls, estuary pipewort, Florida beargrass, Florida five-petaled leaf-flower, Florida lantana, Florida thatch palm, Florida waxweed, Godfrey's blazing star, Godfrey's goldenaster, golden leather fern, gulf coast lupine, locustberry, mangrove berry, milkbark, nodding pinweed, pineland noseburn, rhacoma, sea lavender, seabeach amaranth, silver palm, spoon-leaved sundew, white birds-in-a-nest, white-top pitcherplant.

Coastal Sand over Limestone (C-SAND/LIME): Maritime settings under 20’ elevation on coarse sand over limestone bedrock. Seeps, springs, sinkholes, swales and sandplains

Coastal Loam over Limestone (C-LOAM/LIME): Maritime settings under 20’ elevation on loam and sandy loam over limestone bedrock. Springs, sinkholes, forests and grasslands

Coastal Fine Sediment over Limestone (C-FINE/LIME): Maritime settings under 20’ elevation on fine silts and mud over limestone bedrock. Springs, flushes, swamps, floodplain and marshes

Low Elevation (20’ to 1700’)

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

Rare or Uncommon species found mostly in this elevation zone inludes the following:

Vertebrates: **Amphibians** bird-voiced treefrog, Brimley's chorus frog, dwarf siren, flatwoods salamander, Florida bog frog, many-lined salamander, oak toad; **Reptiles** Alabama map turtle, alligator snapping turtle, Barbour's map turtle, black pinesnake, black swamp snake, black-knobbed sawback, blue-tailed mole skink, chicken turtle, coachwhip, common rainbow snake, copperbelly watersnake, copperhead, Eastern coral snake, Eastern diamond-backed rattlesnake, Eastern indigo snake, Escambia map turtle, flattened musk turtle, Florida brown snake, Florida crowned snake, Florida green water snake, Florida pine snake, Florida redbelly turtle, Florida scrub lizard, Florida softshell, Florida worm lizard, glossy crayfish snake, gopher tortoise, gulf coast smooth softshell, island glass lizard, mimic glass lizard, Mississippi green watersnake, mole snake, Northern Florida swamp snake, Northern mole skink, pigmy rattlesnake, pine or gopher snake, pine woods snake, rainbow snake, short-tailed snake, slender glass lizard, southern hognose snake; **Birds** Bachman's sparrow, Bell's vireo, eastern henslow's sparrow, Florida burrowing owl, Florida grasshopper sparrow, greater sandhill crane, limpkin, loggerhead shrike, Louisiana waterthrush, Mississippi kite, painted bunting, purple gallinule, red-cockaded woodpecker, red-headed woodpecker; **Mammals** Florida black bear, Florida long-tailed weasel, Florida mouse, Florida panther, Northern yellow bat, round-tailed muskrat, Sherman's fox squirrel, Southeastern weasel, Southeastern fox squirrel, Southeastern myotis, Southeastern pocket gopher

Plants: hundreds of rare plants including Apalachicola dragon-head, awned mountain-mint, beautiful pawpaw, Carolina spleenwort, chalky indian-plantain, comfortroot, Confederate huckleberry, Florida coontie, Florida scrub frostweed, Florida skullcap, giant water-dropwort, green flatsedge, lance-leaf seedbox, large-leaved jointweed, longstem adder's-tongue fern, lowland loosestrife, myrtle-leaf oak, night flowering wild petunia, plymouth gentian, powdery thalia, purple silkyscale.

Geophysical Settings in the Low Elevation Group

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

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

Low Elevation Acidic Sedimentary: Coastal Plain (L-SEDCP): Coastal plain settings on sandstone, siltstone, conglomerate may show bedrock outcops overlain with sandy surficial soils.

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

The following six settings are found primarily in the Coastal Plain:

Low Elevation Fine Sediment (L-FINE): Fertile silt or clay setting in stream beds, floodplains, clayplains, and tidal marshes.

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

Low Elevation Loam (L-LOAM): Deep loams, sandy loams, and sandy clay loam supporting acidic forests and marshes.

Low Elevation Loam over Limestone (L-LOAM/LIME): Deep loams, sandy loams, and sandy clay loam over limestone bedrock. This setting is associated with spring, seeps, deep cut rivers, and sinkholes. The surface communities resemble loam types.

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

Low Elevation Sand over Limestone (L-SAND/LIME): Coarse sand over limestone bedrock. Surface communitiese are similar to sand but associated with spring, seeps, deep cut rivers, and sinkholes.

The following seven settings are found primarily in the Mountains and Piedmont regions:

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

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

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 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 Surficial (L-SURFMT): Surficial sand and fine sediment substrates of floodplains or old lake beds occurring in the Mountains or Piedmont. (These are separated by texture in the Coastal plain).

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

Mid Elevation (1700’ to 2500’)

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

Rare or Uncommon Species found in this zone include:

Vertebrates: **Amphibians** Wehrle's salamander, green salamander, Southern zigzag salamander, seepage salamander, dwarf black-bellied salamander, shovel-nosed salamander, crevice salamander, **Reptiles** Eastern milk snake, Northern coal skink, bog turtle, **Birds** cerulean warbler, blue-winged warbler, sharp-shinned hawk, American peregrine falcon, warbling vireo, **Mammals** Southern Appalachian woodrat, Southern pygmy shrew, Eastern small-footed myotis, Southern bog lemming.

Plants: Aaron's rod, Oswego tea, small sundrops, broadleaf phlox, broad-leaved tickseed, sweet-fern, climbing fumitory, Virginia stickseed, silverling, sweet gale, shooting-star, northern evening-primrose, shale-barren blazing-star, Fraser's loosestrife, bog candles, branching draba, sweet indian-plantain, pink turtlehead, mountain sweet pitcher plant, umbrella-leaf, phlox-leaved aster, marsh marigold, american bittersweet, wild bleeding-heart.

Geophysical Settings in the Mid Elevation Group

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

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

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

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 Granite (M-GRAN): Foothill settings supporting natural communities typical of acid nutrient-poor shallow-soil environments.

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

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

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

High Elevation (2500’ to 4500’)

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

Rare or Uncommon Species in this elevation zone include:

Vertebrates: **Amphibians** Southern Appalachian salamander, dwarf blackbelly salamander, Yonahlossee salamander, red-legged salamander, weller's salamander, santeetlah dusky salamander, Southern pigmy salamander; **Birds** common raven, Appalachian bewick's wren, black-billed cuckoo, yellow-bellied sapsucker, brown creeper, Northern saw-whet owl; **Mammals** American water shrew, hairy-tailed mole, woodland jumping mouse, masked shrew, cinereus shrew, Appalachian cottontail, least weasel, Appalachian woodrat, Southern red-backed vole, Southern water shrew, long-tailed shrew, Virginia big-eared bat, long-tailed or rock shrew.

Plants: Oconee bells, round-leaf watercress, Cuthbert's turtlehead, robin runaway, squarrose goldenrod, rough bedstraw, pale corydalis, white heath aster, stone mountain mint, heartleaf hedge-nettle, Appalachian dwarf huckleberry, linear-leaved willow-herb, prairie bold goldenrod, buttonbush dodder, red turtlehead, Carolina saxifrage, Tennessee mountain-mint, rough hawkweed, mountain watercress, mountain golden-heather, Northern blue cohosh, rock skullcap, squirrel-corn, roundleaf serviceberry, kelsey's locust, divided-leaf ragwort, Appalachian violet, American wintergreen, purpleleaf willowherb, meehania, swamp saxifrage, cliff spurge, blue ridge golden ragwort, purple giant hyssop, fruitful locust, longleaf stitchwort, buck creek aster, cliffside goldenrod, greenland sandwort, granite dome goldenrod, Small's beardtongue.

These settings occur from 2500’ to 4500’ elevation and all are in the high mountains of the Southern Appalachians.

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

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

High Elevation Granite (H-GRAN): Mountainous granitic settings supporting natural communities typical of acid nutrient-poor shallow-soil environments.

High 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.

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

Very High Elevation (over 4500')

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

Rare or Uncommon Species in this elevation zone include:

Vertebrates: **Amphibians** Northern pigmy salamander; **Birds** olive-sided flycatcher, Southern Appalachian red crossbill, alder flycatcher, magnolia warbler, northern saw-whet owl, swainson's thrush, Southern Appalachian black-capped chickadee, hermit thrush, yellow-rumped warbler; **Mammals** southern rock vole, carolina northern flying squirrel.

Plants: Appalachian fir clubmoss, appalachian oak fern, arctic bentgrass, blue ridge goldenrod, blue ridge st. john's-wort, cumberland azalea, highland rush, long-stalked holly, mountain bittercress, mountain clematis, mountain paper birch, mountain sandwort, mountain st. john's-wort, narrow-leaved gentian, northern beechfern, northern lady fern, northern lowbush blueberry, purple bee-balm, roan mountain bluet, roseroot, rosy twisted-stalk, Smoky Mountains mannagrass, spreading avens, three-toothed cinquefoil, yellow bead-lily.

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

Very High Elevation Granite or Mafic (VH-GRAN/MAFIC): Bedrock mountain setting of intrusive granitic rock with minor plutons of mafic rock or volcanic basalts.

Very High Sedimentary (VH-SED/MODCALC): Bedrock mountain setting of sandstone, quartzite, conglomerate and minor includsions of moderately calcareous sedimentary rocks.

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

Summary of Geophysical Settings

Coastal, 6 settings

- Coastal Fine Sediment over Limestone (C-FINE/LIME)
- Coastal Fine (C-FINE) silts and clays
- Coastal Loam (C-LOAM)
- Coastal Loam over Limestone (C-LOAM/LIME)
- Coastal Sand (C-SAND)
- Coastal Sand over Limestone (C-SAND/LIME)

Low elevation, 15 settings

- Low Elevation Acidic Sedimentary – coastal plain (L-SEDCP)
- Low Elevation Acidic Sedimentary – mountains and piedmont (L-SEDMT)
- Low Elevation Acidic Shale (L-SHALE)
- Low Elevation Calcareous (L-CALC)
- Low Elevation Fine Sediment (L-FINE)
- Low Elevation Fine Sediment over Limestone (L-FINE/LIME)
- Low Elevation Granite (L-GRAN)
- Low Elevation Loam (L-LOAM)
- Low Elevation Loam over Limestone (L-LOAM/LIME)
- Low Elevation Mafic (L-MAFIC)
- Low Elevation Moderately Calcareous (L-MODCALC)
- Low Elevation Sand (L-SAND)
- Low Elevation Sand over Limestone (L-SAND/LIME)
- Low Elevation Surficial (L-SURFMT)
- Low Elevation Ultramafic (L-ULTRA)

Mid elevation, 8 settings

- Mid Elevation Acidic Sedimentary (M-SED)
- Mid Elevation Acidic Shale (M-SHALE)
- Mid Elevation Calcareous (M-CALC)
- Mid Elevation Granite (M-GRAN)
- Mid Elevation Mafic (M-MAFIC)
- Mid Elevation Moderately Calcareous (M-MODCALC)
- Mid Elevation Surficial Sediments (M-SURFMT)
- Mid Elevation Ultramafic (M/H/VH-ULTRA)

High elevation, 4 settings

- High Elevation Acidic Sedimentary and Shales (H-SED)
- High Elevation Calcareous and Moderately Calcareous (H-CALC/MOD)
- High Elevation Granite (H-GRAN)
- High Elevation Mafic (H-MAFIC)
- *[High Elevation Ultramafic (M/H/VH-ULTRA)]*

Very high elevation, 2 settings

- Very High Elevation Granite or Mafic (VH-GRAN/MAFIC)
- Very High Sedimentary (VH-SED/MODCALC)

Mapping and Assessing the Geophysical Settings

The source datasets used for mapping the geophysical settings were originally created at a variety of scales. For this study we compiled and processed this information at two scales of analysis:

- 30 meter cells
- 1000 acres (404-ha) hexagons

The 30 m data conveys information at the finest resolution we could measure based on the landform and elevation models derived from the 30 m DEM. To create a consistent analysis, we downscaled many of the other datsets (e.g. geology, soils, local connectedness) to a 30 m resolution even though the source data was at a coarser resolution. This allowed us to use the data as if it had been originally mapped at 30 meters, however, the true resolution was still that of the source data. For example, if an area was mapped as a single geology type ignoring small outcrops of contrasting geology, then the outcrops will not show up in the 30 meter layer. In effect, the 30 meter data preserves and acurrately represents the original data but does not change the original scale of the data.

The 1000 acre hexagon data is the scale most appropriate for interpreting the results because this scale reflects the spatial accuracy of the majority of the datasets. We refer to each hexagon as a “site,” and the hexagon shapes match edge-to-edge to perfectly tessellate the entire landscape – like a soccer ball – allowing for an assessment of relatively fine-scale detail. There were over 100,000 hexagons in the study area and we calculated all the variables described in this report for each one. 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. The hexagon sites can aggregate to form larger “conservation areas,” or larger patches of the same setting.

We attributed each hexagon with basic information about its topography, geology, and waterbodies, its geographic context, and the species and communities it currently contains. The attributes ranged from simple location information, such as the state and ecoregion, to the specific geophysical characteristics described below. We have high confidence that the scores and features (species, communities, geology) given for the hexagon are accurate, even if we are less certain about the positional accuracy of features within the hexagon. See Figure 5.1 in Chapter 5 for a graphic illustration of how we summarized different scales of information into the hexagon.

CHAPTER

3

Estimating Site Resilience

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 phenomena **site resilience**. In this section we describe the concepts, methods, and data used to estimate the relative site resilience of any given place. The two factors important to the estimate - landscape diversity and landscape permeability – are discussed separately, because the tools for assessing and measuring them are distinctly different.

Section 1: Landscape Diversity

The 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 associated with landforms and water bodies. As the climate changes, these microclimates offer options to resident species, and in response to climatic changes, species populations 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 diversity,** can be used to estimate the capacity of the site to maintain species and functions. We measured landscape diversity as a function of topography, elevation range, and the density and configuration of wetlands.

Topography describes the natural surface features of an area, and forms local landforms such as cliffs, summits, coves, basins, and valleys. Landforms are a primary edaphic controller of species distributions, due to the variation they create in rates of erosion and deposition, in soil depth and texture, in nutrient availability, and in the distribution of moisture and temperature (Forman 1995). Because each landform represents a local expression of solar radiation and moisture availability, a variety of landforms results in a variety of meso and micro climates. When climate change is considered, landform variation increases the persistence of species by providing many combinations of temperature and moisture within a local neighborhood, and these options buffer the resident species from the direct effects of the changing regional climate.

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 diversity, 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 diversity was based on landform variety, elevation range and, in flats, wetland density and configuration. 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 availability, exposure, and radiant energy. 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 based on a 30 m DEM (Gesch 2007, Figure 3.1 and 3.2). The methods to develop the model were based on Fels and Matson (1997) and are fully described in Appendix II and in Anderson (1999). 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 a moisture index based on flow accumulation and slope. The landform model can distinguish an unlimited number of landform units, but we used a 15 unit model that captures the major differences in temperature and moisture (Figure 3.1-3.3). The types include the following:

Box 1: The 15 landform types used in the landform variety analysis (Figure 3.4).

- Steep slope cool aspect
- Steep slope warm aspect
- Cliff
- Flat summit/ridgetop
- Hilltop (flat)
- Hill (gentle slope)
- Sideslope cool aspect
- Sideslope warm aspect
- Dry flats
- Wet flats
- Valley/toeslope
- Moist flats
- Flat at bottom of steep slope
- Cove/footslope
- Open water

All landforms that occurred on pixels classified as developed in the 2006 National Land Cover Dataset (NLCD; Fry et al.2011) were removed from the analysis, because landforms that have been developed do not create micro-climate options nor provide habitat for most native species.

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 15 landform types. Scores for each cell ranged from 1 to 15 (Figure 3.4) with a mean of 6.52 and a standard deviation of 2.63. 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.

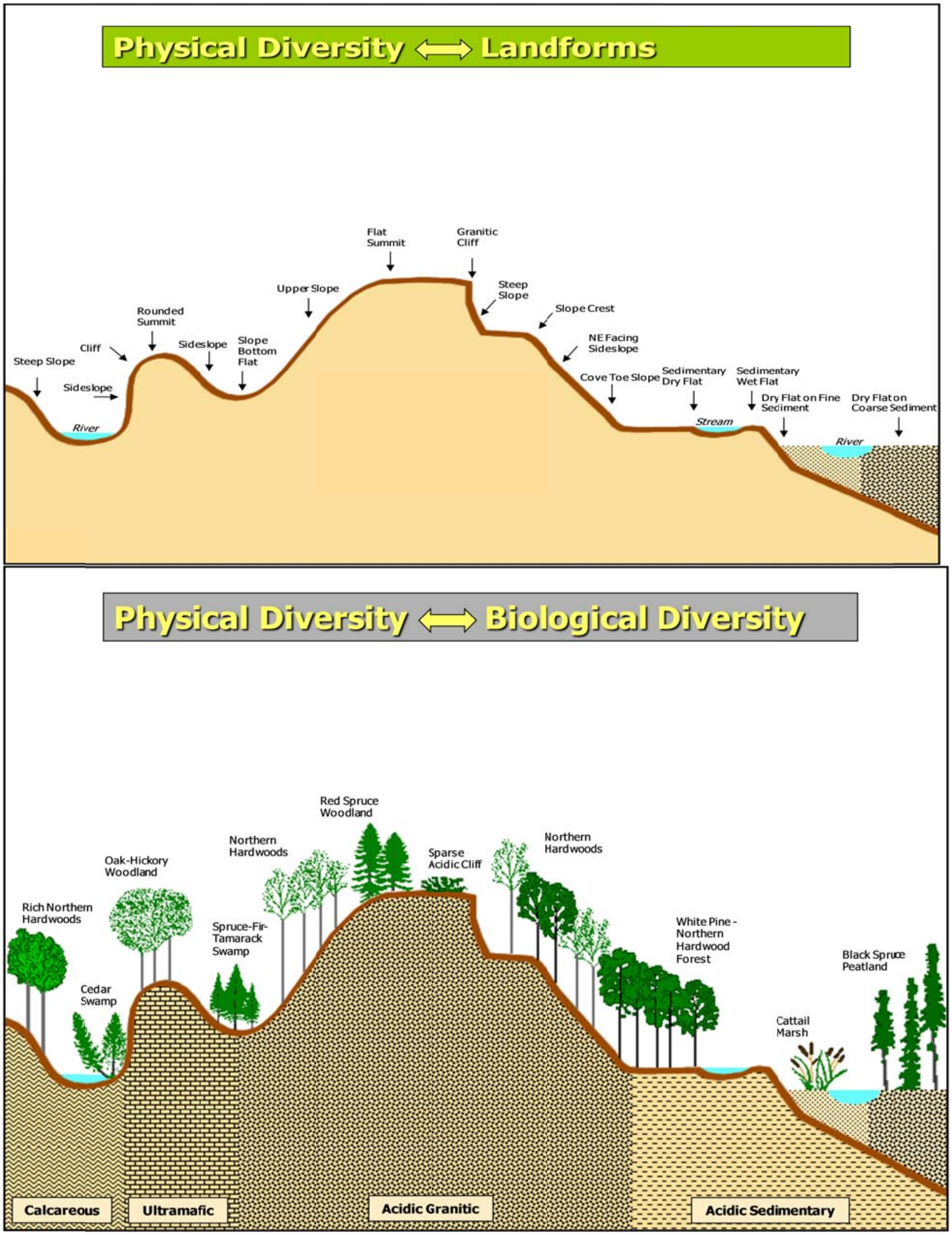


Figure 3.2: The 11-unit landform model. The model used in this report further divided the steep slopes and side slopes by aspect, and separated the slope bottom flats from the convex coves. This graphic shows how the landforms lie across on the landscape.

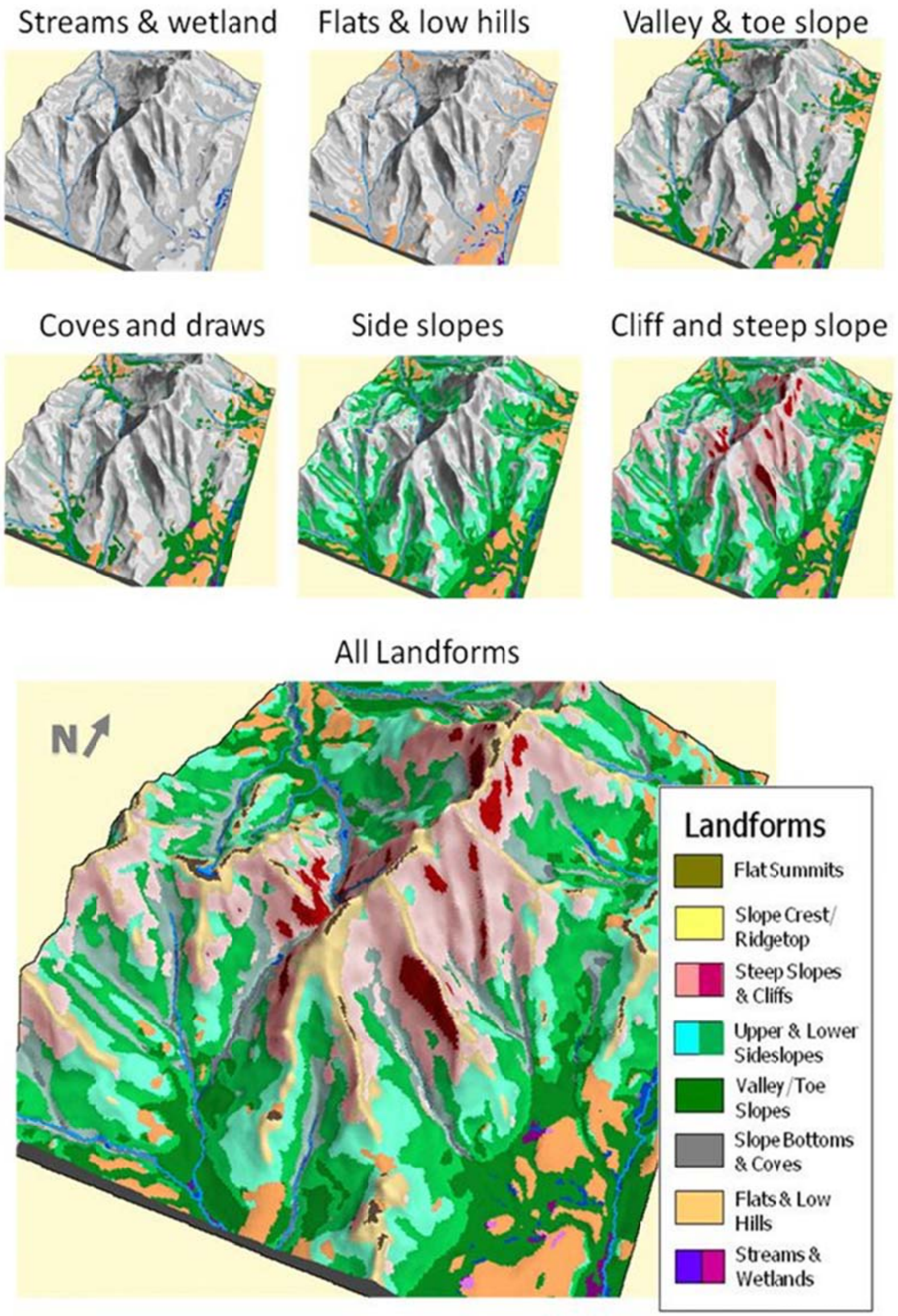
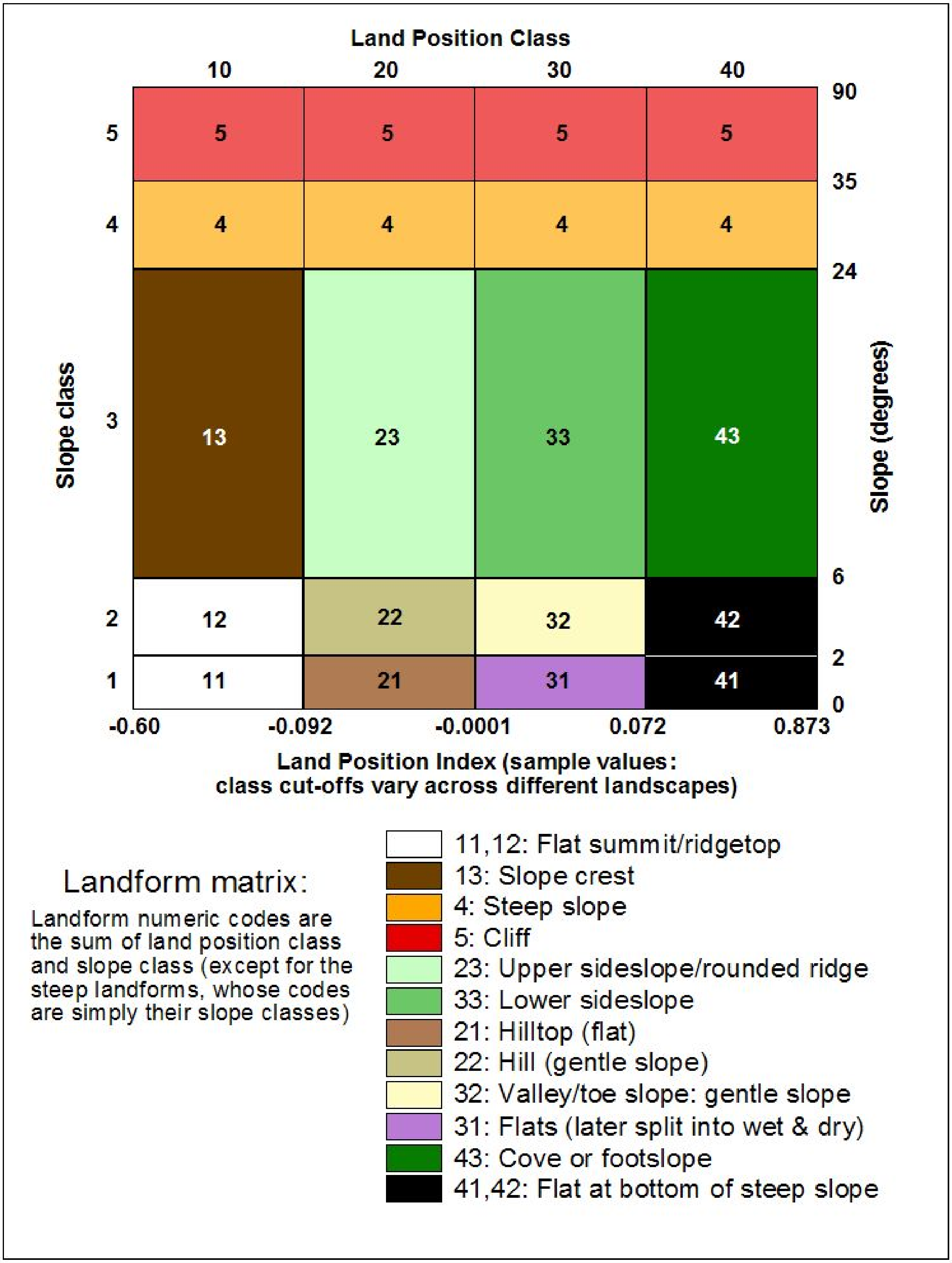


Figure 3.3: The underlying slope and land position model used to create the mapped landform grids. Adapted from Fels and Matson 1997



Slope class	10	20	30	40
5	5	5	5	5
4	4	4	4	4
3	13	23	33	43
2	12	22	32	42
1	11	21	31	41

Landform matrix:

Landform numeric codes are the sum of land position class and slope class (except for the steep landforms, whose codes are simply their slope classes)

- ⬜ 11,12: Flat summit/ridgetop
- 🟫 13: Slope crest
- 🟧 4: Steep slope
- 🟥 5: Cliff
- 🟩 23: Upper sideslope/rounded ridge
- 🟩 33: Lower sideslope
- 🟫 21: Hilltop (flat)
- 🟫 22: Hill (gentle slope)
- 🟨 32: Valley/toe slope: gentle slope
- 🟪 31: Flats (later split into wet & dry)
- 🟩 43: Cove or footslope
- ⬛ 41,42: Flat at bottom of steep slope

The size of the search area was derived by systematically testing many possible sizes (ranging from 4 ha to 400 ha) to find the one with the highest between-cell variance, and thus the maximum discrimination between sites (i.e. too large and all sites had all landforms, too small and all sites had only one landform). After determining this threshold for the landforms, for consistency we used the 100-acre (40 ha) area for all the landscape diversity metrics. Our assumption was that most plant and vertebrate populations could access this relatively small neighborhood to locate suitable microclimates.

The landform model describes major difference in local climatic settings, but it was 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 (Uncorrelated from Landforms)

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 (DEM, Gesch, 2007) for the region and using a focal range analysis to tabulate the range in elevation within a 100-acre circle around each cell. Prior to running the focal range analysis, the DEM was extracted by the modified landform grid so that all null areas (i.e., developed, ocean) were consistent between the two grids. Scores for each cell ranged from 0 to 549 meters with a mean of 35.12 m and a standard deviation of 47.57. The data were highly skewed towards zero and were log transformed for further analysis (mean 2.84 and standard deviation of 1.32).

Examination of the data revealed a strong correlation between the elevation range and the landform variety (Pearson R^2 =0.84). To generate a raster dataset of uncorrelated elevation range – the elevation range not explained by the variety of landforms – we used a robust regression (Hampel et al. 1986) with log-transformed elevation range as the dependent variable and landform variety as the independent variable. A bivariate regression raster was calculated using a randomized subsample of pixels stratified by the three subregions (Coastal Plain, Piedmont, and Mountains) and fitted using an iterated re-weighted least squares algorithm. The resulting dataset estimated the range of elevation present in a 100 acre circle around each 30 m cell that was not due to the variety of landforms (Figure 3.5). For example, if two cells were both surrounded by south-facing sideslopes and summits, some elevation range would be expected due to the presence of the two landforms, however, the one with the longer slopes would have more elevation range, and that range would be independent of the landform number. We calculated the standardized normal score for every cell in the study area, however our goal was to add a positive value to cells where the elevation range added more resilience to the cell and not to subtract it from cells where the elevation range was equal to the landfrom diversity. To ensure this, we took all cells with positive values greater than 2.44 meters (the vertical accuracy of the DEM), and we subtracted a constant from the calculated z-scores so that the raw value of 2.44 was equal to 0.5 SD. Cells with higher scores received their adjusted z-score and all cells with lower scores were set to 0 (Figure 3.5).

Wetland Density

A large part of the coastal plain is flat and wet. Because the landform variety is inherently low and the elevation range is minimal in these areas, the characteristic that creates habitat options and imparts the most resilience is the density and patchiness of wetlands. A high density of wetland patches is correlated with extensive micro-topography which creates climate and moisture options for wetland and upland species. Micro-topographic heterogeneity has long been recognized as a major factor structuring freshwater wetland communities and influencing diversity by creating the small-scale hummock and hollow microhabitats favored by different species (Vivian-Smith 1997). After experimentation with calculating local rugosity measures (which did not perform well in very flat landscapes) we determined that directly measuring wetland density based on aerial interpreted photo imagery provided the best available gauge of small and micro-scale topographic diversity. We assumed that areas with a high density of wetlands and a high number of wetland patches had the highest topographic variation and that small isolated wetlands were assumed to be more vulnerable to shrinkage and disappearance than wetlands embedded in a landscape crowded with other wetlands.

We calculated **wetland desnity**, we created a wetland grid for the region by combining the National Wetland Inventory (NWI 2013) for the study area, except in Florida where there was better wetlands data available from Florida Natural Areas Inventory's (FNAI 2012) functional wetlands dataset. We reviewed the FNAI functional wetlands to ensure they were similar in level of detail and that they matched on the state border with the NWI wetlands. From the NWI wetlands we removed the non-wet classes (wetland type = estuarine and marine deepwater, freshwater pond, lake, riverine, other) to create the wetlands grid for the region at 30 meters.

To ensure that the wetland density values were on the same scale as landform variety and elevation range, we calculated 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 calculated the percent of wetlands of an area one magnitude larger (1000 acre circle) around each 30-meter cell in the region. For coastal areas where some 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. We log-transformed the values to approximate a normal distribution and calculated a standardized normalized score for each distance. Standard normalized scores (aka z-scores) have a mean of zero and a standard deviation of one, and we used this transformation to ensure that all datasets had equal weight when combined. To summarize the wetland density for each cell, we combined the standardized values from both search distances, weighting the 100-acre wetland density twice as much as the 1000acre wetland density and summing the values into an integrated metric (Figure 3.6). Raw scores for the 100-acre search area ranged from 0 to 100 percent with a mean of 7.66 percent and a standard deviation of 7.66 percent. Scores for the 1000-acre search radius were: mean 7.68 percent and standard deviation 16.98.

We experimented with calculating the number of individual wetland patches in a given search radius. For this we created a wetland patch dataset that identified all the individual patches of wetlands in the region (details in Appendix I), and used a focal sum to count the number of wetlands in a 1000-acre circle. The average count of wetlands was 3.05 with a standard deviation of 8.20. We log-transformed the values to approximate a normal distribution and calculated the standardized normalized score for the log transformed values. However, upon detailed examination, this dataset revealed inconsistencies among the states on how the wetlands were mapped (e.g. as one wetland or as many small wetland), perhaps having to do with water levels at the time of mapping. Because our confidence in the data was not high we did not use this information in our calculations.

Our final metric of Wetland Density (Figure 3.6) was:
*Wetland Density = (2*wetland density of 100 acres + 1*wetland density of 1000 acres)/2*

Landscape Diversity Combined Index

To create a standardized metric of landscape diversity (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) and then combined them into a single index. We added the wetland index value to the landform variety and elevation range scores only in flat areas defined as having cells with slopes less than 5% (landforms = slope bottom flat, moist flat, wet flat, dry flat, Figure 3.9.)

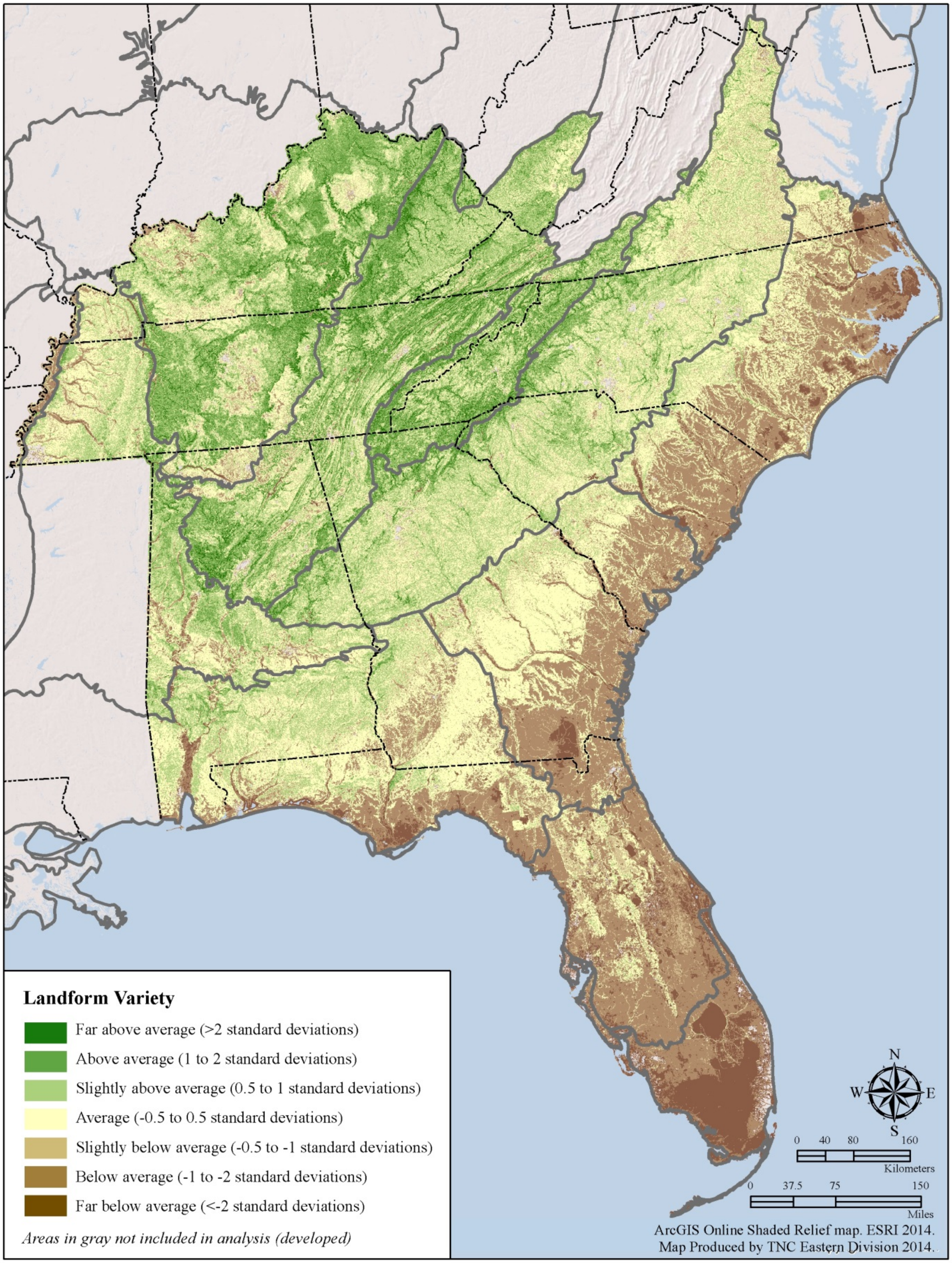
In the combined index we weighted landform variety twice as much as the other two values because of the importance of this feature in creating well defined microclimates (Figure 3.10). The final index was:

Landscape Diversity

Flats = (2 LV + 1 ER + 1WD)/4

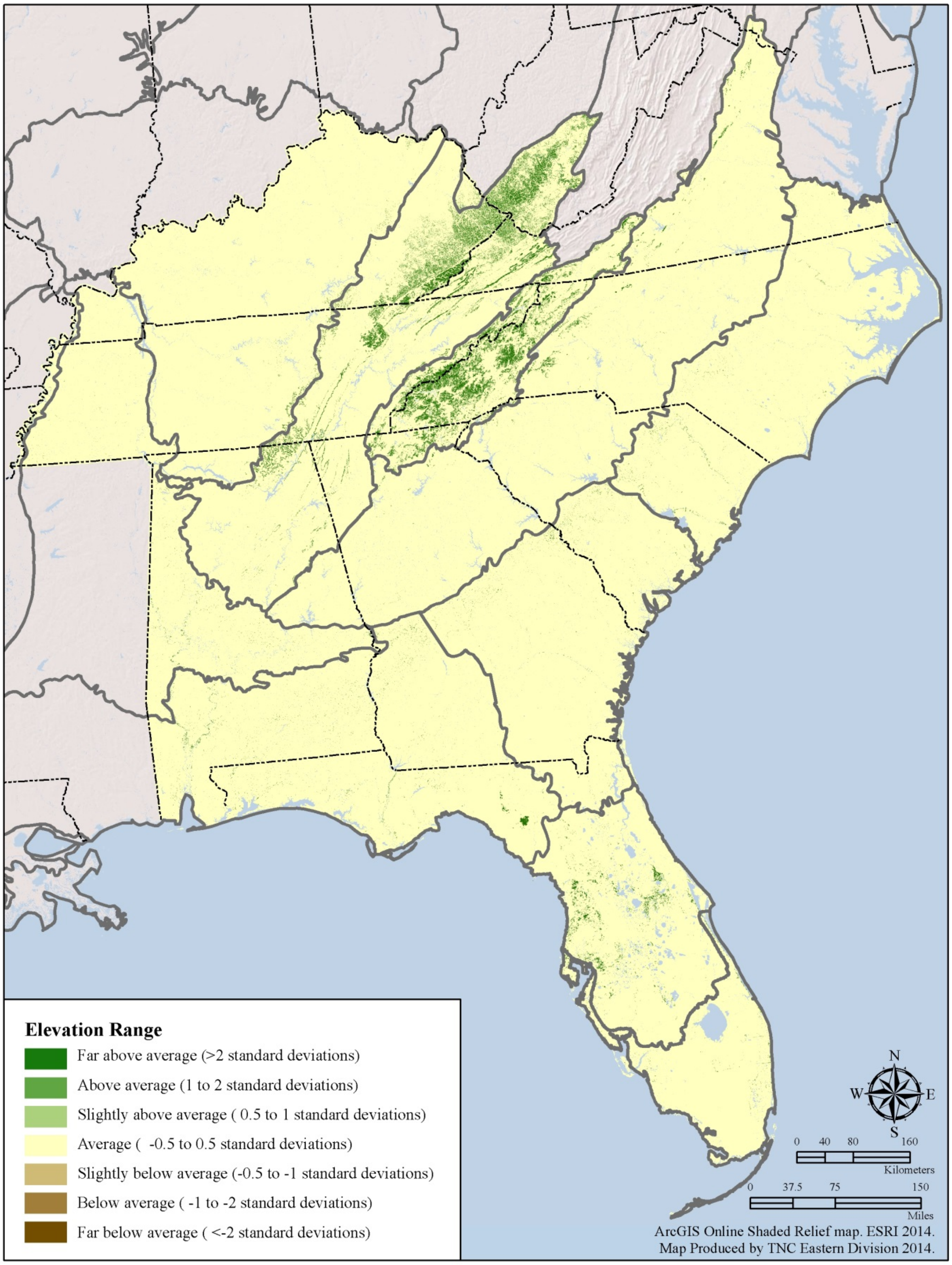
Slopes = (2 LV + 1 ER)/3

Figure 3.4: Landform variety. This map counts the number of landforms (15 possible) in a 100-acre circle around a central cell, and compares it to the regional average.



ArcGIS Online Shaded Relief map. ESRI 2014.
Map Produced by TNC Eastern Division 2014.

Figure 3.5: Elevation range (uncorrelated with landform variety). This map measures the elevation range in a 100-acre circle around a central cell that is not correlated with the number of landforms and compares it to the regional average.



ArcGIS Online Shaded Relief map. ESRI 2014.
Map Produced by TNC Eastern Division 2014.

Figure 3.6: 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.

ArcGIS Online Shaded Relief map. ESRI 2014.
Map Produced by TNC Eastern Division 2014.

Figure 3.9 A-D: A three-dimensional look at the metrics of landscape diversity in southern North Carolina. All metrics are measured in 100-acre circles around every point (30-m cell) on the landscape. A. The original landform model. B The Landform Variety metric shows the number of landforms with dark green as high and dark purple as low. C. The Elevation Range metric shows the range of elevation with darker greens indicating a wider range. D. Wetland Density is shown with purple as high and brown as low.

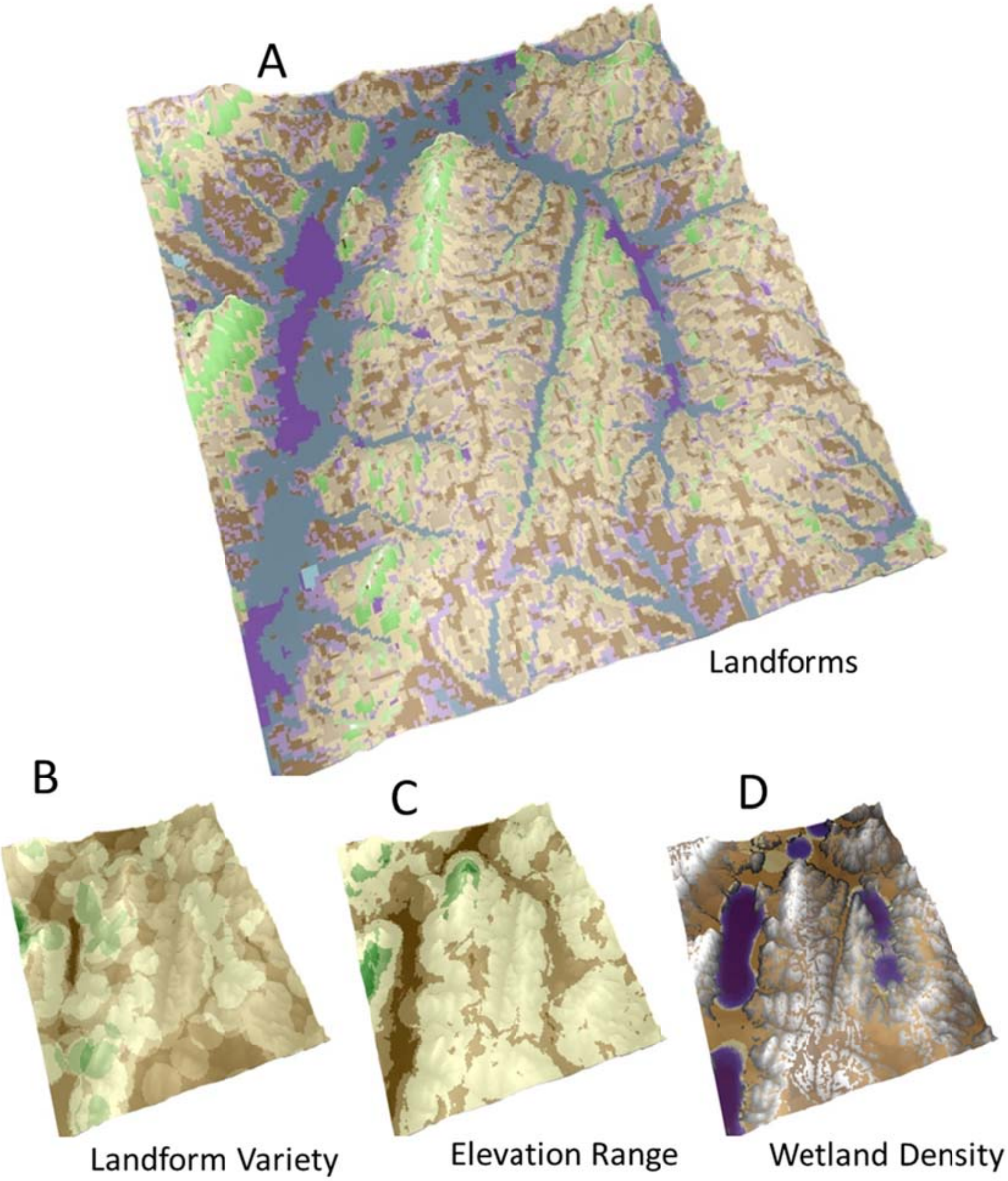
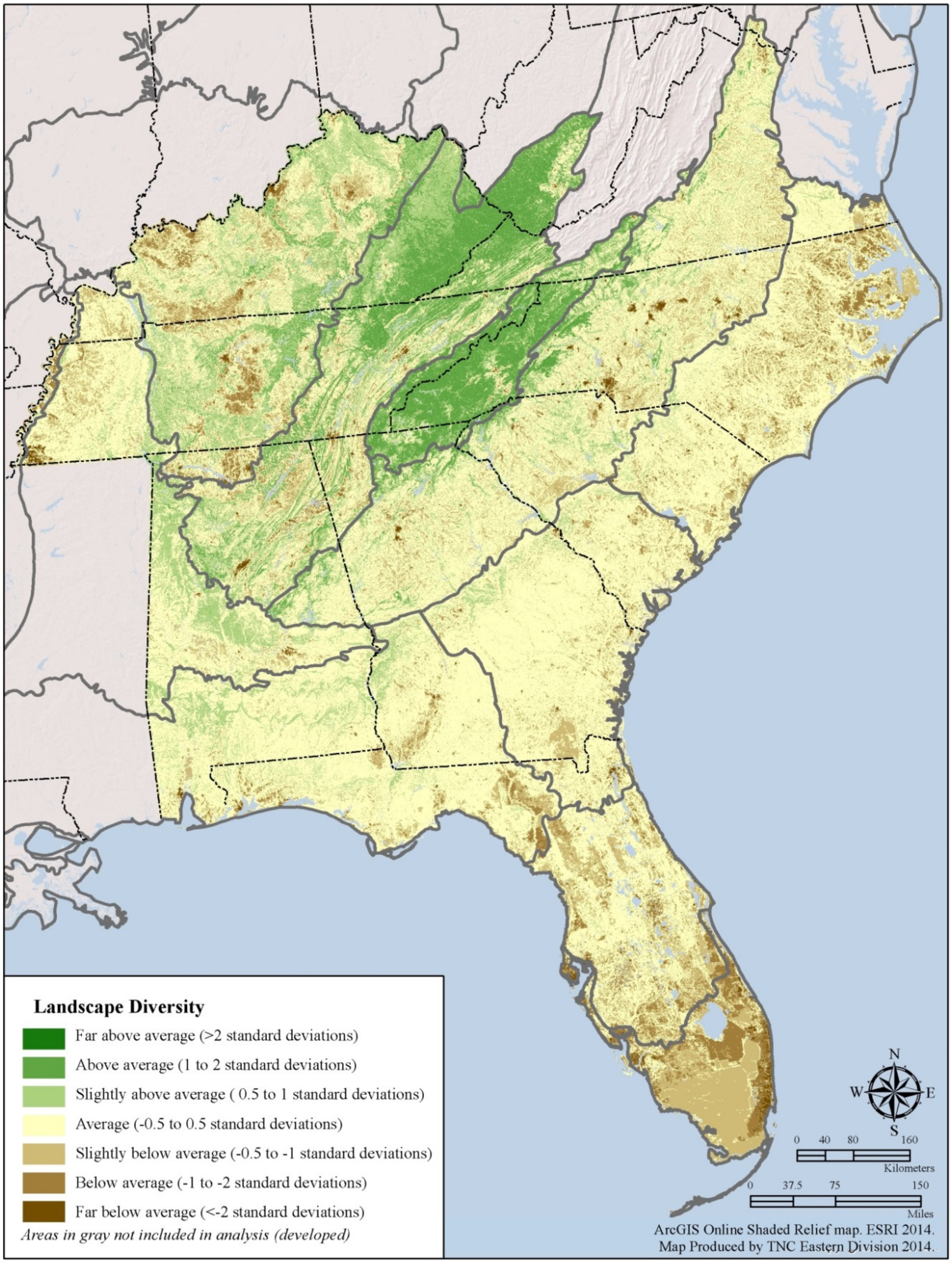


Figure 3.10: Landscape diversity. This map estimates the degree of landscape diversity of a cell based on the combined values of Landform Variety, Elevation Range and Wetland Density, and compares it to the regional average. At this scale the map obscures many of the subtle local changes amplified later in the ecoregion section.



ArcGIS Online Shaded Relief map. ESRI 2014.
Map Produced by TNC Eastern Division 2014.

Section 2: Landscape Permeability

The natural world constantly rearranges, but climate change is expected to accelerate natural dynamics, shifting seasonal temperature and precipitation patterns and altering disturbance cycles of fire, wind, drought, and flood. Rapid periods of climate change in the Quaternary, when the landscape was comprised of continuous natural cover, saw shifts in species distributions but little extinction (Botkin et al. 2007). Now, pervasive landscape fragmentation disrupts ecological processes and impedes the ability of many species to move or adapt to changes. The concern is that broad-scale 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 of species responding to a changing climate.

We use the terms ‘**permeability**’ and **‘connectedness’** instead of ‘connectivity’ because the conservation literature commonly defines ‘connectivity’ as the capacity of individual species to move between areas of habitat via corridors and linkage zones (Lindenmayer and Fischer 2006). Accordingly, the analysis of landscape connectivity typically entails identifying linkages between specific places, usually patches of good habitat or natural landscape blocks, with respect to a particular species (Beier et al. 2010). 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 natural 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. We use the term “ecological flow” to refer to both species movements and ecological processes.

Because permeability is a multidimensional characteristic, we developed two separate analytical models to assess different aspects of its local and regional nature. The first, **local connectedness,** starts with a focal cell and looks at the resistance to flows outward in all directions through the cell’s local neighborhood. The second, **regional flow denisty**, looks 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 is discussed in Chapter 4 because the results were not used as an estimate of site resilience, but rather for identifying connections that link sites into resilient networks.

The 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. forest next to forest or developed next to developed), 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 forest 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, ephemeral, 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 constant modifications to both the structure (e.g. clearing and mowing), and ecological processes (e.g. flood and fire suppression, predator regulation, nutrient enrichment).

Developed lands: 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.

The permeability analyses were intentionally focused on the connections across natural land. Species that thrive in developed or modified lands would need a separate analysis.

Local Connectedness

The **local connectedness** metric measured 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 micro-climates 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 of a resistance grid 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 a focal cell out to a maximum distance of three kilometers (the recommended distance determined by the software developer).

To calculate this metric, **resistance weights** were assigned to the elements of a land cover 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 landscapes 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).

To create the resistance grid, we used landcover, roads and railroads. The source data was the 30-meter 2006 NLCD which identifies each grid cell as belonging to one of 16 classes of land cover (Fry et al. 2011). We burned in the 2012 Tiger roads, as well the latest railroad layer from ESRI (Tele Atlas North America, Inc., 2009) into the NLCD grid. Each element of the resistance grid was then assigned a weight between 1 (no resistence) and 20 (high resistance) to indicate the degree to which the land use hinders species movement (Table 3.1).

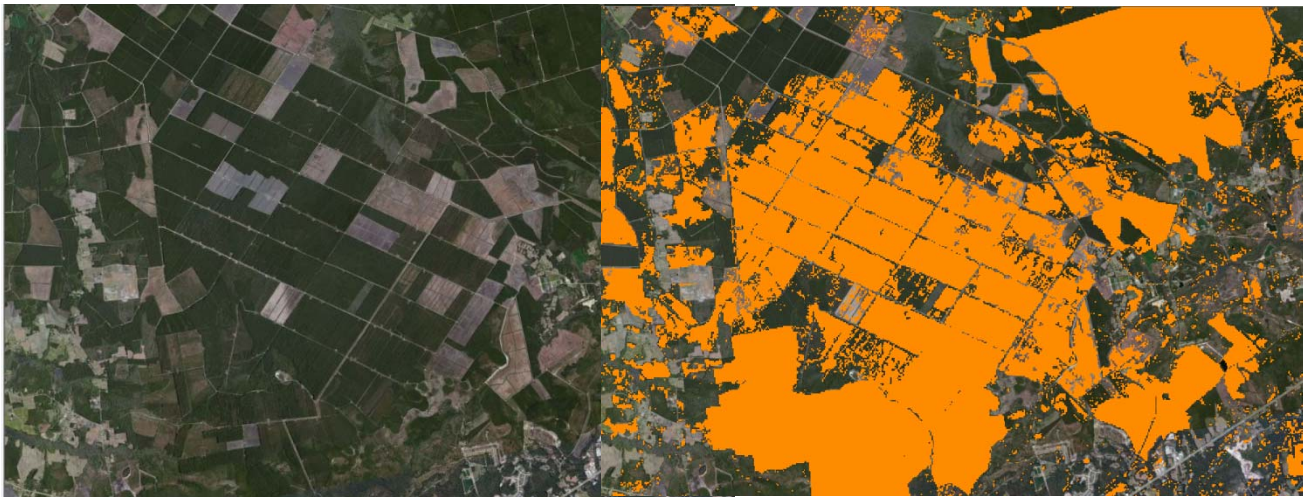
Resistance Grid Improvements

We made improvements to the input resistance grid compared to the input data used in the local connected analysis we conducted for the Northeast (Anderson et al 2011). The improvements related to how we mapped and treated barrens, plantations, agriculture and waterbodies. We enhanced the NLCD classification of barren land by distinguishing natural barrens (e.g., beaches and summits) from highly developed barrens (e.g., airport runways). We used spatial analysis techniques to identify barrens associated with industry or commercial development versus barrens associated with bare rock, exposed beach, lake shoreline, and other natural settings. We assigned different resistance scores to the two types of barrens.

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

Land Cover Class	Land Element Category	Weight
Developed High Intensity/Major Roads	**Developed: Medium/High Intensity**	**20**
Barren Land (Developed)	**Barren Land (Rock/Sand/Clay)**	**20**
Developed Medium Intensity/Minor Roads	Developed: Medium/High Intensity	9
Developed Open Space	Developed: Low Intensity	8
Developed Low Intensity	Developed: Low Intensity	8
Cultivated Crops	Agriculture	7
Pasture/Hay Mountain Ecoregions	Agriculture	5
Pasture/Hay Coastal Plain & Piedmont Ecoregions	Agriculture	3
Plantation Forest	Semi-Natural	3
Open Water Natural	Water	1/3/5(<200/ 200 – 400/ >400 m)
Barren Land (Natural)	Barren Land (Rock/Sand/Clay)	1
Deciduous Forest	Natural	1
Evergreen Forest	Natural	1
Mixed Forest	Natural	1
Shrub/Scrub	Natural	1
Grassland/Herbaceous	Natural	1
Woody Wetlands	Natural	1
Emergent Herbaceous Wetlands	Natural	1

Figure 3.11: Plantation forest: this shows a satellite image of plantation forest on the left and the same area with mapped locations of plantations on the right.



We distinguished plantation forests from natural forests which are lumped together in the NLCD 2006 land cover dataset. To do this we used information on the locations of plantations from two data sources. The first was the Southeast GAP land use dataset (Southeast GAP Land Cover Dataset, 2010) which classified plantation forests from aerial imagery and spatially mapped three classes: Deciduous Plantations, Evergreen Plantation, and Clear Cut. The second data source was a proprietary dataset from ParcelPoint that has parcel shapes and ownership information for most of the Southeast (ParcelPoint 2013). We conducted queries on the parcel data to identify and map major industrial forest/timber ownership that occurred on land cover classes from the NLCD 2006 that would support plantation forestry. We merged the SEGAP and parcel-based industrial forest datasets with the NLCD 2006. Where two cells overlapped, if the NLCD classified the cell as "natural forest," we overrode the cell as "plantation/industrial forest" and this category received a resistance score of 3 as this land use is subject to frequent cutting, road development and other anthropeogenic disturbances, and typically has less ground over (Figure 3.11).

The differences between pasture/hay and cultivated agriculture were discussed extensively in our advisory committee meetings and it was agreed that cultivated cropland creates more resistance than pasture, and that the resistance of pasture varied depending on how open or forested the surrounding region is. Thus, we assigned a resitance value of "7" to all cultivated crops and we varied the resistance values for pasture/hay depending on the ecoregion: a resistance value of "3" was assigned to pastureland in the Coastal Plain and Piedmont regions (Figure 2.1) where pasture is more similar to natural ecological systems, and a resistance value of "5" was given in the Mountain region where the natural systems are more forested.

Finally we adjusted the resistance score of "water" to reflect the size of the water body because very large waterbodies have greater effect on the movement of terrestrial species than small streams or ponds. To quantify this we selected all water pixels in the NLCD, converted the pixels to polygons, and buffered inward 200 and 400 meters. We assigned water within 200 m of shoreline a resistance value of "1" (natural), water between 200 and 400 meters of shoreline received a resistance value of "3", and water greater the 400 meters from shoreline was given a value of "5" because of the barrier it presents to movement (Figure 3.12).

To run the local connectedness analysis on the resistance surface we decreased the grid cell resolution from 30 meters to 90 meters. This allowed us to run the analysis with a reasonable processing time (weeks) because the CAPS software program is computationally intensive. We aggregated the 30 meter cells to the 90 meter cells using the average of the 30 meter resistance weights (Table 3.1). 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 37.27 and standard deviation of 20.14 for the region (Figures 3.13-3.17)

Figure 3:12. Waterbodies and the zones used in the resistance weighting. Waterbodies are shown in blue on the figure with darker blues indicating higher resistance at 0-200, 200-400, and 400+ meters.

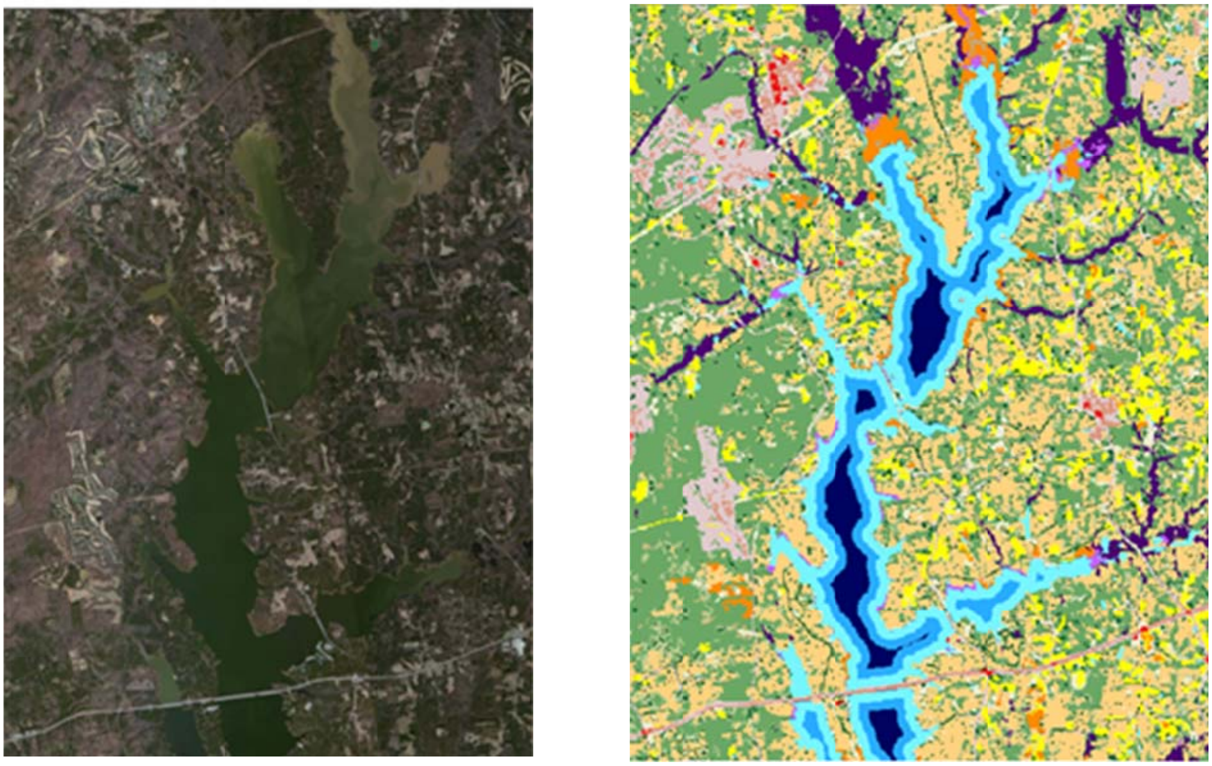


Figure 3.13: Examples of four resistant kernel cells shown against the land cover and roads map. The focal cell is the central point of each kernel and the spread, or size, of the kernel is the amount of constraints, so the score for the focal cell reflects the area around the cell. Kernel A is the most constrained; D is the least constrained.

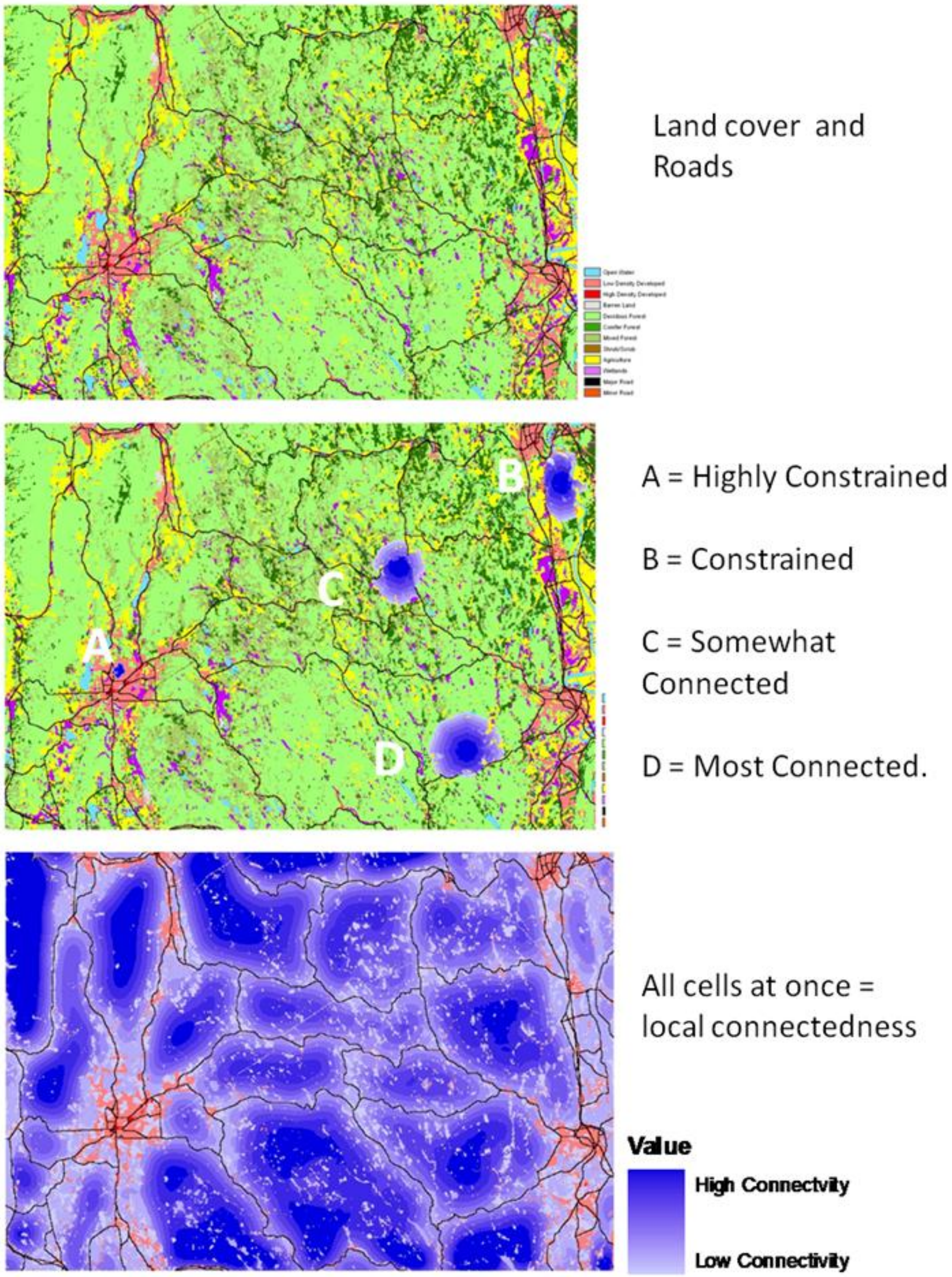


Figure 3.14: Detailed look at Kernel B in Figure 3.5. The top left image shows the topographic map for a rough location. The top right shows detail of the land use grid. The bottom left shows the aerial and the 3km circular resistant kernel distance. The bottom right shows the kernel spread. Kernel B 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.

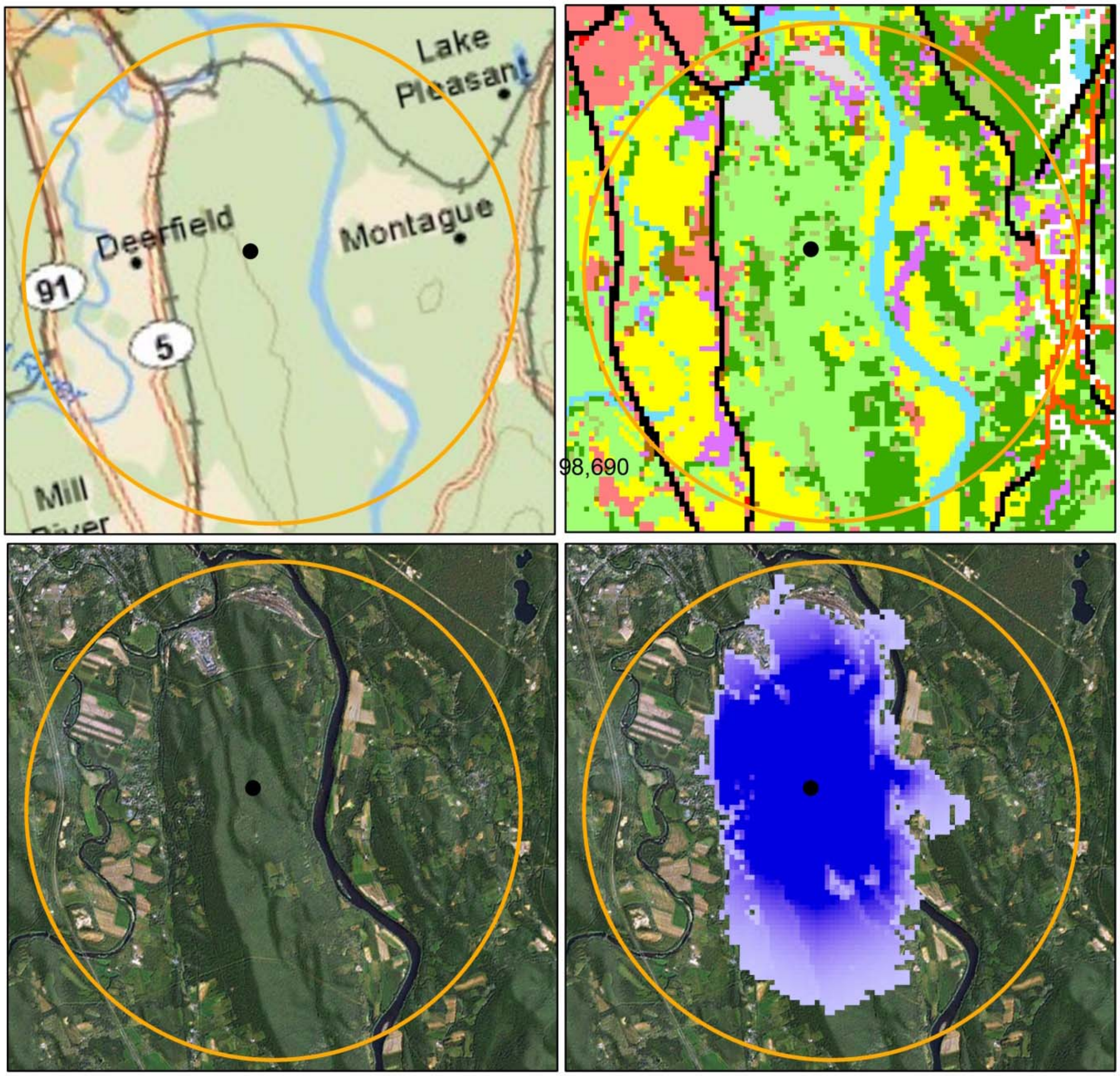


Figure 3.15: Visual comparison of local connectedness grid (top) with aerial photo of site (bottom). This shows a fragmented landscape on Prince Edward Island. The top image is a close up of the local connectedness surface with the site shown in blue outline. The bottom image shows a photo of the area with the approximate site area shown as a blue circle (mean = 6.0, z-score = -0.83).

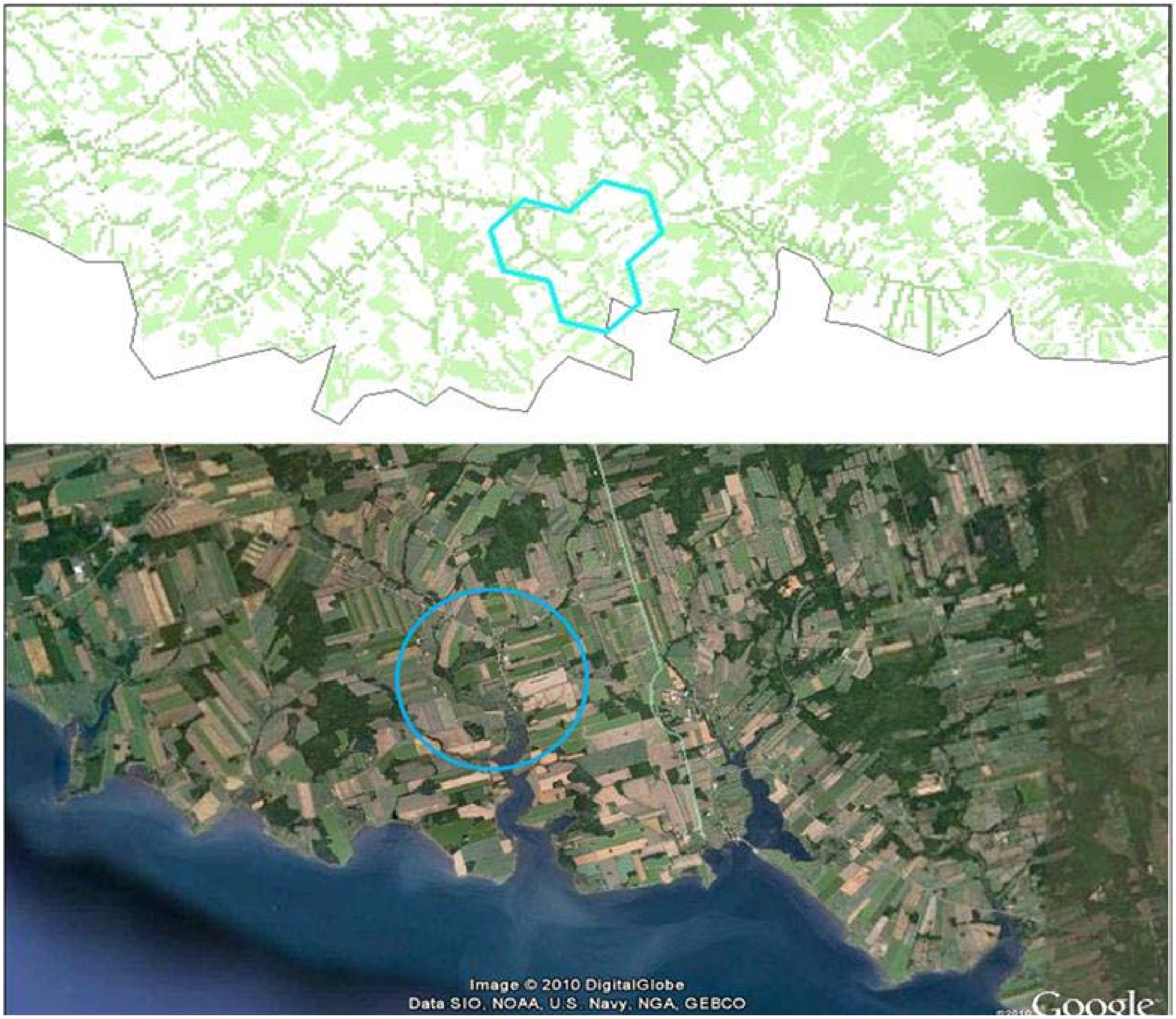


Figure 3.16: A gallery of satellite images and their corresponding local connectedness (lc) scores. The mean scores are based on a roughly circular site positioned at the center of each image (not shown). Z is units of standard deviation from the regional mean.

Local Connectedness = 20
Z-score = -0.83

Local Connectedness = 50
Z-score = 0.55

Local Connectedness = 80
Z-score = 1.974

Local Connectedness = 100
Z-score = 2.9933

Map 3.17: 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.

ArcGIS Online Shaded Relief map. ESRI 2014.
Map Produced by TNC Eastern Division 2014.

Section 3: Combined Resilience Factors

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

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

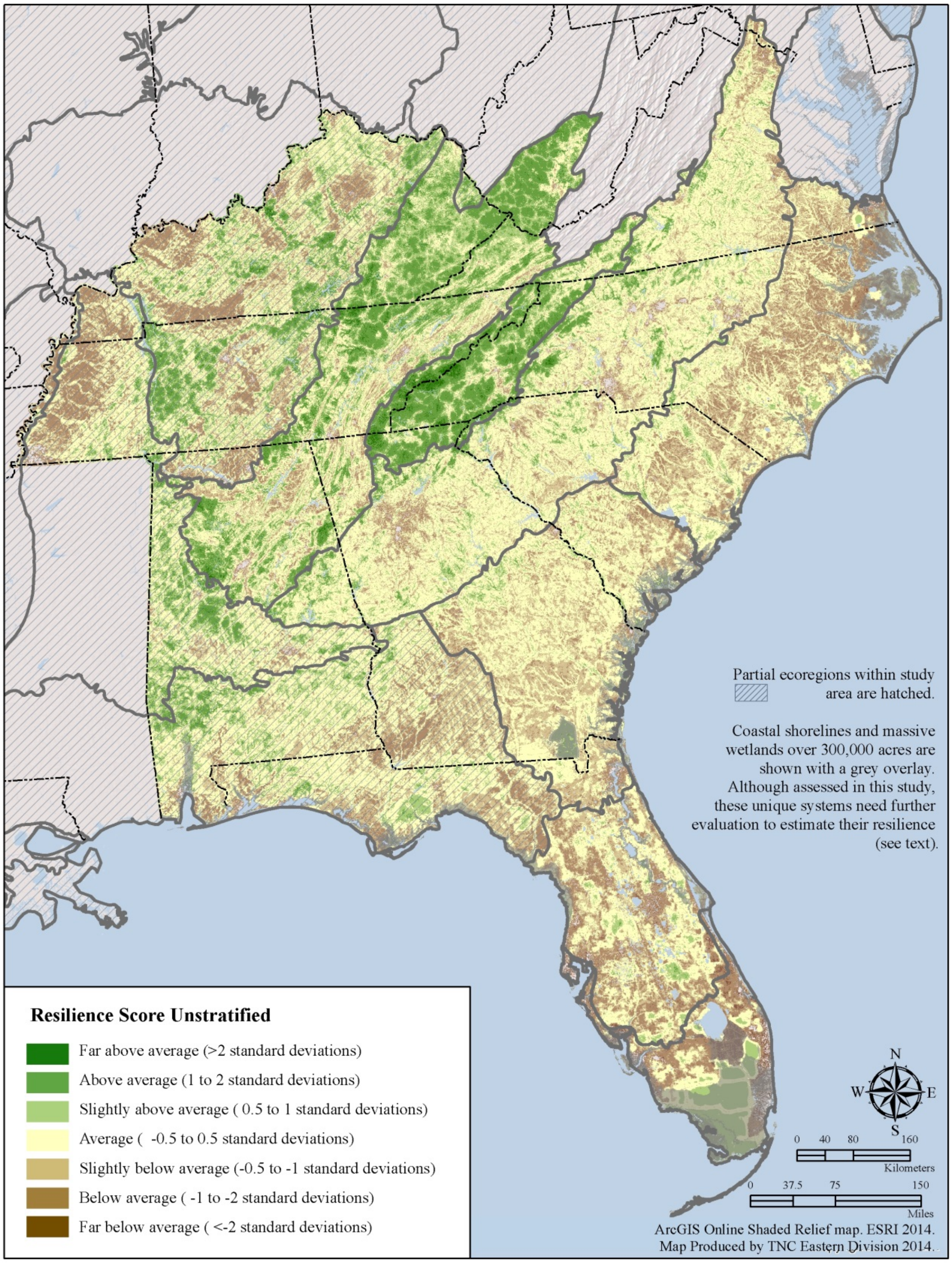
$$z = \frac{x - \mu}{\sigma}$$

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

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

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

Map 3.18: Unstratified resilience score. This map shows the raw cell scores for estimated resilience (landscape diversity + local connectedness) before we stratified the score by geophysical setting and ecological region.



Partial ecoregions within study ▨ area are hatched.

Coastal shorelines and massive wetlands over 300,000 acres are shown with a grey overlay. Although assessed in this study, these unique systems need further evaluation to estimate their resilience (see text).

ArcGIS Online Shaded Relief map. ESRI 2014.
Map Produced by TNC Eastern Division 2014.

CHAPTER

4

Regional Linkages

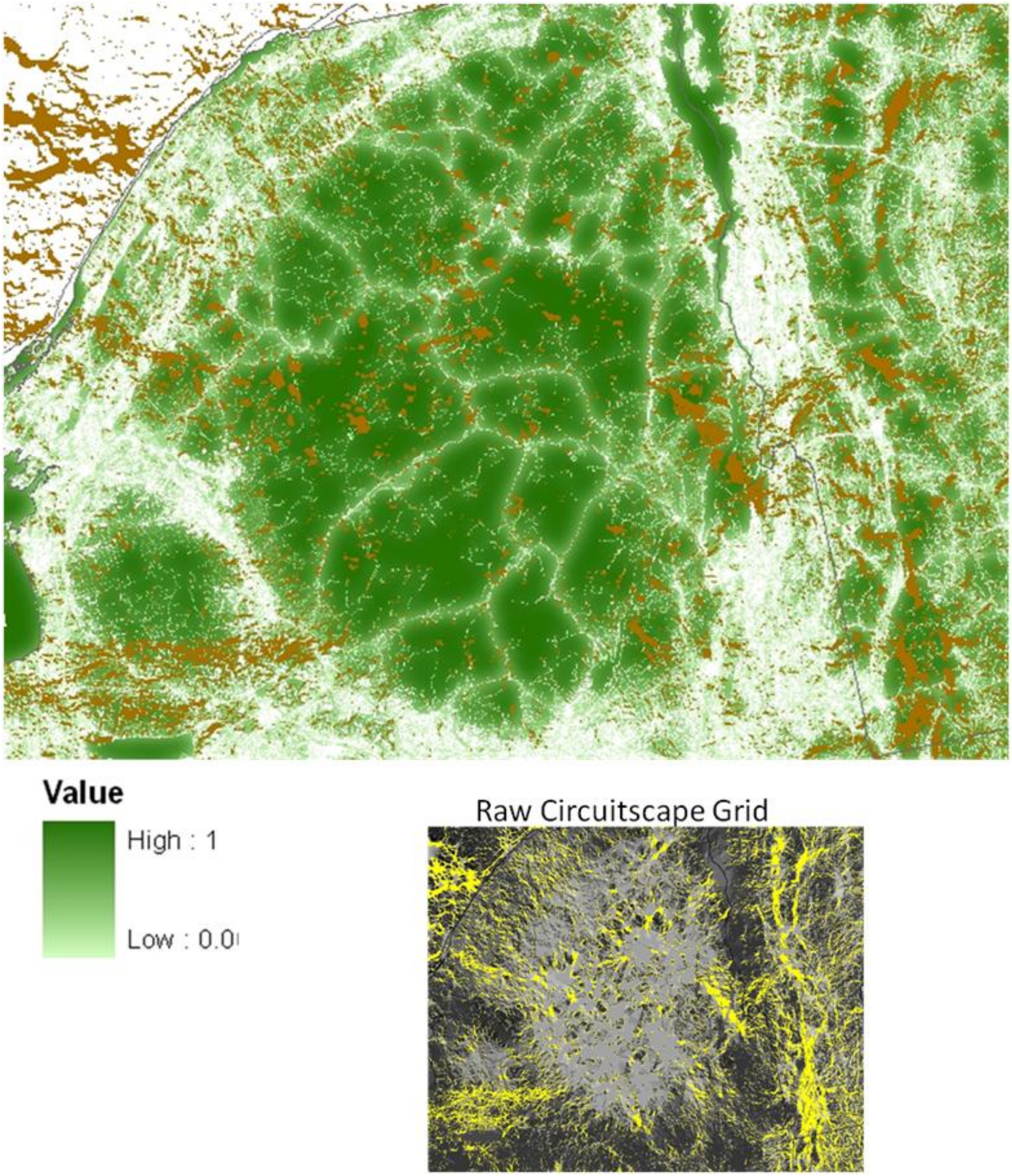
In this chapter we develop a mothod to evaluate large region-scale patterns of potential movement such as directional range shifts, north-south migrations, or upslope dispersal patterns. The previously described "local connectedness" metric quantified the permeability of the landscape based on the local neighborhood surrounding every cell in the region, but did not account for these broader scale movements. This metric, **regional flow**, was designed to identify potential larger-scale directional movements and pinpoint the areas where those movements are likely to become concentrated, diffused, or rerouted due to the structure of the landscape. The theory and methods for qualtifying omni-directional connectivity are decribed below and a full account may be found in Pelletier et al. 2014

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 converted to a resistance grid by assigning weights to the cell types based on their similarity to cells of natural cover (see table 3.1). However, instead of quantifying local neighborhoods, the Circuitscape program calculates a surface of effective resistance to current moving directionally 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 resistance of the landscape creates areas of high and low concentrations similar to the rills, gulleys, braided channels, and main channels one associates with overland flow. The analysis reveals three basic patterns in the current flow: 1) *low flow* in areas of low permeability, 2) *diffuse flow* in highly intact/highly permeable areas, or 3) *concentrated flow* in 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 of New York (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.

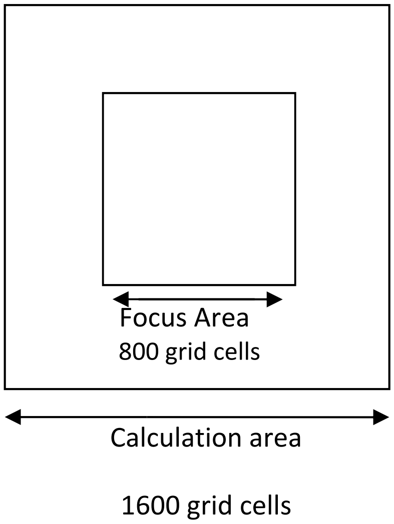
The Circuitscape program "sees" the landscape as made up of individual cells and for this analysis we used a cell size of 270 meters. Each cell was coded with a resistance score derived by assigning it a resistance value based on land cover and roads (Table 3.1). We used the same land cover maps supplemented 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. 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 Beier (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.

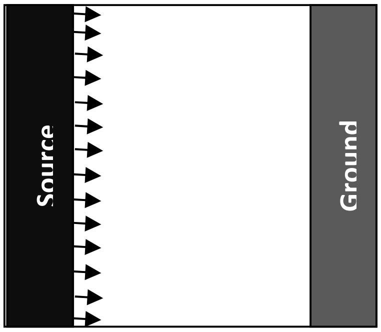


Circuitscape was originally designed to run resistance-based connectivity metrics from one focal area (habitat patch) to another. To assess overall landscape permeability, however, we measured current accumulation using continuous equal inputs across the entire landscape rather than providing a set of points/patches to connect. After many trials, test runs, and conversations with the software developer, we developed a method to obtain 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 56 tiles – or calculation areas – comprised of 1600 cells by 1600 cells (~ 432 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 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 56 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 (Figure 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.

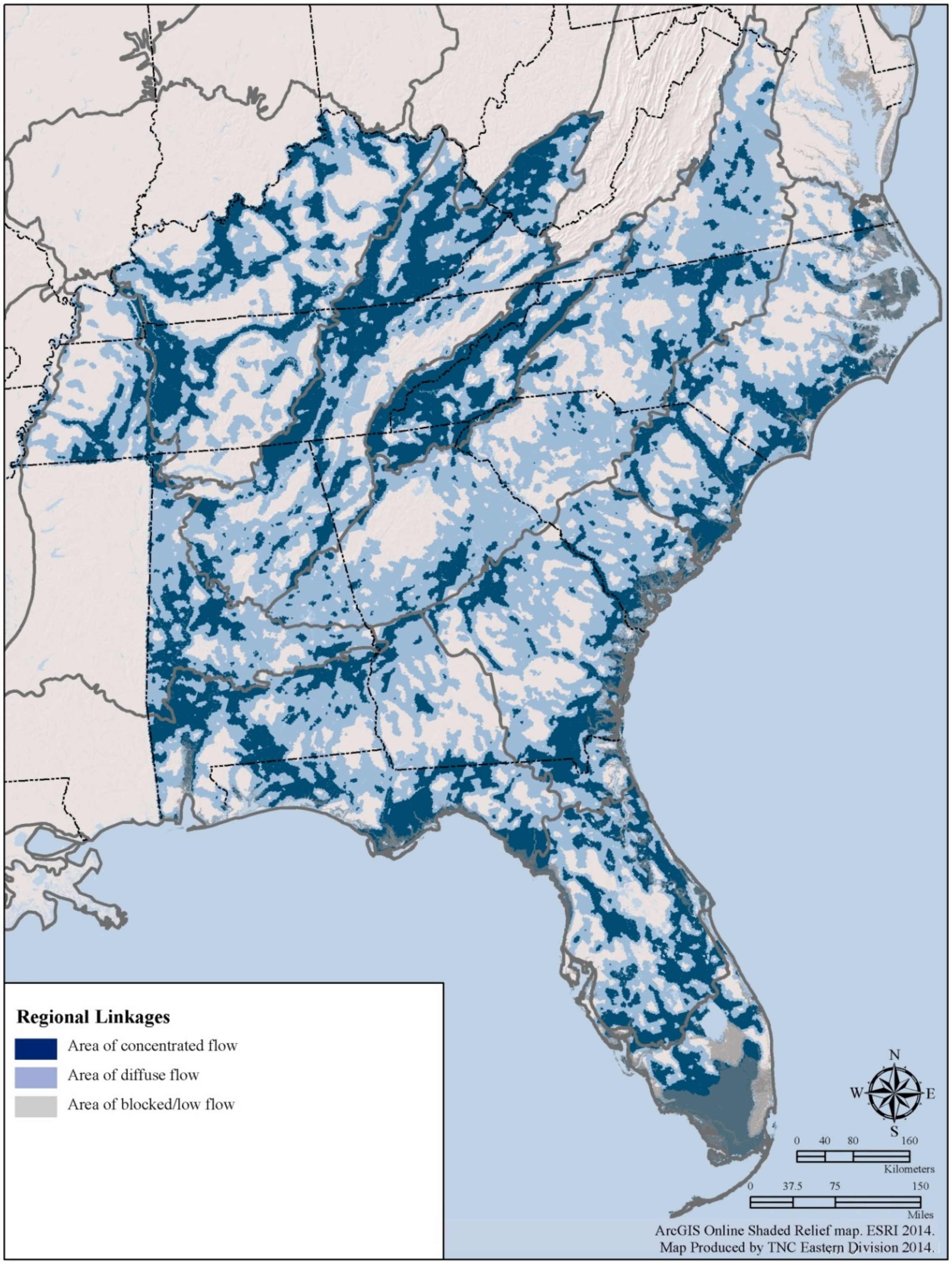
Integration with Other Metrics

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 the 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 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 wolverines, 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 minimize categorization errors.

Figure 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).

Figure 4.3: Regional flow patterns and linkages. This map shows the results of a density analysis on the regional flow patterns grid (Figure 4.2) where we grouped areas of concentrated flow (above average), diffuse or dispersed flow (average) and low or blocked flow (below average).



ArcGIS Online Shaded Relief map. ESRI 2014.
Map Produced by TNC Eastern Division 2014.

CHAPTER

5

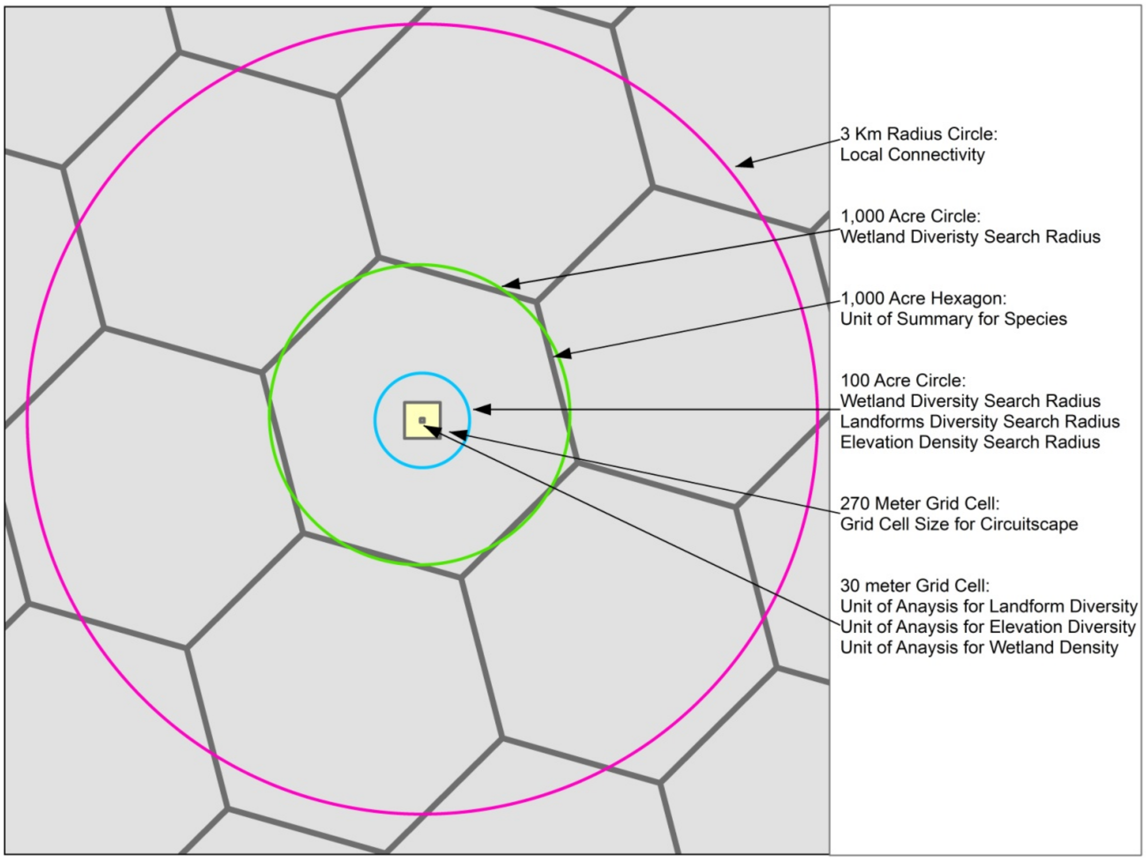
Results:
Estimated Resilience Scores

In this chapter, we present the results derived by integrating the geophysical settings and the estimated resilience scores within the context of ecoregions, and overlaying those results with the regional flow concentration areas. We map the places and networks revealed by this integration.
To inform conservation decisions, we compare sites that score high for their resilience characteristics with sites identified by TNC for their important biodiversity values, and we note areas that score high for both estimated resilience and current biodiversity. Further, we compare the high-scoring sites with the protected lands – land secured against conversion to development- to understand which geophysical settings are underrepresented in the secured lands network, and to identify resilient areas for conservation focus.

We applied the estimates and attributes of resilience to each 1000 ac hexagon and 30 m grid cell in the study area to identify the most resilient areas of each geophysical setting within each ecoregion. To estimate a score for an individual hexagon, we combined information collected across a variety of scales: from a 100-acre circle for landscape diversity to a three kilometers radius for local connectedness. 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.

Each hexagon was attributed and scored for the resilience factors described in the previous chapters: landform variety, elevation range, wetland index, 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 a zonal statistics operation in a GIS. Additionally, we overlaid point locations of rare species and natural communities compiled from the nine state Natural Heritage program’s ongoing inventory.

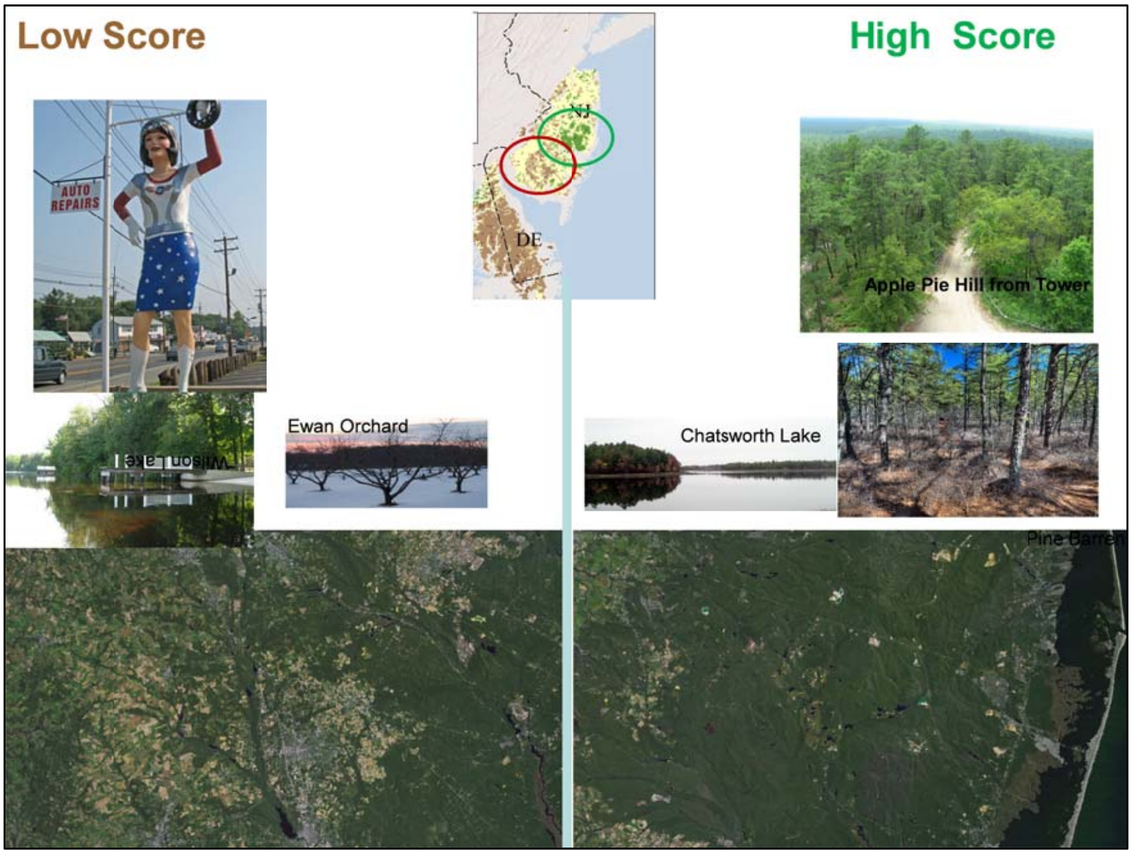
Figure 5.1: The variety of local neighborhood sizes used in this assessment. The information was all tagged to the 30-meter cell (the smallest center point) and summarized by 1000 acre hexagons. Landscape variety, elevation range, and wetland density all used a 100-acre search radius around each 30-meter cell, with the latter also weighted by a 1000 acre search radius. 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 kilometers (pink circle).



Resilience and Vulnerability

Resilience to climate change and its converse, vulnerability to climate change, are relative concepts for which we currently do not have absolute thresholds. Admittedly, we have a limited understanding of how climate-induced changes will interact, how those interactions will play out on the landscape, and exactly how systems will recover and transform. In this document, a resilient site was defined as one that has characteristics (microclimatic buffering and connectedness) that maintain ecological functions and will likely sustain a diversity of species. We expect that these sites will support an array of specialist and generalist species, even as the composition and ecological processes change. In contrast, a vulnerable site was defined as one where processes are disrupted and fragmented, and where the site is likely to lose diversity. We expect that these sites will increasingly favor opportunistic “weedy” species adapted to high levels of disturbances and anthropogenic degradation. Climate change is expected to greatly exacerbate the degradation of vulnerable sites; however, these sites may still perform many natural services, such as buffering storm effects or filtering water. Thus, vulnerable sites are not without value, but they are places where it will be increasingly difficult to sustain the natural functions and species diversity of whole ecological systems over time (Figure 5.2).

Figure 5.2. Estimated resilience and vulnerability. This image shows aerial photos for two areas in New Jersey. The one on the left is flat and fragmented, and scores low for resilience while the one on the right has greater landscape diversity and connectedness, and scores higher for resilience.



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

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

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

Resilience and Geophysical Settings

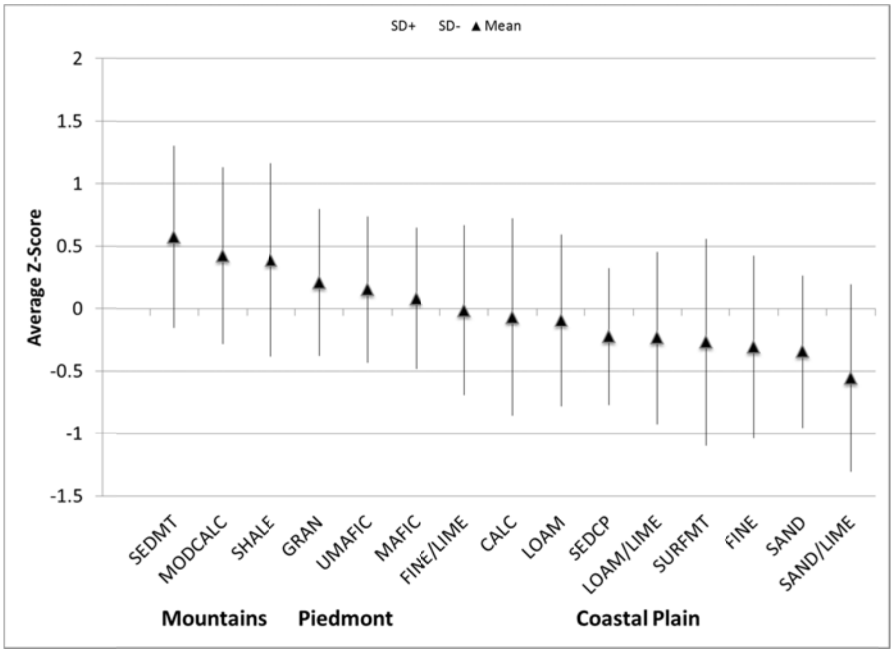
People have been aware of the differences between geophysical settings for centuries, particularly the fertility of the soils, the structural properties of the bedrock, and the hydrologic cycle of the groundwater flow. Not surprisingly, most settlement has occurred in the gentle landscapes with productive soils, while most conservation areas are located on poor soils with steep slopes. As a result, settings like low elevation limestone and coastal sands are not only less complex in structure, but also more fragmented by human use (Figure 5.3).

For each geophysical setting we identified the area with the highest resilience scores by calculating the mean estimated resilience score for all cells of each setting, and then identifying those hexagons that scored above the mean or that were above the mean for the entire region. To account for the inherent differences in landscape diversity and local connectedness between settings, each was evaluated individually and the results were combined into a single map that showed the highest scoring areas for each setting (Figure 5.4).

The various geophysical setting also differed dramatically in their conservation securement status, reflecting, to some extent, the degree of utility of the setting for agriculture, settlement or other human uses (Figure 5.5). Like the low scoring settings, the underrepresented settings were predominantly low elevation regions with soils derived from surficial sediments or calcareous bedrock.

Figure 5.3: Average resilience acores of geologic classes and elevation zones. This chart shows the average resilience score for each non-combined geology classes (a) and elevation zone (b) in relation to the mean score of the whole study area. Scores are in standard normal units. For example, the mafic geology class has an average score that is 0.5 SD higher than the average score. Scores for settings in the mountain and piedmont settings are inherently higher than scores for the coastal plain.

(a)



(b)

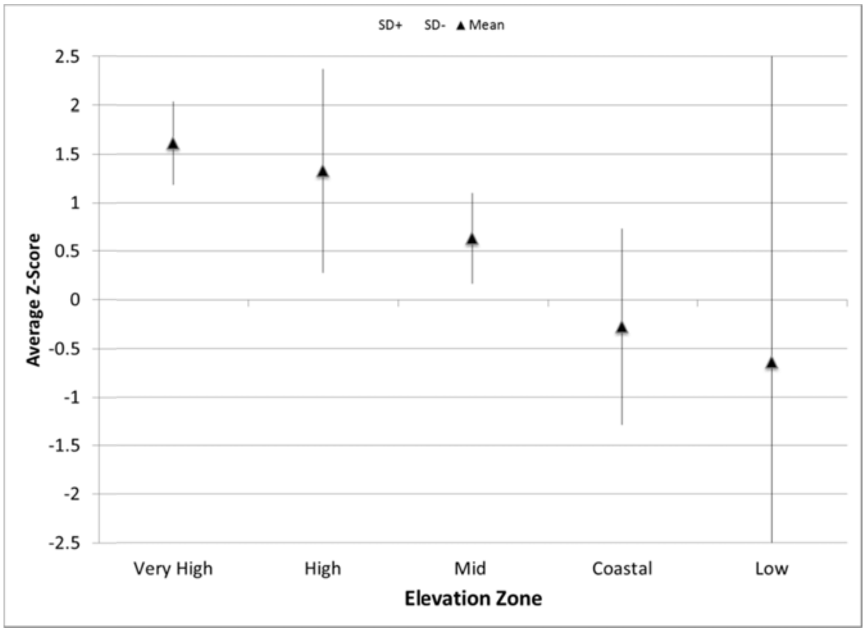


Figure 5.4. Resilience score by geophysical setting. This map shows the estimated resilience score stratified by each of the 35 geophysical settings. For each setting we calculated the mean and standard deviation of the scores for the entire setting. The map shows areas that are above (green) or below (brown) the mean.

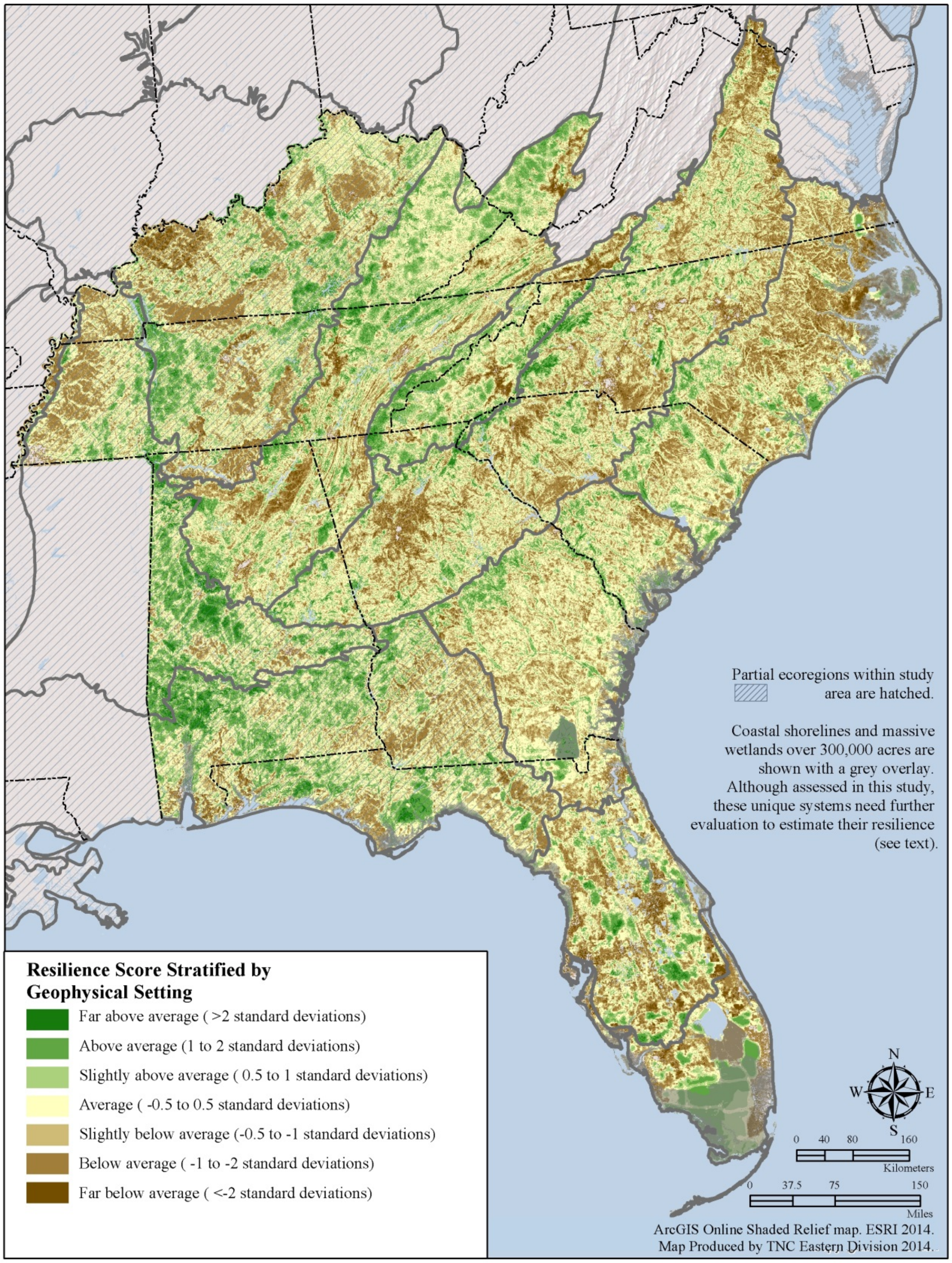
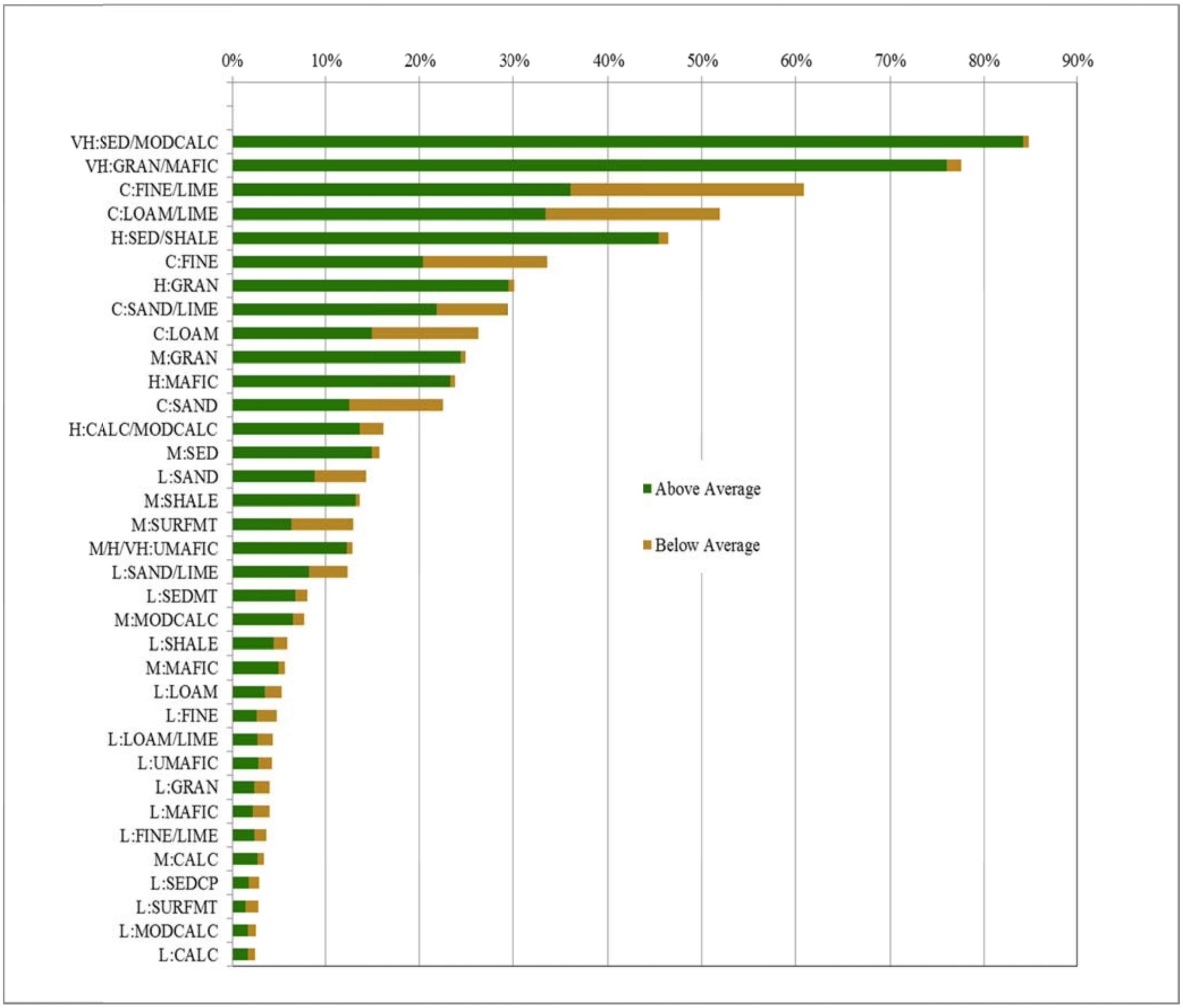
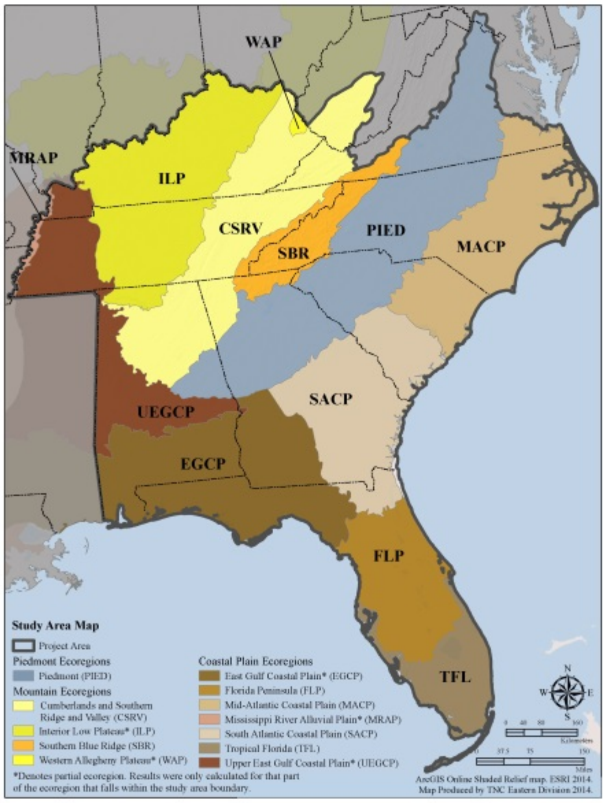


Figure 5.5: Securement status of the geophysical settings. This chart shows the proportion of total securement for each setting, further divided by whether the site scored above average or below average for resilience. This chart suggests that for most settings at least half of the securement has been 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 Bailey of the USFS. In recent decades, ecoregions have become a defining construct of larger conservation efforts because they provide a needed ecological context for understanding conservation activities by enabling the evaluation of properties considered critical to conserving biodiversity (e.g. representation, redundancy, ecological function, linkages, and endemism).



*Denotes partial ecoregion. Results were only calculated for that part of the ecoregion that falls within the study area boundary.

ArcGIS Online Shaded Relief map. ESRI 2014.
Map Produced by TNC Eastern Division 2014.

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

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

Cumberland and Southern Ridge and Valley (CSRV)
Mountainous regions of WV, KY, TN, AL, GA
Southern Blue Ridge (SBR)
Mountains of VA, NC, SC, GA, TN
Piedmont (PIED)
Flat plateau of MD, VA, NC, SC, GA, AL
Mid-Atlantic Coastal Plain (MACP)
An extensive low-relief plain from VA, NC, SC
South-Atlantic Coastal Plain (SACP)
An extensive low-relief plain from SC, GA
Penisular Florida (FLP)
Coastal plain region on the Florida peninsula
Tropical Florida (TFL)
Southern third of Florida peninsula

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 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:

Interior Low Plateau (ILP)
Upper East Gulf Coastal Plain (UEGCP)
East Gulf Coast Plain (EGCP)
Western Allegheny Plateau (WAP)

Ecoregion Results

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

1) Estimated resilience for all geophysical settings in the ecoregion,
2) The most resilient examples of each geophysical setting in the ecoregion,
3) Resilience scores of the protected lands,
4) Resilient areas and TNC biodiversity sites: integration of current and future biodiversity, and
5) Resilient areas and regional linkages.

All results are relative to the geophysical settings within the ecoregion. Explanations, interpretation, and, in some cases, the method of mapping, are described below. Partially included ecoregions are not shown except in the finals series of region-wide maps that show the whole study area, and these maps are composites of the individual ecoregion maps plus the results for the partial ecoregions. The latter areas are lightly hatched on the maps to remind users of the incomplete results in the partial ecoregions.

Estimated Resilience for all Geophysical Settings in the Ecoregion

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

A small, but logical, modification to the regional and ecoregional maps was the incorporation of a **regional override**. Essentially, we overrode the ecoregional score in places where the hexagon was one of the highest scoring in the whole region but not in the ecoregion. This was necessary when all the examples of the setting in the ecoregion were high scoring; in these cases our method of calculating the average and showing the examples above and below the mean forced half of these examples to appear below the mean – even if they were among the best in the region. By adding the sites that had scores >0.05 SD for the entire study area we corrected for this problem.

Resilient Examples of each Geophysical Setting in the Ecoregion

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

Resilience Scores of the Protected Lands

These maps display how the existing protected lands – land that is permanently secured against conversion to development – score with respect to their resilience characteristics. To make the map, each 100 acre hexagon was coded by its percent secured. The legend displays the protected status of the resilient areas in each ecoregion, and the resilience of the existing protected areas.

Resilient Areas and TNC's Portfolio of Biodiversity Sites

These maps compare the areas that scored high for resilience with the areas that were identified as important places for current biodiversity in TNC'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 reviewed in the assessments included rare species, upland and wetland communities, and subterranean caves. Streams and rivers were also assessed but are not shown here. 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.

Overlaying the ecoregional portfolio sites on the resilient sites identified areas that have both significant current biodiversity and the potential for long term resilience. 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 suggests places where conservation practitioners have much to work with, and where they might succeed in sustaining a resilient system over the long term.

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 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, such as many of the linkage areas. We recommend that the latter areas be examined further for their biodiversity features before investing deeply in land conservation.

TNC, along with many partners, 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. These have been done for terrestrial and freshwater features. Marine ecoregions are underway in the South Atlantic Bight. Full information on all of the southeastern ecoregional assessments, as well as the maps, reports and data for each ecoregion may be found at http://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/edc/reportsdata/terrestrial/ecoregional/Pages/default.aspx.

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.

Resilient Areas and Regional Linkages

The final maps show the linkages and flow concentration areas in relation to the high-scoring sites. 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 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.

Cumberlands and Southern Ridge and Valley

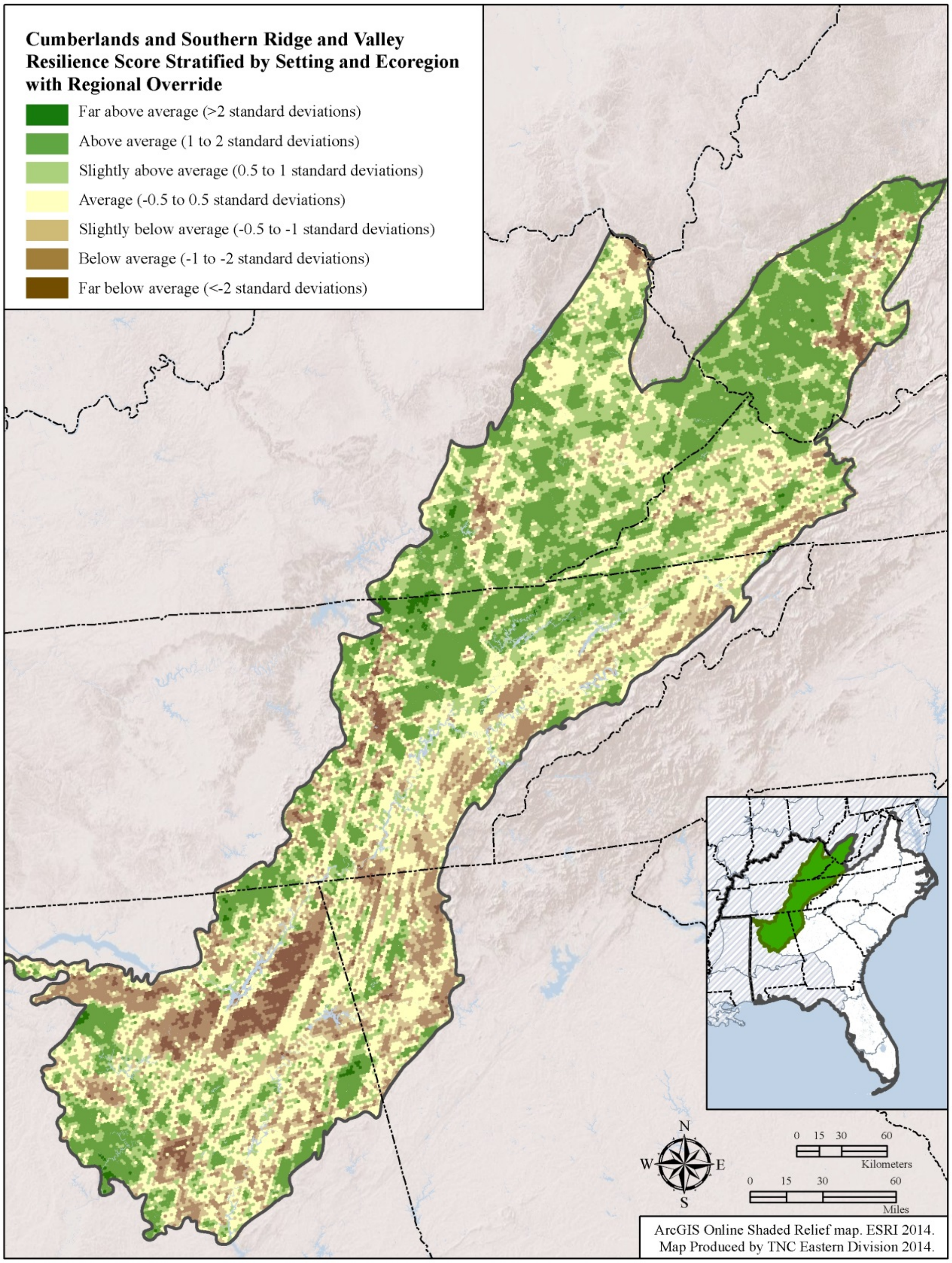
The Cumberlands and Southern Ridge & Valley Ecoregion is a highly variable landscape with a complex geologic history. Stretching over 500 miles from northern Alabama to southern West Virginia, the ecoregion encompasses approximately 37 million acres in portions of six states. Overall, the CSRV is bordered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

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

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

Figure 5.6	Estimated resilience for all geophysical settings in the ecoregion,
Figure 5.7	Resilient areas for each geophysical setting in the ecoregion,
Figure 5.8	Resilience scores of the protected lands,
Figure 5.9	Resilient areas and TNC biodiversity sites: integration of current and future biodiversity
Figure 5.10	Resilient areas and regional linkages

Figure 5.6: Cumberlands and Southern Ridge and Valley: Resilience Estimates. Areas in yellow are comprised of cells with an average estimated resilience score based on their geophysical setting, landscape diversity 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.



ArcGIS Online Shaded Relief map. ESRI 2014.
Map Produced by TNC Eastern Division 2014.

Figure 5.7: Cumberlands and Southern Ridge and Valley: 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.

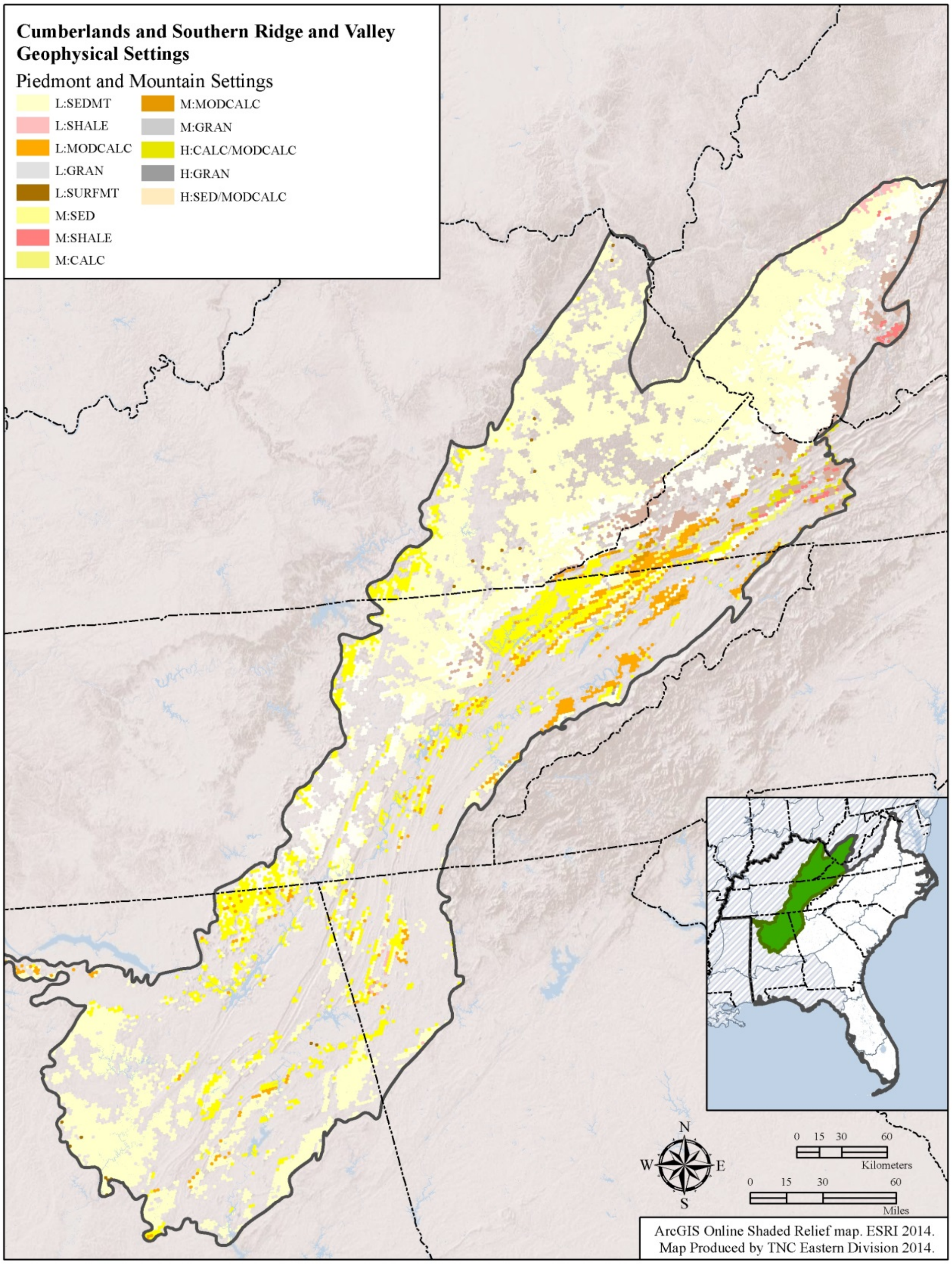
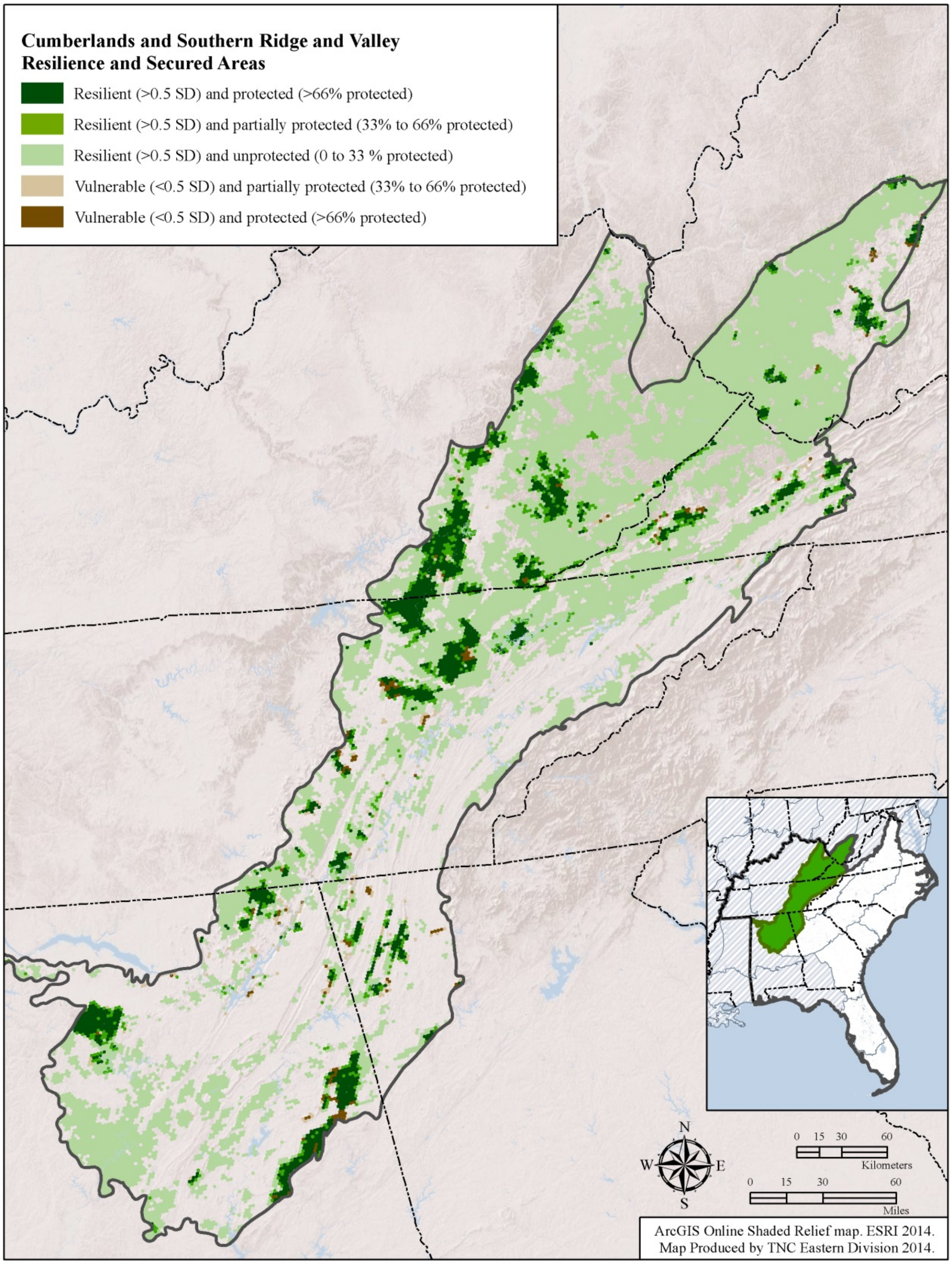


Figure 5.8: Cumberlands and Southern Ridge and Valley: Resilience scores of the protected land. This map displays how the existing secured lands compare to resilient sites in the ecoregion. Each 1000 ac hexagon was coded by what percent is currently secured, and this is visually compared to the resilient areas in the ecoregion.



ArcGIS Online Shaded Relief map. ESRI 2014.
Map Produced by TNC Eastern Division 2014.

Figure 5.9: Cumberlands and Southern Ridge and Valley: Resilient Areas and TNC Portfolio sites. This map identifies the resilient areas that correspond with TNC'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.

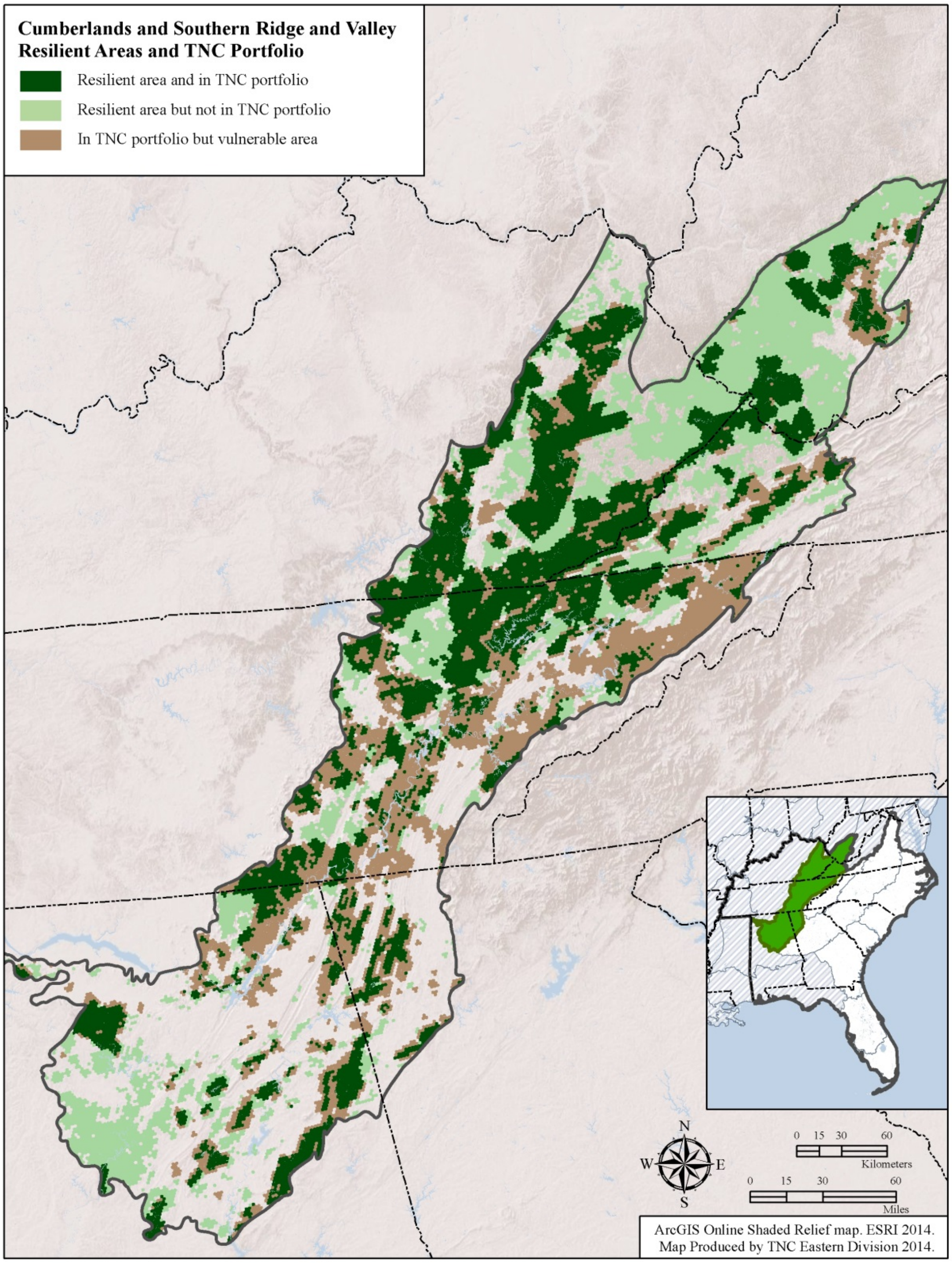
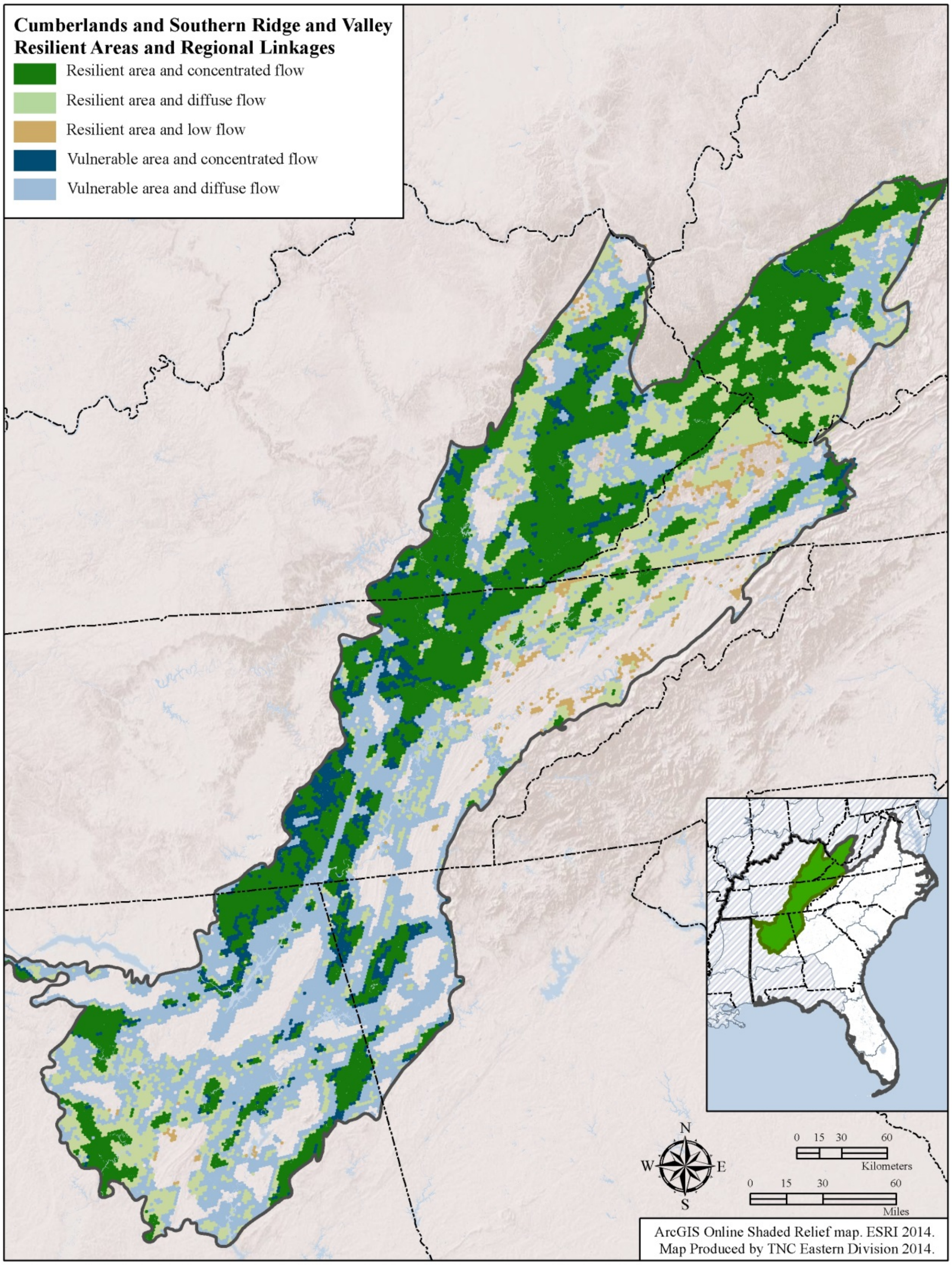


Figure 5.10: Cumberlands and Southern Ridge and Valley: Resilient areas and regional linkages. This map integrates resilient areas with the regional flow concentrations. In the map, resilient areas located in areas of high flow concentrations area shown in olive green. Resilient areas that are large and highly intact have diffuse flow and are shown in pale green. Key linkages are shown in areas with no resilient areas but high amounts of concentrated flow, and these are shown in dark blue. Blue-green areas are fairly intact regions with diffuse flow and vulnerable areas.



ArcGIS Online Shaded Relief map. ESRI 2014.
Map Produced by TNC Eastern Division 2014.

Southern Blue Ridge

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

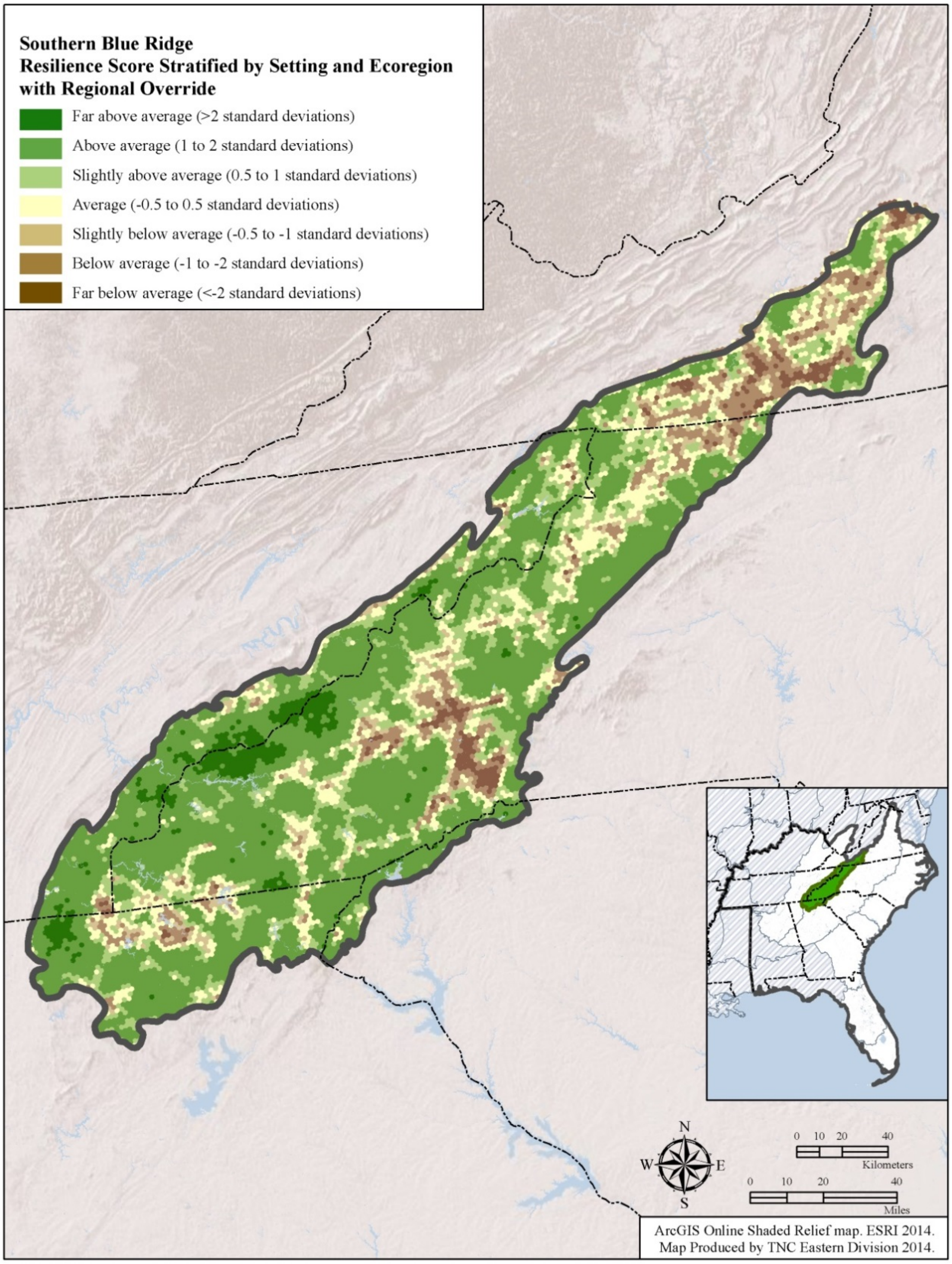
The ecoregion is over 9.4 million acres in size and spans portions of Virginia, Tennessee, South Carolina, and Georgia, with the greatest portion falling in North Carolina. Almost 35% of the ecoregion is owned and managed by public agencies. The largest land management agency is the USFS, managing 26% of the land in the SBR. The extensive land ownership by public agencies and the re-growth of the forest from turn of the century logging has resulted in an ecoregion that is predominately forested. The human population of the ecoregion is an estimated 1.3 million and the economy is dependent primarily on tourism, timber production, the nursery industry, and agriculture and grazing in the lowlands (SAMAB 1996c).

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

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

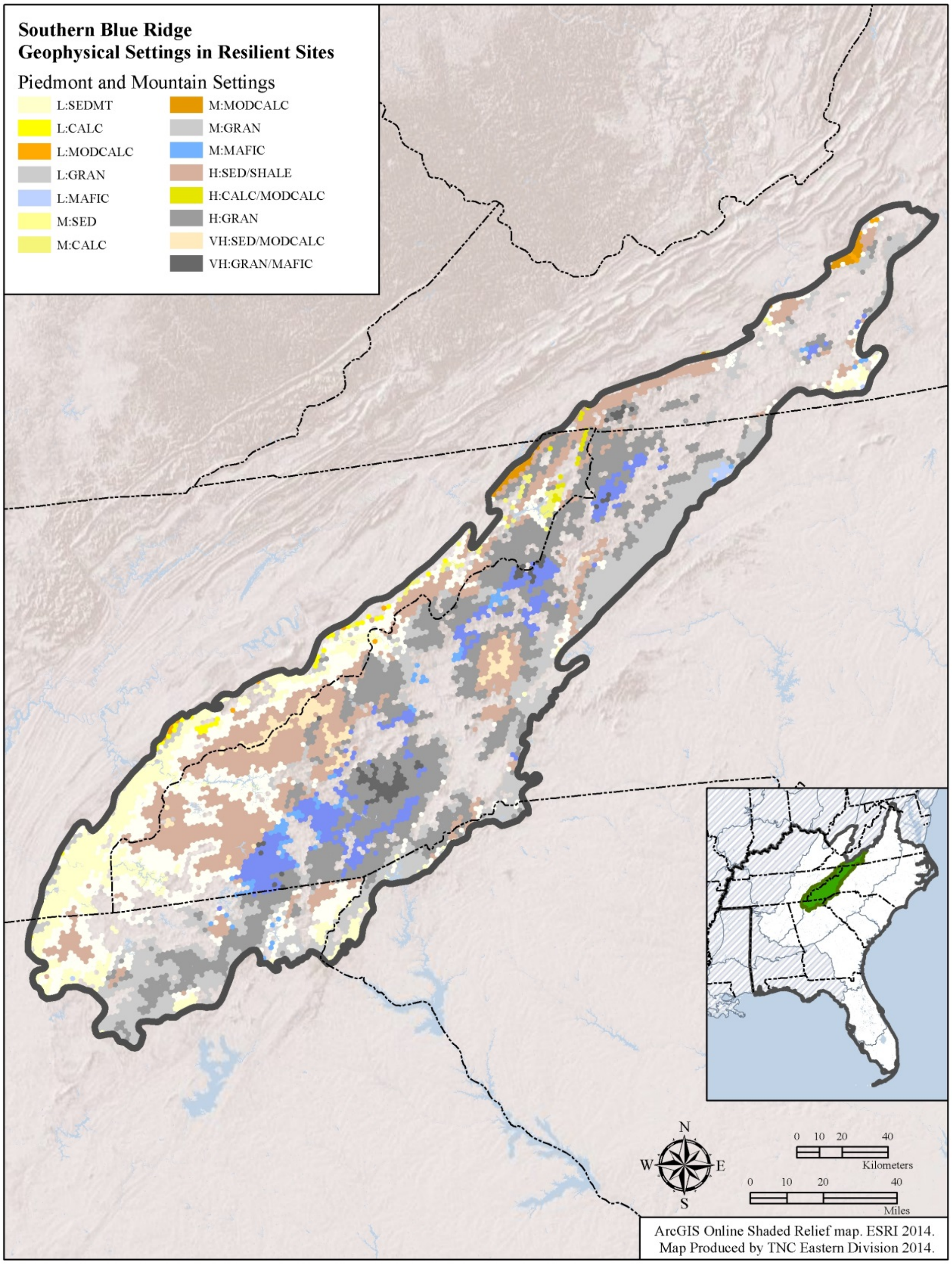
Figure 5.11	Estimated resilience for all geophysical settings in the ecoregion,
Figure 5.12	Resilient areas for each geophysical setting in the ecoregion,
Figure 5.13	Resilience scores of the protected lands,
Figure 5.14	Resilient areas and TNC biodiversity sites: integration of current and future biodiversity
Figure 5.15	Resilient areas and regional linkages

Figure 5.11: Southern Blue Ridge: Resilience Estimates. Areas in yellow are comprised of cells with an average estimated resilience score based on their geophysical setting, landscape diversity 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.



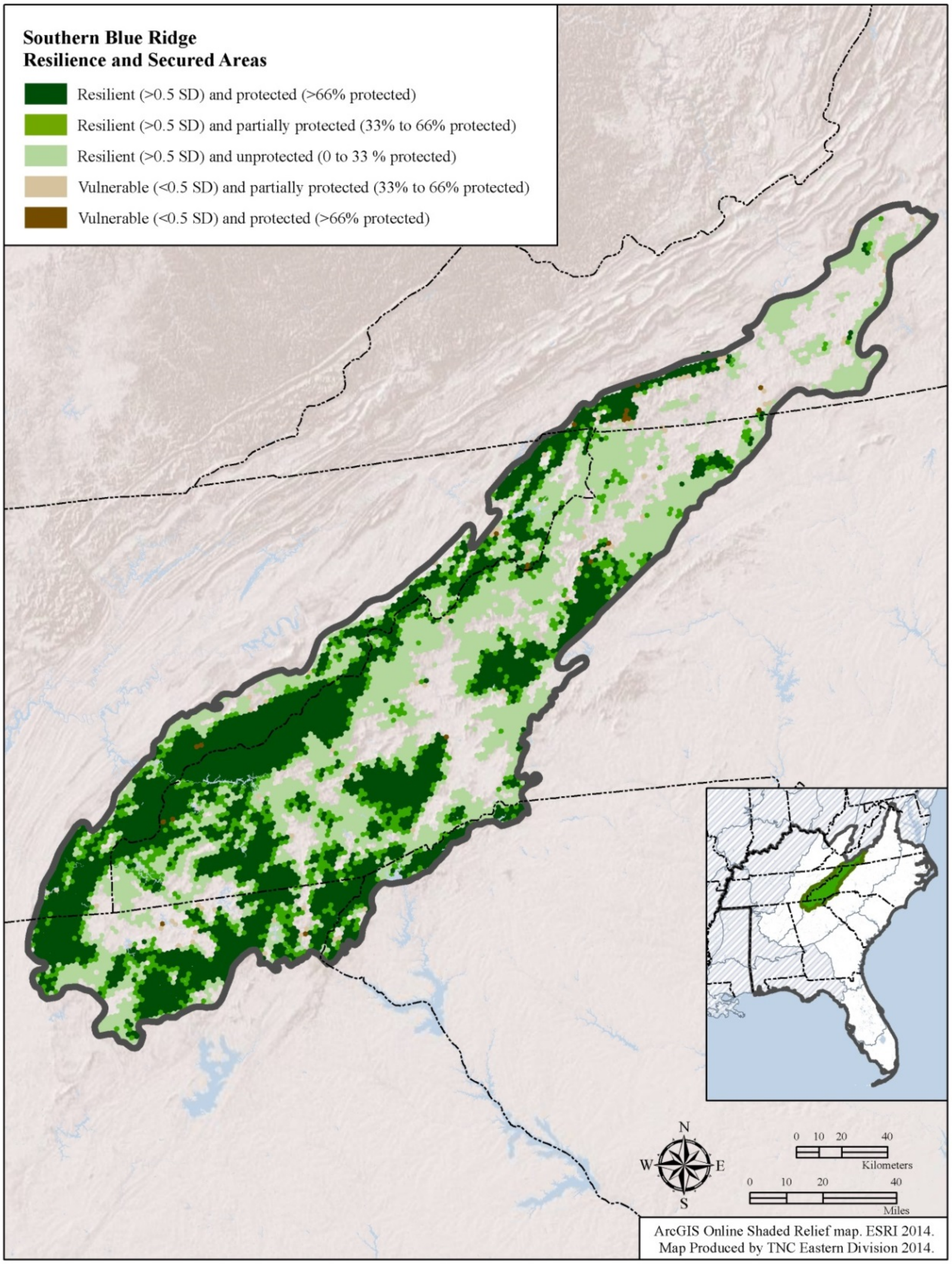
ArcGIS Online Shaded Relief map. ESRI 2014.
Map Produced by TNC Eastern Division 2014.

Figure 5.12: Southern Blue Ridge: 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.



ArcGIS Online Shaded Relief map. ESRI 2014.
Map Produced by TNC Eastern Division 2014.

Figure 5.13: Southern Blue Ridge: Resilience scores of the protected land. This map displays how the existing secured lands compare to resilient sites in the ecoregion. Each 1000 ac hexagon was coded by what percent is currently secured, and this is visually compared to the resilient areas in the ecoregion.



ArcGIS Online Shaded Relief map. ESRI 2014.
Map Produced by TNC Eastern Division 2014.

Figure 5.14: Southern Blue Ridge: Resilient Areas and TNC Portfolio sites. This map identifies the resilient areas that correspond with TNC'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.

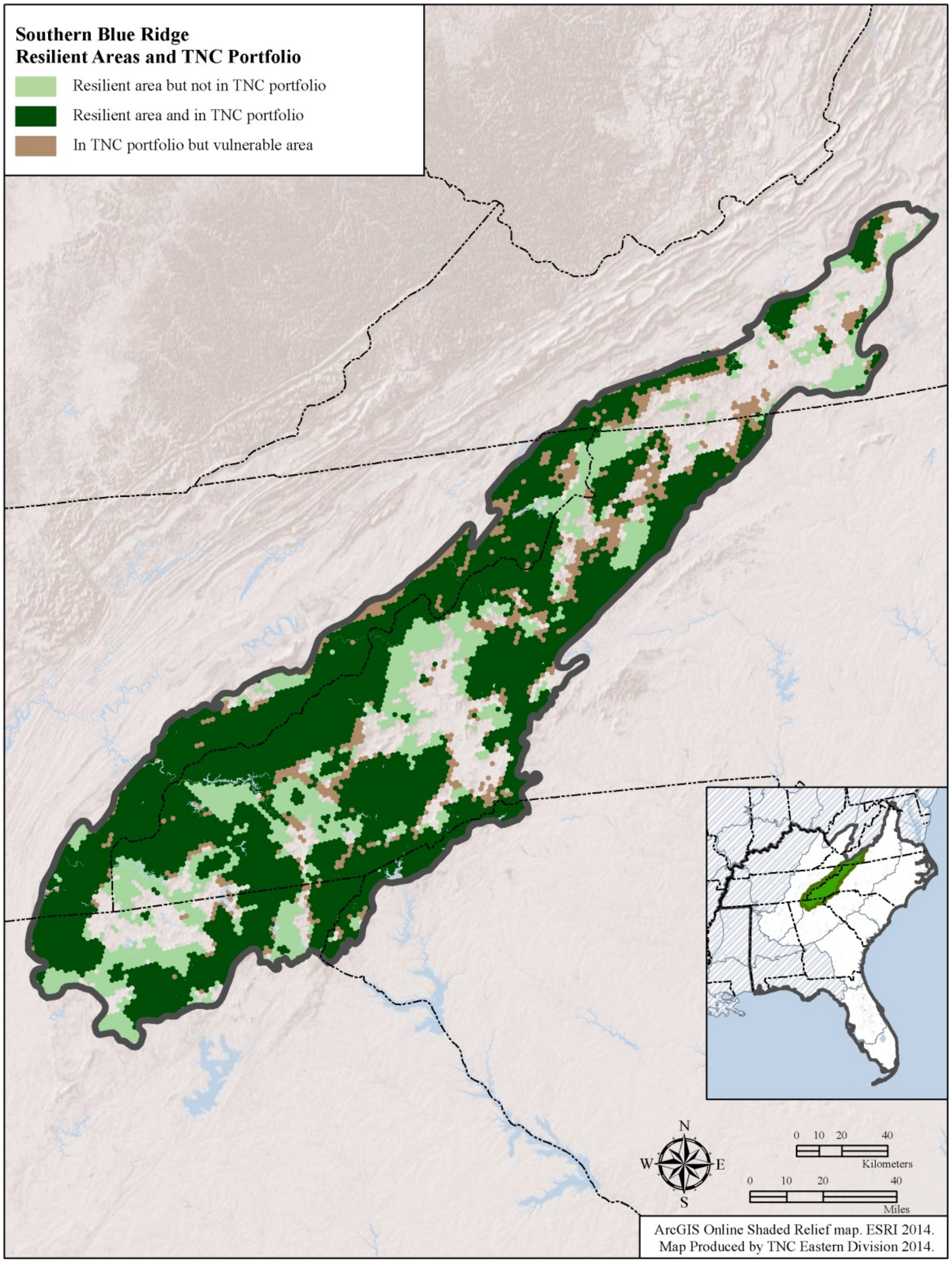
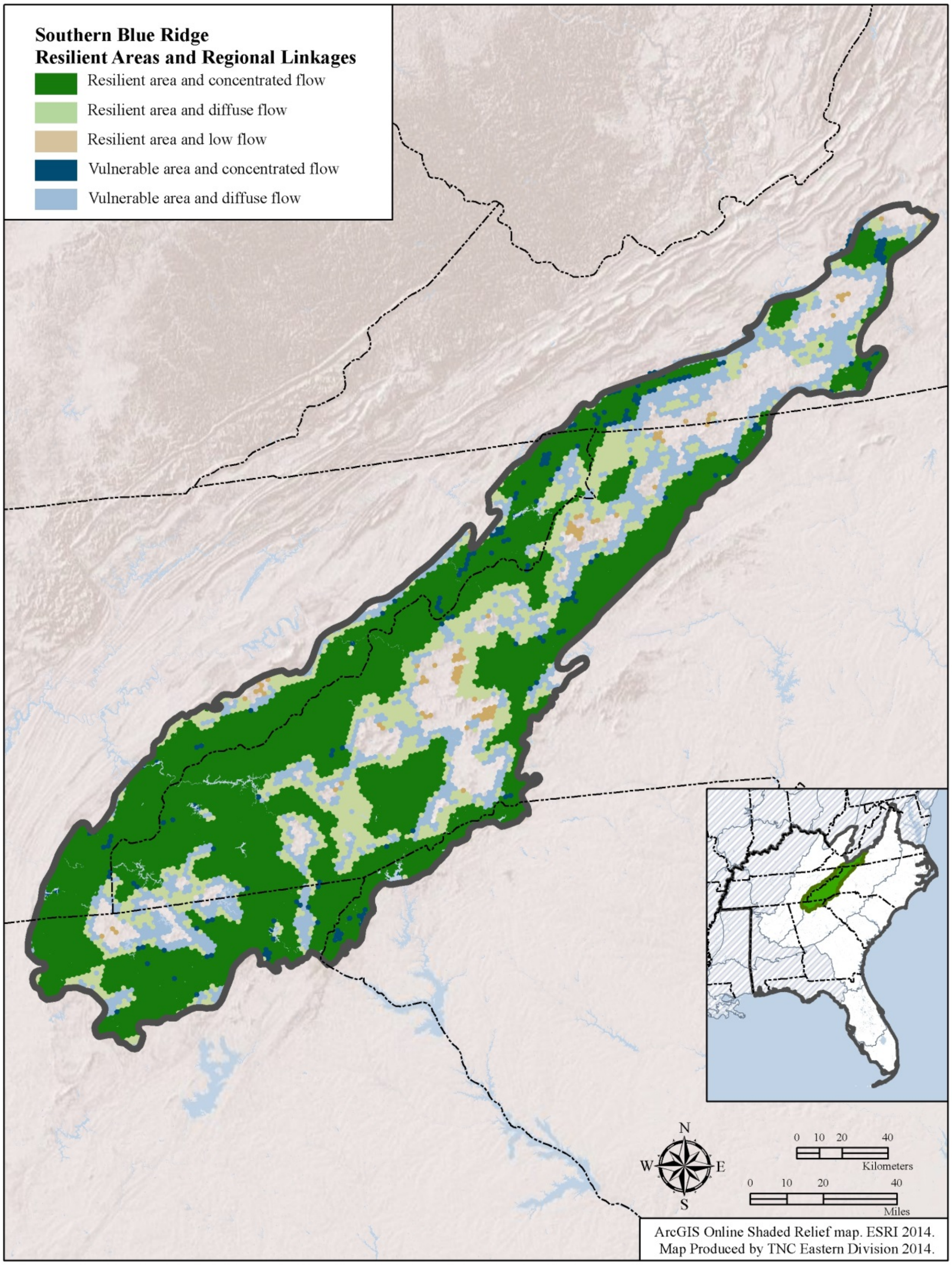


Figure 5.15: Southern Blue Ridge: Resilient areas and regional linkages. This map integrates resilient areas with the regional flow concentrations. In the map, resilient areas located in areas of high flow concentrations area shown in olive green. Resilient areas that are large and highly intact have diffuse flow and are shown in pale green. Key linkages are shown in areas with no resilient areas but high amounts of concentrated flow, and these are shown in dark blue. Blue-green areas are fairly intact regions with diffuse flow and vulnerable areas.



ArcGIS Online Shaded Relief map. ESRI 2014.
Map Produced by TNC Eastern Division 2014.

Piedmont

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

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

Figure 5.16	Estimated resilience for all geophysical settings in the ecoregion,
Figure 5.17	Resilient areas for each geophysical setting in the ecoregion,
Figure 5.18	Resilience scores of the protected lands,
Figure 5.19	Resilient areas and TNC biodiversity sites: integration of current and future biodiversity
Figure 5.20	Resilient areas and regional linkages

Figure 5.16: Piedmont: Resilience Estimates. Areas in yellow are comprised of cells with an average estimated resilience score based on their geophysical setting, landscape diversity 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.

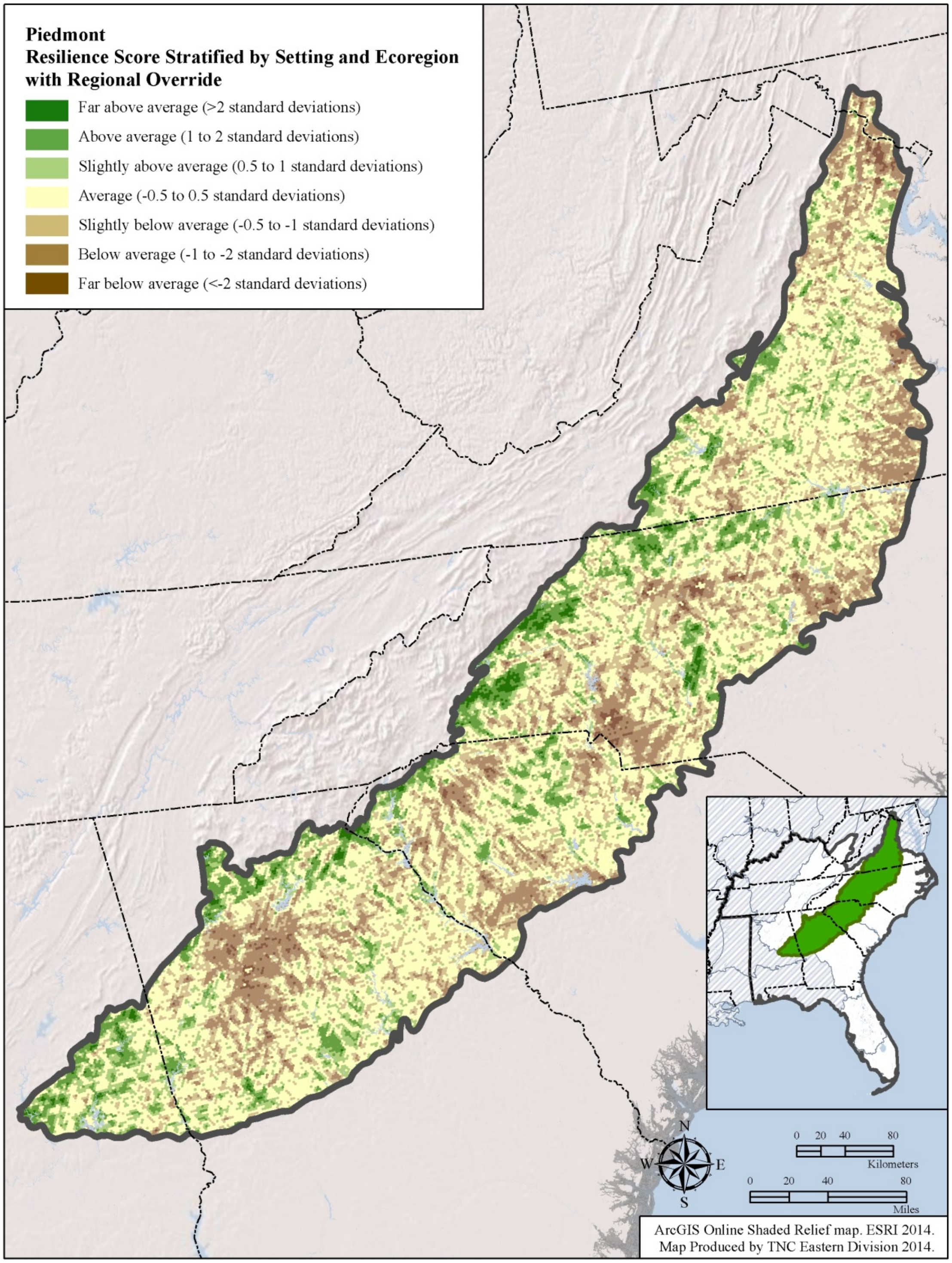
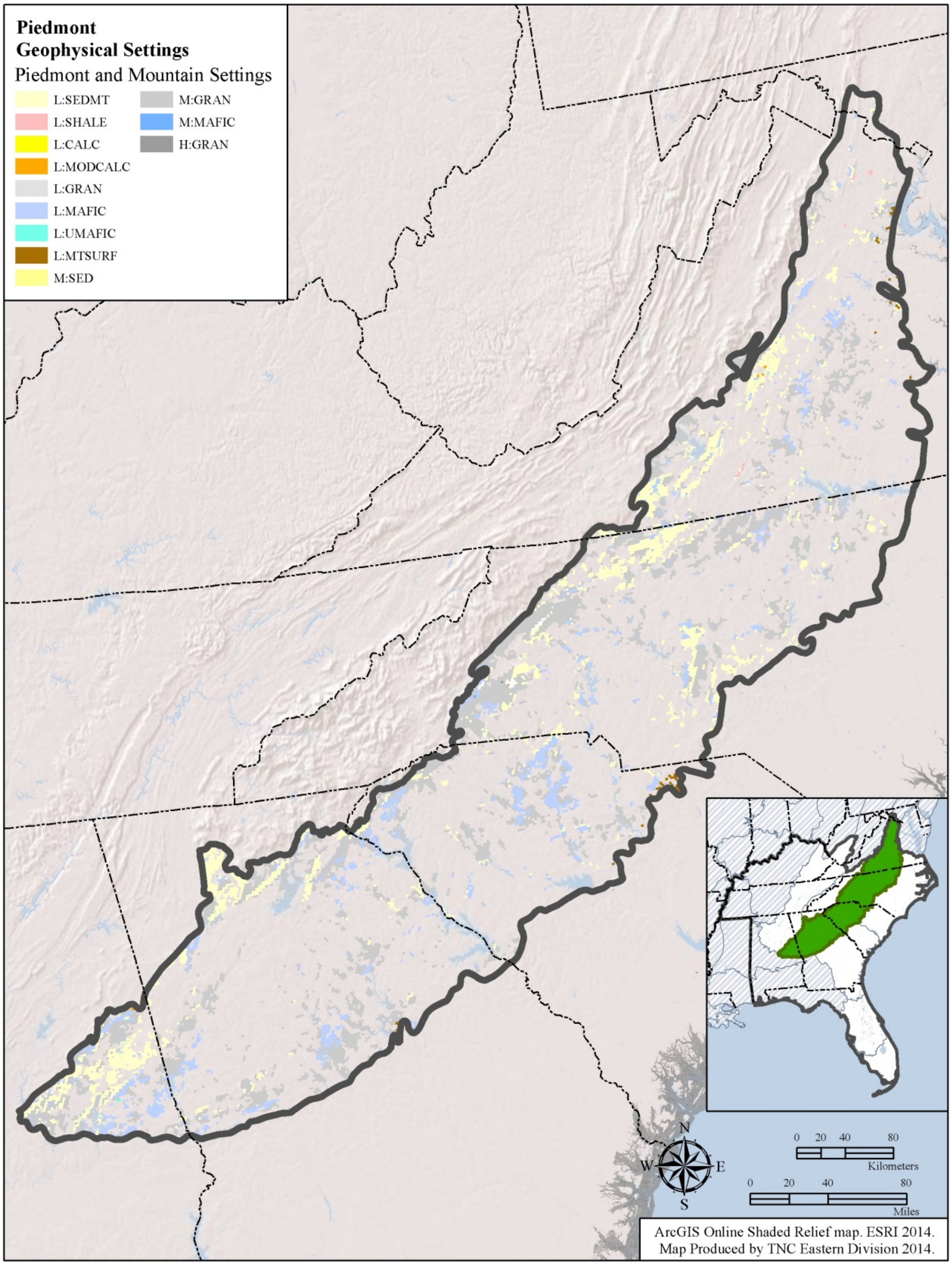
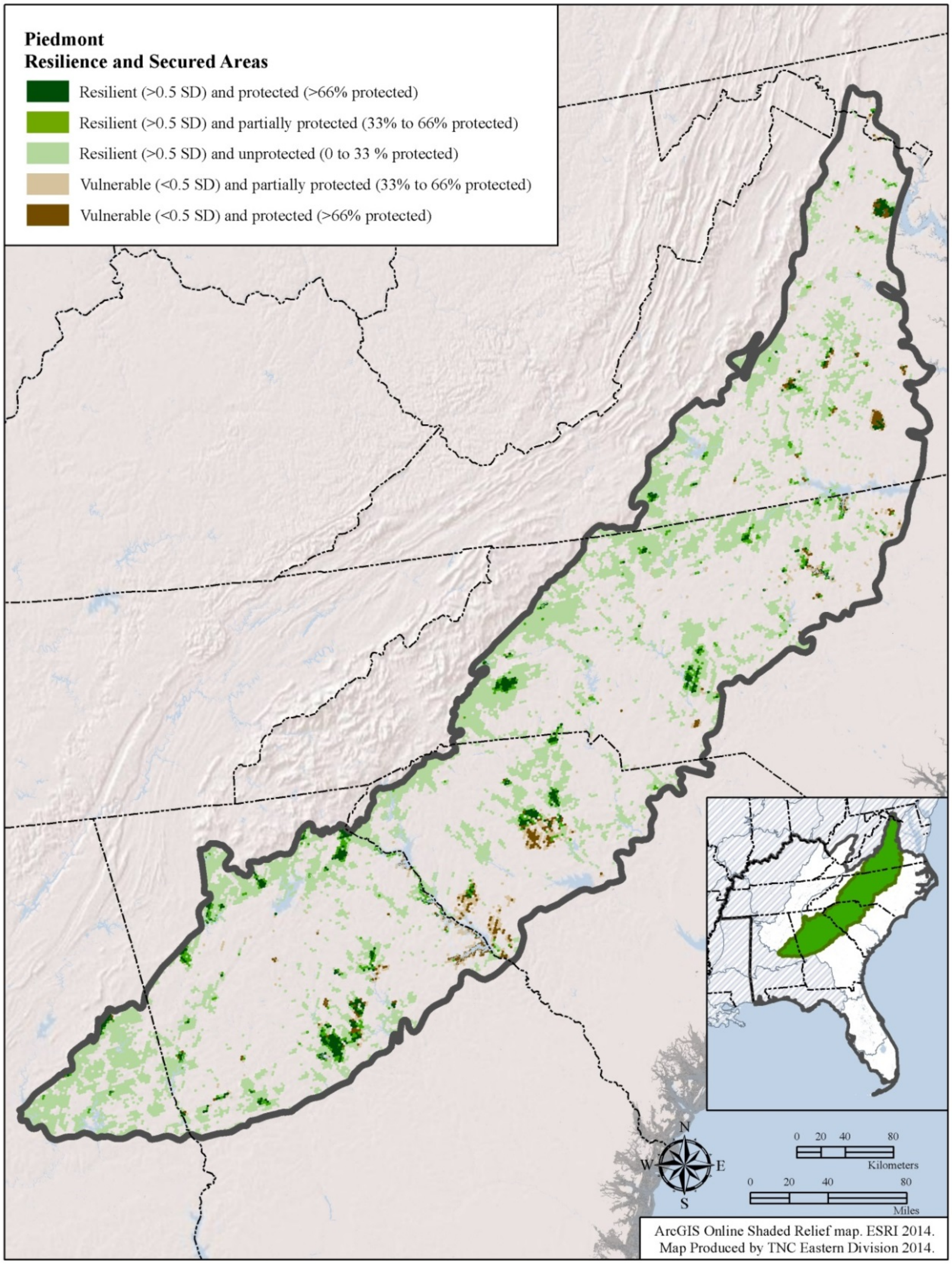


Figure 5.17: Piedmont: Resilient Areas for each Setting. This map shows only the 1000-acre hexagons that score above the mean for estimated resilience; each high scoring hexagon is colored based on its corresponding geophysical setting. This map reveals how the settings are reflected in the resilience scores.



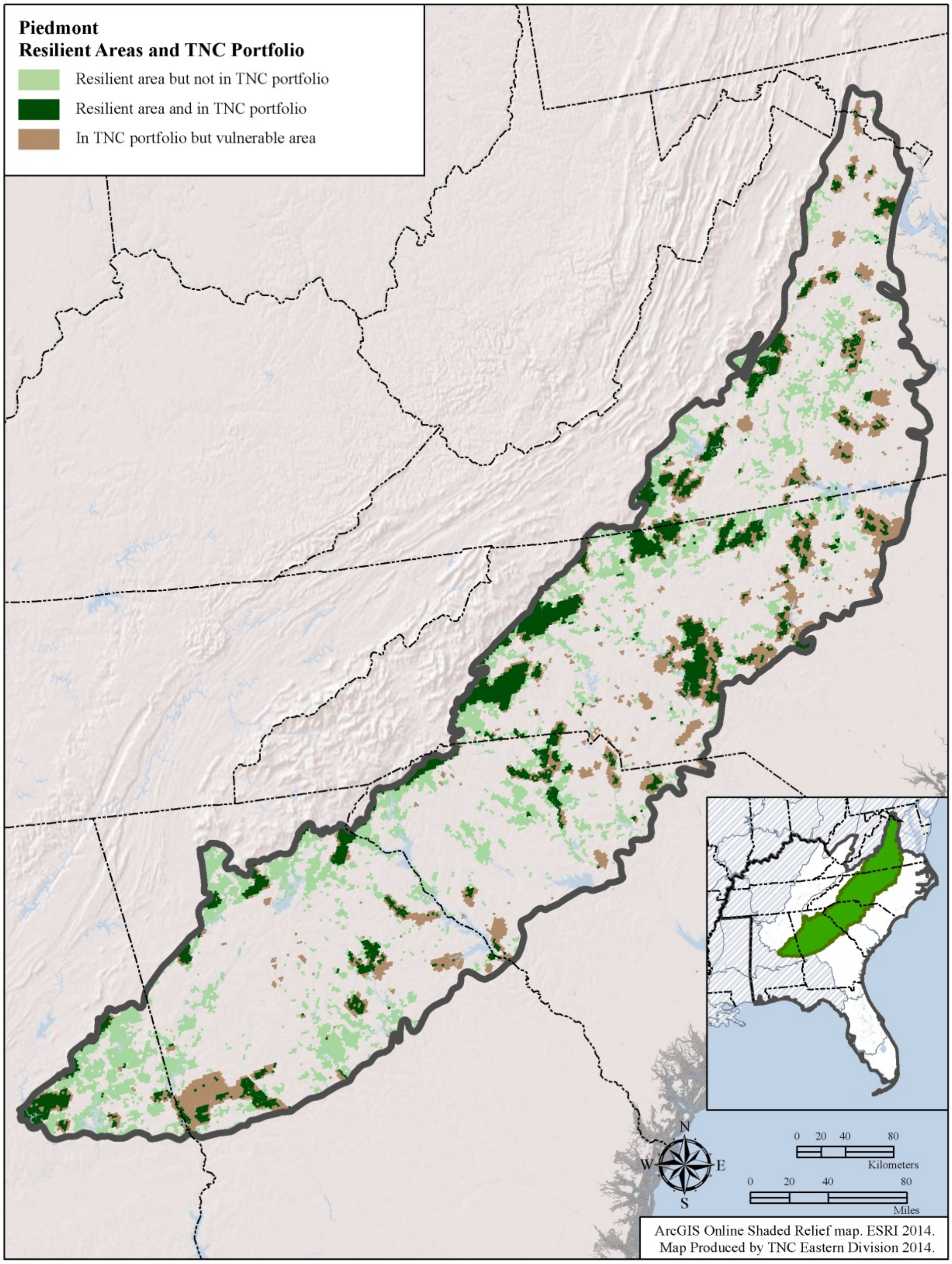
ArcGIS Online Shaded Relief map. ESRI 2014.
Map Produced by TNC Eastern Division 2014.

Figure 5.18: Piedmont: Resilience scores of the protected land. This map displays how the existing secured lands compare to resilient sites in the ecoregion. Each 1000 ac hexagon was coded by what percent is currently secured, and this is visually compared to the resilient areas in the ecoregion.



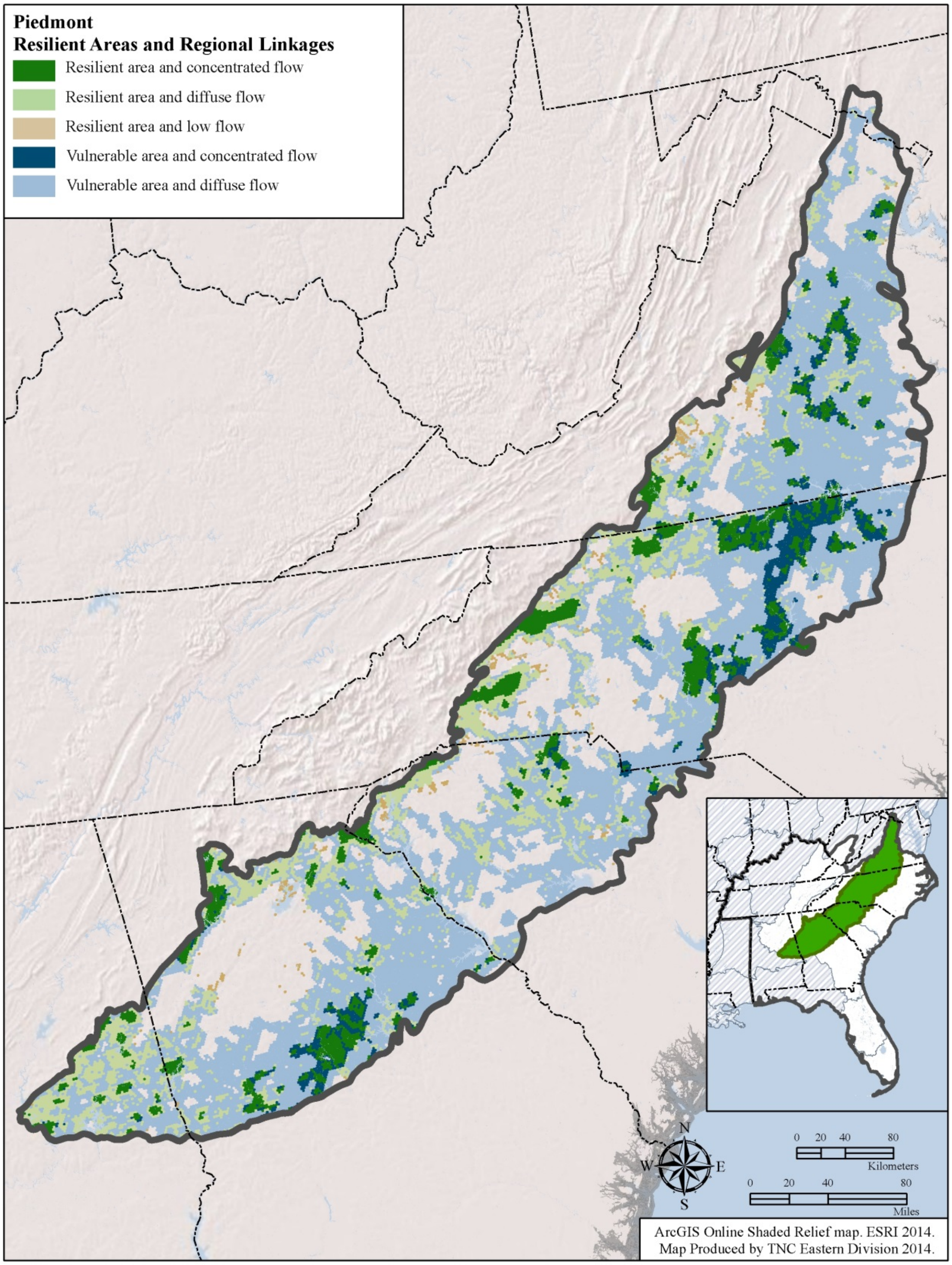
ArcGIS Online Shaded Relief map. ESRI 2014.
Map Produced by TNC Eastern Division 2014.

Figure 5.19: Piedmont: Resilient Areas and TNC Portfolio sites. This map identifies the resilient areas that correspond with TNC'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.



ArcGIS Online Shaded Relief map. ESRI 2014.
Map Produced by TNC Eastern Division 2014.

Figure 5.20: Piedmont: Resilient areas and regional linkages. This map integrates resilient areas with the regional flow concentrations. In the map, resilient areas located in areas of high flow concentrations area shown in olive green. Resilient areas that are large and highly intact have diffuse flow and are shown in pale green. Key linkages are shown in areas with no resilient areas but high amounts of concentrated flow, and these are shown in dark blue. Blue-green areas are fairly intact regions with diffuse flow and vulnerable areas.



ArcGIS Online Shaded Relief map. ESRI 2014.
Map Produced by TNC Eastern Division 2014.

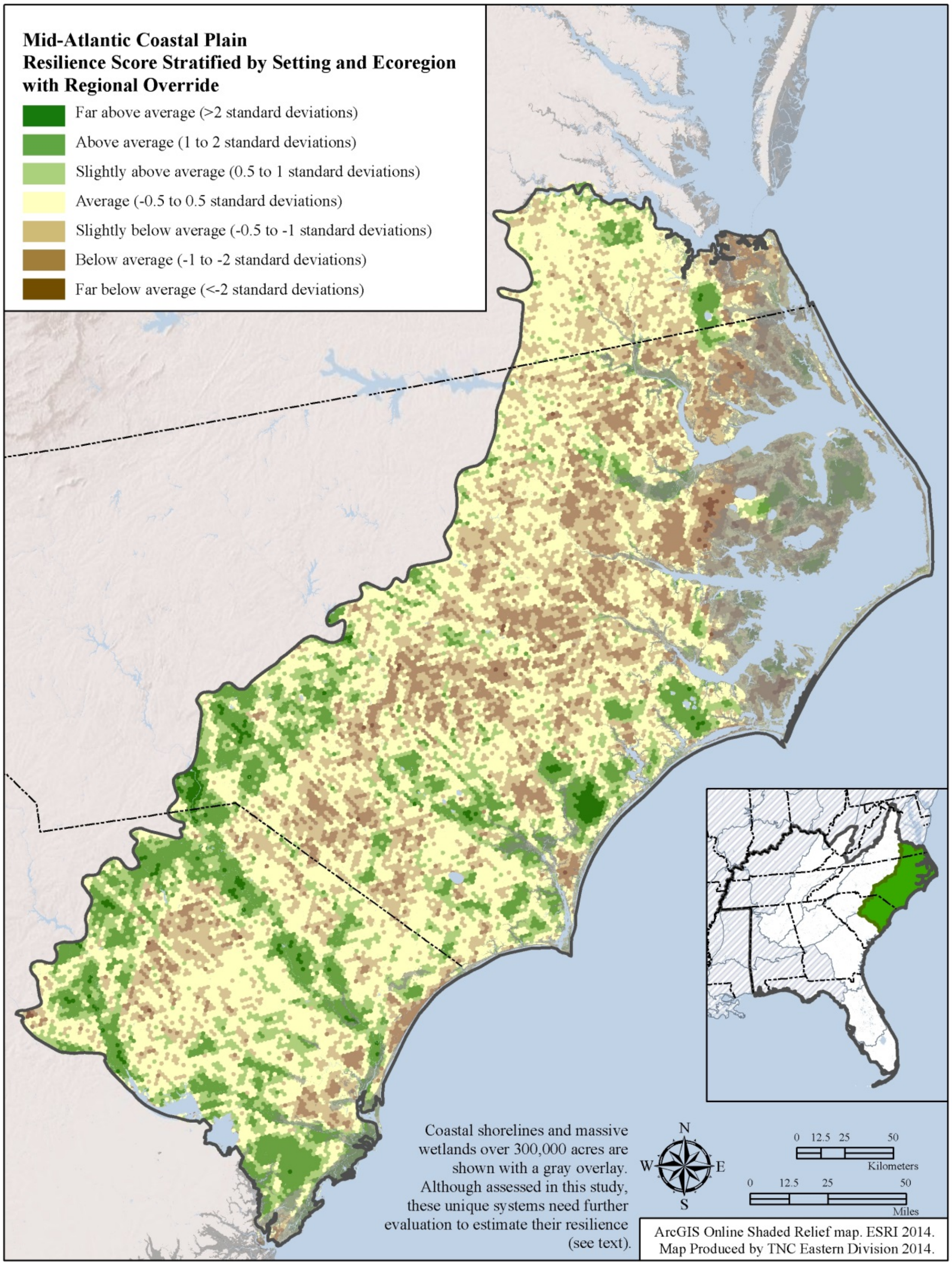
Mid-Atlantic Coastal Plain

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

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

Figure 5.21	Estimated resilience for all geophysical settings in the ecoregion,
Figure 5.22	Resilient areas for each geophysical setting in the ecoregion,
Figure 5.23	Resilience scores of the protected lands,
Figure 5.24	Resilient areas and TNC biodiversity sites: integration of current and future biodiversity
Figure 5.25	Resilient areas and regional linkages

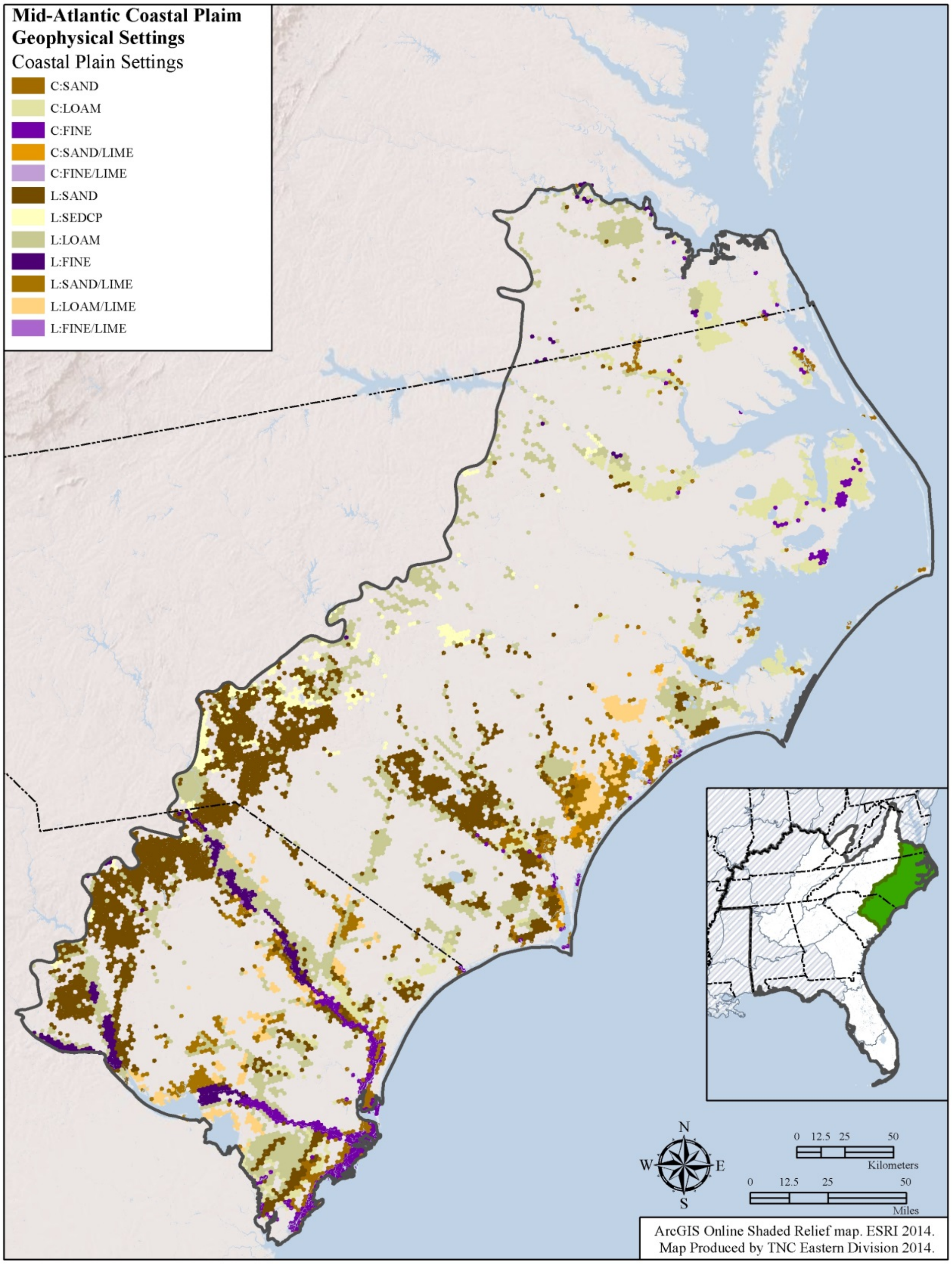
Figure 5.21: Mid-Atlantic Coastal Plain Resilience Estimates. Areas in yellow are comprised of cells with an average estimated resilience score based on their geophysical setting, landscape diversity and local connectedness. Areas in green score above average and are estimated to be more resilient. Areas in brown are below average and are estimated to be vulnerable to climate change and other factors.



Coastal shorelines and massive wetlands over 300,000 acres are shown with a gray overlay. Although assessed in this study, these unique systems need further evaluation to estimate their resilience (see text).

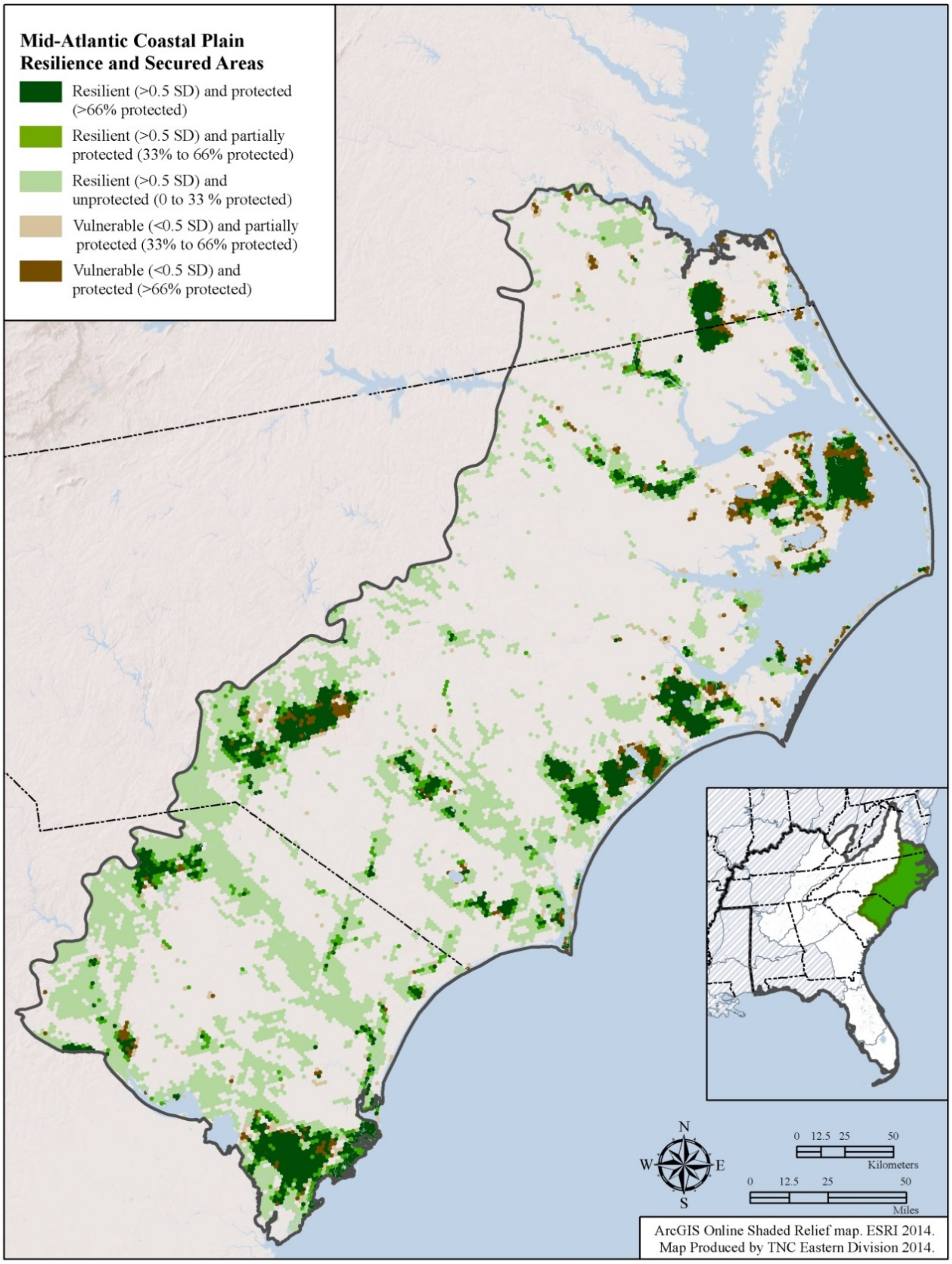
ArcGIS Online Shaded Relief map. ESRI 2014.
Map Produced by TNC Eastern Division 2014.

Figure 5.22: Mid-Atlantic Coastal Plain 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.



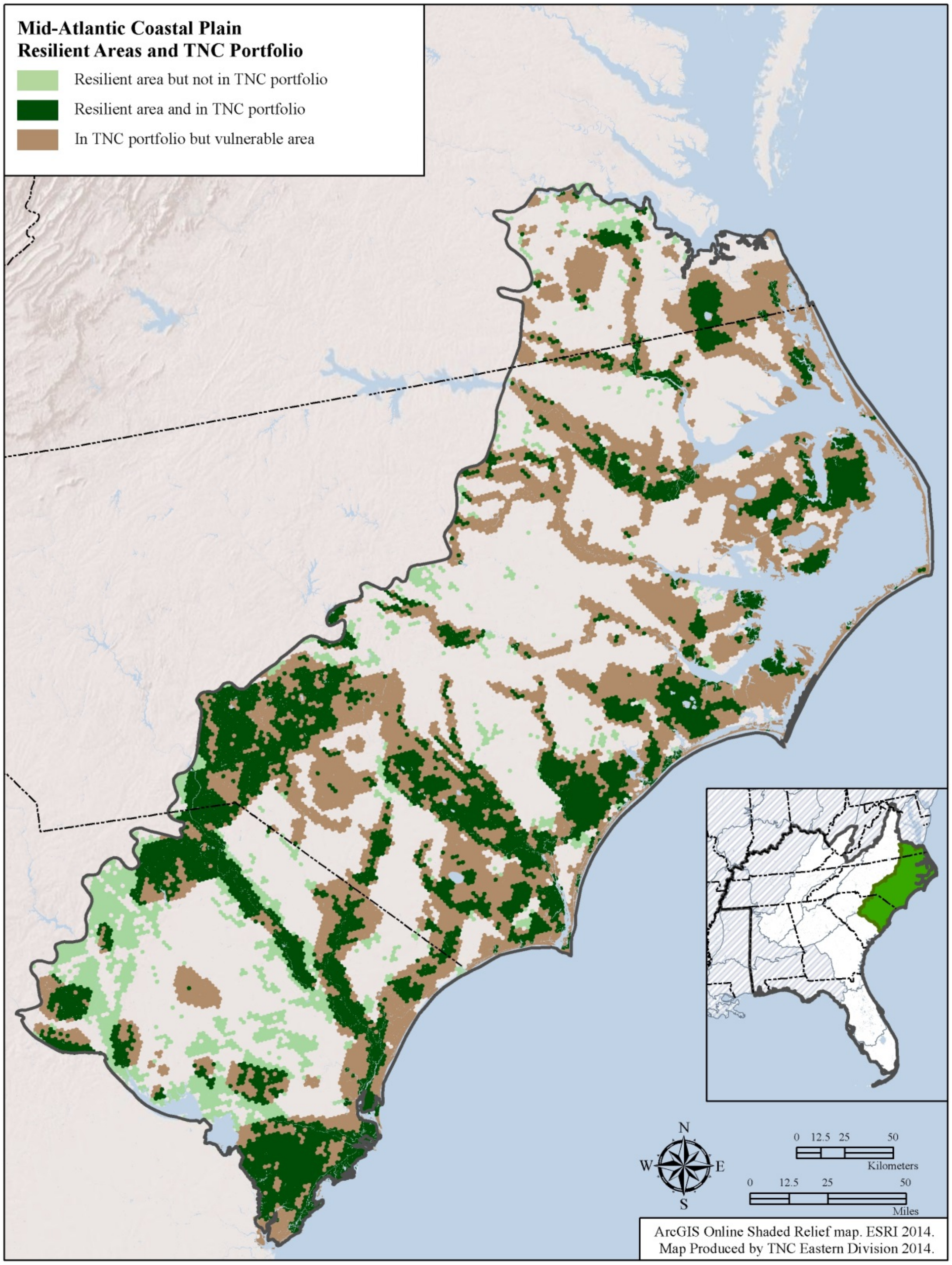
ArcGIS Online Shaded Relief map. ESRI 2014.
Map Produced by TNC Eastern Division 2014.

Figure 5.23: Mid-Atlantic Coastal Plain Resilience scores of the protected land. This map displays how the existing secured lands compare to resilient sites in the ecoregion. Each 1000 ac hexagon was coded by what percent is currently secured, and this is visually compared to the resilient areas in the ecoregion.



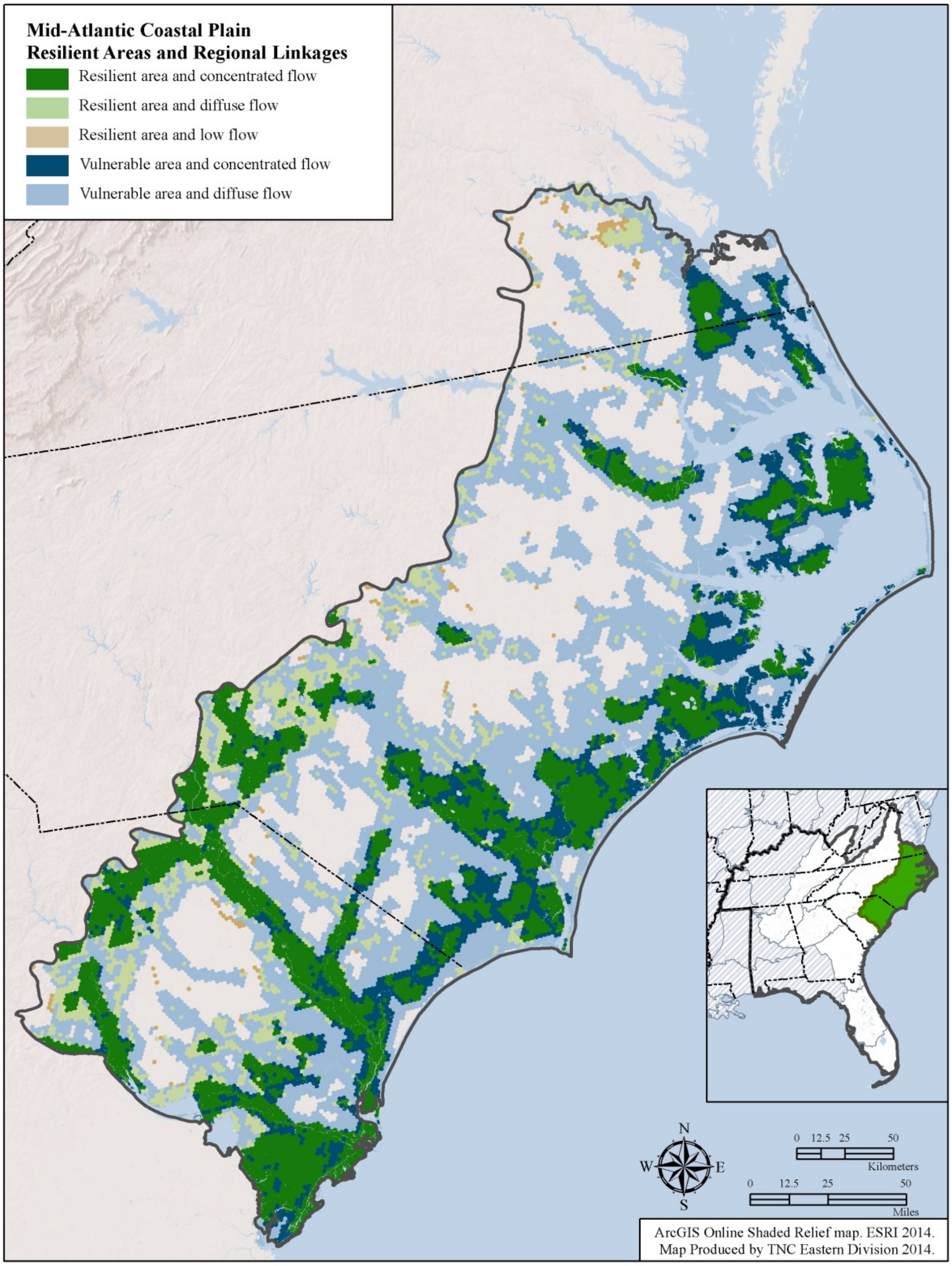
ArcGIS Online Shaded Relief map. ESRI 2014.
Map Produced by TNC Eastern Division 2014.

Figure 5.24: Mid-Atlantic Coastal Plain Resilient Areas and TNC Portfolio sites. This map identifies the resilient areas that correspond with TNC'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.



ArcGIS Online Shaded Relief map. ESRI 2014.
Map Produced by TNC Eastern Division 2014.

Figure 5.25: Mid-Atlantic Coastal Plain Resilient areas and regional linkages. This map integrates resilient areas with the regional flow concentrations. In the map, resilient areas located in areas of high flow concentrations area shown in olive green. Resilient areas that are large and highly intact have diffuse flow and are shown in pale green. Key linkages are shown in areas with no resilient areas but high amounts of concentrated flow, and these are shown in dark blue. Blue-green areas are fairly intact regions with diffuse flow and vulnerable areas.



ArcGIS Online Shaded Relief map. ESRI 2014.
Map Produced by TNC Eastern Division 2014.

South-Atlantic Coastal Plain

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

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

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

Figure 5.26	Estimated resilience for all geophysical settings in the ecoregion,
Figure 5.27	Resilient areas for each geophysical setting in the ecoregion,
Figure 5.28	Resilience scores of the protected lands,
Figure 5.29	Resilient areas and TNC biodiversity sites: integration of current and future biodiversity
Figure 5.230	Resilient areas and regional linkages

Figure 5.26: South-Atlantic Coastal Plain Resilience Estimates. Areas in yellow are comprised of cells with an average estimated resilience score based on their geophysical setting, landscape diversity 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.

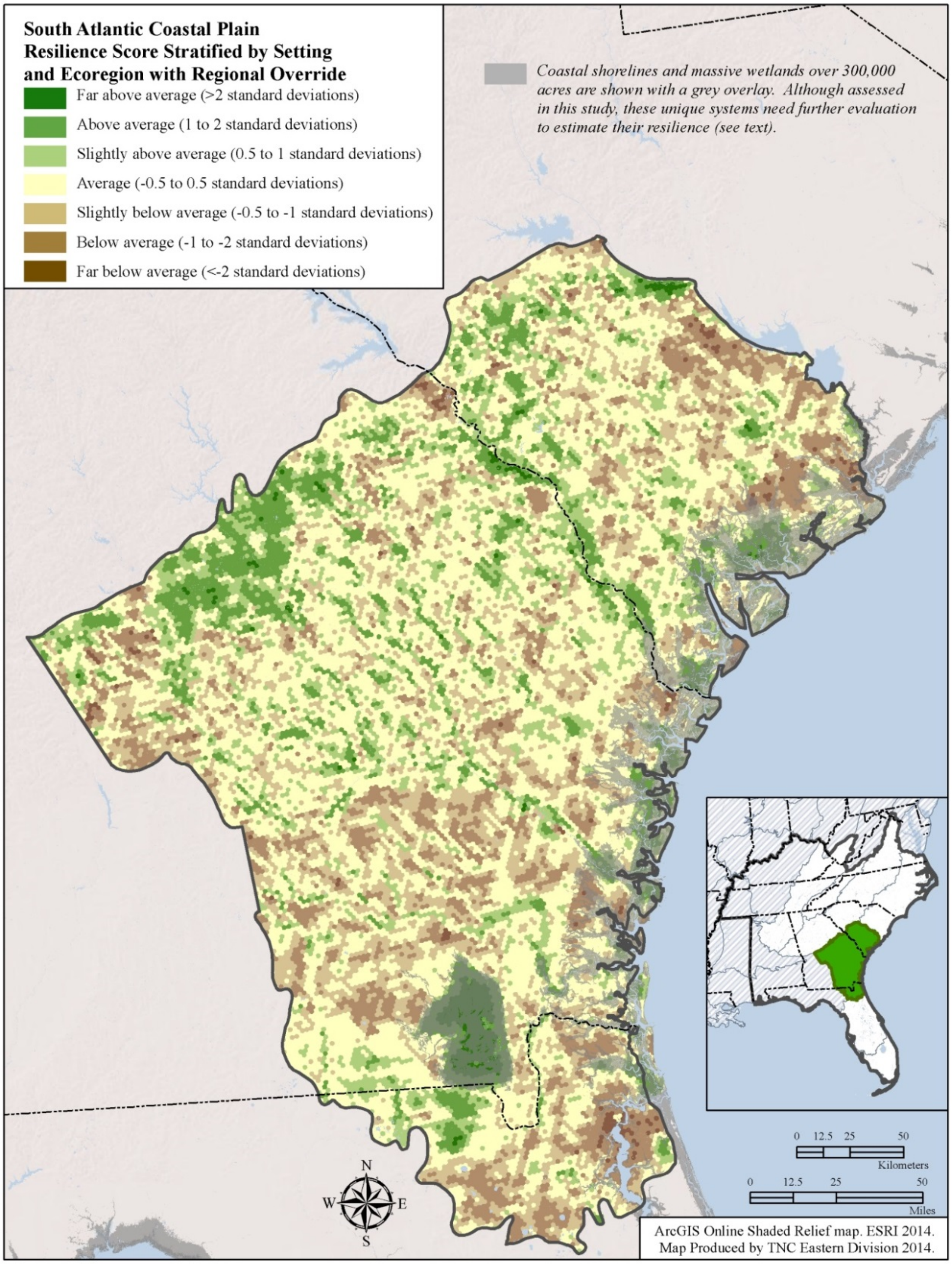
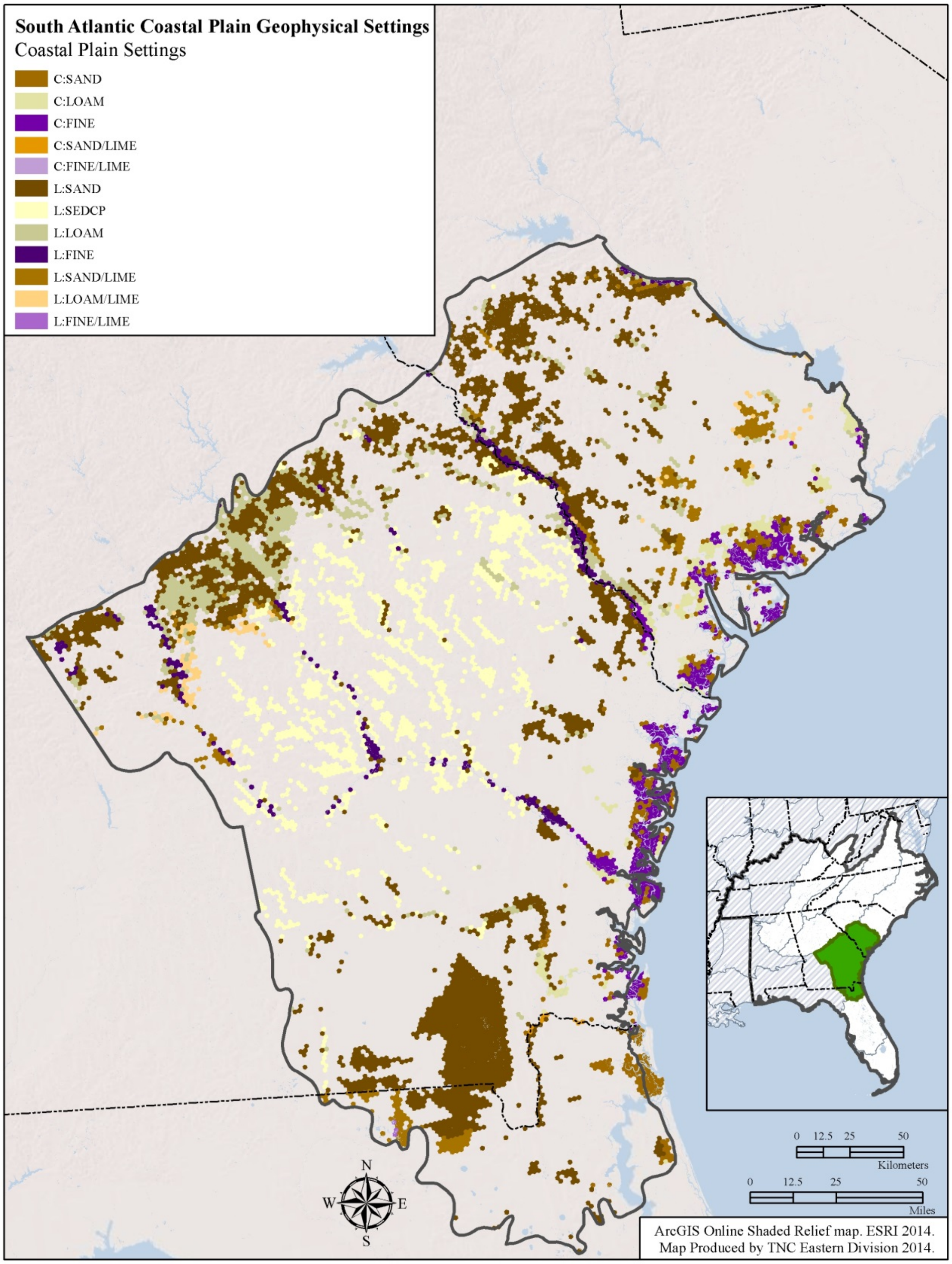


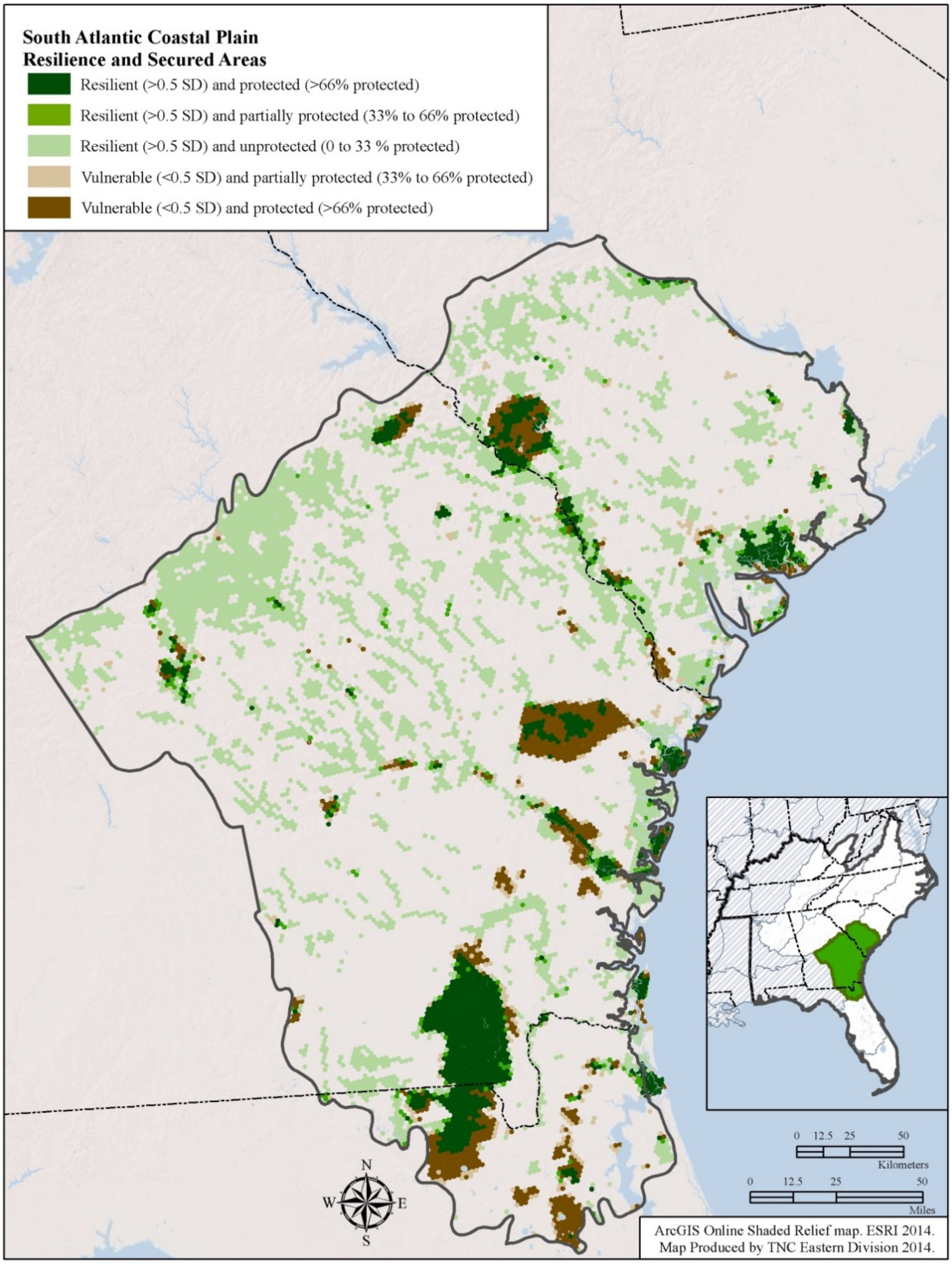
Figure 5.27: South-Atlantic Coastal Plain Resilient Areas for each Setting. This map shows only the 1000-acre hexagons that score above the mean for estimated resilience; each high scoring hexagon is colored based on its corresponding geophysical setting. This map reveals how the settings are reflected in the resilience scores.



South Atlantic Coastal Plain Geophysical Settings

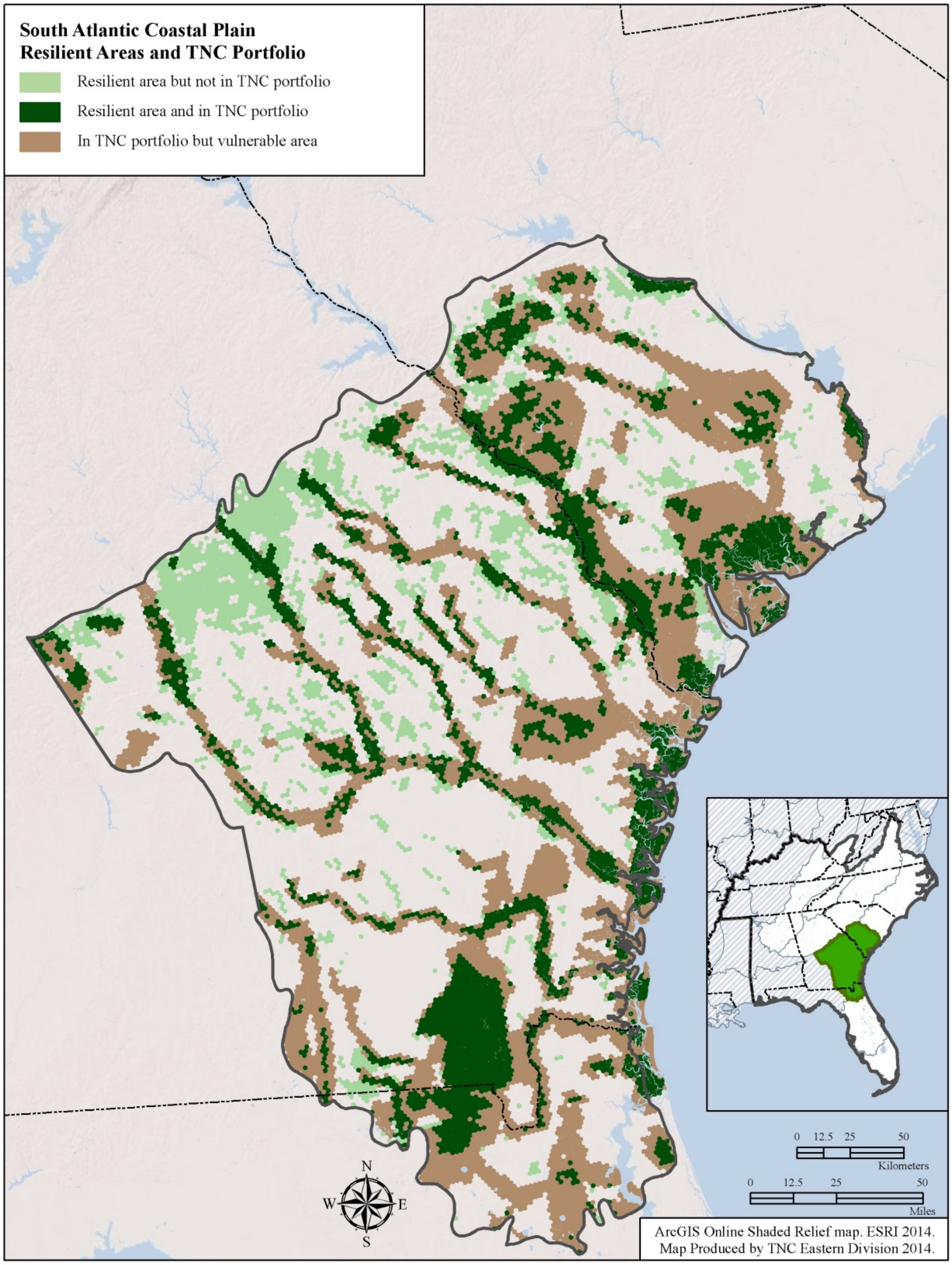
ArcGIS Online Shaded Relief map. ESRI 2014.
Map Produced by TNC Eastern Division 2014.

Figure 5.28: South-Atlantic Coastal Plain Resilience scores of the protected land. This map displays how the existing secured lands compare to resilient sites in the ecoregion. Each 1000 ac hexagon was coded by what percent is currently secured, and this is visually compared to the resilient areas in the ecoregion.



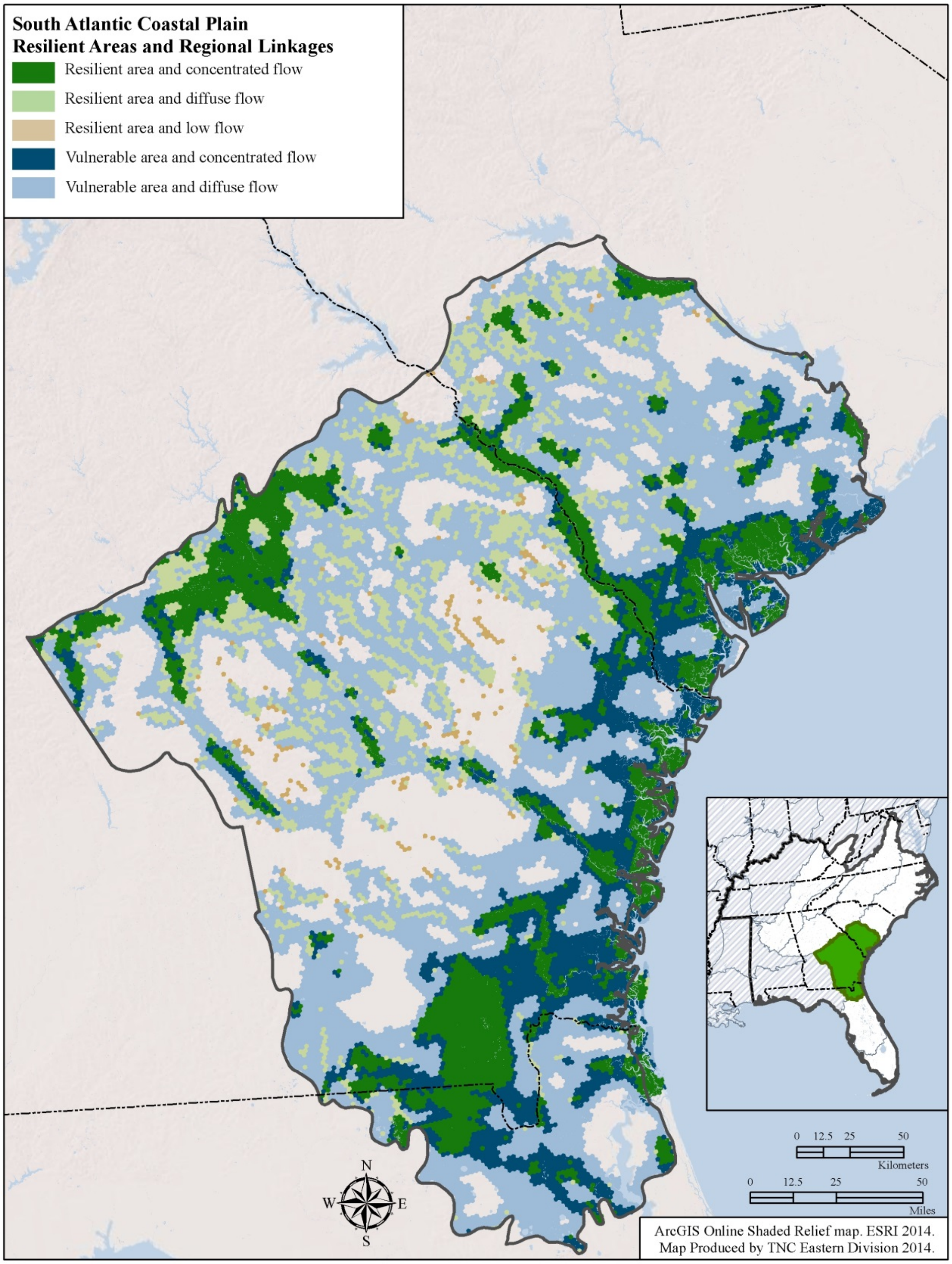
ArcGIS Online Shaded Relief map. ESRI 2014.
Map Produced by TNC Eastern Division 2014.

Figure 5.29: South-Atlantic Coastal Plain Resilient Areas and TNC Portfolio sites. This map identifies the resilient areas that correspond with TNC'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.



ArcGIS Online Shaded Relief map. ESRI 2014.
Map Produced by TNC Eastern Division 2014.

Figure 5.30: South-Atlantic Coastal Plain Resilient areas and regional linkages. This map integrates resilient areas with the regional flow concentrations. In the map, resilient areas located in areas of high flow concentrations area shown in olive green. Resilient areas that are large and highly intact have diffuse flow and are shown in pale green. Key linkages are shown in areas with no resilient areas but high amounts of concentrated flow, and these are shown in dark blue. Blue-green areas are fairly intact regions with diffuse flow and vulnerable areas.



ArcGIS Online Shaded Relief map. ESRI 2014.
Map Produced by TNC Eastern Division 2014.

Florida Peninsula

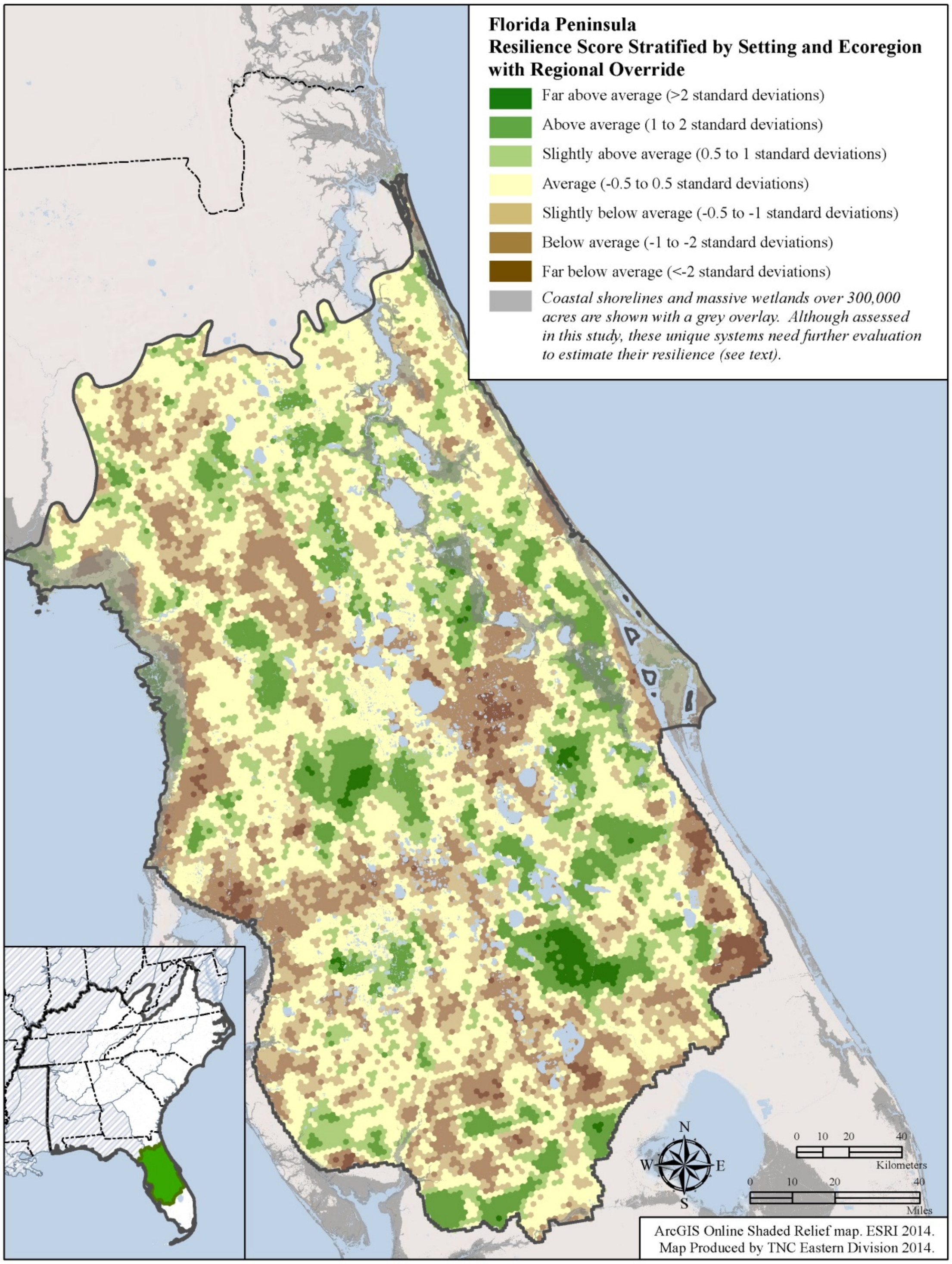
Covering some three-and-a-half degrees of latitude, the Florida Peninsula Ecoregion includes areas having a temperate flora and fauna characteristic of the Carolinian Biotic Province in its northern reaches, to species and communities with definite tropical affinities of the Caribbean Biotic Province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

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

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

Figure 5.31	Estimated resilience for all geophysical settings in the ecoregion,
Figure 5.32	Resilient areas for each geophysical setting in the ecoregion,
Figure 5.33	Resilience scores of the protected lands,
Figure 5.34	Resilient areas and TNC biodiversity sites: integration of current and future biodiversity
Figure 5.35	Resilient areas and regional linkages

Figure 5.31: Florida Peninsula: Resilience Estimates. Areas in yellow are comprised of cells with an average estimated resilience score based on their geophysical setting, landscape diversity 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.



ArcGIS Online Shaded Relief map. ESRI 2014.
Map Produced by TNC Eastern Division 2014.

Figure 5.32: Florida Peninsula: 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.

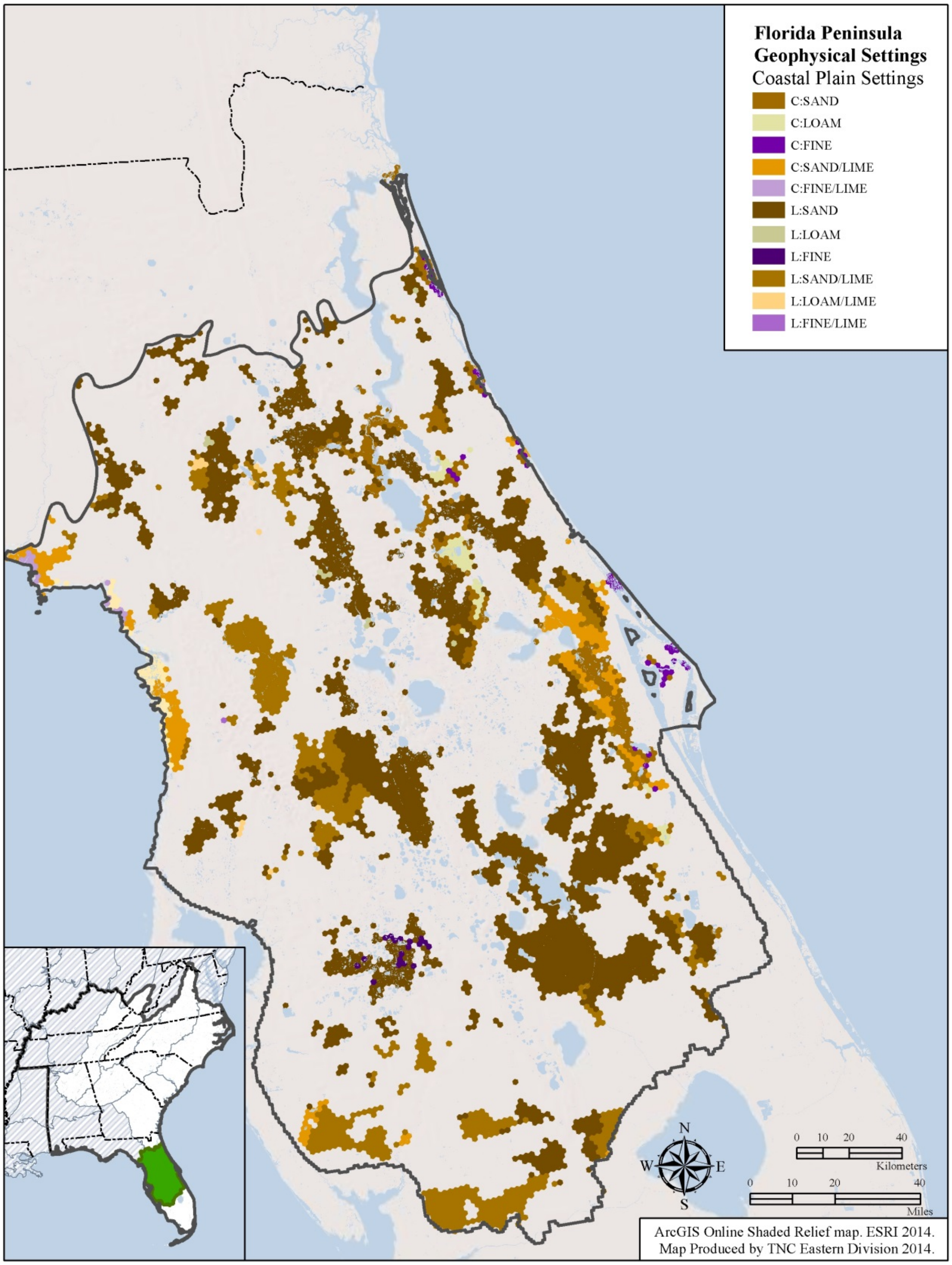
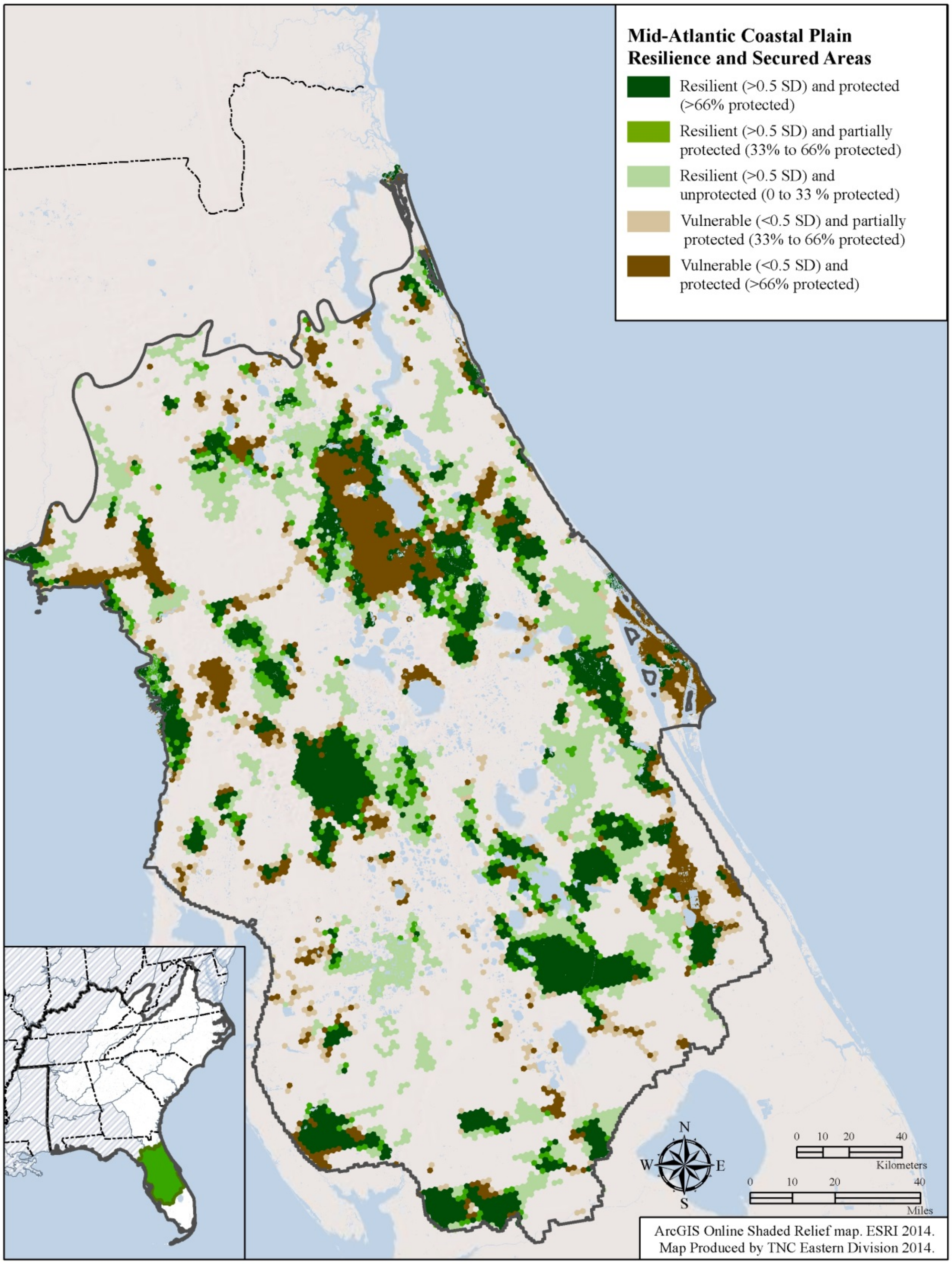
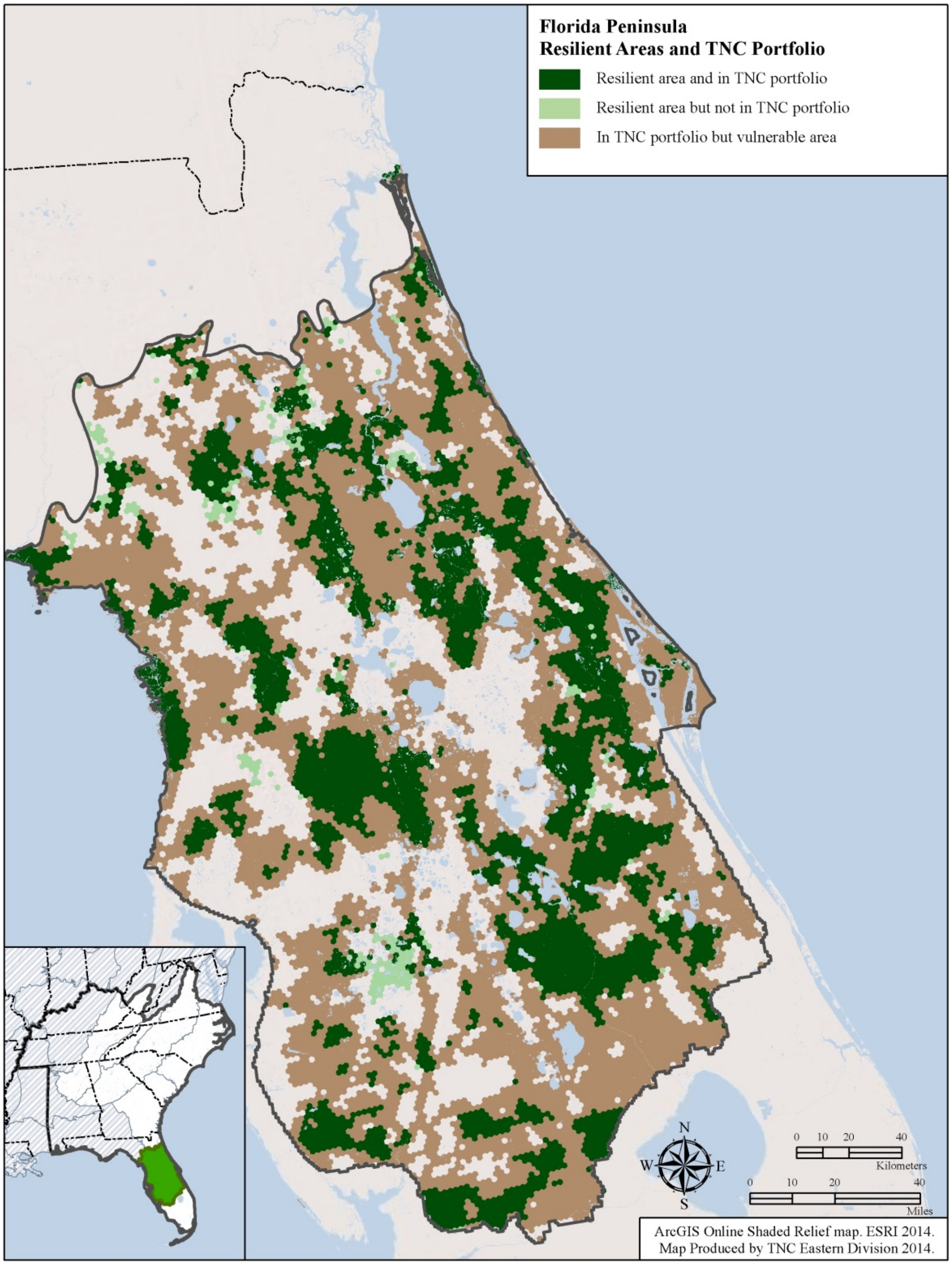


Figure 5.33: Florida Peninsula: Resilience scores of the protected land. This map displays how the existing secured lands compare to resilient sites in the ecoregion. Each 1000 ac hexagon was coded by what percent is currently secured, and this is visually compared to the resilient areas in the ecoregion.



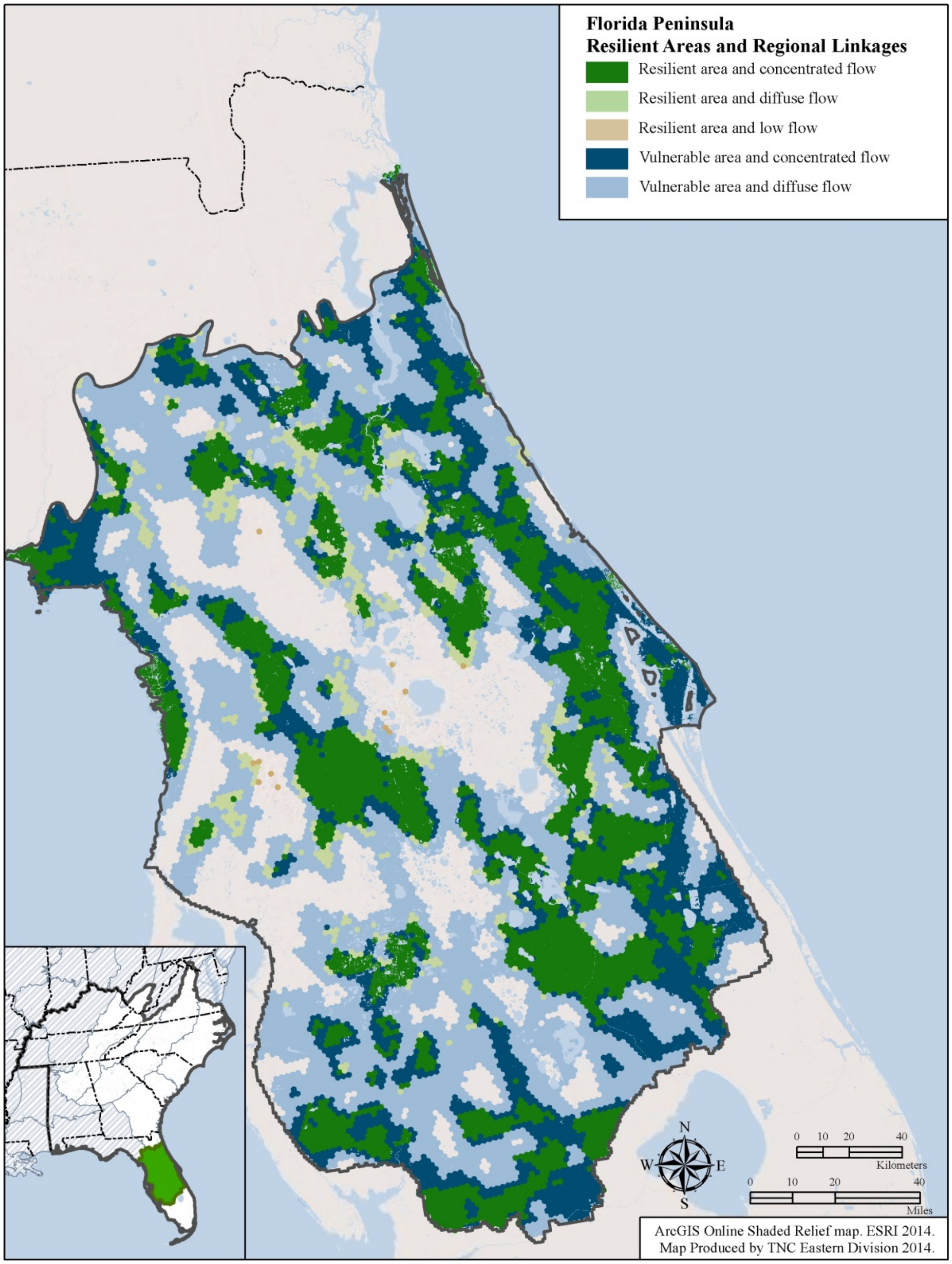
ArcGIS Online Shaded Relief map. ESRI 2014.
Map Produced by TNC Eastern Division 2014.

Figure 5.34: Florida Peninsula: Resilient Areas and TNC Portfolio sites. This map identifies the resilient areas that correspond with TNC'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.



ArcGIS Online Shaded Relief map. ESRI 2014.
Map Produced by TNC Eastern Division 2014.

Figure 5.35: Florida Peninsula: Resilient areas and regional linkages. This map integrates resilient areas with the regional flow concentrations. In the map, resilient areas located in areas of high flow concentrations area shown in olive green. Resilient areas that are large and highly intact have diffuse flow and are shown in pale green. Key linkages are shown in areas with no resilient areas but high amounts of concentrated flow, and these are shown in dark blue. Blue-green areas are fairly intact regions with diffuse flow and vulnerable areas.



Tropical Florida

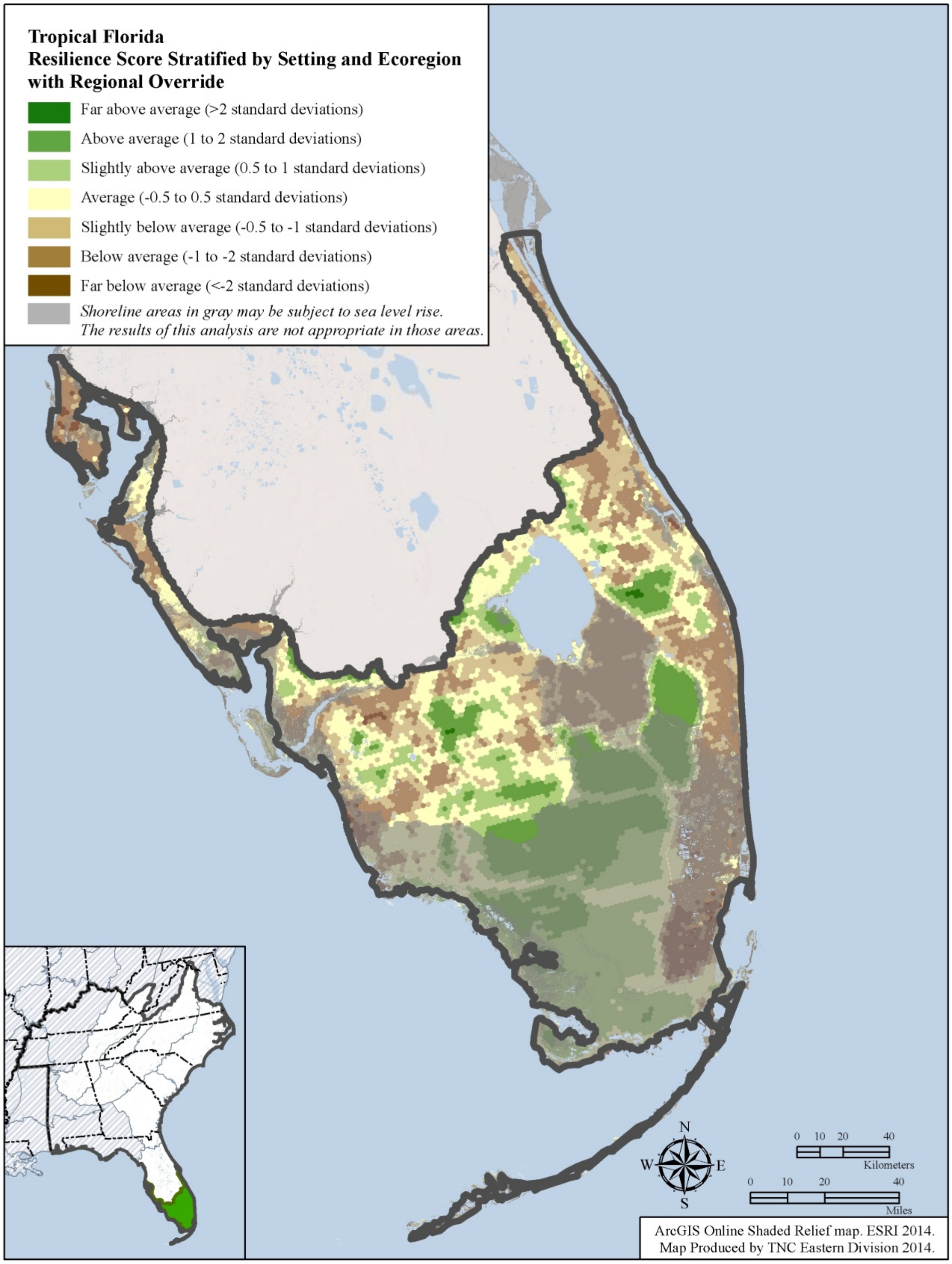
Tropical Florida is a landscape under siege. It is also a landscape of great contrasts between highly fragmented upland terrestrial ecological communities/systems and vast expanses of herbaceous wetlands. The tip of the Florida peninsula that comprises the Tropical Florida Ecoregion is surrounded by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

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

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

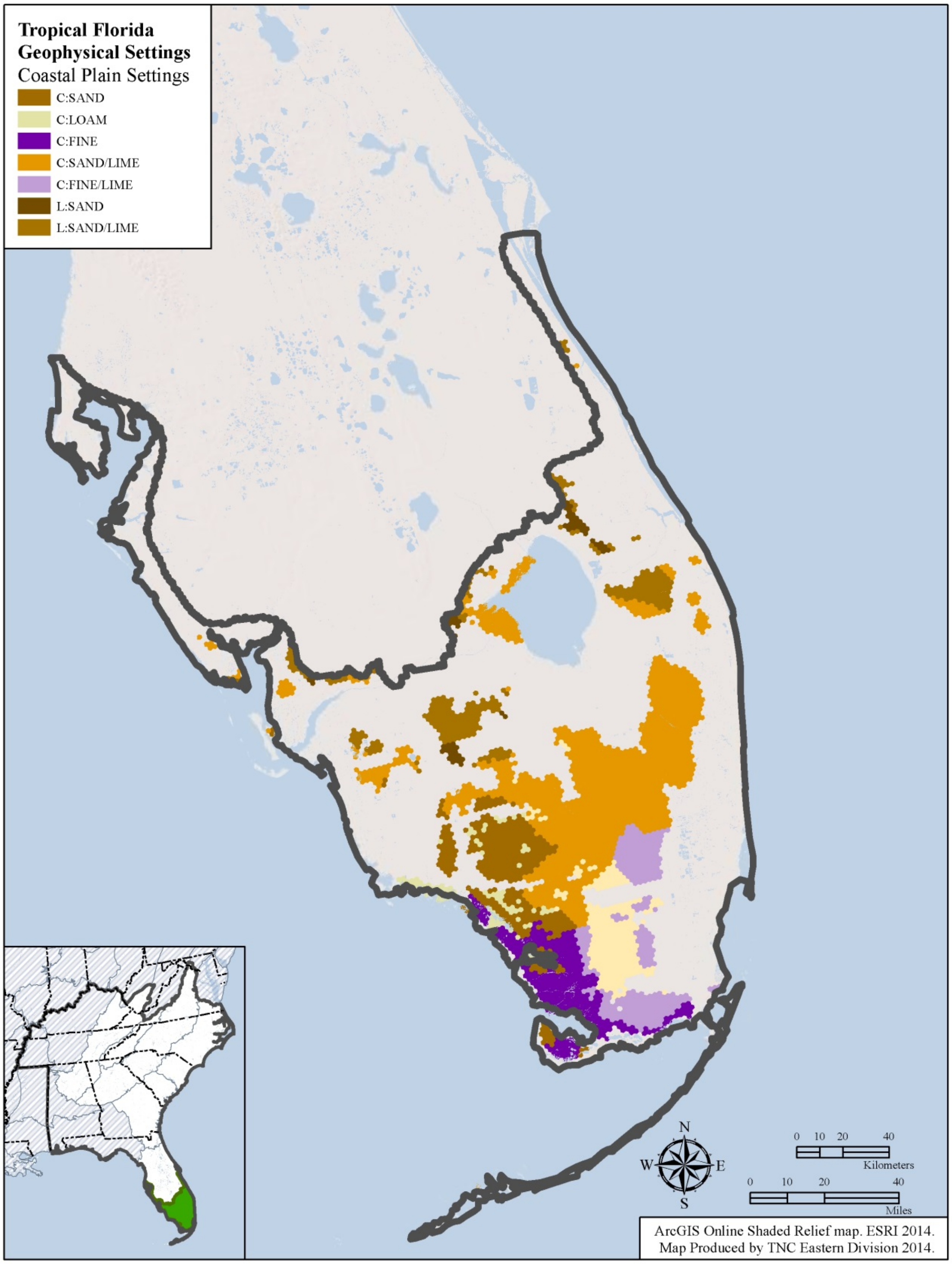
Figure 5.36	Estimated resilience for all geophysical settings in the ecoregion,
Figure 5.37	Resilient areas for each geophysical setting in the ecoregion,
Figure 5.38	Resilience scores of the protected lands,
Figure 5.39	Resilient areas and TNC biodiversity sites: integration of current and future biodiversity
Figure 5.40	Resilient areas and regional linkages

Figure 5.36: Tropical Florida: Resilience Estimates. Areas in yellow are comprised of cells with an average estimated resilience score based on their geophysical setting, landscape diversity 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.



ArcGIS Online Shaded Relief map. ESRI 2014.
Map Produced by TNC Eastern Division 2014.

Figure 5.37: Tropical Florida: 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.



ArcGIS Online Shaded Relief map. ESRI 2014.
Map Produced by TNC Eastern Division 2014.

Figure 5.38: Tropical Florida: Resilience scores of the protected land. This map displays how the existing secured lands compare to resilient sites in the ecoregion. Each 1000 ac hexagon was coded by what percent is currently secured, and this is visually compared to the resilient areas in the ecoregion.

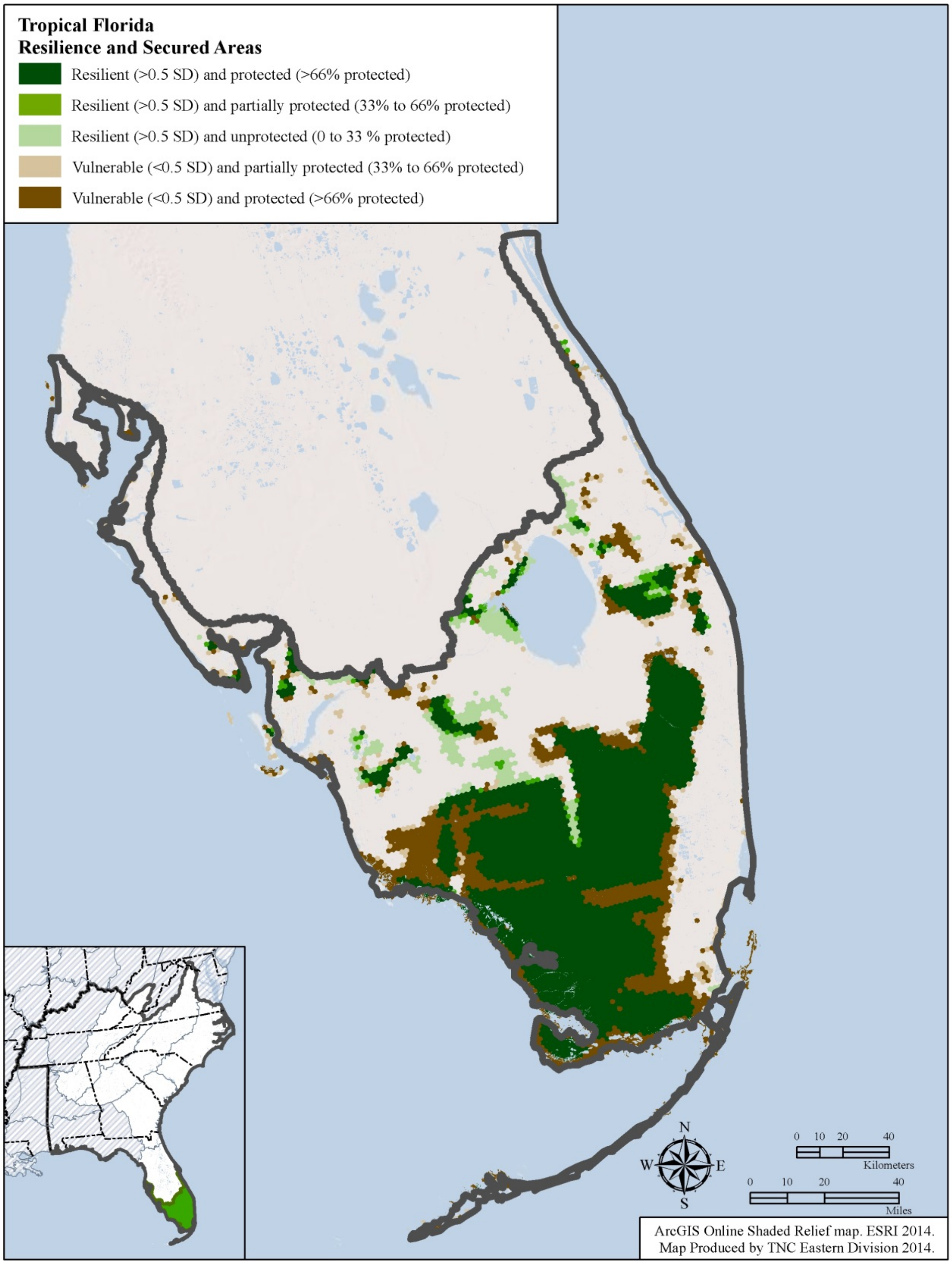
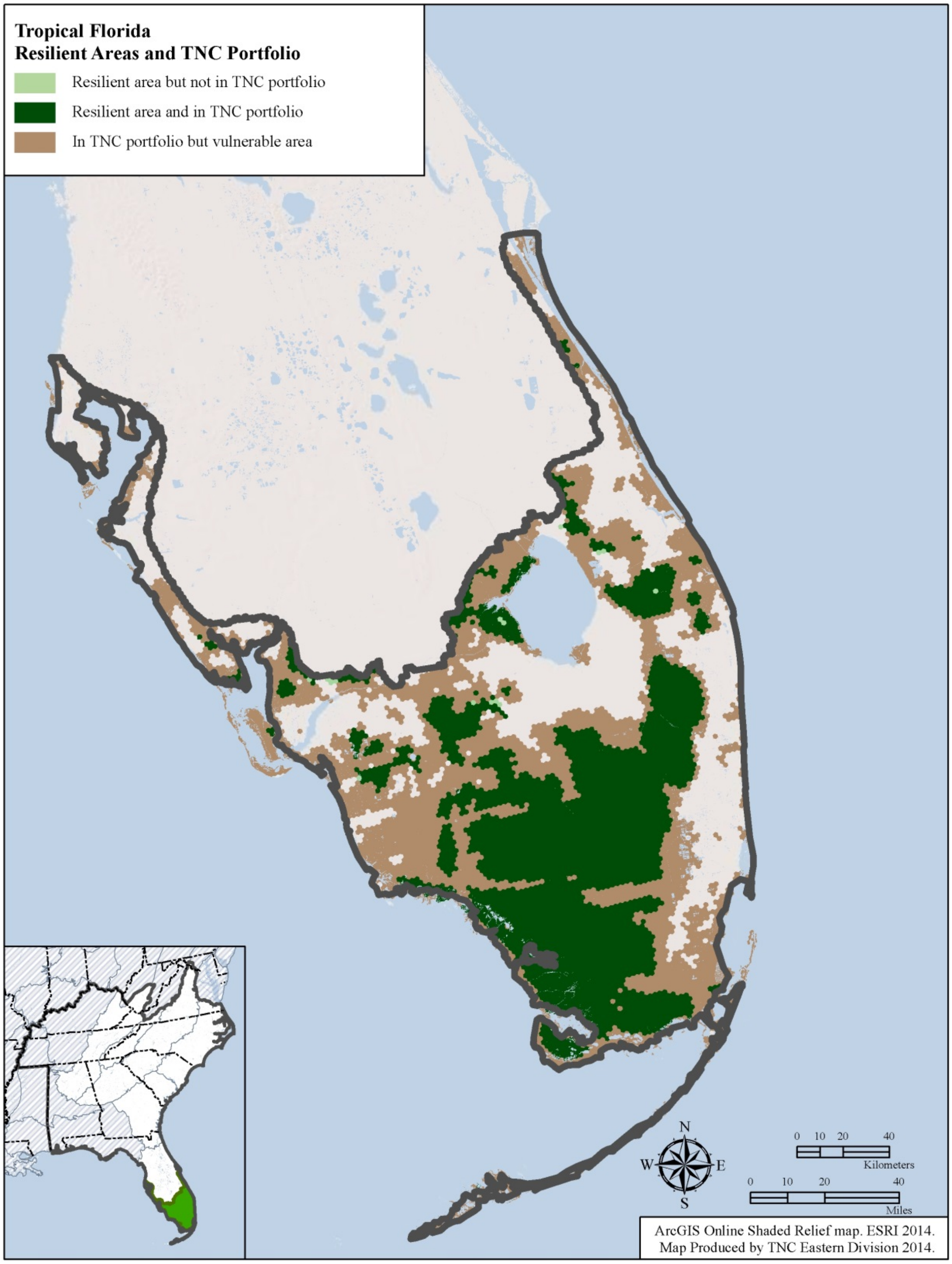
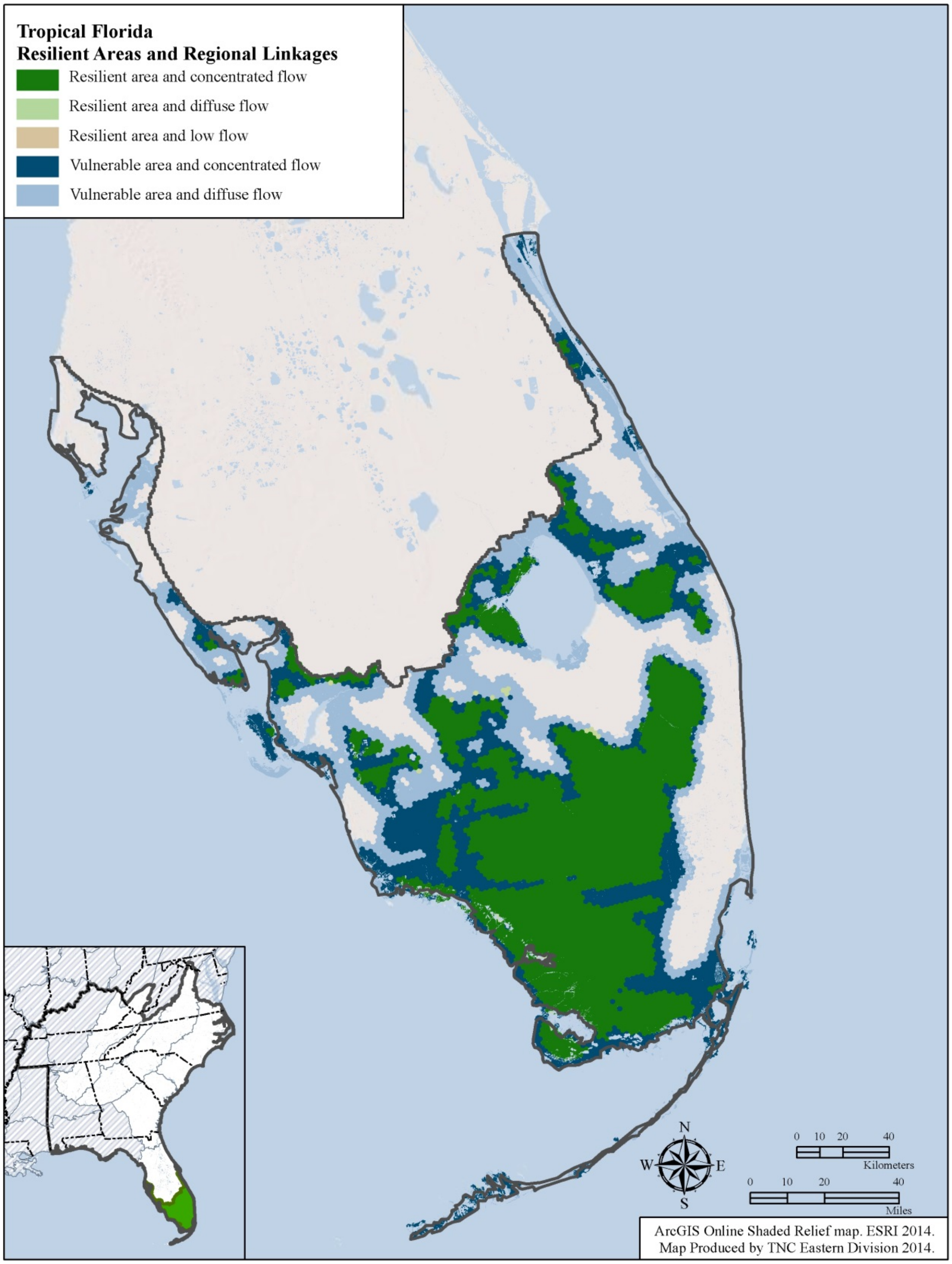


Figure 5.39: Tropical Florida: Resilient Areas and TNC Portfolio sites. This map identifies the resilient areas that correspond with TNC's ecoregional portfolio of sites with significant biodiversity. The portfolio sites contain the best known occurrences of a forest, wetland, or unique natural community, 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.



ArcGIS Online Shaded Relief map. ESRI 2014.
Map Produced by TNC Eastern Division 2014.

Figure 5.40: Tropical Florida: Resilient areas and regional linkages. This map integrates resilient areas with the regional flow concentrations. In the map, resilient areas located in areas of high flow concentrations area shown in olive green. Resilient areas that are large and highly intact have diffuse flow and are shown in pale green. Key linkages are shown in areas with no resilient areas but high amounts of concentrated flow, and these are shown in dark blue. Blue-green areas are fairly intact regions with diffuse flow and vulnerable areas.



ArcGIS Online Shaded Relief map. ESRI 2014.
Map Produced by TNC Eastern Division 2014.

CHAPTER

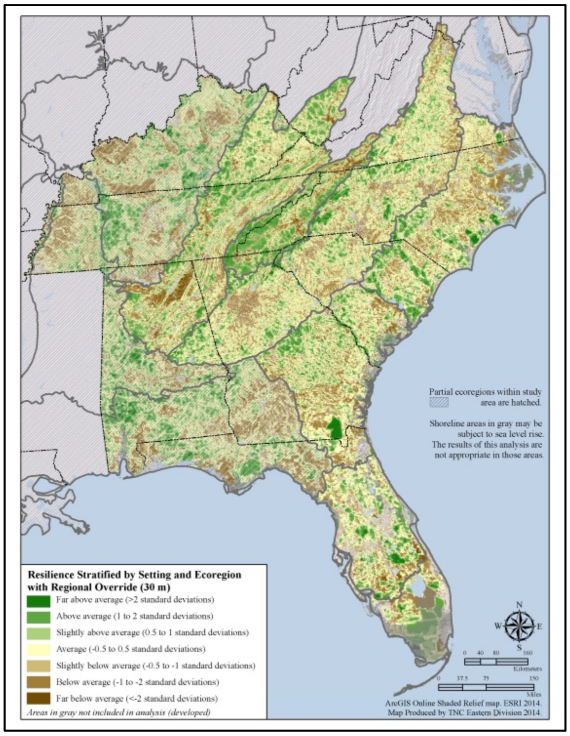
6

Regional Results and Discussion

Results for the Nine-State Region

The regional maps were made be joining the ecoregion and partial ecoregion analyses together into a single map, with the partial ecoregions hatched to reflect that fact that these sections may be incomplete. The results include six regional maps plus one map that does not use ecoregions:

Figure 6.1	Estimated resilience for all geophysical settings in the ecoregion
Figure 6.2	Resilient areas for each geophysical setting in the ecoregion
Figure 6.3	Resilience scores of the protected lands
Figure 6.4	Resilient areas and TNC biodiversity sites:integration of current and future biodiversity
Figure 6.5	Resilient areas and regional linkages
Figure 6.6	Comparision of Resilience Scores
Figure 6.7	Close-up of the highest scoring areas for estimated resilience by setting across the region.



The map above (shown full page as figure 6.1) is the final result of this project showing the places within each ecoregion that have the highest estimated resilience score and represent all settings.

Partial ecoregion results are biased towards the portion of the ecoregion analysed and do not reflect the full ecoregional patterns.

Coastal Shorlines and Massive Wetlands

Coastal Shorelines

Coastline ecosystems of the southeast are subject to a variety of climate related changes that threaten to alter or undermine their natural resilience. Foremost among these is sea level rise that has been conservatively estimated to reach six meters by 2100 (IPPC 2007). We did not address this issue, nor the related issues connected of sediment transport, accretion, or erosion rates, and this study should not be used to make determinations on the resilience of systems in the coastal zone. To make this clear on the maps we put a grey transparency over the 0-3 meter coastal zone, showing the area subject to sea level rise by 2060 while allowing users to see the underlying results.

Massive Wetlands

The coastal plain contains two massive and well-known wetland systems: the Okefenokee a 430,000 acre peat swamp in southern Georgia, and the Everglades a 2 million acre complex of sawgrass marsh, cypress swamp and pine flats over a porous limestone substrate. Both of these unique systems operate at a fundamentally different scale than the other features we assessed, and play a regional role in storing and filtering water and mediating the climate. Being extraordinarily large and connected, these wetlands defined the upper end of our local connectedness score (along with a section of the Great Smoky Mts, Figure 3.17), and by that measure they are the most intact areas in the entire study area. However, the landscape diversity of both wetlands is inherently low, and although their wetland density scored very high it was defined not by many wetland patches but by a single large wetland (Figure 3.6). The hydrology of these systems is linked to regional precipitation and in the case of the Everglades; the hydrology has been greatly altered. Thus, in spite of their extraordinary connectedness, more research is needed to understand the extent of their resilience to climate change.

To emphasize both their uniqueness and our uncertainty we put a grey transparency over these two wetlands on the regional maps, using the criteria off wetlands over 300,000 acreas. There are 209 wetlands on the coastal plain that are 1000 acres in size or larger, and their average size is 36,908 acres. The two discussed above are over 3.5 SD outside the size range of these large wetlands. This caveat was added to maps of the final results *“Coastal shorelines and massive wetlands over 300,000 acres are shown with a grey overlay. Although assessed in this study, these unique systems need further evaluation to estimate their resilience (see text).”*

Figure 6.1: 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 diversity 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.

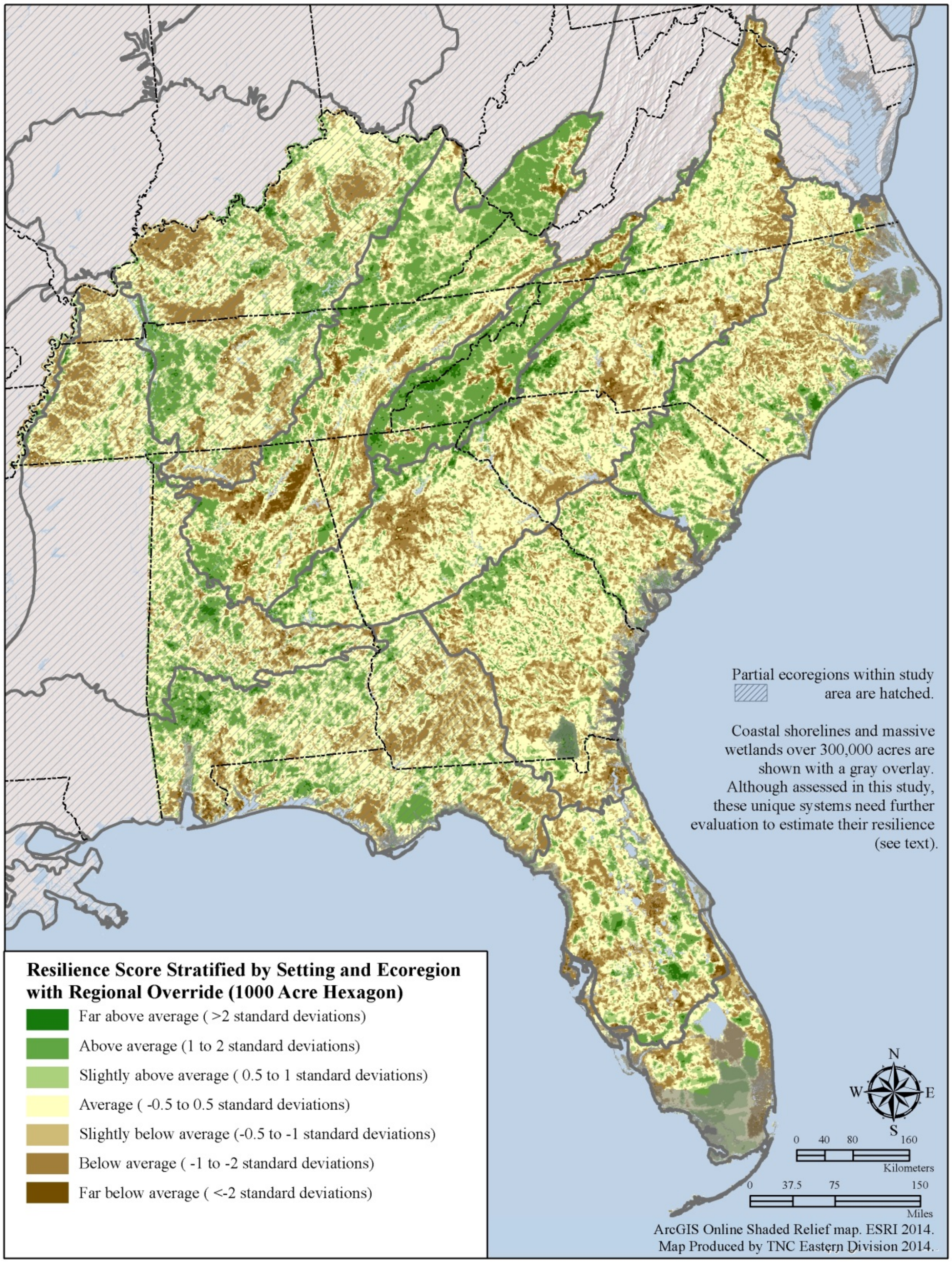
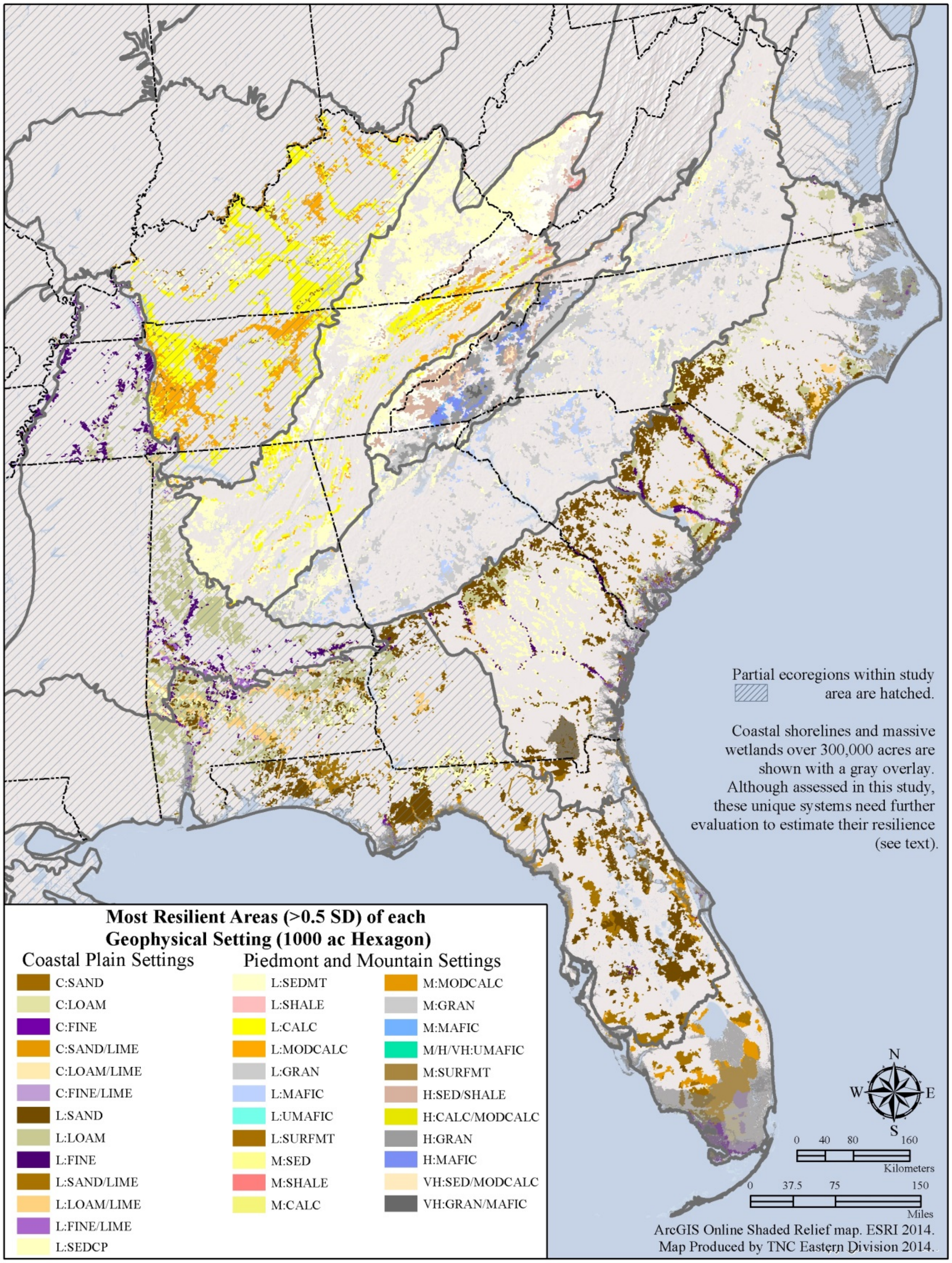


Figure 6.2: The most resilient examples of each geophysical setting in the region. This map shows only the 1000-acre hexagons that score above the mean for estimated resilience as compared to others in their ecoregion; each high scoring hexagon is colored based on its corresponding geophysical setting. This map reveals how the settings are reflected in the resilience scores.



Partial ecoregions within study area are hatched.

Coastal shorelines and massive wetlands over 300,000 acres are shown with a gray overlay. Although assessed in this study, these unique systems need further evaluation to estimate their resilience (see text).

ArcGIS Online Shaded Relief map. ESRI 2014.
Map Produced by TNC Eastern Division 2014.

Figure 6.3: Estimated resilience in relation to protected lands. This map shows the resilience score of land in the Southeast that is secured against conversion to development.

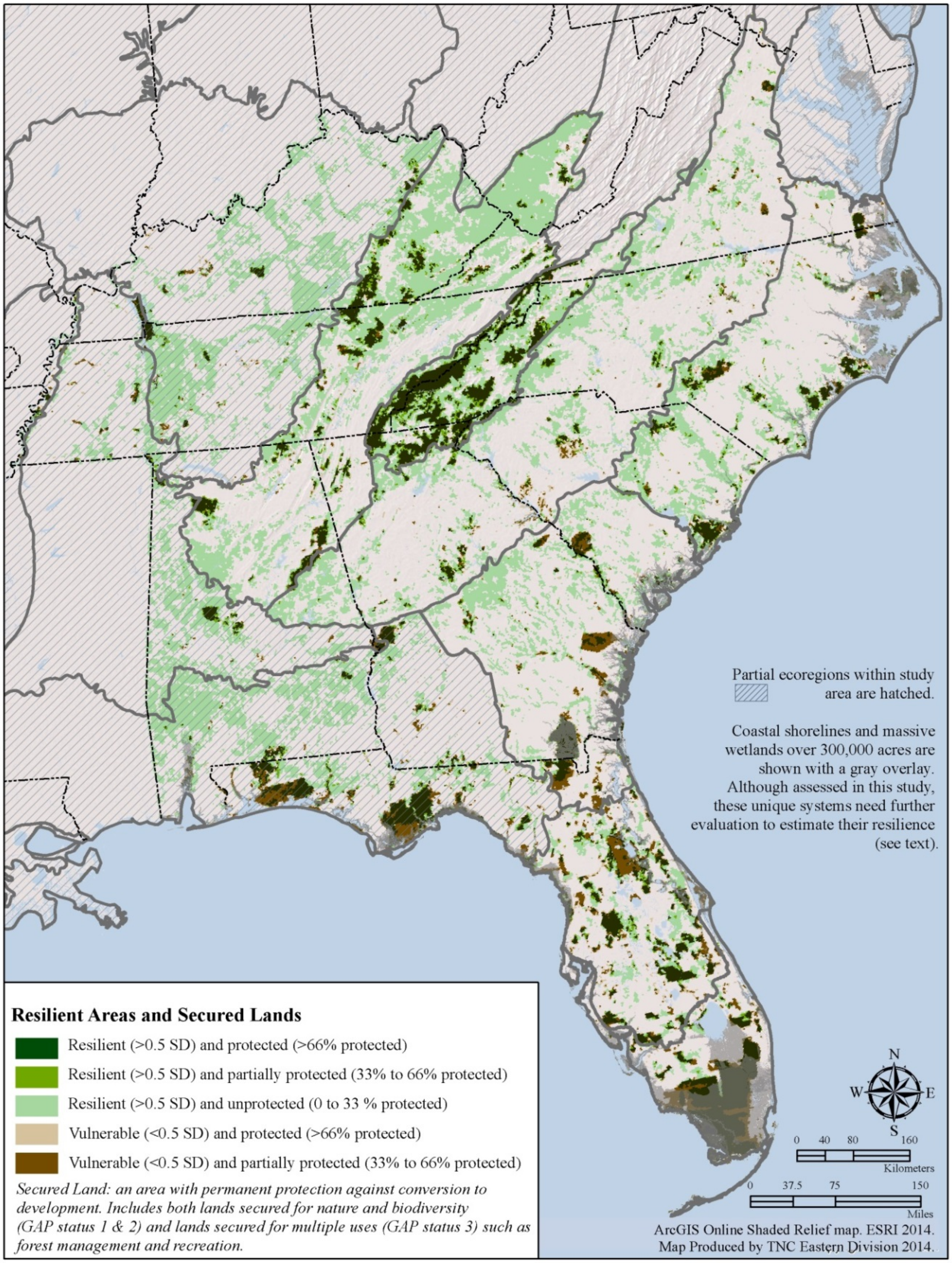
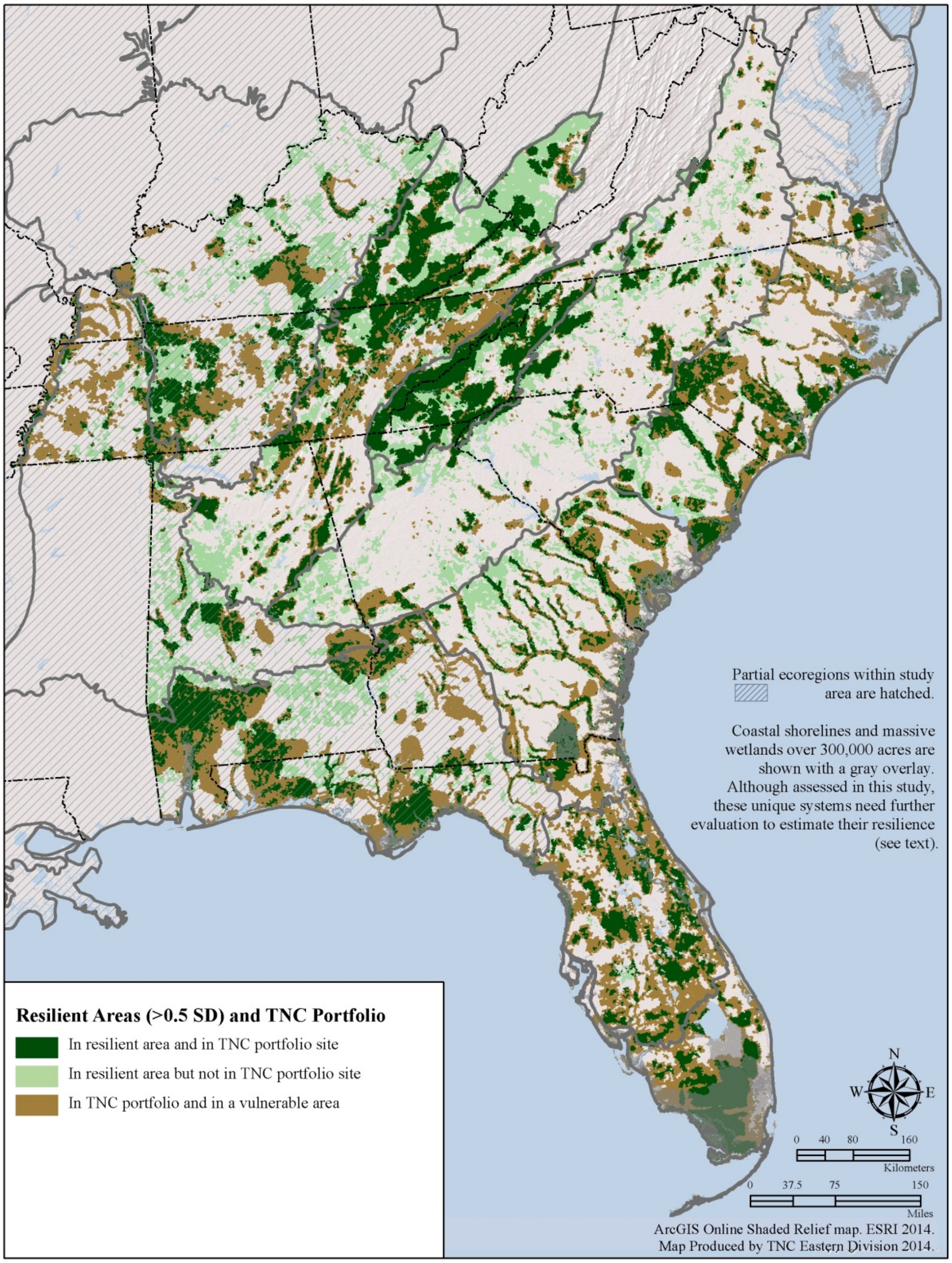


Figure 6.4: Key places of current and future biodiversity. This map identifies the focal areas that correspond with TNC's ecoregional portfolio of sites with significant biodiversity. The portfolio sites contain the best known occurrences of a forest, wetland or unique natural community, a rare species, 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.



Partial ecoregions within study ▨ area are hatched.

Coastal shorelines and massive wetlands over 300,000 acres are shown with a gray overlay. Although assessed in this study, these unique systems need further evaluation to estimate their resilience (see text).

ArcGIS Online Shaded Relief map. ESRI 2014.
Map Produced by TNC Eastern Division 2014.

Figure 6.5: 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.

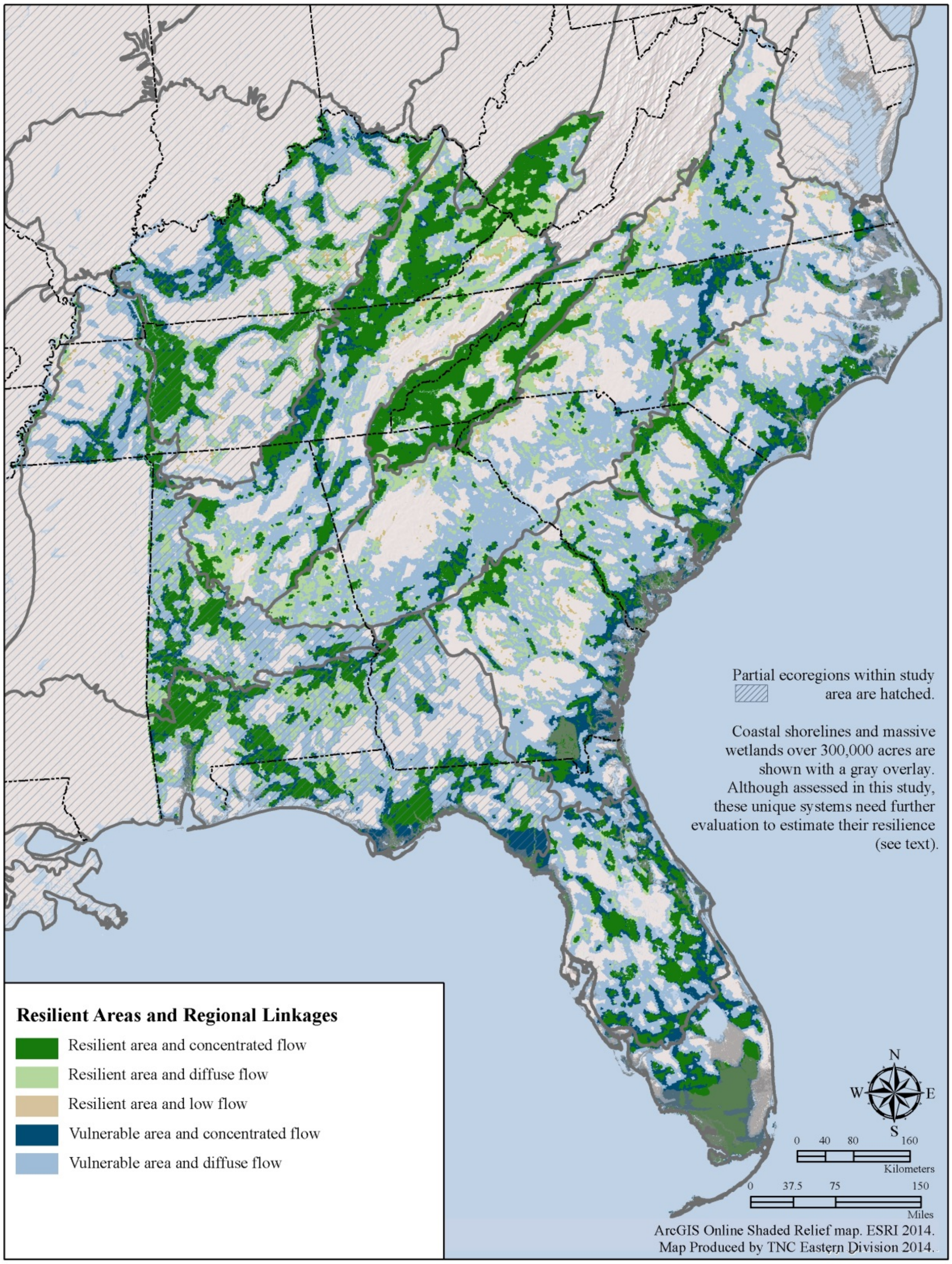


Figure 6.6: Comparison of Resilience Scores: A. Raw scores applied to the whole study area, B. The 35 geophysical settings, C. Scores applied to each geophysical setting, D. Scores applied to each geophysical setting within each ecoregion with regional override (sites greater than 1 SD above the mean in map A). **Map D is the final map.**

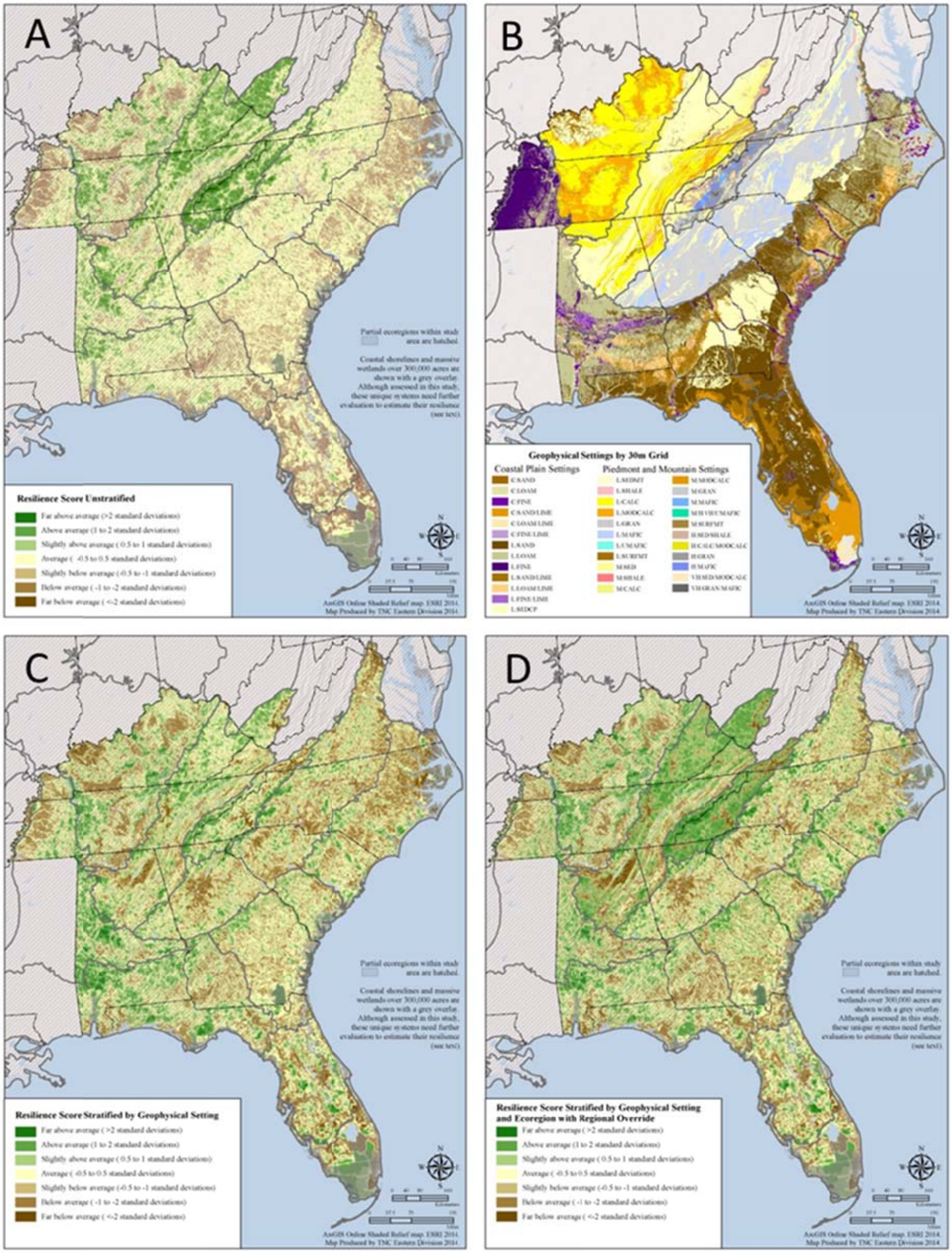
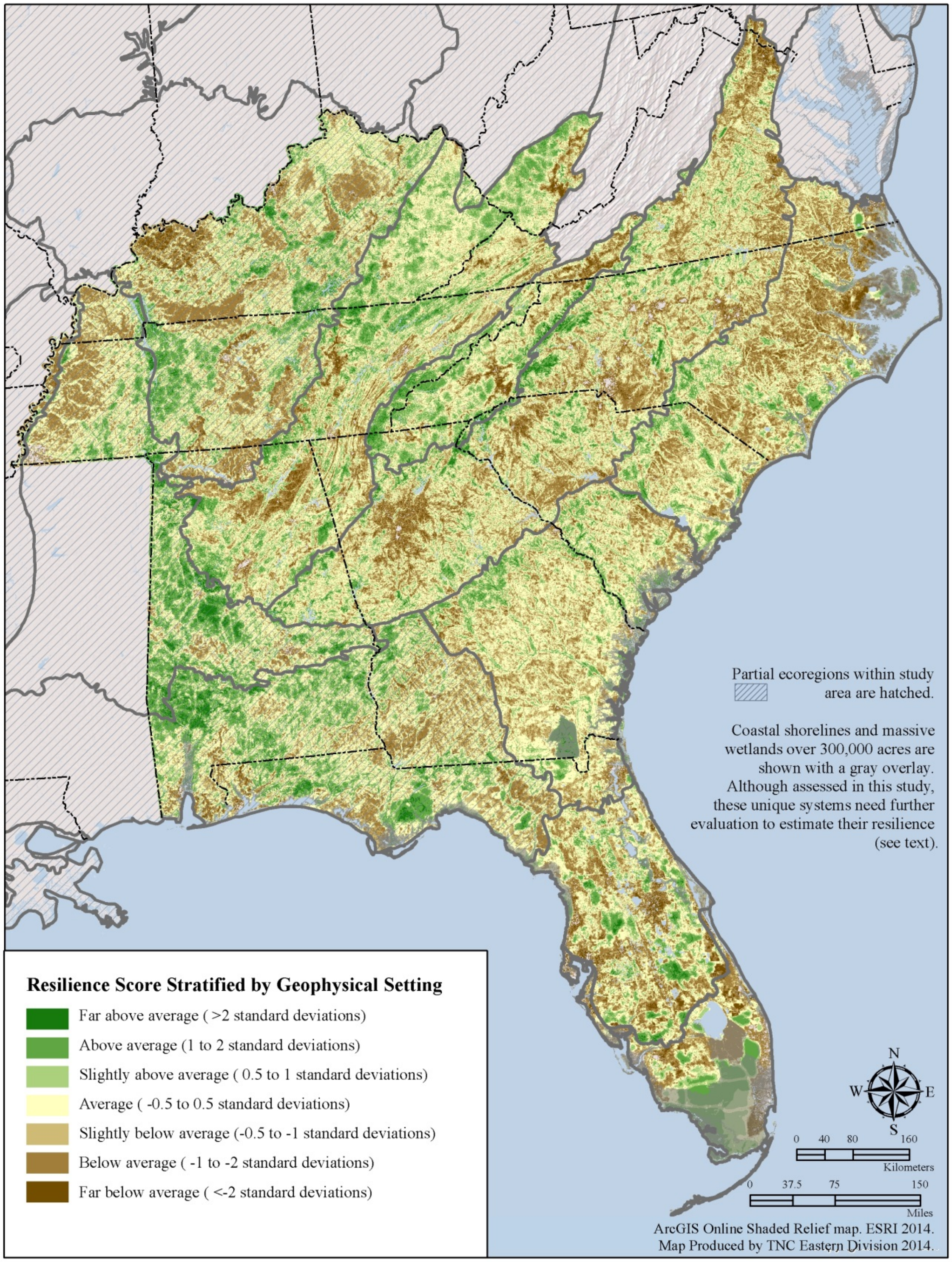


Figure 6.7: Close-up of the highest scoring areas for estimated resilience by setting across the region (map c from Figure 6.6). Areas in yellow are comprised of cells with an average estimated resilience score based on their geophysical setting, landscape diversity and local connectedness. Areas in 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.



Partial ecoregions within study area are hatched.

Coastal shorelines and massive wetlands over 300,000 acres are shown with a gray overlay. Although assessed in this study, these unique systems need further evaluation to estimate their resilience (see text).

ArcGIS Online Shaded Relief map. ESRI 2014.
Map Produced by TNC Eastern Division 2014.

Discussion

Estimating the resilience of distinct geophysical settings across the Southeast US revealed striking patterns and there was high correspondence between sites identified by their geophysical characteristics and those selected for the high quality of their biodiversity features in TNC portfolios (Figure 6.4). Because this method identified sites for every geophysical setting that are likely to retain species and functions longer under a changing climate, it reveals places for future conservation that could correct the bias in current secured lands.

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

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

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

Many of TNC's portfolio sites scored high for resilience (Figure 6.4). The Conservancy's set of high-quality biodiversity sites was developed independently, but landscape context (similar to local connectedness) was used as one of three selection criteria, and this could explain some correspondence. Alternatively, it may be that topographically diverse and connected areas within each geophysical setting simply contain most of the remaining biodiversity. This is an important area for further research, but in either case, sites that have both significant current biodiversity and high site resilience are worthy places for conservation action, with the understanding that their specific biota may change with the climate. Further, we can cautiously assume that because the system is currently functioning close to a natural state, this feature should enhance the system's ability to adapt to changes, and continue to support a diverse array of species.

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 forportfolio 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 (e.g., a rare species or a natural community), 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 were currently protected from development tended to score high for resilience (Figure 6.3) 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 diversity 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 Eastern US 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 nine states (this boundary was admittedly arbitrary from an ecological perspective, but politically it encompassed all of the Southeast US.) The results (Figure 6.7) however, show a spread across ecoregions suggesting that most geophysical settings naturally had some scoring areas within each ecoregion. The final stratified results (Figure 6.1) can be thought of as a composite of the individual setting maps presented in Chapter 5.

When viewed regionally, the flow concentration areas reveal interesting and potentially important linkages across the region. For instance, the position and context of the Cumberland and Blue Ridge Mountains, the large river systems linking the Piedmont to the coast, and the host of connections that run through the state of Alabama 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 (Figure 6.5). 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 plan to explore this further over the next two years so that our conservation vision is not just a collection of good places, but 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.

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

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

APPENDIX

I

Detailed Data Sources and Methods

Elevation

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

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

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

Calculating the Uncorrelated Elevation Range

To generate a raster of uncorrelated elevation range we used a robust regression (Hampel et al. 1986) to factor out the elevation range explained by the landform variety and measure the residual variation explained only by true elevation changes. The regression calculated a bivariate regression raster with log-transformed elevation range as the dependent variable and landform variety as the independent variable. The regression was calculated using a randomized subsample of pixels stratified by the three subregions (Coastal Plain, Piedmont, and Mountains) and fitted using an iterated re-weighted least squares algorithm (Detail in appendix II). Different sample sizes were explored before selecting the final model for each ecoregion. In the large Coastal Plain ecoregion, the final model used 250,000 samples and had a mean residual error of 0.00306. The Piedmont ecoregion model used 50,000 samples and had a mean residual error of 0.00291. The Mountains ecoregion model consisted of 100,000 samples with a mean residual error of 0.01107. A raster of the regression residuals was generated for each ecoregion and then back-transformed to create a grid of elevation range unexplained by landform variety. All analyses were conducted in R 3.0.1 (R Core Team 2013) using the raster Regression.R script written by Dr. Jeffrey S. Evans, Senior Landscape Ecologist at The Nature Conservancy (personal communication, October 8, 2013) and the following R packages: *raster* (Hijmans 2013); *sp* (Pebesma & Bivand 2005; Bivand et al. 2013); and *MASS* (Venebles & Ripley 2002). In the Coastal Plain ecoregion, the average elevation range unexplained by landform variety was 0.16 m with a standard deviation of 0.73 m and a maximum of 51.46 m. The Piedmont ecoregion had a mean of 0.09 m and a standard deviation of 0.57 m with a maximum unexplained elevation range of 24.35 m, while the Mountains ecoregion had a mean of 0.47 m, a standard deviation of 1.60 m, and a maximum of 35.93 m. Because the NED has a vertical accuracy of 2.44 meters we ignored elevation ranges below this threshold.

Landforms

Several steps were taken to prepare the 15-class landform raster for use in the landform variety calculation. First, to ensure that all rivers were classified as open water, flowlines from the National Hydrography Dataset Plus version 2 (NHDPlusv2) hydrography (USEPA & USGS 2012) were assigned to one of seven stream and river size classes (Olivero & Anderson 2008) based on the NHDPlusv2 divergence-routed cumulative drainage area (km2). All flowlines classified as small rivers and larger were selected and converted to a 30-m grid that was merged on top of the landforms as open water. As the resilience analysis does not consider coastal and marine processes or sea level rise, all landform pixels that coincided with the NHDPlusv2 polygons coded as sea, ocean, or nearshore were converted to null values so they would not be included in the analysis.

Geology

The bedrock geology data for the southeast states were downloaded 10-18-2013 from
http://mrdata.usgs.gov/geology/state/
Original Map Sources for these data are as follows:
AL: Szabo, M. W., Osborne, E. W., Copeland, C. W. Jr., Neathery; T. L., 1988, Geologic Map of Alabama, Geological Survey of Alabama Special Map 220, scale 1:250,000.
FL: Scott, T. M., Campbell, K. M., Rupert, F. R., Arthur, J. D., Missimer, T. M., Lloyd, J. M., Yon, J. W., and Duncan, J. G., 2001, Geologic Map of the State of Florida, Florida Geological Survey & Florida Department of Environmental Protection, Map Series 146. C.L. Dicken polygon edits. Additionally, when using US001 state boundary file, water polygons have been generated.
GA: Lawton, D.E., and others, 1976, Geologic Map of Georgia: Georgia Geological Survey, scale = 1:500,000. 1:500k GEOLOGY COVER: geology.zip available at Georgia GIS Data Clearinghouse http://gis1.state.ga.us/index.asp Do a theme search category "geology", keyword "geology" Data was indicated to be "free" therefore public domain Information available at site: Title: Geology Location: Georgia Scale: 1:500,000 File Format: ArcInfo Export File Projection: Lambert Conformal Conic Originator: Georgia Department of Natural Resources Index: Published: 1999 Updated: 10/9/2000 Abstract: Purpose: For more information about this dataset please visit the Georgia Department of Natural Resources.
KY: Noger, M.C., compiler, 1988, Geologic map of Kentucky: sesquicenntennial edition of the Kentucky Geological Survey: U.S. Geological Survey and the Kentucky Geological Survey, scale 1:500,000.
NC: The North Carolina Dept. of Environment, Health, and Natural Resources, Division of Land Resources, NC Geological Survey, in cooperation with the NC Center for Geographic Information and Analysis, 1998, Geology - North Carolina (1:250,000), coverage data file geol250. The data represents the digital equivalent of the official State Geology map (1:500,000 scale), but was digitized from (1:250,000 scale) base maps.
SC: Horton, J.Wright, and Dicken, Connie L., 2001, Preliminary Geologic Map of the Appalachian Piedmont and Blue Ridge, South Carolina Segment: U.S. Geological Survey, Open-File Report 01-298, CD
Newell, Wayne L., Prowell, David (retired), Krantz, David, Powars, David, Mixon, Robert (retired), Stone, Byron, and Willard, Debra, in review, Surficial Geology and Geomorphology of the Atlantic Coastal Plain: U.S.G.S. Open File Report,

TN: Greene, D.C., and Wolfe, W.J. 2000 Superfund GIS - 1:250,000 Geology of Tennessee. Geology available at Tennessee Spatial Data Server which can be found at http://www.tngis.org/geology.html which links to a USGS Water Resources Division site: http://water.usgs.gov/lookup/getspatial?geo250k Tennessee Spatial Data Server site notes: Thanks goes to Jim Julian for researching this improved geology layer from the Tennessee Division of Geology. **Note** - The Tennessee Division of Geology does not endorse this coverage, stating this version is still incomplete and not fit for distribution. Polygon edits made my C.L. Dicken based on paper source (TN002).
Portions of the following Mid-Atlantic state's bedrock geology were also integrated into the Southeast resilience dataset.
MD: 1968 Geologic Map of Maryland (blueline). 1:250,000. Maryland Geological Survey; compiled and edited by Cleaves, E.T., J. Edwards, Jr., and Glaser, J.D.; supervised by K.N. Weaver.
VA: Berquist, C.R., Jr., and Uschner, N. E., 1999, Spatial data of the digital geologic map of Virginia: VA Div. of Mineral Res. Digital Pub. 14B. Based on 1993, Geologic map of Virginia: Virginia Division of Mineral Resources, scale 1:500,000.
WV: 1968 State Geologic Map of West Virginia, 1:250,000. Digitized by West Virginia DEP, TAGIS Unit.

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

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

Soils sand, silt, and clay attributes were extracted for all available mapunits from the SSURGO and STATSGO December 30, 2009 snapshot dataset by Norman B. Bliss, Ph.D. Principal Scientist ASRC Research and Technology Solutions, Contractor to the USGS Earth Resources Observation and Science Center, Sioux Falls, SD 57198 bliss@usgs.gov. The sand, silt, and clay grams per square centimeter of surface for each soil depth were calculated using the standard NRCS weighted average method. The representative value (or percent total) for sand, silt, and clay provided was the result of dividing a particular texture type, for example sand (in grams) by the total mass_fines (in grams) and multiplying by 100%. The definition is comparable to the definition of "representative value" in the original SSURGO data. For the purposes of the Southeast Resilience Analysis, the representative values of sand, silt, and clay for the 0-20cm depth zone were used to develop soil group classes.

Simplified soils texture groups were developed in the Southeast Resilience project. All map units with reported sand, silt, and clay totals > 0 were analyzed. In R (R Core Team 2013), the Soil Texture Wizard package (Moeys 2012) functions for working with soil texture data was used to assign each map unit to one of the 12 soil type from the USDA Soil Triangle. Before assignment to these types, the records were first normalized so the percent of sand, silt, and clay equaled 100% if they did not already equal 100%. These rare cases where the percent sand, silt, and clay did not equal 100% were either small rounding errors in the source data or were due to the presence of organic material content in the soils. The 12 USDA soils groups were then collapsed into four major groups for the Southeast Resilience Project as follows: Group 1: Sand, Loamy Sand; Group 2: Loam, Sandy Loam, Sandy Clay Loam; Group 3: Silt Loam, Silt Clay Loam, Clay Loam, Silt; and Group 4: Clay, Silt Clay, Sandy Clay. Later Groups 3 and 4 were combined to form a "fine" soils setting.

To seamlessly map these four soil texture groups across the Southeast, we worked to integrate the SSURGO and STATSGO soil texture data. Given the finer mapping scale of the SSURGO (1:12,000 to 1:24,000) vs. the STATSGO (1:250,000) data, any geographic area covered by SSURGO should be represented with the soil texture class from the SSURGO finer data. However, SSURGO was not available for all areas of the Southeast. It was missing entirely for 32 counties and was missing in a few large areas within a handful of other counties. After study of the areas missing SSURGO data, we decided to fill missing whole counties and any other very large missing areas >10,000 acres in size with the coarser STATSGO data. Missing areas < 10,000 acres were filled by simply expanding the surrounding four summary types into the missing area using the Euclidean nearest neighbor "nibble" command in ArcGIS. Many of these smaller missing areas were wide river or lake features. Finally, a few areas were still missing a soil texture group because they were missing even from the coarser national STATSGO data. These included very large lakes and a few very large areas of organic soils in the Everglades area. These missing areas were filled in by simply expanding the surrounding STATSGO group into the missing area using the Euclidean nearest neighbor "nibble" command.

Roads: 2012 TIGER/Line Shapefiles. Prepared by the U.S. Census Bureau, 2012
Topologically Integrated Geographic Encoding and Referencing (TIGER) products are spatial extracts from the Census Bureau's MAF/TIGER database, containing features such as roads, railroads, rivers, as well as legal and statistical geographic areas. They are developed by the U.S. Department of Commerce, Geography Division, U.S. Census Bureau and available for download at
http://www.census.gov/geo/maps-data/data/tiger.html

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

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

NLCD 2006 Land Cover provides 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.

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

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

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

Natural Heritage Species and Community Data

To quantify the types of species and communities currently found in each setting, we compiled the locations of rare species and exemplary natural communities tracked and inventoried by the State Natural Heritage field inventory programs and overlaid them on the other datasets. 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 locations 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. Examples from the species and 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.

Natural Heritage Species and Community Data Sources

Much of this data falls under one of many data use agreements signed with the Natural Heritage Programs and is explicitly for use in TNC's Southeast Resilience Analysis. These programs do not portray their databases as representing exhaustive or comprehensive inventories for rare species or significant natural features. Field verification of the absence or presence of sensitive species will always be an important obligation of users of these data.

1. Data sources for Southeast State Natural Heritage Species and Natural Community data are as follows
   ALABAMA - Alabama Natural Heritage Program 2013.
   FLORIDA - Florida Natural Area Inventory 2013.
   GEORGIA - Georgia Department of Natural Resources, Wildlife Resources Division, Georgia Natural Heritage Program 2013.
   KENTUCKY - Information provided by the Kentucky State Nature Preserves Commission. Further information is available by contacting the Data Manager, KSNPC the Kentucky Natural Heritage Program as a source of information. 2013.
   NORTH CAROLINA - North Carolina Natural Heritage Program. 2012. Biotics Database.

Department of Environment and Natural Resources, Raleigh, North Carolina.
SOUTH CAROLINA - South Carolina Department of Natural Resources, Heritage Trust Program 2013.
TENNESSEE - Tennessee Division of Natural Areas 2013.

2. Data sources for Mid-Atlantic State Natural Heritage Species and Natural Community data are as follows:
   NatureServe 2011 Multi-Jurisdictional Dataset of Species Occurrences (MJD) NatureServe Central Databases. Arlington, Virginia. U.S.A. Precise locational polygons for all species in the District of Columbia, Maryland, Virginia, and West Virginia were obtained from the NatureServe Multi-Jurisdictional Dataset (MJD), exported 2/2011. These data are dependent on the research and observations of many member natural heritage programs, 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.

   Element Occurrence Precise Point Locations for Communities and Species from State Natural Heritage Programs 2005-2008 for MD,VA, and WV.

Terrestrial Portfolio Hexagon Data

With each state chapter of The Nature Conservancy we reviewed the original portfolio of areas that encompassed the biodiversity sites within the state as assembled in each ecoregional assessment. For each state we compiled any additions, deletions, or modifications to that original portfolio to represent the current terrestirial portfolio. We aggregated the current terrestrial portfolio polygons to the southeast 1,000 acre hexagons. Edits were made to the hexagon attributes to reflect the names of the sites contained in the hexagon and to reflect if the hexagon contains Longleaf Pine focal areas and/or matrix forest areas.

APPENDIX

Species Names

II

Common Name	**Scientific Name**	**Taxa**
Aaron's Rod	*Thermopsis villosa*	Plant
Alabama Map Turtle	*Graptemys pulchra*	Vertebrate
Alabama Red-bellied Turtle	*Pseudemys alabamensis*	Vertebrate
Alder Flycatcher	*Empidonax alnorum*	Vertebrate
Alligator Snapping Turtle	*Macrochelys temminckii*	Vertebrate
Alligator Snapping Turtle	*Macrochelys temminckii*	Vertebrate
American Alligator	*Alligator mississippiensis*	Vertebrate
American Bittersweet	*Celastrus scandens*	Plant
American Oystercatcher	*Haematopus palliatus*	Vertebrate
American Peregrine Falcon	*Falco peregrinus anatum*	Vertebrate
American Water Shrew	*Sorex palustris*	Vertebrate
American Wintergreen	*Pyrola americana*	Plant
Apalachicola Dragon-head	*Physostegia godfreyi*	Plant
Appalachian Bewick's Wren	*Thryomanes bewickii altus*	Vertebrate
Appalachian Cottontail	*Sylvilagus obscurus*	Vertebrate
Appalachian Dwarf Huckleberry	*Gaylussacia orocola*	Plant
Appalachian Fir Clubmoss	*Huperzia appalachiana*	Plant
Appalachian Oak Fern	*Gymnocarpium appalachianum*	Plant
Appalachian Violet	*Viola walteri var. appalachiensis*	Plant
Appalachian Woodrat	*Neotoma magister*	Vertebrate
Arctic Bentgrass	*Agrostis mertensii*	Plant
Atlantic Salt Marsh Snake	*Nerodia clarkii taeniata*	Vertebrate
Awned Mountain-mint	*Pycnanthemum setosum*	Plant
Bachman's Sparrow	*Aimophila aestivalis*	Vertebrate
Bahama Brake	*Pteris bahamensis*	Plant
Bald Eagle	*Haliaeetus leucocephalus*	Vertebrate
Barbour's Map Turtle	*Graptemys barbouri*	Vertebrate
Beaked Spikerush	*Eleocharis rostellata*	Plant
Beautiful Pawpaw	*Deeringothamnus pulchellus*	Plant
Bell's Vireo	*Vireo bellii*	Vertebrate
Bird-voiced Treefrog	*Hyla avivoca*	Vertebrate
Black Pinesnake	*Pituophis melanoleucus lodingi*	Vertebrate
Black Rail	*Laterallus jamaicensis*	Vertebrate
Black Skimmer	*Rynchops niger*	Vertebrate
Black Swamp Snake	*Seminatrix pygaea*	Vertebrate
Black Swamp Snake	*Seminatrix pygaea*	Vertebrate
Black-billed Cuckoo	*Coccyzus erythropthalmus*	Vertebrate
Black-crowned Night-heron	*Nycticorax nycticorax*	Vertebrate

Black-knobbed Sawback	*Graptemys nigrinoda nigrinoda*	Vertebrate
Black-necked Stilt	*Himantopus mexicanus*	Vertebrate
Black-throated Green Warbler - Coastal Plain pop.	*Dendroica virens waynei*	Vertebrate
Black-whiskered Vireo	*Vireo altiloquus*	Vertebrate
Blodgett's Wild-mercury	*Argythamnia blodgettii*	Plant
Blue Ridge Golden Ragwort	*Packera millefolia*	Plant
Blue Ridge Goldenrod	*Solidago spithamaea*	Plant
Blue Ridge St. John's-wort	*Hypericum mitchellianum*	Plant
Blue-tailed Mole Skink	*Plestiodon egregius lividus*	Vertebrate
Blue-winged Warbler	*Vermivora cyanoptera*	Vertebrate
Bog Candles	*Lysimachia terrestris*	Plant
Bog Turtle	*Glyptemys muhlenbergii*	Vertebrate
Branching Draba	*Draba ramosissima*	Plant
Brimley's Chorus Frog	*Pseudacris brimleyi*	Vertebrate
Brittle Thatch Palm	*Thrinax morrisii*	Plant
Broadleaf Phlox	*Phlox amplifolia*	Plant
Broad-leaved Tickseed	*Coreopsis latifolia*	Plant
Brown Creeper	*Certhia americana*	Vertebrate
Brown Pelican	*Pelecanus occidentalis*	Vertebrate
Buck Creek Aster	*Symphyotrichum rhiannon*	Plant
Buttonbush Dodder	*Cuscuta cephalanthi*	Plant
Carolina Northern Flying Squirrel	*Glaucomys sabrinus coloratus*	Vertebrate
Carolina Saxifrage	*Micranthes caroliniana*	Plant
Carolina Spleenwort	*Asplenium heteroresiliens*	Plant
Carolina Watersnake	*Nerodia sipedon williamengelsi*	Vertebrate
Caspian Tern	*Hydroprogne caspia*	Vertebrate
Cerulean Warbler	*Dendroica cerulea*	Vertebrate
Chalky Indian-plantain	*Arnoglossum album*	Plant
Chapman's Crownbeard	*Verbesina chapmanii*	Plant
Chicken Turtle	*Deirochelys reticularia*	Vertebrate
Chicken Turtle	*Deirochelys reticularia*	Vertebrate
Christmas Berry	*Crossopetalum ilicifolium*	Plant
Cinereus Shrew	*Sorex cinereus*	Vertebrate
Cliff Spurge	*Euphorbia commutata*	Plant
Cliffside Goldenrod	*Solidago simulans*	Plant
Climbing Fumitory	*Adlumia fungosa*	Plant
Coachwhip	*Masticophis flagellum*	Vertebrate
Coastal Vervain	*Glandularia maritima*	Plant
Comfortroot	*Hibiscus aculeatus*	Plant
Common Rainbow Snake	*Farancia erytrogramma erytrogramma*	Vertebrate
Common Raven	*Corvus corax*	Vertebrate
Common Tern	*Sterna hirundo*	Vertebrate
Confederate Huckleberry	*Gaylussacia nana*	Plant

Copperbelly Watersnake	*Nerodia erythrogaster neglecta*	Vertebrate
Copperhead	*Agkistrodon contortrix*	Vertebrate
Corkwood	*Leitneria floridana*	Plant
Crested Caracara	*Caracara cheriway*	Vertebrate
Crevice Salamander	*Plethodon yonahlossee pop. 1*	Vertebrate
Cruise's Goldenaster	*Chrysopsis gossypina ssp. cruiseana*	Plant
Cumberland Azalea	*Rhododendron cumberlandense*	Plant
Curtiss' Sandgrass	*Calamovilfa curtissii*	Plant
Cuthbert's Turtlehead	*Chelone cuthbertii*	Plant
Delta Map Turtle	*Graptemys nigrinoda delticola*	Vertebrate
Diamondback Terrapin	*Malaclemys terrapin*	Vertebrate
Divided-leaf Ragwort	*Packera millefolium*	Plant
Dune Bluecurls	*Trichostema sp. 1*	Plant
Dwarf Black-bellied Salamander	*Desmognathus folkertsi*	Vertebrate
Dwarf Blackbelly Salamander	*Desmognathus folkertsi*	Vertebrate
Dwarf Siren	*Pseudobranchus striatus*	Vertebrate
Eastern Coral Snake	*Micrurus fulvius*	Vertebrate
Eastern Diamond-backed Rattlesnake	*Crotalus adamanteus*	Vertebrate
Eastern Henslow's Sparrow	*Ammodramus henslowii susurrans*	Vertebrate
Eastern Indigo Snake	*Drymarchon couperi*	Vertebrate
Eastern Indigo Snake	*Drymarchon couperi*	Vertebrate
Eastern Milk Snake	*Lampropeltis triangulum triangulum*	Vertebrate
Eastern Painted Bunting	*Passerina ciris ciris*	Vertebrate
Eastern Small-footed Myotis	*Myotis leibii*	Vertebrate
Egmont Key mole skink	*Plestiodon egregius pop. 1*	Vertebrate
Escambia Map Turtle	*Graptemys ernsti*	Vertebrate
Estuary Pipewort	*Eriocaulon parkeri*	Plant
Flattened Musk Turtle	*Sternotherus depressus*	Vertebrate
Flatwoods Salamander	*Ambystoma cingulatum*	Vertebrate
Florida Beargrass	*Nolina atopocarpa*	Plant
Florida Black Bear	*Ursus americanus floridanus*	Vertebrate
Florida Black Bear	*Ursus americanus floridanus*	Vertebrate
Florida Bog Frog	*Rana okaloosae*	Vertebrate
Florida Brown Snake	*Storeria dekayi victa*	Vertebrate
Florida Burrowing Owl	*Athene cunicularia floridana*	Vertebrate
Florida Burrowing Owl	*Athene cunicularia floridana*	Vertebrate
Florida Clapper Rail	*Rallus longirostris scottii*	Vertebrate
Florida Coontie	*Zamia integrifolia*	Plant
Florida Crowned Snake	*Tantilla relicta*	Vertebrate
Florida Five-petaled Leaf-flower	*Phyllanthus pentaphyllus var. floridanus*	Plant
Florida Grasshopper Sparrow	*Ammodramus savannarum floridanus*	Vertebrate
Florida Green Water Snake	*Nerodia floridana*	Vertebrate
Florida Keys Mole Skink	*Plestiodon egregius egregius*	Vertebrate

Florida Lantana	*Lantana depressa var. depressa*	Plant
Florida Long-tailed Weasel	*Mustela frenata peninsulae*	Vertebrate
Florida Mouse	*Podomys floridanus*	Vertebrate
Florida Mouse	*Podomys floridanus*	Vertebrate
Florida Panther	*Puma concolor coryi*	Vertebrate
Florida Pine Snake	*Pituophis melanoleucus mugitus*	Vertebrate
Florida Pine Snake	*Pituophis melanoleucus mugitus*	Vertebrate
Florida Pinewood Privet	*Forestiera segregata var. pinetorum*	Plant
Florida Prairie Warbler	*Setophaga discolor paludicola*	Vertebrate
Florida Redbelly Turtle	*Pseudemys nelsoni*	Vertebrate
Florida Scrub Frostweed	*Crocanthemum nashii*	Plant
Florida Scrub Lizard	*Sceloporus woodi*	Vertebrate
Florida Scrub Lizard	*Sceloporus woodi*	Vertebrate
Florida Scrub-Jay	*Aphelocoma coerulescens*	Vertebrate
Florida Scrub-Jay	*Aphelocoma coerulescens*	Vertebrate
Florida Skullcap	*Scutellaria floridana*	Plant
Florida Softshell	*Apalone ferox*	Vertebrate
Florida Thatch Palm	*Thrinax radiata*	Plant
Florida Waxweed	*Cuphea aspera*	Plant
Florida Worm Lizard	*Rhineura floridana*	Vertebrate
Fraser's Loosestrife	*Lysimachia fraseri*	Plant
Fruitful Locust	*Robinia hispida var. fertilis*	Plant
Giant Water-dropwort	*Oxypolis greenmanii*	Plant
Glossy Crayfish Snake	*Regina rigida*	Vertebrate
Glossy Crayfish Snake	*Regina rigida*	Vertebrate
Glossy Ibis	*Plegadis falcinellus*	Vertebrate
Godfrey's Blazing Star	*Liatris provincialis*	Plant
Godfrey's Goldenaster	*Chrysopsis godfreyi*	Plant
Golden Leather Fern	*Acrostichum aureum*	Plant
Gopher Tortoise	*Gopherus polyphemus*	Vertebrate
Gopher Tortoise	*Gopherus polyphemus*	Vertebrate
Granite Dome Goldenrod	*Solidago simulans*	Plant
Great Egret	*Ardea alba*	Vertebrate
Great White Heron	*Ardea herodias occidentalis*	Vertebrate
Greater Sandhill Crane	*Grus canadensis tabida*	Vertebrate
Green Flatsedge	*Cyperus virens*	Plant
Green Salamander	*Aneides aeneus*	Vertebrate
Greenland Sandwort	*Minuartia groenlandica*	Plant
Gulf Coast Lupine	*Lupinus westianus*	Plant
Gulf Coast Smooth Softshell	*Apalone mutica calvata*	Vertebrate
Gulf Salt Marsh Snake	*Nerodia clarkii clarkii*	Vertebrate
Gulf Saltmarsh Watersnake	*Nerodia clarkii clarkii*	Vertebrate
Gull-billed Tern	*Gelochelidon nilotica*	Vertebrate

Hairy-tailed Mole	*Parascalops breweri*	Vertebrate
Hawksbill Seaturtle	*Eretmochelys imbricata*	Vertebrate
Heartleaf Hedge-nettle	*Stachys cordata*	Plant
Hermit Thrush	*Catharus guttatus*	Vertebrate
Highland Rush	*Juncus trifidus*	Plant
Island Glass Lizard	*Ophisaurus compressus*	Vertebrate
Joewood	*Jacquinia keyensis*	Plant
Johnson's Seagrass	*Halophila johnsonii*	Plant
Kelsey's Locust	*Robinia hispida var. kelseyi*	Plant
Kemp's or Atlantic Ridley	*Lepidochelys kempii*	Vertebrate
Key Deer	*Odocoileus virginianus clavium*	Vertebrate
Key Largo Woodrat	*Neotoma floridana smalli*	Vertebrate
Key Ringneck Snake	*Diadophis punctatus acricus*	Vertebrate
Key Vaca Raccoon	*Procyon lotor auspicatus*	Vertebrate
Key West Raccoon	*Procyon lotor incautus*	Vertebrate
Key West Raccoon	*Procyon lotor incautus*	Vertebrate
Lance-leaf Seedbox	*Ludwigia lanceolata*	Plant
Largeleaf Pondweed	*Potamogeton amplifolius*	Plant
Large-leaved Jointweed	*Polygonella macrophylla*	Plant
Large-leaved Jointweed	*Polygonella macrophylla*	Plant
Least Bittern	*Ixobrychus exilis*	Vertebrate
Least Tern	*Sternula antillarum*	Vertebrate
Least Weasel	*Mustela nivalis*	Vertebrate
Leatherback	*Dermochelys coriacea*	Vertebrate
Limpkin	*Aramus guarauna*	Vertebrate
Limpkin	*Aramus guarauna*	Vertebrate
Linear-leaved Willow-herb	*Epilobium leptophyllum*	Plant
Little Blue Heron	*Egretta caerulea*	Vertebrate
Little-spike Spikerush	*Eleocharis parvula*	Plant
Locustberry	*Byrsonima lucida*	Plant
Loggerhead	*Caretta caretta*	Vertebrate
Loggerhead Shrike	*Lanius ludovicianus*	Vertebrate
Longleaf Stitchwort	*Stellaria longifolia*	Plant
Long-stalked Holly	*Ilex collina*	Plant
Longstem Adder's-tongue Fern	*Ophioglossum petiolatum*	Plant
Long-tailed or Rock Shrew	*Sorex dispar*	Vertebrate
Long-tailed Shrew	*Sorex dispar*	Vertebrate
Louisiana Waterthrush	*Seiurus motacilla*	Vertebrate
Lower Keys Cotton Rat	*Sigmodon hispidus exsputus*	Vertebrate
Lower Keys Rabbit	*Sylvilagus palustris hefneri*	Vertebrate
Lower Keys Rabbit	*Sylvilagus palustris hefneri*	Vertebrate
Lowland Loosestrife	*Lysimachia hybrida*	Plant
Magnolia Warbler	*Dendroica magnolia*	Vertebrate

Mangrove Berry	*Psidium longipes*	Plant
Mangrove Cuckoo	*Coccyzus minor*	Vertebrate
Mangrove Rivulus	*Rivulus marmoratus*	Vertebrate
Many-lined Salamander	*Stereochilus marginatus*	Vertebrate
Marian's Marsh Wren	*Cistothorus palustris marianae*	Vertebrate
Marsh Marigold	*Caltha palustris*	Plant
Masked Shrew	*Sorex cinereus*	Vertebrate
Meehania	*Meehania cordata*	Plant
Merlin	*Falco columbarius*	Vertebrate
Migrant Loggerhead Shrike	*Lanius ludovicianus migrans*	Vertebrate
Milkbark	*Drypetes diversifolia*	Plant
Mimic Glass Lizard	*Ophisaurus mimicus*	Vertebrate
Mississippi Green Water Snake	*Nerodia cyclopion*	Vertebrate
Mississippi Green Watersnake	*Nerodia cyclopion*	Vertebrate
Mississippi Kite	*Ictinia mississippiensis*	Vertebrate
Mole Snake	*Lampropeltis calligaster*	Vertebrate
Mountain Bittercress	*Cardamine clematitis*	Plant
Mountain Clematis	*Clematis occidentalis var. occidentalis*	Plant
Mountain Golden-heather	*Hudsonia montana*	Plant
Mountain Paper Birch	*Betula cordifolia*	Plant
Mountain Sandwort	*Minuartia groenlandica*	Plant
Mountain St. John's-wort	*Hypericum graveolens*	Plant
Mountain Sweet Pitcher Plant	*Sarracenia jonesii*	Plant
Mountain Watercress	*Cardamine rotundifolia*	Plant
Myrtle-leaf Oak	*Quercus myrtifolia*	Plant
Narrow-leaved Gentian	*Gentiana linearis*	Plant
Nightflowering Wild Petunia	*Ruellia noctiflora*	Plant
Nodding Pinweed	*Lechea cernua*	Plant
Northern Beechfern	*Phegopteris connectilis*	Plant
Northern Blue Cohosh	*Caulophyllum giganteum*	Plant
Northern Coal Skink	*Eumeces anthracinus anthracinus*	Vertebrate
Northern Evening-primrose	*Oenothera parviflora*	Plant
Northern Florida Swamp Snake	*Seminatrix pygaea pygaea*	Vertebrate
Northern Lady Fern	*Athyrium filix-femina ssp. angustum*	Plant
Northern Lowbush Blueberry	*Vaccinium angustifolium*	Plant
Northern Mole Skink	*Eumeces egregius similis*	Vertebrate
Northern Pigmy Salamander	*Desmognathus organi*	Vertebrate
Northern Saw-whet Owl	*Aegolius acadicus*	Vertebrate
Northern Yellow Bat	*Lasiurus intermedius*	Vertebrate
Oak Toad	*Bufo quercicus*	Vertebrate
Oconee Bells	*Shortia galacifolia*	Plant
Olive-sided Flycatcher	*Contopus cooperi*	Vertebrate
Osprey	*Pandion haliaetus*	Vertebrate

Oswego Tea	*Monarda didyma*	Plant
Painted Bunting	*Passerina ciris*	Vertebrate
Painted Bunting	*Passerina ciris*	Vertebrate
Pale Corydalis	*Corydalis sempervirens*	Plant
Peregrine Falcon	*Falco peregrinus*	Vertebrate
Phlox-leaved Aster	*Symphyotrichum phlogifolium*	Plant
Pigmy Rattlesnake	*Sistrurus miliarius*	Vertebrate
Pine or Gopher Snake	*Pituophis melanoleucus*	Vertebrate
Pine Woods Snake	*Rhadinaea flavilata*	Vertebrate
Pineland Jacquemontia	*Jacquemontia curtissii*	Plant
Pineland Noseburn	*Tragia saxicola*	Plant
Pink Turtlehead	*Chelone lyonii*	Plant
Piping Plover	*Charadrius melodus*	Vertebrate
Plymouth Gentian	*Sabatia kennedyana*	Plant
Porter's Broad-leaved Spurge	*Chamaesyce porteriana*	Plant
Powdery Thalia	*Thalia dealbata*	Plant
Prairie Bold Goldenrod	*Solidago rigida var. rigida*	Plant
Pride-of-big-pine	*Strumpfia maritima*	Plant
Purple Bee-balm	*Monarda media*	Plant
Purple Gallinule	*Porphyrio martinica*	Vertebrate
Purple Giant Hyssop	*Agastache scrophulariifolia*	Plant
Purple Silkyscale	*Anthaenantia rufa*	Plant
Purpleleaf Willowherb	*Epilobium ciliatum*	Plant
Rainbow Snake	*Farancia erytrogramma*	Vertebrate
Red Rat Snake, Lower Keys Pop	*Pantherophis guttatus pop. 1*	Vertebrate
Red Turtlehead	*Chelone obliqua*	Plant
Red-cockaded Woodpecker	*Picoides borealis*	Vertebrate
Red-cockaded Woodpecker	*Picoides borealis*	Vertebrate
Reddish Egret	*Egretta rufescens*	Vertebrate
Red-headed Woodpecker	*Melanerpes erythrocephalus*	Vertebrate
Red-legged Salamander	*Plethodon shermani*	Vertebrate
Rhacoma	*Crossopetalum rhacoma*	Plant
Rim Rock Crowned Snake	*Tantilla oolitica*	Vertebrate
Roan Mountain Bluet	*Hedyotis purpurea var. montana*	Plant
Robin Runaway	*Rubus dalibarda*	Plant
Rock Skullcap	*Scutellaria saxatilis*	Plant
Roseate Spoonbill	*Platalea ajaja*	Vertebrate
Roseate Tern	*Sterna dougallii*	Vertebrate
Roseroot	*Rhodiola rosea*	Plant
Rosy Twisted-stalk	*Streptopus roseus*	Plant
Rough Bedstraw	*Galium asprellum*	Plant
Rough Hawkweed	*Hieracium scabrum*	Plant
Roundleaf Serviceberry	*Amelanchier sanguinea*	Plant

Round-leaf Watercress	*Cardamine rotundifolia*	Plant
Round-tailed Muskrat	*Neofiber alleni*	Vertebrate
Royal Tern	*Thalasseus maximus*	Vertebrate
Saltmarsh Spikerush	*Eleocharis halophila*	Plant
Sandwich Tern	*Thalasseus sandvicensis*	Vertebrate
Santeetlah Dusky Salamander	*Desmognathus santeetlah*	Vertebrate
Scott's Seaside Sparrow	*Ammodramus maritimus peninsulae*	Vertebrate
Scott's Seaside Sparrow	*Ammodramus maritimus peninsulae*	Vertebrate
Sea Lavender	*Argusia gnaphalodes*	Plant
Seabeach Amaranth	*Amaranthus pumilus*	Plant
Seepage Salamander	*Desmognathus aeneus*	Vertebrate
Shale-barren Blazing-star	*Liatris turgida*	Plant
Sharp-shinned Hawk	*Accipiter striatus*	Vertebrate
Sherman's Fox Squirrel	*Sciurus niger shermani*	Vertebrate
Sherman's Fox Squirrel	*Sciurus niger shermani*	Vertebrate
Shooting-star	*Dodecatheon meadia*	Plant
Shoreline Sea-purslane	*Sesuvium portulacastrum*	Plant
Shore-line Sedge	*Carex hyalinolepis*	Plant
Short-tailed Hawk	*Buteo brachyurus*	Vertebrate
Short-tailed Snake	*Lampropeltis extenuata*	Vertebrate
Shovel-nosed Salamander	*Desmognathus marmoratus*	Vertebrate
Silver Palm	*Coccothrinax argentata*	Plant
Silverling	*Baccharis glomeruliflora*	Plant
Slender Glass Lizard	*Ophisaurus attenuatus attenuatus*	Vertebrate
Small Sundrops	*Oenothera perennis*	Plant
Small's Beardtongue	*Penstemon smallii*	Plant
Smoky Mountains Mannagrass	*Glyceria nubigena*	Plant
Snail Kite	*Rostrhamus sociabilis plumbeus*	Vertebrate
Snowy Egret	*Egretta thula*	Vertebrate
Snowy Plover	*Charadrius nivosus*	Vertebrate
Southeastern Beach Mouse	*Peromyscus polionotus niveiventris*	Vertebrate
Southeastern Beach Mouse	*Peromyscus polionotus niveiventris*	Vertebrate
Southeastern Fox Squirrel	*Sciurus niger niger*	Vertebrate
Southeastern Myotis	*Myotis austroriparius*	Vertebrate
Southeastern Myotis	*Myotis austroriparius*	Vertebrate
Southeastern Pocket Gopher	*Geomys pinetis*	Vertebrate
Southeastern Weasel	*Mustela frenata olivacea*	Vertebrate
Southern Appalachian Black-capped Chickadee	*Poecile atricapillus practica*	Vertebrate
Southern Appalachian Red Crossbill	*Loxia curvirostra pop. 1*	Vertebrate
Southern Appalachian Salamander	*Plethodon teyahalee*	Vertebrate
Southern Appalachian Woodrat	*Neotoma floridana haematoreia*	Vertebrate
Southern Bog Lemming	*Synaptomys cooperi*	Vertebrate
Southern Hognose Snake	*Heterodon simus*	Vertebrate

Southern Hognose Snake	*Heterodon simus*	Vertebrate
Southern Pigmy Salamander	*Desmognathus wrighti*	Vertebrate
Southern Pygmy Shrew	*Sorex hoyi*	Vertebrate
Southern Red-backed Vole	*Clethrionomys gapperi*	Vertebrate
Southern Rock Vole	*Microtus chrotorrhinus carolinensis*	Vertebrate
Southern Water Shrew	*Sorex palustris punctulatus*	Vertebrate
Southern Zigzag Salamander	*Plethodon ventralis*	Vertebrate
Spoon-leaved Sundew	*Drosera intermedia*	Plant
Spotfin Killifish	*Fundulus luciae*	Vertebrate
Spottail Goby	*Ctenogobius stigmaturus*	Vertebrate
Spotted Turtle	*Clemmys guttata*	Vertebrate
Spreading Avens	*Geum radiatum*	Plant
Squarrose Goldenrod	*Solidago squarrosa*	Plant
Squirrel-corn	*Dicentra canadensis*	Plant
Stone Mountain Mint	*Pycnanthemum curvipes*	Plant
Striped Mud Turtle - Lower Florida Keys	*Kinosternon baurii pop. 1*	Vertebrate
Suwannee Cooter	*Pseudemys concinna suwanniensis*	Vertebrate
Swainson's Thrush	*Catharus ustulatus*	Vertebrate
Swallow-tailed Kite	*Elanoides forficatus*	Vertebrate
Swamp Saxifrage	*Micranthes pensylvanica*	Plant
Sweet Gale	*Myrica gale*	Plant
Sweet Indian-plantain	*Senecio suaveolens*	Plant
Sweet-fern	*Comptonia peregrina*	Plant
Tennessee Mountain-mint	*Pycnanthemum curvipes*	Plant
Thick-leaved Water-willow	*Justicia crassifolia*	Plant
Three-toothed Cinquefoil	*Potentilla tridentata*	Plant
Tiny-leaved Buckthorn	*Sageretia minutiflora*	Plant
Toothed Flatsedge	*Cyperus dentatus*	Plant
Tricolored Heron	*Egretta tricolor*	Vertebrate
Umbrella-leaf	*Diphylleia cymosa*	Plant
Virginia Big-eared Bat	*Corynorhinus townsendii virginianus*	Vertebrate
Virginia Stickseed	*Hackelia virginiana*	Plant
Warbling Vireo	*Vireo gilvus*	Vertebrate
Wehrle's Salamander	*Plethodon wehrlei*	Vertebrate
Weller's Salamander	*Plethodon welleri*	Vertebrate
West Indies Mahogany	*Swietenia mahagoni*	Plant
White Birds-in-a-nest	*Macbridea alba*	Plant
White Heath Aster	*Symphyotrichum ericoides var. ericoides*	Plant
White Ibis	*Eudocimus albus*	Vertebrate
White-crowned Pigeon	*Patagioenas leucocephala*	Vertebrate
White-top Pitcherplant	*Sarracenia leucophylla*	Plant
Wild Bleeding-heart	*Dicentra eximia*	Plant
Wilson's Plover	*Charadrius wilsonia*	Vertebrate

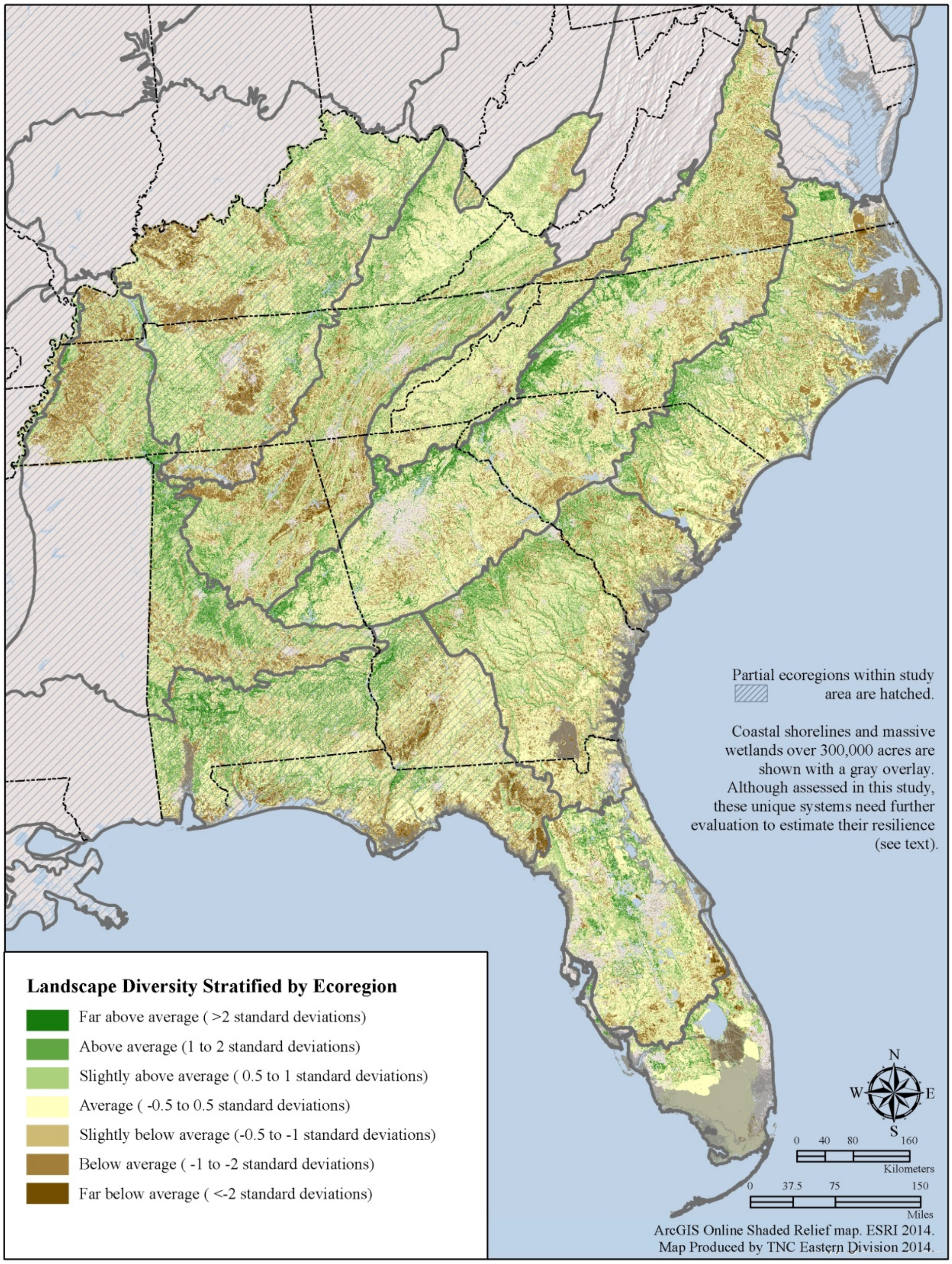
Wood Stork	*Mycteria americana*	Vertebrate
Woodland Jumping Mouse	*Napaeozapus insignis*	Vertebrate
Yellow Bead-lily	*Clintonia borealis*	Plant
Yellow-bellied Sapsucker	*Sphyrapicus varius*	Vertebrate
Yellow-crowned Night-heron	*Nyctanassa violacea*	Vertebrate
Yellow-rumped Warbler	*Dendroica coronata*	Vertebrate
Yonahlossee Salamander	*Plethodon yonahlossee*	Vertebrate

APPENDIX

Additional Review Maps

III

Landscape Diversity – stratified by Ecoregion



Partial ecoregions within study ▨ area are hatched.

Coastal shorelines and massive wetlands over 300,000 acres are shown with a gray overlay. Although assessed in this study, these unique systems need further evaluation to estimate their resilience (see text).

ArcGIS Online Shaded Relief map. ESRI 2014.
Map Produced by TNC Eastern Division 2014.

Local Connectedness – stratified by Ecoregion