Resilient Sites
for Terrestrial Conservation
in the Great Plains Region

Mark Anderson, Marissa Ahlering,
Melissa Clark, Kimberly Hall,
Arlene Olivero Sheldon,
Jim Platt & John Prince

The Nature Conservancy
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Resilient Sites for Terrestrial Conservation in the Great Plains Region.
June 14, 2018.

The Nature Conservancy, Eastern Conservation Science
Eastern Regional Office
99 Bedford St, 5th Floor
Boston, MA 02111
eScience@tnc.org

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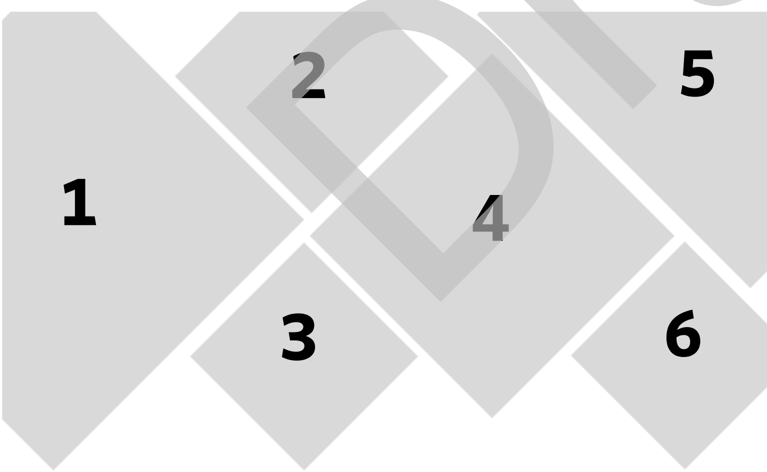

About the Cover:

1. Silky prairie clover and restored sand prairie at The Nature Conservancy's Platte River Prairies, Nebraska. © Chris Helzer

2. Bison, key grassland ecosystem engineers, graze on tallgrass prairie at The Nature Conservancy's Tallgrass Prairie Preserve in Pawhuska, Oklahoma. Their grazing patterns play a key role in growing plant diversity, spreading seeds and maintaining healthy grass height, all of which have cascading effects that support other wildlife. © Morgan Heim

3. Bug (Hemiptera) on purple prairie clover at The Nature Conservancy's Platte River Prairies, Nebraska. © Chris Helzer/TNC

4. TNC Niobrara Valley Preserve, Brown County Nebraska. Sandhills prairie. May 1999. Central Mixed-Grass Ecoregion. © Chris Helzer

5. Sandhill cranes roosting in Central Platte River. Early morning in March 1999. Studnicka Tract – The Nature Conservancy. Central Mixed-Grass Ecoregion. © Chris Helzer/TNC

6. Four-point evening primrose (Oenothera rhombipetala) and sunrise in sand prairie at The Nature Conservancy's Platte River Prairies, Nebraska. © Chris Helzer

The authors dedicate this report, and our continuing work to highlight places where conservation actions are most needed to sustain the wild and wandering flow of nature, to our dear friend and colleague Dr. Brad McRae.

The power of imagination makes us infinite

– John Muir

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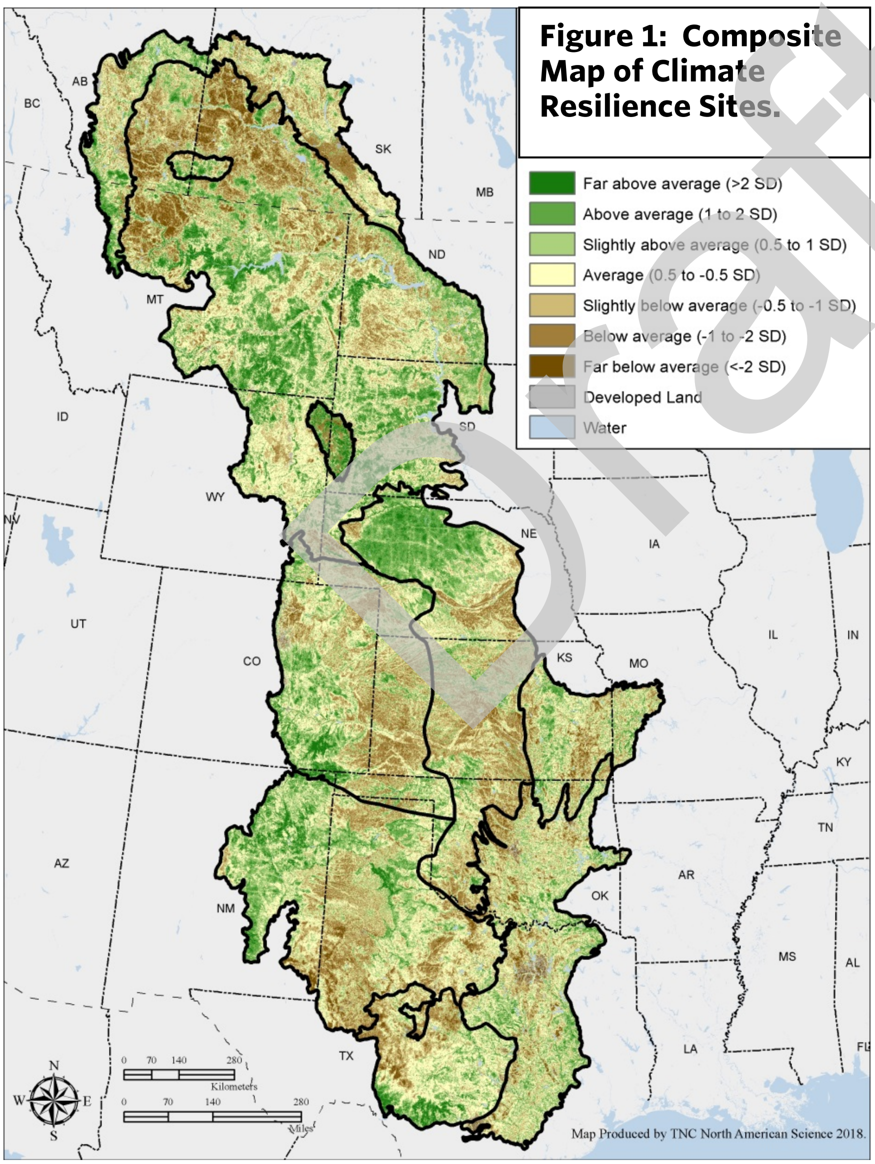
EXECUTIVE SUMMARY

Resilient Sites in the Great Plains Region <u>June 2018</u>

This report presents the results of a 3-year project to identify and map climate resilient sites across the Great Plains region of the United States and Canada (Figure 1). The work was made possible by a grant from the Doris Duke Charitable Foundation, along with matching funds from the many State Chapter and Regional Offices of The Nature Conservancy (TNC) within the central US. It will be followed by a second report on climate corridors and confirmed biological diversity areas to identify a resilient and connected network of sites.



We gratefully acknowledge the support of twenty-nine scientists and conservation planners from across the region that served on our Steering Committee[1], and helped us adapt our methods to the ecological drivers, biodiversity patterns, and land use characteristics that define this region.

Figure 1. Composite Map of Climate Resilient Sites. In each ecoregion (dark outlines), areas in green scored above-average and are estimated to be more climate resilient. Areas in brown received below-average scores, suggesting these sites may be more vulnerable to climate change impacts.

[1] See acknowledgments for full list of contributors

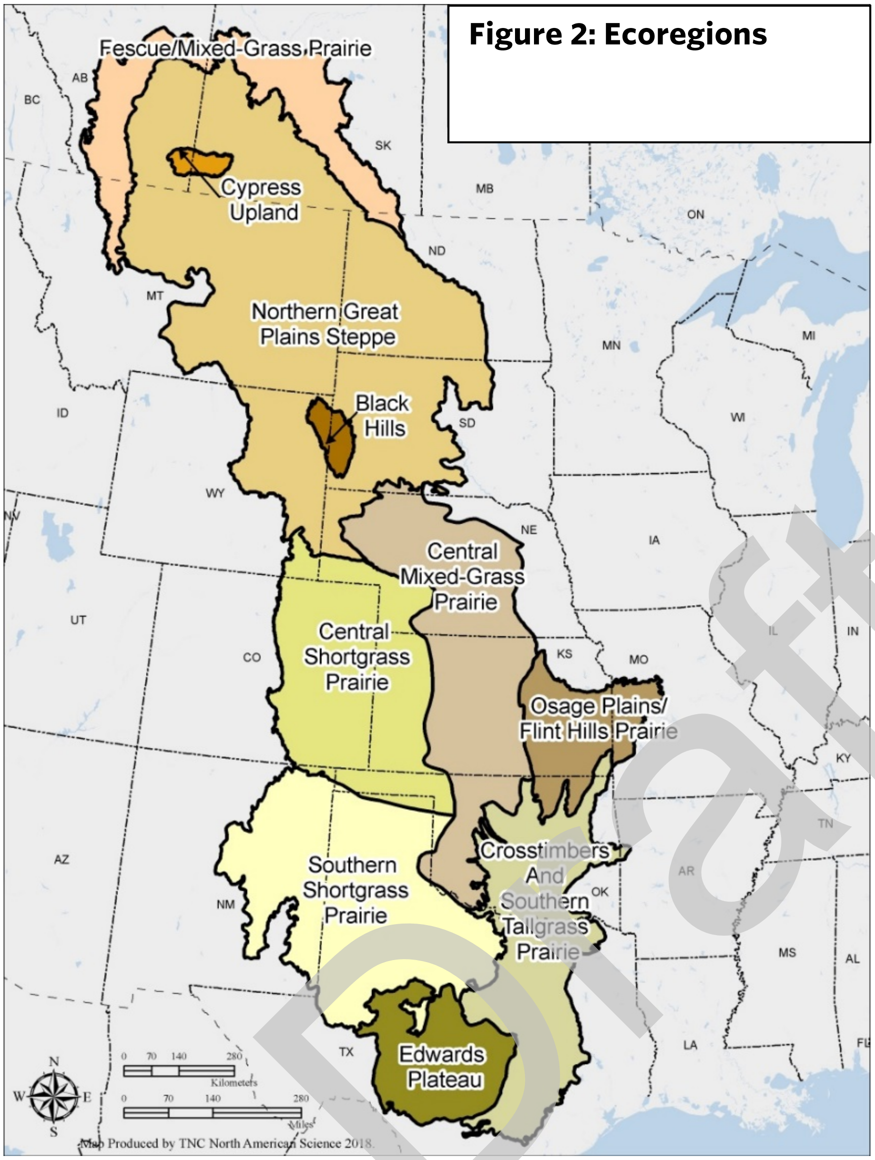


Figure 2: Ecoregions

The Great Plains region includes ten TNC ecoregions (Figure 2), and encompasses portions of twelve states: MT, ND, SD, WY, NE, CO, KS, MO, NM, OK, AR, and TX. We analyzed these ecoregions in their entirety, which led us to include portions of two Canadian provinces, Alberta and Saskatchewan, in our assessment. Ecoregions are large contiguous units of land with similar environmental conditions, a roughly similar climate, and a distinct assemblage of natural communities and species. They provide a needed ecological context for understanding landscape-scale conservation activities. We describe resilience scores and trends by ecoregion, and roll the ecoregion results up to a composite map of the full study area (Figure 1).

Climate change projections suggest the Great Plains region is likely to show some of the highest warming rates in North America. These temperature increases, along with a tendency toward more extreme precipitation patterns, will likely impact many sensitive species. These changes will occur far from coastal regions or mountain ranges that offer large-scale gradients in regional temperature, thus putting more emphasis on microclimatic refugia. The need to identify “climate-resilient” sites most likely to support species adaptation in the Great Plains was further heightened by the extensive loss of native prairie biodiversity and degradation of key processes in this region that have occurred over more than a century of grassland conversion and species extirpations.

Climate Resilient Sites: We defined site resilience as *the capacity of a site to maintain biological diversity, productivity and ecological function as the climate changes.*[2] This means that the character of the existing ecosystem, such as species assemblages and structures, may change even as the core functions and biodiversity of the evolving ecosystem continue to provide the ecosystem services we value. Site resilience differs from the classic definition of resilience in the ecological literature, which holds that an ecosystem demonstrates resilience if it quickly returns to a steady-state equilibrium after a disturbance.[3] Under changing conditions, however, there is no steady-state to return to. Over time, the definition of resilience in the published literature has evolved to include changing environments—for example Gunderson's (2000) definition, "the capacity for renewal in a dynamic environment."[4] The meaning also varies depending on the object being impacted (e.g., wildlife species, plant communities, human communities). The American Heritage Dictionary defines resilience as "the ability to recover quickly after change or misfortune." Our definition of resilient sites, actual mapped places, revives an idea of land health that originated with Aldo Leopold: "Health is the capacity of the land for self-renewal. Conservation is our effort to understand and preserve this capacity."[5]

Resilient sites will likely change in composition in response to a changing climate, but if adequately conserved they will be more likely to continue to support a diversity of species into the future that reflect the individual character (i.e., soil type, topography, etc.) of the site. Vulnerable sites may also be important to biodiversity and ecosystem services, but are more likely to lose diversity and/or show evidence of degradation as the climate changes.

[2] Anderson et al. (2014b)
[3] Holling (1973)
[4] Gunderson (2000)
[5] Leopold (1949)

Conserving Nature's Stage (Chapter 2)

Diversity and productivity are relative to a site's physical character because soils and bedrock differ in their inherent qualities (Figure 2). The deep loess deposits underlying the fertile prairies in the east-central section of the Great Plains region support a diversity of native species quite different from what is found on shallow soils derived from sandstone and shale in the woodlands and forests of the Black Hills. While some prairie species are widely distributed, the mix of species and the productivity of prairie on loess soils differs from those on sand, or those on saline substrates. The current biota of these different geophysical settings reflects contrasting site conditions, and while each type of site is expected to shift over time through a process of immigration and establishment of new species, the new species that persist are likely to be adapted to these different physical and chemical characteristics. Thus, to conserve biological diversity in a changing world, a key step is to conserve the full spectrum of geophysical environments that create diversity in the first place. In this region, that means the loess, silts and calcareous loams of the prairies as well as the bedrock of the forests, canyons, and caves (Figure 3).

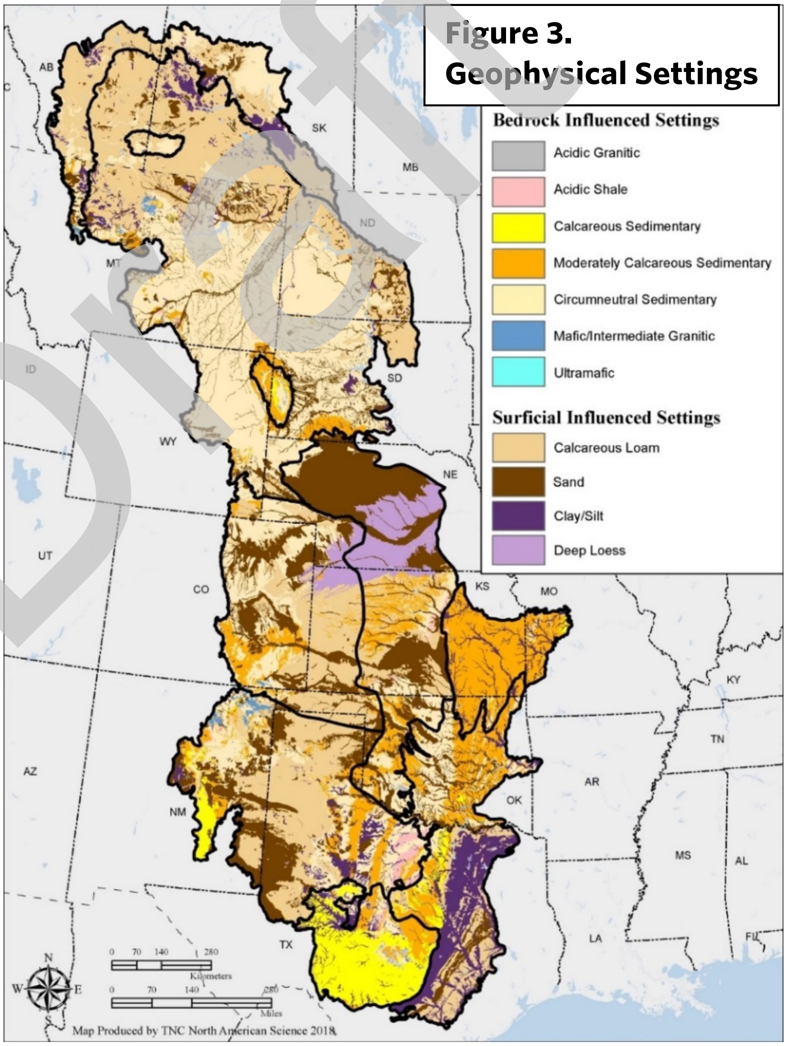


Figure 3. Geophysical Settings

This approach to biodiversity conservation, known colloquially as Conserving Nature's Stage (CNS), is a strategy to account for the uncertainty attendant to climate change[6], and it is supported by extensive evidence[7]. To extend G. E. Hutchinson's (1965) metaphor of the ecological theater and the evolutionary play, we should focus on conserving a variety of geophysical settings as "stages" for the ever-changing cast of

[6] Hunter et al. (1988)
[7] Bier et al. (2015), Lawler et al. (2015), Anderson and Ferree (2010)

actors on the move in the climate change era. The approach provides a framework for conserving current and future biological diversity while allowing species and communities to rearrange in response to change.

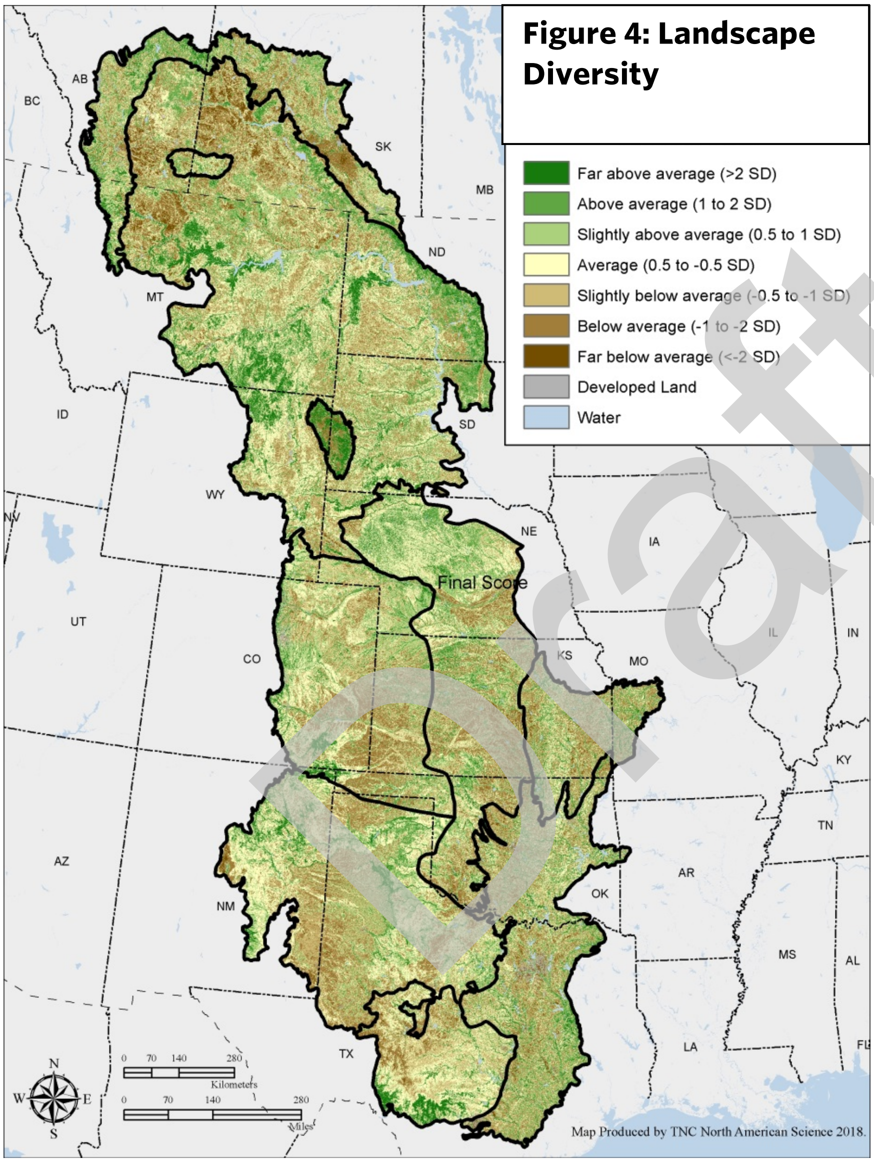
Mapping Resilient Sites (Chapter 3)

The Nature Conservancy and its partners have spent years identifying resilient places as part of a network of sites and linkages that, if conserved, would sustain the diversity of a region[8]. We accomplished this task by studying how species associate with certain geologic settings, how topographic micro-climates buffer species from the regional climate, and how natural cover and riparian corridors connect essential landscape features.

The CNS approach to identifying a network of resilient sites in the Central U.S. and Canada is based on two key observations. First, species diversity is highly correlated with geophysical diversity. Abiotic factors, like soils and topography, shape the region's ecosystems and influence the distribution of biodiversity. Evidence from the past or from other climatic regions suggest that these drivers will continue to influence the distribution and abundance of species, as climatic conditions change. Second, under a changing climate species take advantage of local microclimates to persist in the landscape. Yet, species populations can use microclimates to adjust to change only if the area is permeable and well connected. The core concept of this research lies in protecting examples of all geophysical settings and identifying those sites with the most microclimate diversity and highest landscape permeability. Chapter 3 describes the site-based characteristics that promote function and diversity and the methods we used to assess and map them. Our estimates of site resilience were based on landscape diversity and local connectedness. These two properties were assessed for every 30-m patch of land and then summed to create a resilience score for each patch.

[8] Anderson et al. (2012), (2014a), Buttrick et al. (2015)

Landscape Diversity (Figure 4) estimates the number of microclimates available within a given area. It is measured by counting the variety of landforms, and the density and connectivity of wetlands. Microclimate diversity buffers species against regional climatic effects by providing a range of local climates, many of which might be suitable for a species under stress. At a site, we expect high landscape diversity to increase species persistence and slow the transition to new communities.



Local Connectedness (Figure 5) is defined as the number of barriers and the degree of fragmentation within the same area. A highly permeable landscape promotes resilience by facilitating population movements and the reorganization of communities. Roads, development, industrial agriculture, and other structures create resistance that interrupts or redirects movement. Maintaining a connected landscape is the most widely cited strategy for building resilience.

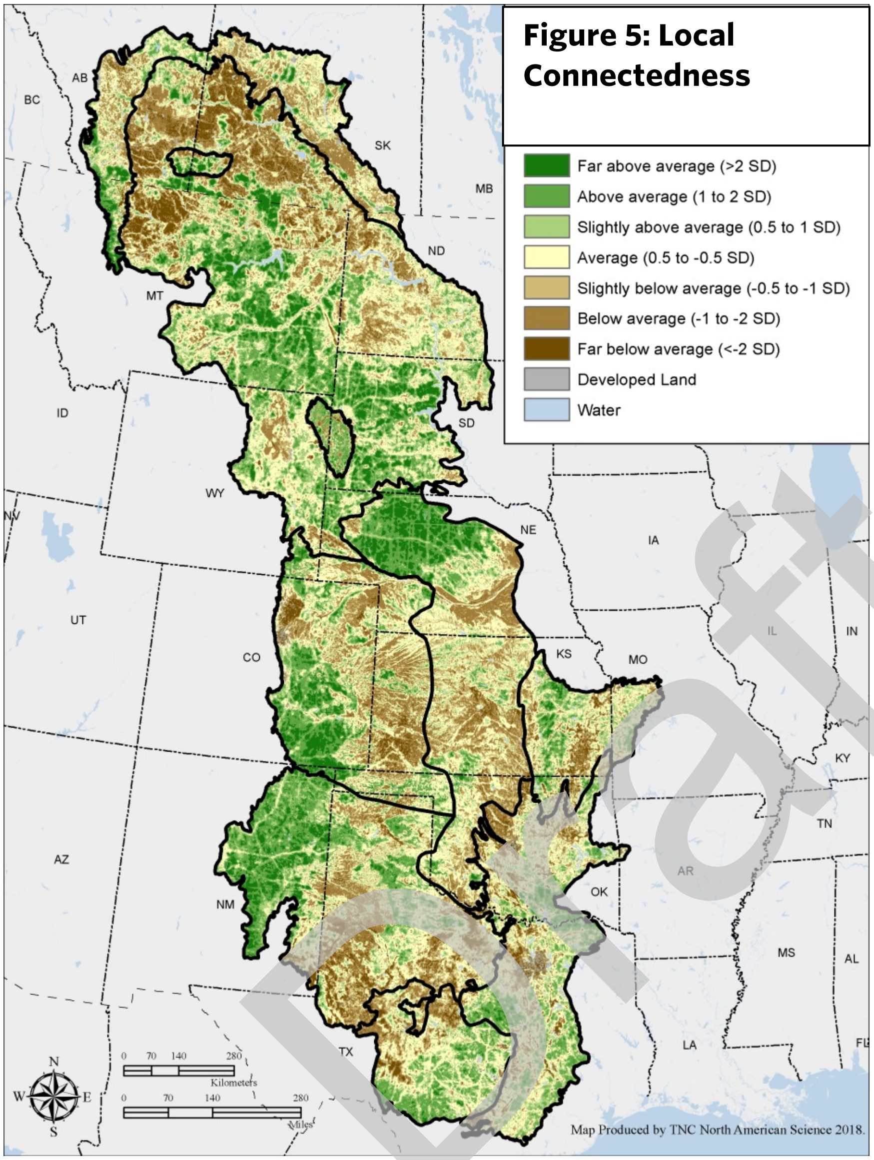
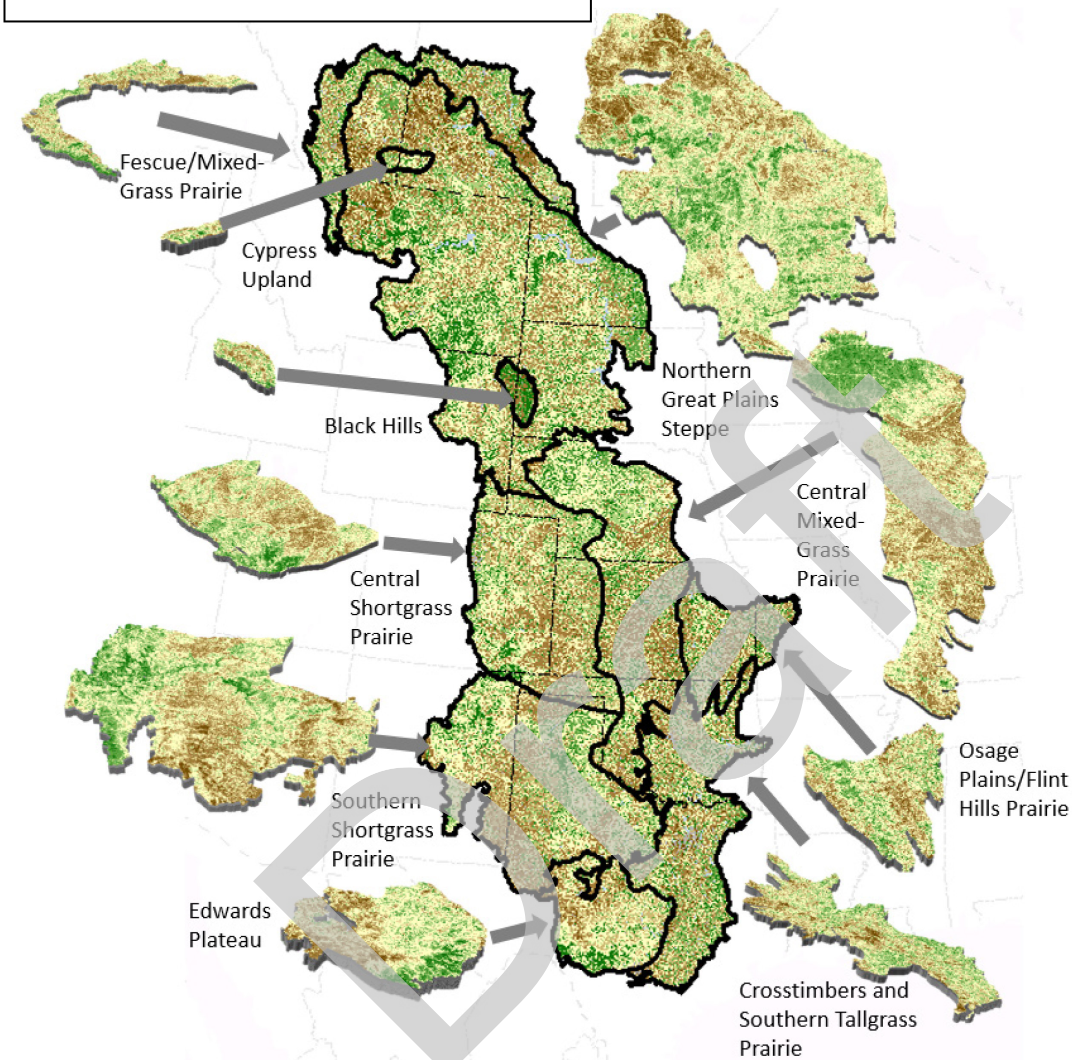


Figure 5: Local Connectedness

Resilience Scores (Chapters 4 and 5)

Resilience scores are presented in units of standard deviations (SD) above or below the mean score for a geophysical setting within an ecoregion. For example, a score of 2 SD ("far above average") for a patch of limestone bedrock in the Edwards Plateau ecoregion indicates that the patch scored higher than 98% (+2 SD) of the other limestone patches in the ecoregion. Thus, the limestone patch (calcareous sedimentary setting) had more microclimates and was more connected than almost all other patches in the ecoregion; as a result, it is considered a resilient site.

Figure 6: Ecoregions by Resilience



The legend is interpreted as follows:

Score	Numeric Value	Meaning	Interpretation
Far below average	(<-2 SD)	Below 98%	**Most Vulnerable**
Below average	(-1 to -2 SD)	Below 84%	**More Vulnerable**
Slightly below average	(-0.5 to -1 SD)	Below 69%	**Somewhat Vulnerable**
Average	(-0.5 to 0.5 SD)	Between 31-69%	**Average**
Slightly above average	(0.5 to 1 SD)	Above 69%	**Somewhat Resilient**
Above average	(1- 2 SD)	Above 84%	**More Resilient**
Far above average	(>2 SD)	Above 98%	**Most Resilient**

The composite map (Figure 6) is an efficient way to display all the resilience information in a single map, but users should remember that the scores are relative to setting and ecoregion. A resilience score of +2 SD in the more fragmented Fescue/Mixed-Grass Prairie ecoregion is not equivalent in an absolute sense to a resilience score of +2 SD in the more intact regions of the Northern Great Plains Steppe, because the average score of the latter ecoregion is higher. This relative scale was intentionally used to identify resilient areas across the full range of geophysical settings, and by association, capture the full range of biological diversity. If, for example, biological diversity was concentrated only on the sandstone settings that support many of the region's shortgrass and mixed-grass prairies, then we could conserve diversity simply by focusing on sandstone-based of sites. However, that approach would miss all the inherent diversity of the loess prairie systems of Nebraska and Kansas, the sandhill systems that support many of Texas' endemic plants, and the limestone outcrops that provide essential habitats for rare snails in the Black Hills.

Using the Results for Conservation Decisions

Habitats at Risk

The ratio of conversion to securement—the conservation risk index—can provide an idea of the relative vulnerability of a setting to the threat of conversion. We calculated these ratios and found that deep loess had the highest risk (102 to 1), followed by clay/silt (13 to 1) and calcareous loam (12 to 1). Overall, settings with relatively fertile soils (e.g., deep loess, clay/silt, calcareous loam) had the highest risk, while acidic settings (e.g. acidic granitic, mafic/intermediate granitic) were less converted and more secured. However, even in the heavily converted settings such as deep loess we found that roughly 50% of the remaining unconverted deep loess setting scored high for resilience and could theoretically be secured for conservation. By studying the locations of resilient unsecured lands, practitioners can focus attention on at-risk settings and begin to address disparities in conservation coverage.

Natural Strongholds

More than half of the areas selected for their rare species or exemplary communities in The Nature Conservancy's ecoregional portfolio also scored high (58%) or average (30%) for climate resilience. The high-scoring sites make good targets for land protection or restoration because as natural strongholds for biodiversity, the biota will be buffered from the regional effects of climate change. The inevitable transition to new communities in these places will be slower and more manageable. Additionally, the presence of confirmed diversity suggests that the geophysical properties of these sites are in good condition, and that they are good candidates for sustaining biodiversity into the future.

Key Messages

1) Resilient sites are those we expect to sustain biological diversity and ecological functions even as they change in composition in response to a changing climate.
2) Vulnerable sites may also be important to biodiversity and ecosystem services, but are more likely to degrade or lose diversity as the climate changes.
3) The resilience map shows the estimated climate-resilience of every 30-meter square of land in each ecoregion relative to the soil or bedrock type the land represents. Scores range from +3 (most resilient) to -3 (most vulnerable). http://maps.tnc.org/resilientland/
4) Resilience scores reflect the inherent microclimate variation and connectedness of the site. They may be improved through restoration, especially when fragmentation is lowering the connectedness of the site.
5) Many resilient sites support rare species or exemplary natural communities as identified and confirmed in the TNC portfolio. These natural strongholds are suitable and essential targets for land protection.
6) In many ecoregions, vast expanses of prairies on the most fertile soils (calcareous loam and deep loess), have been converted to agriculture and have little protection. The results of this study can be used to identify and prioritize resilient examples of these underrepresented settings to conserve the full spectrum of prairie diversity.
7) In ecoregions or sections of ecoregions with higher rates of conversion, such as the Fescue/Mixed-Grass Prairie and the southern two-thirds of the Central Mixed-Grass Prairie, the most resilient examples may still need restoration and management to sustain biodiversity and the ecological processes characteristic of prairie ecosystems.
8) Rivers create microclimates, connect wetlands and often remain in natural cover. In this low relief landscape, many floodplains and wetland-dominated areas scored high for resilience, reflecting the vital role of riparian regions in sustaining diversity and function.

"Health is the capacity of the land for self-renewal. Conservation is our effort to understand and preserve this capacity." - Aldo Leopold 1949

Assumptions and Limitations

Site Resilience Only: This analysis estimates the potential resilience of land-based sites using physical characteristics that are not expected to change under a changing climate (soils, topography, geology). Site resilience is not necessarily equivalent to ecological resilience which is defined as the capacity of an ecosystem to respond to a disturbance by resisting damage and recovering quickly. From an ecological perspective, prairie communities are thought to be resilient because they are dependent on disturbances and may be preadapted to some types of climatic change. Managing to improve ecological resilience may be a matter of increasing the size and connectivity of the biotic system. In this study, we assume that even ecologically resilient communities must occur on sites and that sites vary in their ability to sustain diversity over time due to the degree of fragmentation and climate variation present within them. The question addressed here is: "of all the sites that may someday support prairie which are most resilient?"

Use the Resilience Information with Other Data to Make Decisions: This analysis does not make decisions. Instead, it provides estimates of resilience that should be integrated and interpreted with additional data to inform conservation decisions. The results can augment local information by providing data on the presence and influence of land characteristics that could improve the long-term persistence of species under a changing climate. USFWS, for example, prioritized areas for conservation in the North Atlantic region based on three characteristics: rare species, intact communities and resilient land. Similarly, sites selected for high climate resilience can be compared to those selected for their biodiversity value in the TNC ecoregional plans (see Chapter 5). Finally, practicing conservationists will still need to prioritize among resilient sites using traditional conservation feasibility factors such as cost, landowner intent or return-on-investment to determine their strategy.

A Coarse Filter Strategy: The Conserving Nature's Stage approach is intended as a 'coarse-filter' for land use decision-making. The approach aims to sustain the maximum amount of biological diversity, but some species may occur largely in climate-vulnerable sites. Sustaining these species will require "fine-filter" conservation strategies aimed specifically at their populations and the management of more vulnerable lands. Finer-scale information may also reveal resiliency considerations and opportunities that were not 'visible' in the coarser-scale datasets. While CNS data can and should be used to inform site-specific decisions, it should not be relied on alone. Ideally, the results should be used in combination with finer-scale datasets and field validation. The strength of the 30-m scale analysis is that each patch of land is compared to thousands of similar patches to quantify the relative amount microclimates or connectedness. The strength of finer-scale field observations is that there may be subtle microtopographic variation, exemplary species richness, or intact biological legacies present, and this provides information not available in the GIS analysis. These observable characteristics of the biotic community may facilitate resilience at sites and under some circumstances may override the coarse-scale analysis. In general, the resilience data is best used at a landscape-scale, should be combined with finer-scale data to make site level decisions, and will need to be supplemented with detailed population data for individual species that occur predominantly in vulnerable landscapes.

Confidence Considerations: The datasets we used vary in their scale, resolution and accuracy. The 30-m landform models that underlie the microclimate analysis, and the Natural Heritage Program element occurrences had the highest precision and were the most consistently mapped. In contrast, the National land cover, wetland, geology and soil datasets all have known accuracy limits. Although we took steps to integrate finer-resolution data, there are still accuracy and mismatch problems. Users should have higher confidence in high-ranked sites, and realize that lower rankings may result from data gaps or limitations. A takeaway is that users can feel relatively confident about protecting sites ranked as highly resilient, but should look closer before writing-off a site because it has a low resilience score to ensure that the rank is not due to a data gap or limitation.

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CHAPTER 1

INTRODUCTION

This report presents the results of a 3-year project to identify and map climate resilient sites across the **Great Plains region** of the United States and Southern Canada. This work was made possible by a grant from the Doris Duke Charitable Foundation (DDCF), along with matching funds from the many State Chapter and Regional Offices of The Nature Conservancy (TNC) within this geography. It is the second of three analyses to identify a comprehensive and connected network of resilient lands across the Great Lakes and Tallgrass Prairie region, and the Great Plains region. The first report (Anderson et al. 2018) was completed in early 2018, and focused on mapping resilient sites in the Great Lakes and Tallgrass prairie region. Our third report, to be completed in the fall of 2018, will build from the previous two, identifying a resilient and connected network of sites across both geographies.

Project History and Scope

In November of 2014, The Nature Conservancy received an award from the Doris Duke Charitable Foundation (DDCF) to identify climate resilient sites in the Central United States. At that time, the Conserving Nature's Stage (CNS) approach had already been applied to the United States Northeast, Southeast, and Pacific Northwest regions (Anderson and Ferree 2010; Anderson et al. 2012; Anderson et al. 2014a; Anderson et al. 2016a; Buttrick et al. 2015). All three geographies were analyzed using CNS methods pioneered by Dr. Mark Anderson and colleagues, and further refined in each geography by teams of TNC scientists supported by regional Steering Committees. Our goal is to continue this work in the remaining ecoregions of the coterminous US, and aggregate them into a single map.

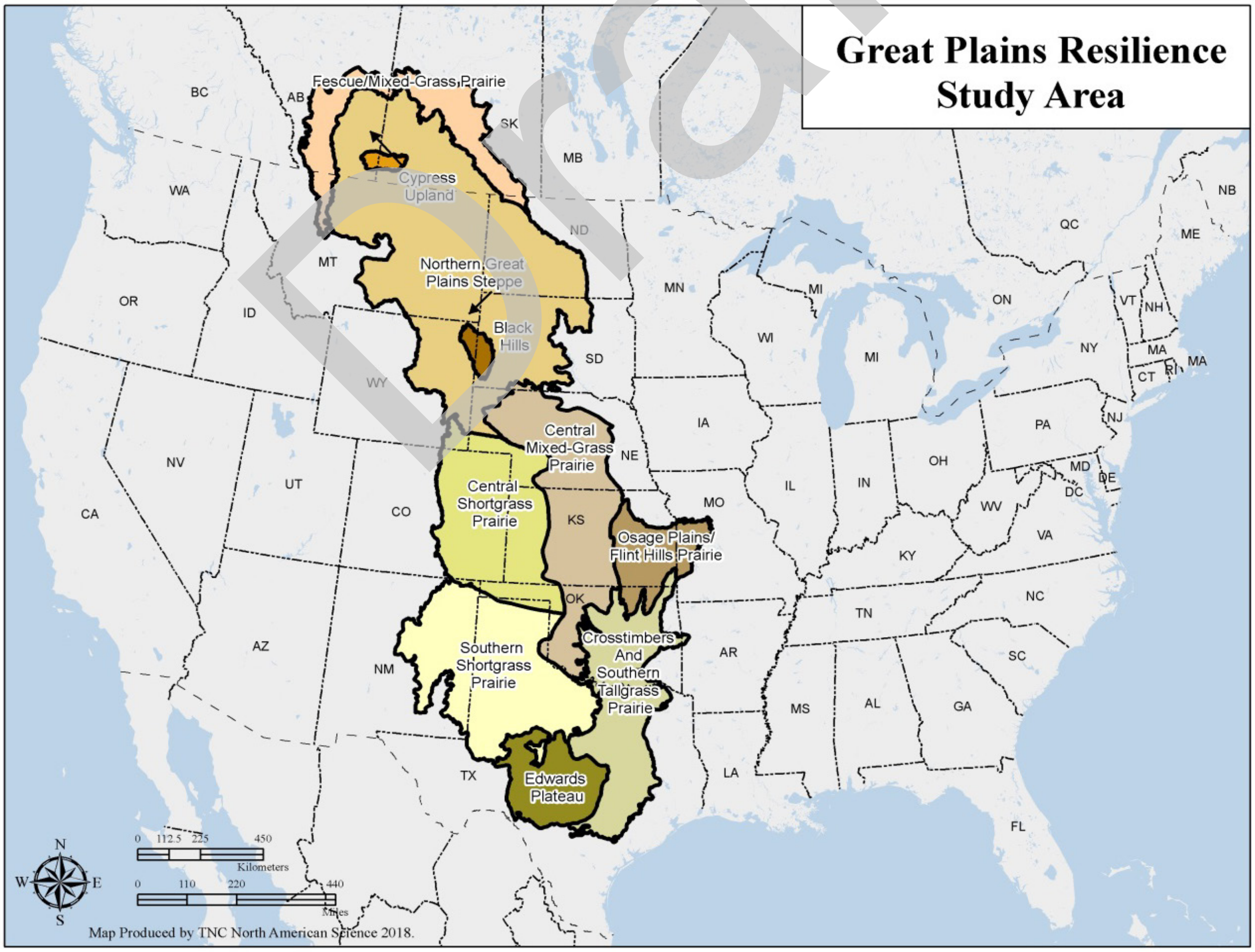
In this project, we expanded the CNS approach to the Central US, identifying the enduring geophysical drivers of biodiversity and the land characteristics that create resilience, and mapping a suite of places that capture these features across the region. In the third report mentioned above, we will identify important pathways that connect these places to allow for dispersal and migration. We envision developing a blueprint for conservation priorities across this broad region, creating a resilient network that can link to similar networks previously identified in the northeastern, southeastern, and northwestern regions of the US (Anderson et al. 2016b; McRae et al. 2016), ultimately seeking to support investments that enhance the resilience of biodiversity as climate changes at a continental scale (see Saxon et al. 2005).

All results in this report are presented within a framework of **ecological regions** or "**ecoregions**" as defined by TNC based on the subsections delineated by the US Forest Service (USDA Forest Service 2007) and Canadian Provinces (Ecological Stratification Working Group 1995). Because each ecoregion represents an area of similar physiography and landscape features, it is an appropriate natural unit in which to evaluate geophysical representation and to compare sites. Within each ecoregion, the final datasets map resilience at the scale of 30 meter cells.

Applying CNS methods in the Central US posed some major challenges, including the subtle topography, fragmented nature, and sheer size of this expansive geography. However, the importance of tackling these challenges was clear. Climate change projections suggest that some of the most severe seasonal temperature increases and increases in precipitation extremes in the US will occur here in the "heartland," far away from coastal regions or mountains that might provide climatic refugia for sensitive species (Dobrowski 2011, Dobrowski et al. 2013). From a biodiversity standpoint, the urgency to develop adaptation strategies in the Central US has been further heightened by widespread land cover change across this region over the last century (Gage et al. 2016). This loss of natural ecosystem cover has been particularly dramatic in prairie/grassland ecosystems, the dominant system type in the Great Plains.

The focal geography of this study was the Great Plains region that includes all or part of twelve states (Figure 1.1). The region is defined by the boundaries of ten TNC ecoregions, and encompasses portions of MT, ND, SD, WY, NE, CO, KS, MO, NM, OK, AR, and TX. We analyzed these ecoregions in their entirety, which led us to include portions of two Canadian provinces, Alberta and Saskatchewan, in our assessment.

Figure 1.1: Study Area. The ten TNC ecoregions comprising the Great Plains study area (in colors) as well as the 14 states and provinces fully or partially included.



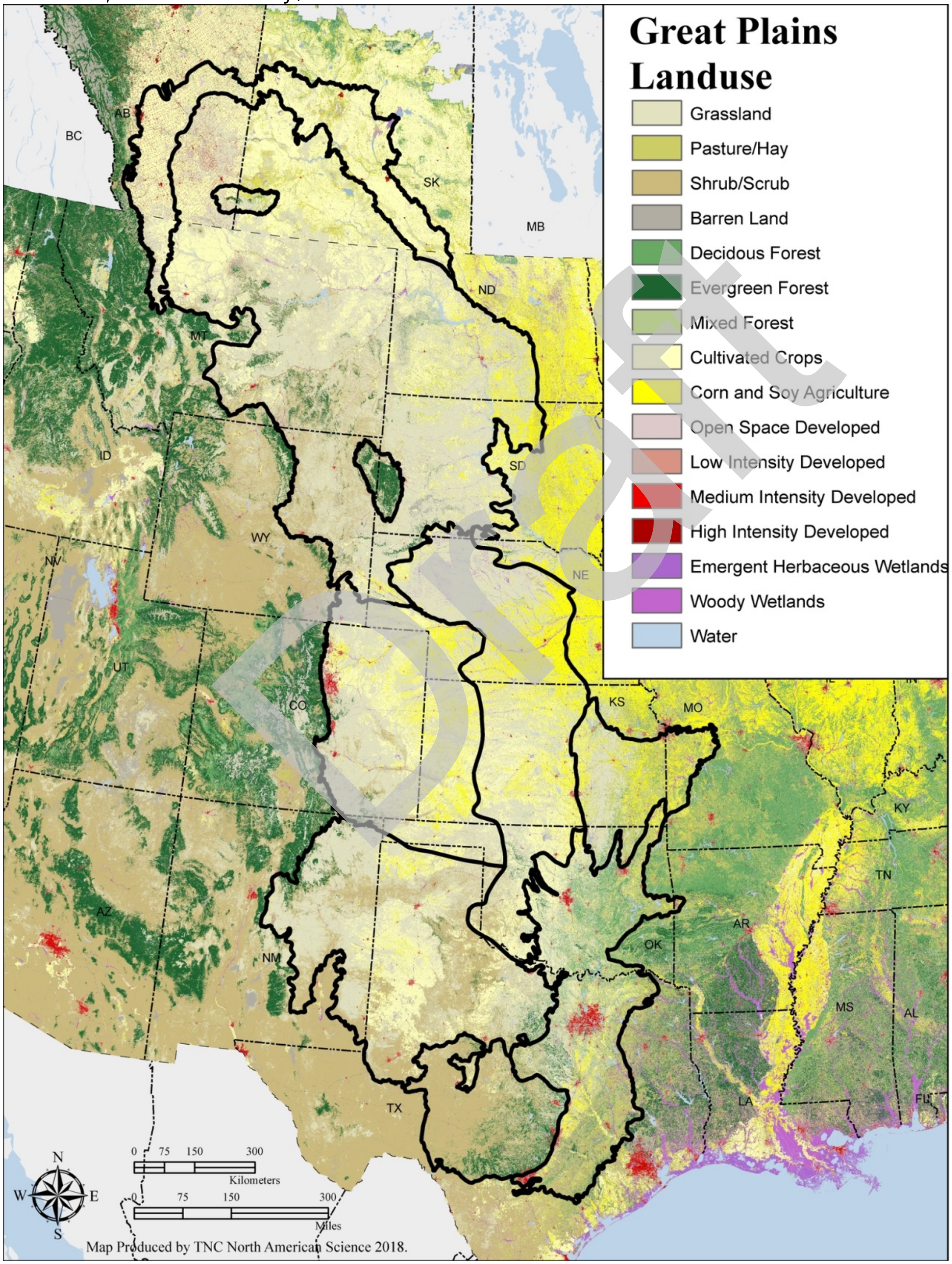
Scientists and conservation planners from most of these states and provinces served on our Steering Committee, and played an essential role in helping us to adapt the CNS methods to ecological drivers, biodiversity patterns, and land use characteristics that define this geography. Please see the Acknowledgements section for a list of all contributors.

Situated between the Rocky Mountains to the west, and the more mesic, typically forest-dominated ecoregions to the east, the Great Plains region historically supported as much as 10% of the world's grasslands (Riley et al. 2007). The three dominant factors influencing species distributions and diversity in the Great Plains are climate variability (e.g., drought), fire, and grazing. The Great Plains is characterized by climatic conditions that vary strongly across space and time of year, and the rain shadow effect of the Rocky Mountains plays a large role. Areas closest to the Rocky Mountains receive the least precipitation, creating a west-east gradient, and the Rockies also contribute to large-scale south to north circulation patterns that promote high seasonal and annual variability (Bragg 1995). The Rockies also act as a barrier to immigration for species found further west. A variable climate, reduced soil moisture, and historically high fire potential relative to eastern areas are key constraints on species distributions, especially for woody plants that might otherwise invade native grasslands (Collins and Glenn 1995). In this more arid region, wetlands, including the western extent of the prairie pothole region in the northern Great Plains, and scattered playas and other wetland types across the southern plains, are critically important resources for many species, especially migratory birds.

Within a grassland system, species diversity is a key indicator of system health and productivity (Tilman et al. 1996, Helzer 2010). When species diversity is high, species abundance and biomass can ebb and flow in response to highly variable climate conditions, allowing the grassland to "adapt in place" to a wide range of conditions (Thorpe 2011, Helzer 2018a & b). Some species do best in wetter years, others dominate under dry conditions, or bounce back more quickly after drought. In addition to climate, disturbances from drought, fire, grazing, flooding, and herbivory have played important roles shaping the species diversity and spatial patterns of grassland systems (Bragg 1995, Joern 1995). Large expanses of native prairie are likely some of the most robust systems in North America in terms of their ability to persist and thrive as climate conditions change. However, as species are lost, and grassland patches become smaller and isolated, these systems are likely to become more vulnerable to both current and future climate conditions.

While large expanses of grassland persist in the region (Fig. 1.2), the biodiversity and ecological functions associated with these systems are at high risk due to high rates of conversion, low rates of protection and the westward expansion of the cornbelt (Hoekstra et al. 2005, Wright and Wimberly 2013, Lark et al. 2015, Wright et al. 2017). Over the past few centuries, human actions greatly depleted the biomass of wildlife in the Great Plains, eliminating or greatly reducing the populations of many species, including key herbivores like the plains bison, black-tailed prairie dog, and Rocky Mountain locust (Knowles et al. 2002, Sanderson et al. 2008). As grasslands have been

Figure 1.2: Land Use in the Great Plains. Natural areas, dominated by grasslands, and agriculture are the most common landcover types in the Great Plains. Conversion of grasslands to agriculture show strong spatial patterns, following soil type variations, and with a higher conversion rate in Canada. Low and medium density residential areas are scattered across the region, and a few large cities (e.g., Dallas & Fort Worth, Houston, Oklahoma City) occur in the southern states.



farmed and fragmented, additional processes have been highly altered – for example, fire suppression, and management of many large rivers have changed successional dynamics and diversity patterns, and allowed for woody and non-native species invasions (Ratajczak et al. 2012, Toledo et al. 2014). Conversion of the grasslands to agriculture has been most extreme in the Canadian section of the Great Plains, where roughly two thirds of land has been converted; the conversion rate is lower (closer to one third) in the US (Riley et al. 2007), although these systems are currently experiencing a rapid increase in development pressure from multiple forms of energy development (Copeland et al. 2009, Obermeyer et al. 2011, Jones et al. 2015, Lark et al. 2015, Trainor et al. 2016).

Our ability to conserve the biodiversity and services associated with these natural systems will be more effective if we understand and map the geologic drivers of species distributions, and identify examples of each natural system that offer the most options for current and future species diversity.

Process

To complete this study, we formed a core team of Conservancy scientists to complete the technical analysis, and enlisted a Steering Committee to work with us to co-develop map products and communication materials. During the project, we lost a key member of the Great Plains core team, Dr. Brad McRae, to cancer. We very much appreciate the patience of our Steering Committee as we re-organized our team and modified our schedule to complete the work.

To assemble the Steering Committee, we recruited colleagues representing each TNC state chapter and regional program within the study region. Working in partnership with these individuals and relying on their professional networks, we then reached out to external partners, representing state and federal agencies, academic institutions and non-profit organizations. The purpose of assembling such a large Steering Committee was two-fold. First, we needed the expertise and deep knowledge of fellow scientists across this broad geographic area to help us understand how the CNS concepts should be implemented in the Great Plains, given the geologic history, ecology, land use, and data availability in this region. Second, we wanted to develop a cohort of people from across the region that were invested in the process and products, and thus would be likely to use them in their own work and share the products with colleagues across their networks. The role of the Steering Committee included:

- Advising the core team on the most appropriate regional data sources and approaches for CNS implementation, promoting confidence in methods.
- Providing technical review of results and products (tools, maps, and reports).
- Connecting the TNC team with existing and future conservation applications.
- Assisting with outreach to additional partners to seek input and promote use of products.

We held the first Steering Committee call on March 30, 2015 and followed with an additional 19 Steering Committee meetings (roughly every other month) through May 14, 2018. Each 1.5 to 2-hour online conference call used an interactive format, in which preliminary results from the spatial analysis were shown and each participant was offered a time to comment on specific pre-identified questions. We also held a few targeted calls with a subset of committee members that focused on specific topics (e.g., wetlands, soils, conservation portfolios, energy development datasets, and outreach).

At about the half-way point in our project, we held a two-day in-person meeting at TNC's Minneapolis office. At this meeting, we provided more context for the project, while engaging in in-depth discussions on topics related to key decisions in the analyses. We also interacted with the Steering Committee for the Great Lakes and Tallgrass Prairie region (Anderson et al. 2018), which allowed us to identify similarities and differences across the two regions, and to make initial steps towards finding methods that could work seamlessly across neighboring ecoregions. A high point was hearing from the Steering Committee members about how they intended to use the products to inform their work, and what additional resources would be needed to support engagement with the products and use by additional partners. The meeting strengthened our connection with the Steering Committee, and helped facilitate strong support and extensive peer review for the project.

Site Resilience

We define **site resilience** as ***the capacity of a site to maintain biological diversity, productivity and ecological function as the climate changes*** following Anderson et al. (2014b). This means that the character of the existing ecosystem, such as species assemblages and biotic structures, may change even as the core functions and biodiversity of the evolving ecosystem continue to provide the ecosystem services we value. Site resilience differs from the classic definition of resilience in the ecological literature, which holds that an ecosystem demonstrates resilience if it quickly returns to a steady-state equilibrium after a disturbance (Holling 1973). Under changing conditions, however, there is no steady-state to return to. Over time, the definition of resilience in the published literature has evolved to include change—for example Gunderson's (2000) definition, *"the capacity for renewal in a dynamic environment."* The meaning also varies depending on the object being impacted (e.g., wildlife species, plant communities, human communities). The *American Heritage Dictionary* defines **resilience** as "*the ability to recover quickly after change or misfortune*." Our definition of resilient sites, actual mapped places, revives an idea of land health that originated with Aldo Leopold (1949): "*Health is the capacity of the land for self-renewal. Conservation is our effort to understand and preserve this capacity.*"

Summary of Concepts and Approach

The CNS approach to developing a network of resilient sites for the Central U.S. is based on several key observations. First, species diversity is highly correlated with geophysical diversity (Anderson and Ferree 2010, Lawler et al. 2015). We know abiotic factors, like soils and geology, shape ecosystems and their biodiversity, and historic evidence, along with studies from other climatic regions, suggest that these drivers will continue to influence the distribution and abundance of species even as climatic conditions change (Beier et al. 2015). Second, under a changing climate, species take advantage of local microclimates to persist in the landscape (Weiss et al. 1988, Suggitt et al. 2011, Roth et al. 2014, Albano et al. 2015). Yet, species populations can use microclimates and adjust to change only if the area is permeable and well connected (Heller and Zavaleta 2009). The idea of protecting examples of all geophysical settings, prioritizing those sites with the most microclimate diversity, and highest landscape permeability is the core concept of this project. Background on the approach and detail on how the results relate to current biodiversity patterns can be found in Anderson and Ferree (2010), Anderson et al. (2014a, 2014b), Anderson et al. (2016a) and the papers included in Beier et al. (2015).

We use the term **site resilience** to refer to the capacity of a site to adapt to climate change while maintaining diversity and ecological function (modified from Gunderson 2000).

We assume that if conservation succeeds, each geophysical setting will support species that thrive in the conditions influenced by the physical properties of the setting, although the site may contain different species in the future than are present now. For example, sandy sites would continue to support species that benefit from well-drained, nutrient-poor conditions, while sites in fertile calcareous loams would support species that thrive in alkaline nutrient-rich conditions. **Geophysical setting** is thus broadly defined either based on bedrock or surficial soil texture, depending upon soil depth. We look to the current distribution of species, communities, and terrestrial system types, including wetlands, to help us understand what key characteristics are shifting across the landscape and could thus be captured by this coarse filter, but expect that the specific species and communities on a given example of setting will change over time.

A climate-resilient conservation portfolio includes sites representative of all geophysical settings selected for above-average levels of microclimatic variation and proportion of natural land cover. Chapter 2 describes how we mapped geophysical settings across the entire study area, using data on geology and soil characteristics, as well as information on soil depths. To guide this process, we refer to spatial data on the occurrence patterns of rare species and natural communities, as these data help us identify relationships between the geophysical settings, and distinct patterns of biotic expression. In the Great Plains region, this involved delineating the region into areas most influenced by surficial sediments (e.g., calcareous loams, deep loess, sand), and areas more closely tied to underlying geology (e.g., acidic granite, circumneutral sedimentary, calcareous sedimentary).

The value of conserving a spectrum of physical settings is based on empirical evidence that this approach will help us meet goals of representation, i.e., protection of the breadth of existing biodiversity (Anderson and Ferree 2010), but there are many choices to make to determine how this is accomplished. For example, of all the possible sand plains that could be conserved, which ones are the most likely to remain functional and sustain biological diversity into the future? Chapter 3 describes the site-based characteristics that promote sustained ecosystem function and diversity, and the methods we used to assess and map them. The first characteristic, **landscape diversity**, is an estimate of the number of microclimates and climatic gradients available within the local area. It is measured by counting the variety of landforms (e.g., hillsides with different slopes and aspects; dry, moist, or wet flats), and the density, configuration, and connectivity of wetlands. South-facing slopes will typically be warmer and drier that similar slopes that face northeast; these types of differences provide local variation in climate that provide additional climate “niches” relative to areas without topographic variation. We expect that microclimate diversity buffers species against regional climatic effects by providing them with a range of local climates, many of which might be suitable for extending a species’ ability to persist at a site. By this logic, we expect that the diversity and persistence of species within a local area increases with high landscape diversity relative to other examples of the same geophysical setting (Weiss et al. 1988).

Local connectedness, the second site-based characteristic we use an indicator of sustained ecosystem function and diversity, is defined as the number of barriers to species movement and the degree of fragmentation within the local area. A highly permeable landscape has no or few barriers (low habitat fragmentation) and promotes resilience by allowing plant and animal movements and the reorganization of communities. Roads, development, agriculture, dams, and other structures create barriers, or 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). Connectivity has in fact been hypothesized to explain why relatively few extinctions occurred during the Quaternary (2.5 million years BCE to present), another period of rapid climate change (Botkin et al. 2007)—albeit not as rapid as the current climate change (Holocene/Anthropocene; Masson-Delmotte et al. 2013).

The organization of this report follows the following structure. In Chapter 2, we describe mapping and classification methods used to identify all the distinct geophysical settings in the region. Chapter 3 introduces methods designed to quantify the physical and structural aspects of landscapes using models that measure a site’s physical complexity including variety of microclimates (landscape diversity), natural cover (local connectedness), and combined resilience factors (integration of landscape diversity and connectedness). Finally, in Chapters 4 and 5 we present the results, identifying resilient sites across individual ecoregions and the full study area, respectively.

Importantly, the use of geophysical settings and ecoregions ensured that landscape diversity and local connectedness were ranked relative to sites of the same underlying type within an ecoregion. Thus, the resulting maps of resilient sites are always relative to the setting and ecoregion. Some geophysical settings, such as calcareous loams, have subtler microclimates and are more fragmented (i.e. have less site resilience) than other settings, but our goal was to identify the most resilient sites for each geophysical type. This ensured that we were mapping a blueprint of resilient sites that could sustain all biological diversity, and was not biased towards a particular type of soil or bedrock. The analysis was performed within each of the ten ecoregions, and the regional map is a composite of the individual ecoregion maps.

DATA SOURCES

Ecological Stratification Working Group. 1995. A National Ecological Framework for Canada. Agriculture and Agri-Food Canada, Research Branch, Center for Land and Biological Resources Research and Environment Canada, State of the Environment Directorate, Ecozone Analysis Branch, Ottawa/Hull. Report and national map at 1:7,500,000 scale. http://sis.agr.gc.ca/cansis/nsdb/ecostrat/index.html

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

DEFINING THE GEOPHYSICAL SETTINGS

CHAPTER 2

This chapter describes our process to characterize and classify the Great Plains study area into distinct geophysical "stages" based on the geology and soils. Our premise is that the characteristics of a geophysical setting represent enduring features that influence biotic differences in the flora, fauna, and natural communities (e.g. due to differences in pH, nutrients, drainage, erodibility) now, and these differences will continue to favor or select against different subsets of species under future climates. These physical characteristics often also correlate with human land use patterns because properties such as bedrock type, soil texture and chemistry contribute to the value and suitability of sites for agriculture, development, or mining.

In addition to shaping parent materials and soils, geophysical environments tend to share topographic characteristics and land use properties, both of which are key components of our site resilience metric (Chapter 3). Typically, bedrock based environments are more topographically complex and have more intact natural landcover than deep soil environments, which are generally flatter and more likely to be converted to agriculture. Within these deep soil settings, remaining natural areas often have poorer soils or more topographic diversity than the surrounding farmlands due to the conversion of sites that are easiest to farm.

The correlation between the geophysical settings and our site resilience factors highlights the important roles that settings play in this study. Geophysical settings are key drivers of biological diversity, so representation of the full range of settings is a critical conservation goal. Further, the correlation between setting types, topography, and land use suggests that direct comparisons of our site diversity metrics would favor some settings over others. As we determined how to partition the study area into geophysical settings, we considered these dual roles as (1) "coarse filters" for capturing the full range of abiotic conditions that support biodiversity, and as (2) a spatial stratification prior to identifying examples of sites that have the most microclimatic variety and natural cover. Without a stratification to ensure "apples to apples" comparisons, our results would be biased towards bedrock-based settings and their associated flora and fauna due to the higher topographic relief and lower conversion rate on those settings.

Ecoregions

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

The TNC ecoregions used for this analysis are modified from Bailey (1995), and were based on the subsections delineated by the U.S. Forest Service (USDA Forest Service ECOMAP Team 2007) and the Canadian Provinces (Ecological Stratification Working Group 1995). In comparison to Bailey's ecoregions, TNC's grouping of subsections puts more emphasis on physical characteristics and natural communities and less on climatic patterns. The Great Plains study area encompassed 10 ecoregions (Figure 2.1):

1. Black Hills
2. Central Mixed-Grass Prairie
3. Central Shortgrass Prairie
4. Crosstimbers and Southern Tallgrass Prairie
5. Cypress Upland
6. Edwards Plateau
7. Fescue/Mixed-Grass Prairie
8. Northern Great Plains Steppe
9. Osage Plains/Flint Hills Prairie
10. Southern Shortgrass Prairie

Geophysical Settings

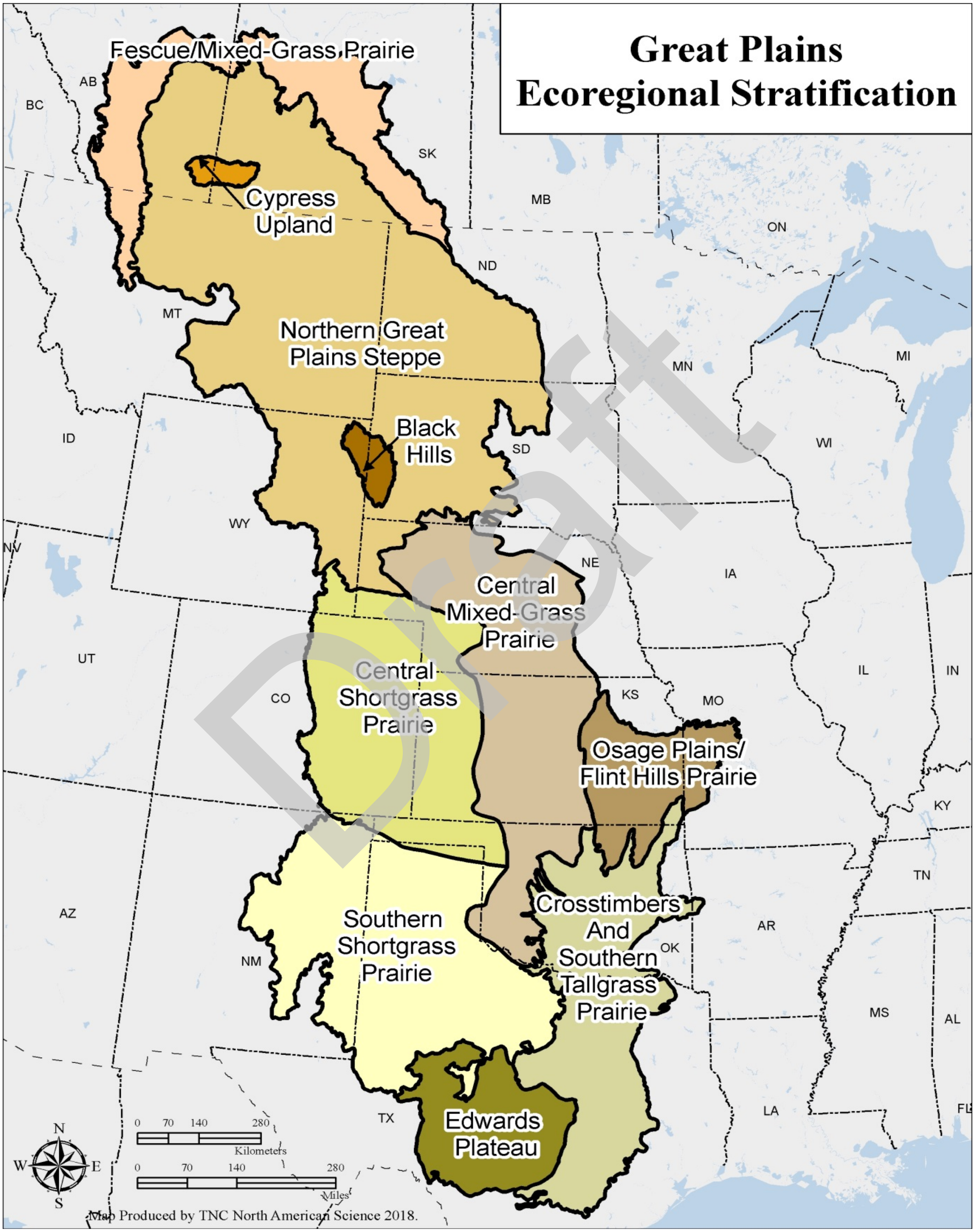
First, we discuss the definition of each geophysical setting, and the data sources, thresholds and distinctions used to map it in the Great Plains. In the later sections, we summarize the natural communities and species associated with each setting.

The section on delineating settings is divided into five parts:

1. Concepts and Confirming Data
2. Delineating the Surficial and Bedrock Zones
3. Classifying and Mapping the Bedrock Geology
4. Classifying and Mapping the Surficial Sediments
5. Integrating Bedrock Geology and Soil Texture

While elevation has been used as a stratification factor in our resilient site assessments in the East (Anderson et al. 2016a) and Pacific Northwest (Buttrick et al. 2105), it was not used as a stratification factor in the Great Plains. As in the Great Lakes and Tallgrass Prairie assessment (Anderson et al. 2018), elevation was not included because of a general lack of influence of elevation change on the biota. Although some areas, such as the Black Hills, do include sites with relatively large elevation gradients, these are typically well separated from other sites by setting type. The western boundary of the region aligns with the foothills of the Rocky Mountains, where elevation becomes a key factor determining the structure and composition of biotic communities on settings.

Figure 2.1: Ecoregions. TNC Ecoregions included in the Great Plains study area.



Concepts and Confirming Data for Delineating Settings

To map the geophysical settings, we first split the study area into a region of deep surficial soils and a region of shallow bedrock-based soils. The surficial (deep soil) settings were further divided based on soil texture and pH. Ranging from deposits of pure sand to wind-blown loess to calcareous loams, these surficial settings support many of the region's iconic communities, such as sand prairies, loess hill prairies, and saline marshes. The bedrock settings were further divided based on the composition and alkalinity of the bedrock. These settings support species adapted to thin dry soils, and natural communities and features like limestone glades and caves, sedimentary canyons, and mafic outcrops.

To gauge the accuracy of various soil and geology data layers, and to confirm the biological distinctiveness of each setting, we compiled point locations of 70,310 natural community and rare species occurrences (sources listed in Element Occurrence Data Sources at the end of this chapter). This invaluable biotic information consisted of points and polygons called "element occurrences" or "EOs" (i.e., elements of natural diversity), and were provided by State Natural Heritage Programs and NatureServe, who track and collect this information using ground inventory methods. In contrast to many other regional or national datasets, the spatial precision of EO locations is extremely high. The high precision made it possible to use these points locations to identify important transitions and thresholds within each geophysical characteristic, and to evaluate the relative value of different geology, soil, or pH datasets, especially those that were coarser in scale.

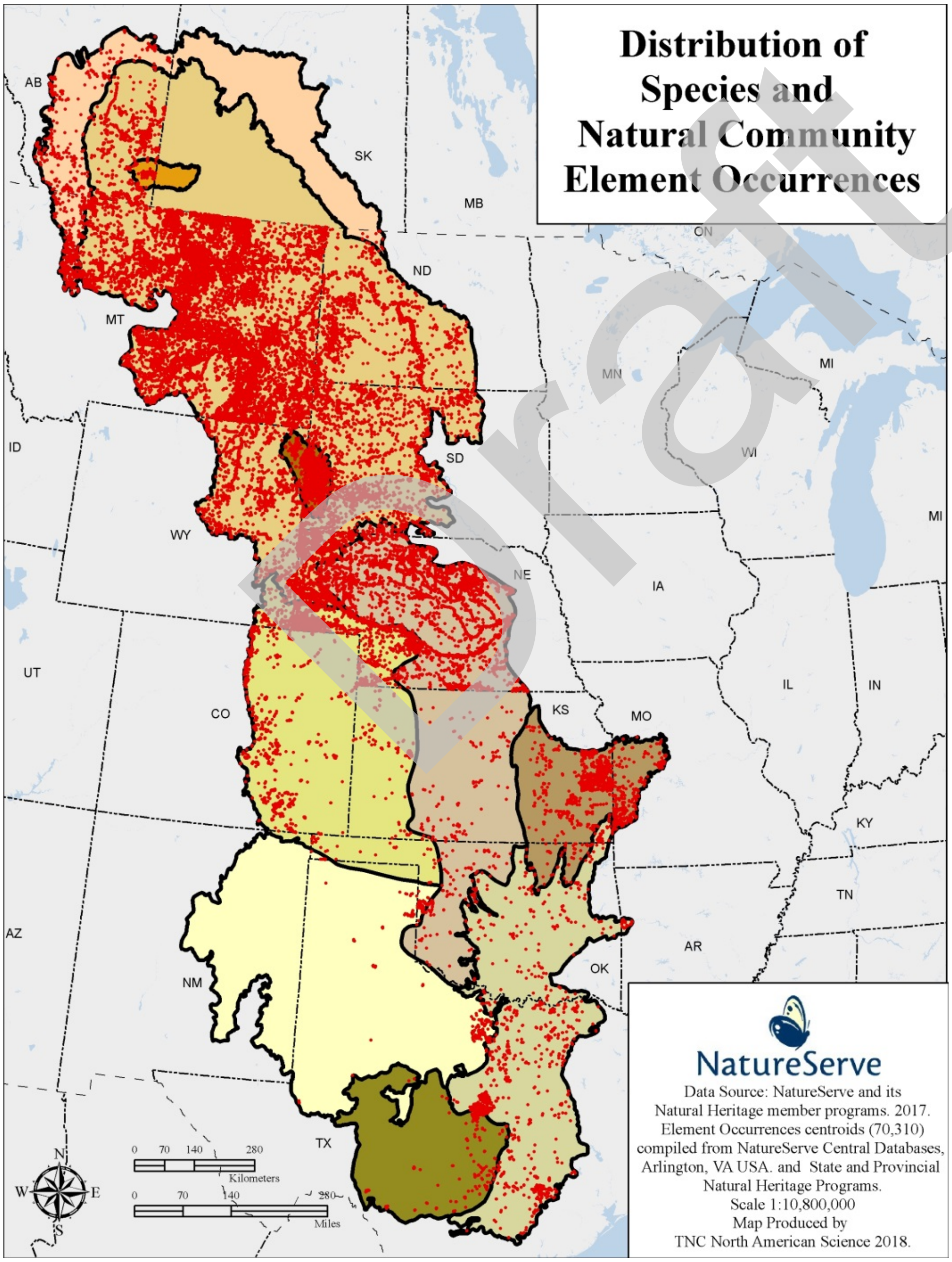
Each EO represents an area of land or water where a species, population or distinct natural community type was present (NatureServe 2002). Natural Heritage Programs generally create EOs for native species considered at-risk within their jurisdictions, and for all representative natural communities. Each mapped location of an EO has an associated level of mapping accuracy, and these are recorded at 3 primary levels (seconds, minutes and general), which range from highly precise locations mapped on 1:24,000 scale maps to lower precision mapping.

Natural Communities are described and mapped in accordance with a state natural community classification, most of which are published and available on-line (i.e., on *NatureServe Explorer*, http://explorer.natureserve.org). A natural community is defined as an assemblage of interacting plants, animals and other organisms that repeatedly occurs under similar environmental conditions across the landscape and is predominantly structured by natural processes rather than modern anthropogenic disturbances (NatureServe 2002). Because natural communities are often linked to distinct geophysical settings (e.g., limestone glade or loess hill prairie), the natural community data are extremely helpful for assessing the accuracy of various geology and soil type datasets, providing an additional line of evidence that helps us to refine our delineation of setting types, and correctly map their distributions. Species data are more complete for vertebrates and vascular plants, but include selected species of invertebrates from groups such as beetles, snails, and butterflies.

One challenge we encountered is a strong variation in EO sampling/mapping intensity across the Great Plains. The distribution of EOs was skewed towards the northern part of our focal area, with 77% coming from the northern four ecoregions (Fescue/Mixed-

Grass Prairie, Cypress Uplands, Northern Great Plains Steppe, Black Hills) and only 4% from the southern three (Osage Plains/Flint Hills Prairie, Crosstimbers and Southern Tallgrass Prairie, and Edwards Plateau, Figure 2.2). The EOs composition was biased toward animals (71%), especially birds (41%). Although we considered all species' EOs, some were for very wide-ranging species and were not very helpful for identifying settings or setting boundaries. Most of our testing focused on the natural community EOs (10,351) for which we had a more even distribution across all ecoregions, averaging 1,150 per ecoregion (range 86 to 3900).

Figure 2.2: Element Occurences. Distribution of Species and Natural Community Element Occurrences (shown as red dots) from NatureServe and Partner Natural Heritage Programs.



Delineating the Surficial and Bedrock Zones

Our first step in mapping the geophysical settings was to separate the region into areas of deep surficial deposits and areas of shallow soils with exposed bedrock. The natural communities, associated species, and ecological processes differ markedly between these two environments, which separate the deep soil prairies, loess hills, sand dunes and floodplains from the more restricted areas of bedrock outcrops, bluffs, glades, and shallow prairie and slope communities.

To identify and map the surficial/bedrock split, we reviewed several datasets, listed below, and evaluated their resolution and accuracy. Full citations for these and other settings-related datasets are included at the end of this chapter.

- SSURGO (Natural Resources Conservation Service 2014a) contains information about soil as collected by the National Cooperative Soil Survey over the course of a century. The information was collected at scales ranging from 1:12,000 to 1:63,360. We reviewed: depth to restrictive layer, depth to bedrock, and root zone depth.
- STATSGO2 (Natural Resources Conservation Service 2014b) is a digital general soil map of the United States showing a broad-based inventory of soils and non-soil areas that occur in a repeatable pattern on the landscape and that can be cartographically shown at a mapped scale of 1:250,000 in the continental US. We reviewed: depth to bedrock, depth to restrictive layer.
- SOILGRID is a global absolute depth to bedrock dataset (Hengl et al. 2017) which is based on a system for automated soil mapping using state-of-the-art spatial prediction methods that result in a map with 1: 500,000 spatial resolution.
- USGS 425 Represents Surficial Materials in the Conterminous United States (Soller et al. 2009), which was compiled from over 30 sources and maps of surficial deposits at a 1:5,000,000 scale.

We compared these datasets to each other and to the high precision locations of 4,002 shallow-soil or bedrock-based natural community EOs (e.g., bluffs, cliffs, glades, outcrops, barrens etc.) and calculated the correspondence of these community EO locations to shallow depth classes.

Visually, the USGS 425 (Soller et al. 2009) dataset was consistently mapped and spatially cohesive across the whole project area. Although courser in scale than the other datasets, its categorical assignment of areas as "discontinuous or patchy" (defined as map units where the sediments are patchy in distribution; bedrock commonly is exposed at land surface) encompassed 74% of the known shallow-soil community locations and few deep soil communities. This was higher correspondence than we could produce with the finer scale datasets when testing a variety of depth cutoffs, and thus we selected this dataset as the base for mapping the shallow/deep separation. A similar USGS product for the glaciated East (USGS 656, Soller et al. 2012) had been used successfully in a similar project for the Great Lakes and Tallgrass Prairie region (Anderson et al. 2018).

We overlaid the base dataset (USGS 425) with the other datasets to identify and explore the areas of disagreement. For each dataset we identified the depth cut-off that most closely approximated the distribution of the USGS 425 "discontinuous or patchy" category, and then examined the areas where the maps disagreed. For example, using STASGO2, a 120-cm depth cutoff in the 'depth to root restriction" field created a map of shallower soil areas that had 77% agreement with the USGS 425 map. When we applied this approach to datasets we found they agreed over most of the US part of the study region.

In the regions of disagreement, we studied the natural community EOs and landform patterns, which confirmed that in the US, the USGS 425 mapped classes were more accurate representations of the shallow/deep ecological threshold in most ecoregions.

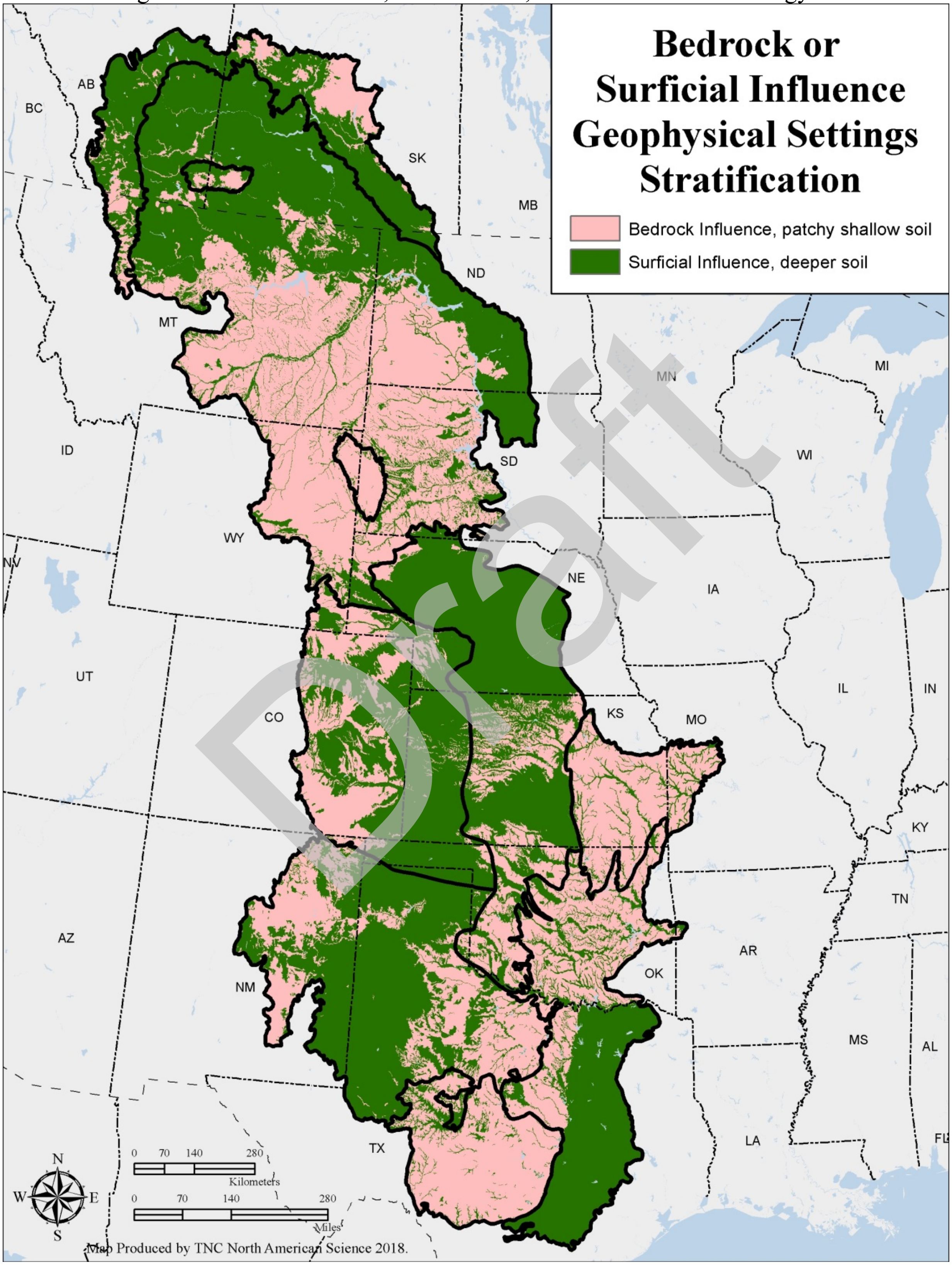
The USGS 425 dataset stops at the US-CAN border, so for the Canadian portion of the study region, we used the global SOILGRID dataset and matched the depth cutoffs to the US side of the region. To match the scale of the USGS 425, we compiled the soil map units from the Canadian Detail Soil Survey (Canadian Provincial Detailed Soil Surveys Version 3, 2010) and assigned each map unit to "shallow" or "deep" based on the mean depth of the map unit.

On the US side, we modified the delineation of shallow/deep from the "discontinuous or patchy" boundary represented in USGS 425 in two cases:

1. In the Central Shortgrass Prairie and Central Mixed-Grass Prairie where USGS 425 and STATSGO2 disagreed, we used the global SOILGRID dataset to resolve discrepancies.
2. In the Crosstimbers and Southern Tallgrass Prairie ecoregion, there were areas in TX where USGS 425 indicated "shallow" and STATSGO2 indicated "deep." We overrode USGS 425 with the STATSGO2 information based on evidence from EOs and local ecologist's expert feedback on the dominant role of surficial sediments in determining plant communities in these areas.

As a last step, we made fine-scale additions to the "Deep" area by adding polygons from the state bedrock geology dataset (Horton et al. 2017) that were classed as sand, clay, silt, or unconsolidated. These areas presumably lacked a bedrock assignment because the bedrock was buried too deep to have relevance to the soils. This integration corrected some small spatial alignment problems and missing deep areas particularly in Montana, Wyoming, Colorado, Oklahoma, and Kansas along rivers. Finally, we applied a minimum mapping unit of 1,000 acres to the dataset to simplify the stratification for mapping dominant depth patterns at a coarse regional scale. This eliminated smaller patches of deep or shallow mapped areas that were unlikely to contain the full flora and fauna expected for the geophysical setting. The final split between bedrock and surficial-influenced zones is shown in Figure 2.3.

Figure 2.3: Bedrock vs. Surficial Influenced Zones. This map is based on USGS 425 with data integrated from STATSGO2, SOILGRIDS, and State Bedrock Geology.



Classifying and Mapping the Bedrock Geology

To develop a spatially comprehensive regional dataset of bedrock geology (Figure 2.4), we obtained digital bedrock layers in vector format from the US Geological Survey *State Geologic Mapping Compilation (various scales*; Horton et al. 2017), the Alberta Energy Regulator and Alberta Geological Survey *Bedrock Geology of Alberta* (1:1,000,000 scale; Prior et al. 2013) and the Saskatchewan Energy and Resources *Bedrock Geology* (1:1,000,000; Macdonald and Slimmon 1999) spatial datasets.

We classified geologic units in each state or province into a simplified set of seven ecologically relevant classes generally following the scheme of Anderson and Ferree (2010). These seven classes support relatively distinct flora and faunas in the Midwestern US and Canada. An overlay of EOs in the Central US supported the relevance of these seven classes to the Great Plains region (details below).

Using attribute data from the compiled geology dataset, we reviewed each geologic taxonomic type based on name and description, and assigned it to one of the seven classes using information on the bedrock's component rock types, genesis, chemistry, weathering properties and texture. Areas that were not mapped in this compiled geology dataset are shown in a separate category ("No bedrock type…"). In some cases, source polygons had multiple rock type assignments in their major and minor class codes and we resolved the assignment of geologic taxonomic types by overlaying Natural Heritage Program rare species and natural community EO locations known to be associated with a specific rock type, and reviewing whether the match was consistent with particularly source major rock types. When rock types were classified differently on either side of a state or country boundaries we resolved the difference using the supplemental information from a variety of sources.

The seven predominant rock components of the bedrock classes are described below:

<u>Circumneutral Sedimentary:</u> sedimentary or meta-sedimentary rock with no reported alkaline components. This group included sandstone, siltstone, mudstone, claystone, shale, conglomerate, arenite, argillite, arkose, and bentonite rocks. In other assessment regions where pH values are lower, we have classified these rock types as "acidic sedimentary" (e.g., Anderson and Ferree 2010).

<u>Acidic Shale:</u> black shale and oil shale.

<u>Calcareous Sedimentary</u>: alkaline sedimentary or metasedimentary rock with high calcium content. This group included limestone, dolostone, marlstone, calcarenite, carbonite, chalk, coquina, marble and marl.

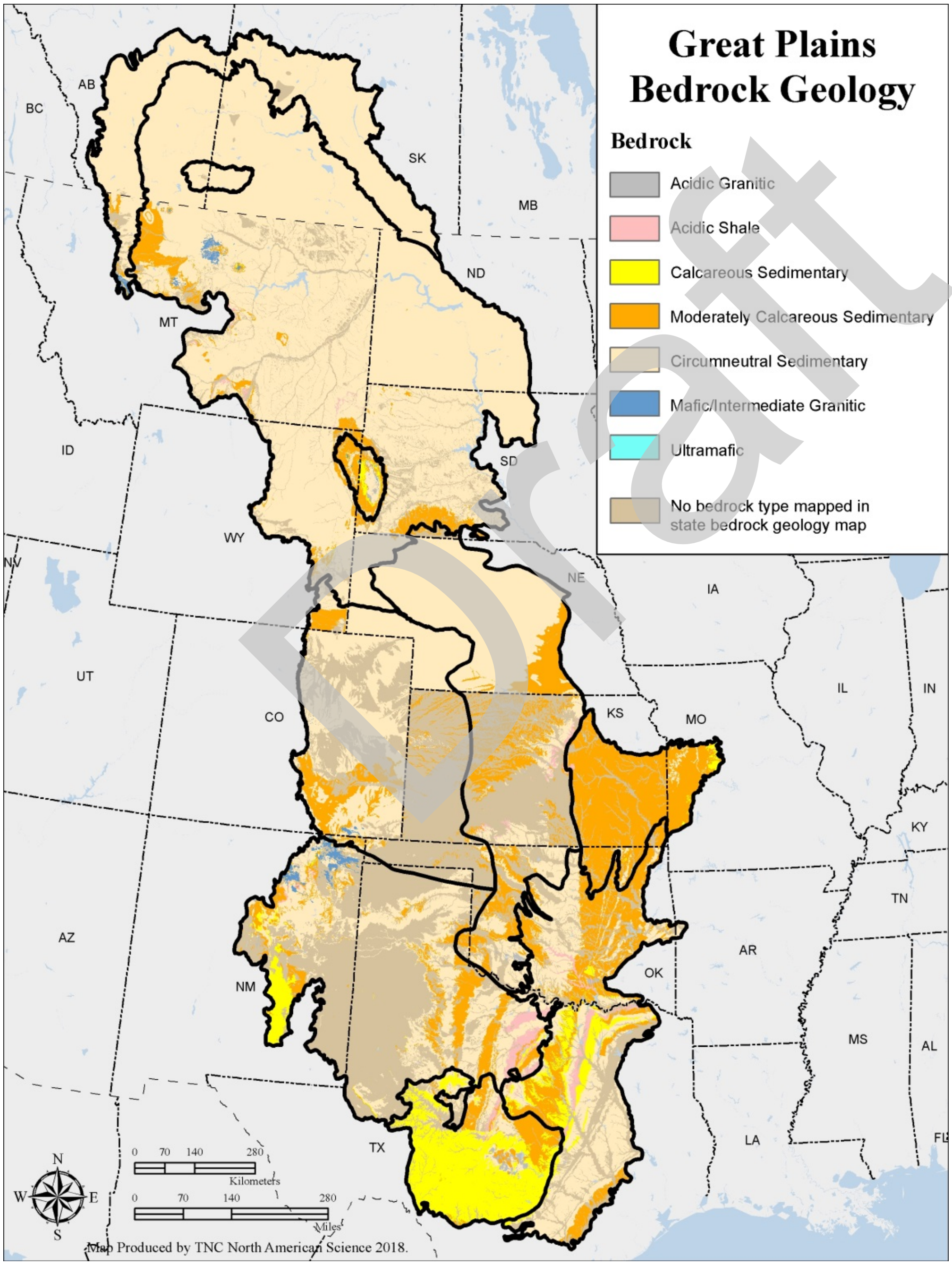
<u>Moderately Calcareous Sedimentary</u>: moderately alkaline sedimentary or meta-sedimentary rock with some calcium but less than rocks in the calcareous rock class. This group is composed of calcareous shales or mixed sedimentary rocks with one or more calcareous components, calcium-silicate, and calcium-silicate schist rocks.

<u>Acidic Granitic</u>: quartz-rich, resistant acidic igneous and meta-igneous rock including very high grade meta-sedimentary rock. This group is primarily composed of granite, granodiorite, dacite, rhyolite, pegmatite, migmatites, quartzite rocks.

Mafic/Intermediate Granitic: quartz-poor alkaline to slightly acidic igneous and meta-igneous rock. This group includes: anorthosite, gabbro, diabase, basalt, diorite, andesite, syenite, trachyte, greenstone, amphibolite, epidiorite and granulite.

Ultramafic: magnesium-rich alkaline igneous and meta-igneous rock. This group includes: rocks generally identified as 'ultramafic' such as serpentine, pyroxenites, peridotites, komatiite and kimberlite. This bedrock is extremely rare in the region.

Figure 2.4: Bedrock Geology. Results of the compilation and classification of state-based geology datasets into a single Great Plains map.



Some states combine deep surficial materials and bedrock types in their state geology map. In these cases, the surficial portion was used in the next section on classifying the surficial material. This included the following categories:

Evaporites/Playas: mineral deposits formed primarily in the lakebeds of evaporating water bodies. This class includes unspecified evaporites, anhydrites, gypsum and salt deposits.

Coarse sediments: surficial deposits designated as boulders, coarse-detrital materials, gravels and sand.

Unconsolidated: an otherwise unqualified designation of unconsolidated surficial materials.

Fine sediments: surficial deposits designated as clay, silt, peat and fine-detrital materials.

Classifying and Mapping the Surficial Sediments

We created a spatially comprehensive regional dataset of surficial texture by integrating data from the following sources:

- U.S. Geological Survey Data Series 425 "Map database for surficial materials in the conterminous United States" (Soller et al. 2009) 1:5,000,000 scale
- USGS State Geologic Mapping Compilation (Horton et al. 2017, various scales). Unconsolidated materials from the state bedrock geology map compilation
- STATSGO2 State level USDA soil surveys (NRCS 2014b) 1:250,000 scale. 0-20 cm topsoil horizon
- SSURGO County-level USDA soil surveys database (NRCS 2014a) 1:24,000 scale 0-20 cm topsoil horizon
- Canadian Provincial Detailed Soil Surveys (Version 3, 2010), 1:100000 scale

To create a unified surficial material map for the Great Plains (Figure 2.5), we classified the above data into four soil texture classes: 1) clay/silt, 2) loess, 3) loam and 4) sand. We tested the accuracy and ecological relevance of these categories by comparing them with the location of natural community EOs that required specific soil types. For example, to test the accuracy of mapped sand, we examined the locations of sand barrens, sand flats, beaches, dunes, and sand prairies. Similarly, for clay/silt we examined various floodplains and wetlands where the location of the community EO was described as being in clay or silt. The definition of each surficial category and the methods used to map it are described below.

Sand: Sand is a coarse-grained substrate composed of loose rock particles smaller than gravel but larger than silt (>0.2 mm). Sand substrates are typically well drained and nutrient poor, and some parts of the study region (e.g. Nebraska Sandhills) are known for their extensive sands. To map this category in the US, we extracted the categories "sand" and "coarse surficial substrate" from USGS 425 which included those denoted as “dune sand,” “mostly sandy,” “sand and gravel,” or “mostly coarse grained.” We augmented this by adding any area mapped as >80% sand in the STATSGO, SSURGO, and Canadian Detailed Soil Survey.

In the four northern ecoregions (Fescue/Mixed-Grass Prairie, Northern Great Plains Steppe, Cypress Uplands, Black Hills), two central ecoregions (Central Shortgrass Prairie, Central Mixed-Grass Prairie) and the western half of Southern Shortgrass Prairie ecoregion, we mapped USGS 425 “alluvial substrates” as “sand,” because investigation suggested that sand was the dominant substrate along large rivers. This generally agreed with the state bedrock maps in these ecoregions. We added “sand” polygons from the state bedrock sources in the four northern ecoregions from the MT, WY, ND, and SD state bedrock maps where it was mapped in sharp detail along rivers. We did not add in “sand” from state bedrock datasets in the Central ecoregions due to state edge disagreement in KS, CO, and WY and because the proposed sand areas were not supported by EOs or other substrate datasets. In the western half of the Southern Shortgrass Prairie ecoregion, the USGS 425 “alluvial substrates” were also mapped as “sand.”

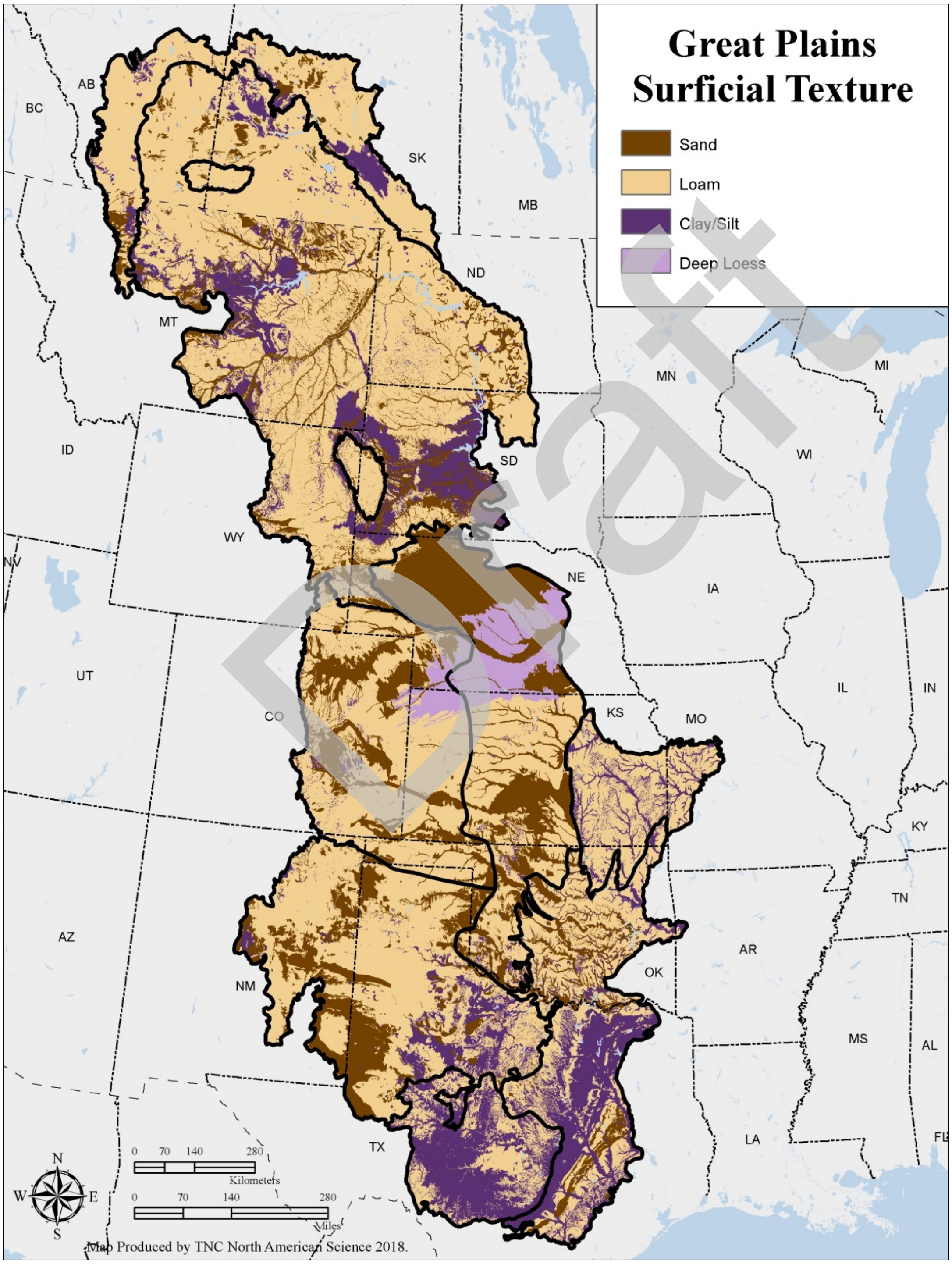
<u>Silt/Clay</u>: Silt and clay are fine-grained substrates (<0.2 mm) typically transported by water and deposited during evaporation. Soils with a high silt and clay content have an increased nutrient and water holding capacity and are often poorly drained. We extracted five fine-grained categories from USGS 425: “mostly clayey,” “fine grained,” “organic-rich muck and peat,” “biological,” and “lacustrine.” We augmented the base map by adding polygons from STATSGO, SSURGO, and the Canadian Detailed Soil Survey dataset that were >40% clay or ≥ 90% silt (i.e. the thresholds for finer clay and silt categories from the USDA soil pyramid triangle classes).

In the three Southern ecoregions (Osage Plains/Flint Hills Prairie, Crosstimbers and Southern Tallgrass Prairie, Edwards Plateau) and the eastern half of the Southern Shortgrass Prairie, we mapped USGS 425 “alluvial substrates” as “silt/clay” because our other sources of information suggested that river channels in these ecoregions were primarily composed of fine grained substrates. We also added areas from the state bedrock coverage classified as “clay/silt” and “mixed unconsolidated alluvial” polygons to our fine clay/silt category. The only exception to this was in northern Oklahoma, where we overrode the fine grain sediment with “sand” on the large rivers to maintain continuity with the northern systems.

<u>Loess</u>: Loess is unconsolidated silt-sized material transported and deposited by wind. “Deep loess” in this region is distinct from “loess” in its form and ecological influence, as it has been molded by wind into hills, and supports loess hill prairies and other loess related communities. Our map of deep loess was guided by a non-digital map from Bettis et al. (2003) that highlighted areas with loess depths greater than five meters. To match the distribution shown on the reference map, we selected polygons defined as “deep loess” from USGS 425 plus additional polygons identified as having greater than 60% silt in the STATSGO dataset. We hand edited the STATSGO polygons until the distribution visually matched the reference Bettis et al. (2003) map and encompassed all the loess-based element occurrences as well.

Calcareous Loam: Loam is a relatively fertile soil reflecting a mixture of sand, silt and clay. We mapped all the remaining deep surficial areas not classed as one of the above categories as loam. In this region, analysis of the soil pH and alkalinity in the SURRGO dataset suggested that all loams were calcareous in nature.

Figure 2.5: Surficial Sediments. Results of the compilation and classification of various surficial datasets into a single Great Plains map.



Integrating Bedrock Geology and Surficial Substrates

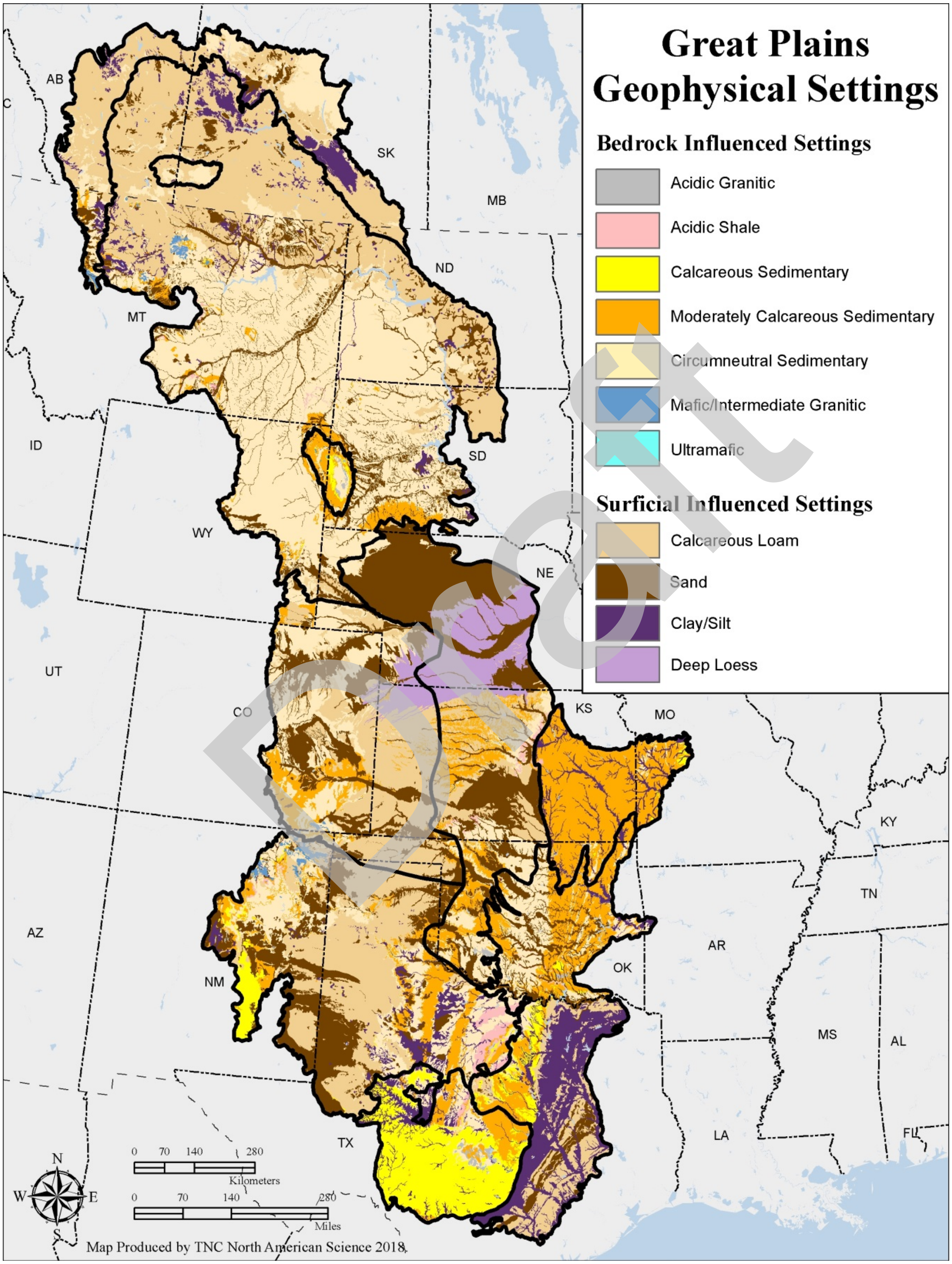
To create the final geophysical setting map for the study area, we applied the bedrock/surficial sediment split (Fig. 2.3) to the bedrock geology map (Fig. 2.4) and the surficial texture map (Fig 2.5). In the final map of 11 geophysical settings (Figure 2.6), bedrock categories are shown on the shallow bedrock influence zone, surficial texture settings are shown on the deep sediment areas (Fig 2.5). We smoothed the final results by eliminating small occurrences of individual settings less than 1000 acres in size, and using the Euclidean "nibble" function in ArcGIS to replace it with the closest adjacent setting type. Small patches of any setting may be nested within a different dominant setting type, but for our purposes we focus on larger patches because they are more likely to "represent" that setting, i.e., support the flora and fauna typical of the setting.

The resulting map indicates that the region is 45% shallow to bedrock settings and 55% deep surficial substrate settings. The most common settings are circumneutral sedimentary (28% of region) and calcareous loam (28% of region, Figure 2.6 and Table 2.1).

Table 2.1: Acres of each Geophysical Setting within the Great Plains Study Area

	Setting	**Acres**	**Percent**
Bedrock Based	Acidic Granitic	924,335	0.20
	Acidic Shale	3,120,823	0.66
	Calcareous Sedimentary	19,716,199	4.20
	Circumneutral Sedimentary	129,887,233	27.65
	Mafic/Intermediate Granitic	1,544,779	0.33
	Moderately Calcareous Sedimentary	55,174,987	11.74
	Ultramafic	2,136	0.00
Surficial Based	Calcareous Loam	131,280,475	27.94
	Clay/Silt	31,042,995	6.61
	Deep Loess	13,447,874	2.86
	Sand	83,678,485	17.81
	TOTAL	469,820,322	100.00

Figure 2.6: Geophysical Settings. The eleven major geophysical settings in the Great Plains study area.



Characterizing the Geophysical Settings

The following descriptions of the geophysical settings highlight the key characteristics of each physical environment and the associated species and communities.

Elevation Zones

The study region consists of a large flat plain with a base altitude that rises gradually from a low of 75 feet in the Crosstimbers and Southern Tallgrass ecoregion to over 5000 feet on the western border where the foothills flank the Rocky Mountains. The local relief is generally small with a few exceptions such as the Black Hills, the Cypress Uplands, and other relatively isolated rocky outcrops, canyons, and mountains in the Edwards Plateau, Northern Great Plains Steppe, and other ecoregions. In most of the region, elevational changes are quite gradual and the climate is arid, which reduces the influence of elevation on vegetation patterns. Discussions with our Steering Committee suggested that areas with larger elevational ranges were relatively small, and well-delineated by changes in geology, so additional delineation by elevation zone was deemed unnecessary to capture the coarse-scale relationships between settings and biodiversity.

Geophysical Settings and their Current Biota

The land's geologic substrate influences the type and diversity of natural communities occurring on a site. To assess the associations between the current biota and each geophysical setting we overlaid the 70,310 natural community and rare species EOs provided by NatureServe and the State Natural Heritage Programs on the geology and soil datasets. The results are summarized below to give users an indication of the type of biodiversity that each geophysical setting favors. We expect the future species composition to be of a similar ecological character, but perhaps not the same taxa. Familiar ecosystem and community types may be present in some form in the future but their exact composition and structure could vary widely from their current expression.

While we do not know exactly how the communities will rearrange, evidence from other climate zones suggests that the geophysical settings will continue to support distinct flora and fauna even under different climatic regimes. For example, around the globe, and under many climates, limestone areas favor distinct alkaline-tolerant flora, as well as fine-filter targets like cave-adapted species. These differ from the drought and fire-adapted species more common in sand (Kruckeberg 2004, Anderson and Ferree 2010, Beier and Brost 2010).

The summaries below list the species and communities that occurred in the described geophysical setting more than any other setting. The lists were developed by overlaying the Natural Heritage Program element occurrences and identifying the communities where 60-100% of the known locations were within the setting. We did not use statistical tests on this dataset because the distribution of points was so unbalanced across ecoregions and setting types. Instead we divided the region into three groups of ecoregions that tended to share similar biotic attributes. These were:

NORTH: (Northern Great Plains Steppe, Black Hills, Fescue/Mixed-Grass Prairie, Cypress Upland)
CENTRAL: (Central Mixed-grass Prairie, Central Shortgrass Prairie, Southern Shortgrass Prairie)
SOUTHEAST: (Osage Plains/Flint Hills Prairie, Crosstimbers and Southern Tallgrass Prairie, Edwards Plateau)

SURFICIAL SETTINGS

Surficial Setting: CLAY/SILT (31,042,995 acres 6.6% of region)

Silt and clay are fine-grained substrates with individual grain sizes less than 0.2 mm. Transported by water or deposited during evaporation, they may indicate ancient lakes and wetlands. Soils are typically very poorly drained and abundant with wetlands and waterbodies.

NORTH (7,848,017 acres, 4% of subregion)
Northern Great Plains Steppe, Black Hills, Fescue/Mixed-Grass Prairie, Cypress Upland

	Communities
Marsh:	Inland Salt Marsh, Inland salt pond, Deep and Shallow Emergent Marsh, Riverine marsh, Northern Tallgrass Saline Wet Meadow
Swamp:	Silver Maple-Ash Swamp, Northern White Cedar Swamp
Prairie:	Slough grass-bluejoint prairie

CENTRAL (3,837,765 acres, 2% of subregion)
Central Mixed-grass Prairie, Central Shortgrass Prairie, Southern Shortgrass Prairie

	Communities
Marsh	Inland Salt Marsh, Inland salt pond, Deep and Shallow Emergent Marsh, Riverine marsh, Northern Tallgrass Saline Wet Meadow
Swamp:	Silver Maple-Ash Swamp, Northern White Cedar Swamp
Prairie:	Slough grass-Bluejoint prairie

SOUTHEAST (19,357,213 acres, 21% of subregion)
Osage Plains/Flint Hills Prairie, Crosstimbers and Southern Tallgrass Prairie, Edwards Plateau

	Communities
Forest	Pecan - Sugarberry Forest, Green Ash-American Elm -Sugarberry/Possumhaw Forest, Eastern cottonwood – Peachleaf Willow -Narrowleaf Willow Woodland, Pin Oak-Pecan /Possumhaw Forest, Pin Oak-Swamp White Oak Forest. Wet Bottomland Forest
Springs and Seeps	Saline Spring, Saline Seep,
Marsh	Bulrush-spikerush marsh, Cattail Marsh Cattail-Hardy Water Canna marsh, Floating Primrose Willow Marsh, Prairie Cord Grass -Sedge Marsh
Prairie:	Mollisol Blackland Prairie, Vertisol Blackland Prairie Little bluestem Prairie Bluestem – Cornflower - Narrowleaf gumweed – Blazingstar Prairie,
River	Ozark - Warmwater - Creek

<u>Surficial Setting: SAND</u> (83,678,485acres, 17.8% of region)

Sands are composed of loose rock particles smaller than gravel, and deposits are well-drained and nutrient poor. Sand deposits often support fire-adapted communities.

<u>NORTH</u> (20,194,064 acres, 10% of subregion)
Northern Great Plains Steppe, Black Hills, Fescue/Mixed-Grass Prairie, Cypress Upland

	Communities
Prairie:	Sandsage Prairie, Sand grass – Needle-and-Thread Grassland Western Alkaline Meadow, Greasewood Shrub Prairie
Woodland:	Cottonwood – Green Ash forest
	Species
Vertebrates:	Bald Eagle, Great Blue Heron, Northern Leopard Frog, Western Box Turtle
Plants:	Fendler Cat's-eye (*Cryptantha fendleri*), Schweinitz's Flatsedge (*Cyperus schweinitzii*), Viscid Tansy-aster (*Rayjacksonia annua*), Annual skeletonweed (*Shinnersoseris rostrate*)

<u>CENTRAL</u> (56,734,871 acres, 31% of subregion)
Central Mixed-grass Prairie, Central Shortgrass Prairie, Southern Shortgrass Prairie

	Communities
Prairie:	Sandhills Mesic Tallgrass Prairie, Sandhills Dune Prairie, Sand Prairie, Northern Sandhill Prairie, Sandsage Prairie, Lowland Tallgrass Prairie
Woodland:	Cottonwood-Diamond Willow Woodland, Plains Cottonwood Riparian Forests Dry-Mesic Bur Oak Forest and Woodland Cottonwood - Willow Floodplain Woodland,
Marsh/fen:	Sandhills Hardstem Bulrush Marsh, Northern Cordgrass Wet Prairie, Freshwater Seep, Sandhills fen, Great Plains Neutral Seep
	Species
Vertebrates:	Piping Plover, Interior Least Tern, Trumpeter Swan, Long-billed Curlew
Invertebrates:	American Burying Beetle
Plants:	Blowout Penstemon (*Penstemon haydenii*), Western Prairie White-fringed Orchid (*Platanthera praeclara*), Boreal Aster (*Symphyotrichum boreale*)

<u>SOUTHEAST</u> (6,748,550 acres, 7% of subregion)
Osage Plains/Flint Hills Prairie, Crosstimbers and Southern Tallgrass Prairie, Edwards Plateau)

Communities	
Forest:	Loblolly Pine-post Oak-blackjack Oak/farkleberry Forest, Post Oak-blackjack Oak Series, Post Oak-black Hickory Series
Marsh:	Sphagnum-beakrush Series, Cattail -Bulrush Marsh, Wet Meadow
Prairie:	Alfisol Coastal Prairie

Surficial Setting: CALCAREOUS LOAM (131,280,475 acres, 28% of region)

Loam is a fertile mixture of sand, silt and clay. Most tills in the study area are derived from circumneutral or calcareous parent materials and weather to calcareous loams. These soils can be productive for agriculture.

NORTH (72,207,052 acres, 37% of subregion)
Northern Great Plains Steppe, Black Hills, Fescue/Mixed-Grass Prairie, Cypress Upland

	Communities
Prairie:	Saltgrass - Western Wheatgrass Meadow, Plains Rough Fescue - Western Porcupine Grass Grassland, Plains Rough Fescue Grassland, Western Wheat grass - Low Sedge Meadow, Needlegrass-Wheatgrass Prairie, Nuttall's Salt-meadow Grass Community, Little Bluestem - Mountain Rough Fescue Grassland,
Woodland:	Green Ash Upland Woodland, Rocky Mountain Juniper / Little-seed Ricegrass Woodland,
Shrubland:	Buckbrush / Giant Wild Rye Shrubland
Wetland:	Baltic Rush Wet Meadow, Samphire emergent marsh, Saline littoral lake
	Species
Vertebrates:	Swift fox, Baird's Sparrow, Chestnut-collared Longspur, Sedge Wren, Yellow Rail, Sharp-tailed Sparrow
Invertebrates:	Rocky Mountain Dotted Blue, Acadian Hairstreak, Two-tailed Swallowtail
Plants:	Nebraska sedge (*Carex nebrascensis)*, Short-stalk Mouse-ear Chickweed (*Cerastium brachypodum)*, Western False Gromwell (*Lithospermum occidentale*), Chaffweed (*Lysimachia minima)*, Hairy pepperwort (*Marsilea vestita)*

CENTRAL (50,806,877 acres, 28% of subregion)
Central Mixed-grass Prairie, Central Shortgrass Prairie, Southern Shortgrass Prairie

	Communities
Prairie:	Shortgrass Prairie, *Bouteloua gracilis - Buchloe dactyloides* herbaceous vegetation, Western Tallgrass Prairie
Woodland:	Rocky Mountain Juniper Woodland
Wetland:	Alkaline Marsh
	Species
Vertebrates:	Tiger Salamander, Grasshopper Sparrow, Common Goldeneye, Chestnut-collared Longspur, White-winged Junco, McCown's Longspur
Plants:	Mat grama (*Bouteloua simplex)*, Crawe's sedge (*Carex crawei*), Streambank groundsel (*Packera pseudaurea*), Meadow Popcorn-flower (*Plagiobothrys scouleri*), Rosinweed (*Silphium integrifolium*)

SOUTHEAST (8,266,546 acres, 9% of subregion)
Osage Plains/Flint Hills Prairie, Crosstimbers and Southern Tallgrass Prairie, Edwards Plateau

Woodland:	Post Oak-blackjack Oak/little Bluestem Cross Timbers Woodland

<u>Surficial Setting: LOESS</u> (13,447,874 acres, 3% of region)

Loess is a silt-sized sediment transported and deposited by wind. In this region, loess deposits can be over 65 feet in depth and weather to a productive soil.

<u>NORTH</u> (27,018 acres, <1% of subregion). Very small amount, no element occurrences.

<u>CENTRAL</u> (13,420,856 acres, 7% of subregion)
Central Mixed-grass Prairie, Central Shortgrass Prairie, Southern Shortgrass Prairie

	Communities
Prairie:	Northern Loess/Shale Bluff Prairie, Loess Mixed-grass Prairie, Loess Prairie, Wheatgrass Playa Grassland
Woodland:	Dry Upland Bur Oak Woodland
Marsh:	Shallow cattail marsh
Vertebrates:	Hispid Cotton Rat, Coachwhip, Plains Blackhead Snake,
Invertebrates:	Fulvia Checkerspot, Western Black Swallowtail
Plants:	Least Spikerush (*Eleocharis acicularis*) Michaurx's Stichwort (*Minuartia michauxii var. texana*) Stemmed Four-nerve Daisy (*Tetraneuris scaposa var. linearis*)

<u>SOUTHEAST</u>**:** (0 acres) Does not occur

BEDROCK SETTINGS

<u>Bedrock Setting: CIRCUMNEUTRAL SEDIMENTARY</u> (129,887,233 acres, 28% of region)

Shallow soil settings on sandstone, siltstone, and conglomerate, may be overlain with thin till.

<u>NORTH</u> (85,446,380 acres, 44% of subregion)
Northern Great Plains Steppe, Black Hills, Fescue/Mixed-Grass Prairie, Cypress Upland

	Communities
Prairie:	Silver Sagebrush Shrub Prairie, Western Sand Prairie Threadleaf Sedge Western Mixed-Grass Prairie, Northwestern Mixed-Grass Prairie, Western Wheatgrass Prairie, Western Little Bluestem Prairie
Shrubland:	Silver Sage-Western Wheatgrass Scrub, Mountain Mahogany Shrubland Round-Leaved Hawthorn / Cow Parsnip - Common Nettle Shrubland, Horizontal Juniper-Little Bluestem Shrubland, Greasewood / Western Wheat Grass Shrubland, Buffaloberry Shrubland,
Woodland:	Dry-Mesic Ponderosa Pine Woodland, Green Ash-Elm-Hackberry Canyon Bottom Woodland, Rocky Mountain Juniper Woodland, Pine-Juniper Scarp Woodland, Dry Ponderosa Pine Open Woodland and Savanna, Bur Oak Upland Woodland

CIRCUMNEUTRAL SEDIMENTARY, NORTH (continued)

Barrens: Badlands Slope, Creeping Juniper / Sun-Loving Sedge - Yellow Umbrella-Plant Badland Community, Rock Outcrop
Wetland: Western Floodplain Forest

Species

Vertebrates: Least Chipmunk, Merriam's Shrew, Upland Sandpiper, Lewis's Woodpecker, Sandhill Crane
Invertebrate: Prairie Long-Lipped Tiger Beetle, Uhler's Arctic, Tawny Crescent
Plants: Prickly milk vetch (*Astragalus kentrophyta var. kentrophyta*), White-scaled Sedge (*Carex xerantica*), Missouri Foxtail Cactus (*Coryphantha missouriensis*), Davis Mountain Stickseed (*Hackelia floribunda*), Prairie Bluebells (*Mertensia lanceolate*), shrubby evening-primrose (*Oenothera serrulate*) Little Indian Breadroot (*Pediomelum hypogaeum*), Silverleaf Scorpionweed (*Phacelia hastata var. hastate*), Horse Cinquefoil (*Potentilla hippiana*), Snowberry (*Symphoricarpos albus*)

CENTRAL (33,981,558 acres, 18% of subregion)
Central Mixed-grass Prairie, Central Shortgrass Prairie, Southern Shortgrass Prairie

Communities

Grassland: Mesic Tallgrass Prairie, Xeric Tallgrass Prairie, Shortgrass Prairie, Montane Grasslands, Threadleaf Sedge Western Mixed-grass Prairie, Great Plains Mixed Grass Prairies (Sandstone/Gravel Breaks)
Shrubland: Mountain Mahogany Shrubland, Mixed Foothill Shrublands
Woodland: Scarp Woodlands, Pine-Juniper Scarp Woodland, Dry Ponderosa Pine Open Woodland and Savanna
Barren/Caves: Terrestrial Cave, Rock Outcrop

Vertebrates: Swift Fox, Ferruginous Hawk, Swainson's Hawk, Mountain Plover, Mountain Short-horned Lizard
Plants: Mountain Cat's-eye (*Cryptantha cana*), Green-flower Hedgehog Cactus (*Echinocereus viridiflorus*), Plains Flax (*Linum puberulum*), Rocky Mountain Oxytrope (*Oxytropis multiceps*), Moss Phlox (*Phlox bryoides*)

SOUTHEAST (10,459,296acres, 11% of subregion)
Osage Plains/Flint Hills Prairie, Crosstimbers and Southern Tallgrass Prairie, Edwards Plateau

Communities

Grassland: Arkansas Valley Prairie and Woodland, Little Bluestem - Narrowleaf Pinweed - Cardinal's-feather Grassland, Little Bluestem – Indiangrass - Splitbeard bluestem - largeflower tickseed Sandstone - Shale Grassland Eastern Gamagrass - Switchgrass - Indiangrass - Maximilian Sunflower Grassland
Woodland: Post Oak - Blackjack Oak / Little Bluestem Woodland Common Name: Crosstimbers Post Oak - Blackjack Oak Woodland
Glade: Ozark Sandstone Glade, Little Bluestem - Churchmouse Three-awn - Willdenow's Croton / Lichens Wooded Grassland

Species

Plants: Rain-Lily (*Cooperia drummondii*), Slender Marsh-Elder (*Iva angustifolia*), Fringed Puccoon, (*Lithospermum incisum*)

Bedrock Setting: ACIDIC SHALE (3,120,823 acres, 1% of region)

Shallow acidic and/or fissile fine-grained shales. Soft and calcareous shales were placed in the moderately calcareous setting.

NORTH (326,140 acres, <1% of subregion)
Northern Great Plains Steppe, Black Hills, Fescue/Mixed-Grass Prairie, Cypress Upland

No communities or species had more than 50% of the locations on this setting. Species that occur on this setting commonly include: Ferruginous Hawk, Greater Sage-Grouse and Brewer's Sparrow.

CENTRAL (2,153,648 acres, 1% of subregion)
Central Mixed-grass Prairie, Central Shortgrass Prairie, Southern Shortgrass Prairie

Glades /Grassland: Ozark Sandstone Glade, West Gulf Coastal Plain Fleming Calcareous Prairie, Little Bluestem - Sideoats Grama - Texas Wintergrass Grassland

SOUTHEAST (641,035vacres, 1% of subregion)
Osage Plains/Flint Hills Prairie, Crosstimbers and Southern Tallgrass Prairie, Edwards Plateau

No communities or species had more than 50% of their locations on this setting. Confirmed types included Little Bluestem-Indiangrass-Needlegrass Herbaceous Vegetation.

<u>Bedrock Setting: MODERATELY CALCAREOUS</u> (55,174,987 acres, 12% of region)

Shallow soils over calcareous shales or mixed bedrock types. Flora and fauna can be similar to calcareous but are less distinctive.

<u>NORTH</u> (6,440,820 acres, 3% of subregion)
Northern Great Plains Steppe, Black Hills, Fescue/Mixed-Grass Prairie, Cypress Upland

	Communities
Shrubland:	Creeping Juniper – Sun Sedge Dwarf Shrubland
Wetland:	Eastern Pondweed Aquatic Wetland
	Species
Vertebrates:	Plains Spotted Skunk, Northern Saw-whet Owl
Plants:	Prairie three-awn (*Aristida oligantha*), Branched False Goldenweed (*Oonopsis multicaulis*), Desert Prince's-plume (*Stanleya pinnata var. pinnata*), Hooker's Townsend-daisy (*Townsendia hookeri*), Smooth Woody-aster (*Xylorhiza glabriuscula*)

<u>CENTRAL</u> (19,056,997 acres, 10% of subregion)
Central Mixed-grass Prairie, Central Shortgrass Prairie, Southern Shortgrass Prairie

	Communities
Glades /Grassland:	Plains Escarpment Prairies (Limestone Breaks), Great Plains Mixed Grass Prairie, New Mexico Feathergrass Mixedgrass Prairie
Shrubland:	Foothills Shrubland, James' Sea-heath / Indian Rice Grass Shrubland,
Woodland:	Juniper / Sagebrush Woodland, Foothills Pinyon-Juniper Woodlands
	Species
Plants	Tassel Flower (*Brickellia grandiflora*), Narrowleaf scurf-pea (*Pediomelum linearifolium*)

<u>SOUTHEAST</u> (29,677,171 acres, 32% of subregion)
Osage Plains/Flint Hills Prairie, Crosstimbers and Southern Tallgrass Prairie, Edwards Plateau

	Communities
Prairie:	Flint Hills Tallgrass Prairie, Unglaciated Tallgrass Prairie Southeastern Tallgrass Prairie, Dry-mesic limestone/dolomite prairie, Dry-mesic sandstone/shale prairie, Hardpan prairie, Prairie swale, Little Bluestem - Tall Dropseed - Cusp Gayfeather Hardpan Prairie, Claypan Tallgrass Prairie, Sandstone Prairie, Wet-mesic bottomland prairie
Wetland:	Central Plains - Warmwater – Headwater, Aquatic Cave
Forest:	Oak - Hickory Forest, Post Oak - Blackjack Oak Forest (Old=cross Timbers Upland Forest)

<u>Bedrock Setting: CALCAREOUS</u> (19,716,199 acres, 4% of region)

Shallow soils over limestone or dolomite that typically support an array of distinctive communities and rare species.

<u>NORTH</u> (384,624 acres, <1% of subregion)

Very little of this setting occurs in this region and no communities or species appear to be restricted to it. It supports two occurrences of Townsend's Big-eared Bat

<u>CENTRAL</u> (2,511,573 acres, 1% of subregion)

Very little of this setting occurs in this region and no communities or species occur appear to be restricted to it.

<u>SOUTHEAST</u> (16,820,003 acres, 18% of subregion)
Osage Plains/Flint Hills Prairie, Crosstimbers and Southern Tallgrass Prairie, Edwards Plateau

	Communities
Prairie:	Dry-mesic chert prairie, Curly mesquite-Sideoats Grama Herbaceous Vegetation, Central Great Plains Little Bluestem Prairie
Shrubland:	Guajillo Shrubland
Woodland:	Ashe Juniper-oak Woodland, Papershell Pinyon-Ashe Juniper-oak Woodland. Texas Oak-Ashe Juniper-Texas Ash Woodland, Plateau Live Oak/curly mesquite Woodland, Plateau Live Oak/little bluestem Woodland, Lacey Oak-Ashe Juniper Woodland
Forest:	Baldcypress-Sycamore Forest

<u>Bedrock Setting: ACIDIC GRANITIC</u> (924,335 acres, <1% of region)

Rocky bedrock-based acidic granites often with hills, outcrops and poorly drained wetlands.

<u>NORTH</u> (257,001 acres, <1% of subregion)

Only one plant species: Divide Bladderpod (*Physaria klausiiery*) was found primarily on granite.

<u>CENTRAL</u> (261,183 acres, <1% of subregion)

Only a small area of granite occurred in this ecoregion and it contained a variety of montane riparian forests and Narrowleaf Cottonwood/Common Chokecherry woodland.

<u>SOUTHEAST</u> (406,152 acres, <1% of subregion)

There is very little granite in this region and no communities appear to be restricted to it. There are examples of Plateau Live Oak/little Bluestem Woodland and Post Oak-Blackjack Oak/Little Bluestem Cross Timbers Woodland where it occurs.

Bedrock Setting: MAFIC (1,544,779 acres, <1% of region)

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 igneous settings.

NORTH (597,781 acres, <1% of subregion)

Little of this setting occurs in the region and only one plant species: Whitebark Pine (*Pinus albicaulis)* is found predominantly on mafic bedrock. Occasional plants include Divide Bladderpod (*Physaria klausii*) and Heart-leaved Buttercup (*Ranunculus cardiophyllus*).

CENTRAL (945,464 acres, 1% of subregion)
Central Mixed-grass Prairie, Central Shortgrass Prairie, Southern Shortgrass Prairie

	Communities
Prairie	Blue Grama - Buffalograss Shortgrass Prairie, Montane Grassland, Parry's oatgrass (*Danthonia parryi*) Grassland, Mountain Muhly (*Muhlenbergia montana*) Grassland
Woodland	Foothills Pinyon-Juniper Woodlands
Shrubland	Mixed Mountain Shrublands

SOUTHEAST (1,533 acres, <1% of subregion)

Only one thousand acres occur in this region, and there are no confirming EOs.

Bedrock Setting: ULTRAMAFIC (2,136 acres, >1% of region)

Setting on volcanic or other mafic rocks extremely high in magnesium (Ma) or iron (Fe). These soils may be toxic to some species and often have a characteristic flora and fauna.

SOUTHEAST (2,136 acres, <1% of subregion)

Only 2,000 acres occur in this region (in the Edwards Plateau), and there are no confirming EOs.

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CHAPTER 3

ESTIMATING SITE RESILIENCE

The physical characteristics of a site—its topography, soil characteristics, and the presence of wetlands—can buffer resident species from the direct effects of climate change. Plants and animals experience climate at such local scales that a landscape with topographic variation is experienced as a mix of microclimates: dry to wet, or cool to hot depending on slope position and aspect. Microclimates allow species to find pockets of suitable moisture and temperature even where the average background climate appears unsuitable. Intact sites with little fragmentation and a large variety of microclimates may enable species to persist longer, even indefinitely, under a changing climate, because individuals and populations can shift their locations locally to take advantage of the microclimate variation.

Wetlands, including groundwater-fed springs and seeps, riparian wetlands, prairie potholes, and playas also can be used to indicate relative differences in site resilience for areas with flatter topography. Especially in semi-arid and arid regions of the Great Plains, the extent and variety of wetlands is likely to provide a good indicator of even subtle differences in topography and soils that contribute to microclimate variation, especially differences in moisture levels.

Sites with little fragmentation and many microclimates are hypothesized to have high **site resilience** because the climatic variation allow them to retain diversity and ecological functions longer than sites that are fragmented and flat. In this section, we describe the concepts, methods, and data used to estimate the relative resilience of any given site. The two factors important to the estimate—**landscape diversity** and **local connectedness**—are discussed separately, because the tools for assessing and measuring them are distinctly different.

Section 1: Landscape Diversity

Our first climate change resilience factor, the landscape diversity metric, addresses variation in topography, an indicator of microclimate variation. In the Great Plains, strong exposure to climate drivers is already occurring. The observed and projected climate change information presented here comes from two chapters in the most recent U.S. National Climate Assessment (Shafer et al. 2014, Walsh et al. 2014), which document that the Great Plains has shown high rates of temperature increase, especially in the northern plains. North Dakota's average temperature has increased faster than any other state in the contiguous United States (Shafer et al. 2014), and the number of days with temperatures over 100°F is projected to double in the Northern Great Plains and quadruple in the Southern Great Plains by 2050 (Walsh et al. 2014).

Precipitation patterns are more spatially and temporally variable, and future conditions are more challenging to project. For example, in the northern plains the amount of winter/spring precipitation and the number of days with heavy downpours and snowfall are projected to increase, while trends for the central part of the region focus on less summer rainfall. Southern states, including Texas and Oklahoma, are also projected to experience longer periods without rainfall, which combined with increasing temperatures, suggests increasing drought stress. Water stress, including drying of wetlands and other waterbodies, is likely to increase across the Great Plains over time, as warming temperatures continue to increase evaporation and transpiration, leading to drier conditions even for places receiving similar or even increased amounts of precipitation (Crausbay et al. 2017).

While projections of future climate patterns should inform our conservation strategies, it's important to remember that these data are regional averages, and that the more local the climate change projection estimate (i.e., the more "downscaled" the climate projection has been from the original global-scale model), the higher the associated uncertainty associated with the values for each pixel on a map. However, these changes in global and regional climate also interact with other factors, such as topography and landform, which modify local microclimate conditions in patterns that are much more predictable at local scales. Understanding and mapping these persistent indicators of local climatic variation is the focus of this section.

Landscape-based climatic variation is substantial, on par with, and often greater than expected climatic changes for a region. These variations can be measured in even a gently rolling landscape, such as Northern England, where temperature loggers placed across gradients of slope, aspect and elevation have revealed site differences in maximum temperature measurements for the same month exceeding 34^0 F (Suggitt et al. 2011). In California's serpentine grasslands, microtopographic thermal climates also showed a 34^0 F difference between maximum values at different slopes (Dobkin et al. 1987). In these serpentine grasslands, areas of high local landscape diversity are important for long-term population persistence of butterfly species and their host plants under variable climatic conditions (Weiss et al. 1988). Vegetation, with its high moisture content, moderates the effect of topography on temperature variation, but even in heavily forested landscapes, variation in aspect and topography can create large differences in temperature. For instance, in the Southern Blue Ridge Mountains scientists have measured a 25^{0}F difference between a hot south-facing slope and a cool sheltered ravine in mid-summer (P. McMillan, pers. comm., October 2010).

The distribution of moisture in a landscape is also correlated with topography and aspect. Topography has been found to explain 40%-72% of soil moisture variation (Yeakley et al. 1998) in Appalachian forests. In grasslands, aspect alone can explain as much of 20% of the local differences in soil moisture (Bennie et al. 2006 & 2008). Many studies of landscape-based climate variation show how strongly local climatic variation explains species distribution patterns, suggesting that understanding microclimates is a key to understanding species persistence (Ashcroft et al. 2009, DeFrenne et al 2013, Dobrowski 2011, Pincebourde et al. 2016, Yeakley et al. 1998).

Topography redistributes temperature and precipitation so dramatically that in some landscapes no areas experience the "average" regional climate: basins are wetter, summits are dryer, south-facing slopes are hotter, and north-facing slopes are cooler. Coarse-scale models predicting the loss of all suitable habitats for plants in the Swiss Alps conversely predicted the persistence of suitable habitats for all species when they were rerun at local scales that captured topographic diversity (Randin et al. 2009).The term “microclimatic buffering” (Willis and Bhagwat 2009) has been coined for the situation where climate interacts with topography, moisture and aspect to create suitable climatic combinations for species in areas where coarse-scale climate models suggest unsuitable climate. In effect, microclimates “buffer” the resident species from the direct effects of regional climate change.

By mapping a landscape’s relevant variation in topography, aspect and moisture, we can incorporate proxies for microclimate variations into conservation planning. Specifically, the number and variety of topographically-derived microclimates present at a site—its **landscape diversity**—can be used to estimate the capacity of the site to maintain biological diversity over time (Anderson et al. 2014a).

In this section we describe our methods to quantify landscape diversity at a relatively fine scale across the study area, and to estimate the number of species-relevant microclimates in 40 ha circle around every 30-m cell. Our spatial models were built from continuous surfaces of digital elevation data, and the landscape diversity estimates were derived from topography, aspect and moisture estimates. The latter step included:

1. Landform Variety: the variety of landforms derived from topographic position, slope and aspect.
2. Wetland Influence: the density of wetlands (including playas), and small waterbodies.

Landform Variety

Landforms are natural features of the earth’s surface created by topography - collectively the set of landforms comprises a region’s terrain. A single landform can be described as a combination of topographic position, aspect, slope, and moisture (e.g. moist north-facing toeslope). The distribution of landforms in a landscape determines local vegetation patterns because these characteristics drive stable patterns of temperature and moisture, and correlate with exposure, nutrient availability, and soil depth (Barnes et al 1982, Forman 1995). Landform variation may create subtle biotic variation, for example in sand prairie species diversity, or distinct habitats such as a depression wetland, cove forest, or summit grassland.

The basic landform unit (a.k.a. ecological land unit, land facet, land segment, elementary landform, or relief unit) is the smallest homogeneous division of the land surface at a given scale. Because each unit is characterized by attributes such as elevation, slope, aspect, exposure, moisture, and topographic position, they can be used at a proxy for topographically-based micro climates, and the number and variety in an area can provide an estimate of the number of microclimates available to species. To map landforms and quantify microclimates, we developed a GIS model that divides and classifies a continuous terrain surface into one of 17 landforms. Our methods are based on those of Fels and Matson (1997), and are described in detail elsewhere (Anderson 1999, Anderson et al. 2012). To delineate landforms we start with a 30-m digital elevation model (DEM; Gesch 2007, Canada Digital Elevation Data 2011), and use it to derive estimates of slope, aspect, land position, and moisture accumulation for each pixel in the study area. For each of these variables, we defined thresholds that allowed us to partition values into different zones (Figures 3.1 and 3.2) that corresponded with recognizable distinctions that had meaning relative to species distributions or other ecological patterns, and could be verified with data collected in the field. The primary divisions in the model were based on relative land position and slope, and then slopes were further divided by aspect, and flats by moisture accumulation (Figures 3.1-3.3).

To create the landform model, we generated the following initial datasets as grids from the 30-m DEM:

- Topographic Position Index: We evaluated the elevation differences between any cell and the surrounding cells within a search radius of 350 m and scored it using a topographic position index (TPI). For example, if the model cell was, on average, higher than the surrounding cells, then it was considered closer to the hill top (a more positive position value), and conversely, if the model cell was, on average, lower than the surrounding cells, then it was considered closer to the slope bottom (a more negative position value).
- Slope: Degree of slope was calculated as the difference in elevation between two neighboring cells, expressed in degrees.
- Aspect: Aspect was calculated using the GIS Aspect tool which fits a plane to the z-values of a 3 x 3 cell neighborhood around a center cell. The direction the plane faces is the aspect for the center cell.
- Moisture Index: We calculated a moisture index using a flow accumulation model which maps variation in moisture accumulation and soil residence time using the equation: *Moist index = ln [(flow accumulation + 1) / (slope + 1)]*.

We used National Wetlands Inventory (NWI) datasets (U. S. Fish and Wildlife Service 2017) and a playa coverage from the Playa Lakes Joint Venture (PLJV Version 4. 2017) to calibrate the moisture index and set a threshold for dividing flat areas into place where moisture is more (moist flat) or less (dry flat) likely to accumulate. To address strong patterns in moisture availability across the study area, we examine each ecoregion separately, and defined moist areas as those with a moisture index >= 0.5 Standard Deviation (SD) above the mean value of the mapped wetlands and playas for that ecoregion. This criterion did a good job of spatially capturing the known wetlands across this very large and variable study region without overpredicting moist areas far outside of the known wet places. The moisture index threshold, i.e., the modeled amount of flow accumulation calculated from the topography that was expected to be associated with moist soils ranged from a low value of 2302 in the more mesic Osage Plains/Flint Hills Prairie ecoregion to a high value of 3638 in the more arid Southern Shortgrass Prairie ecoregion.

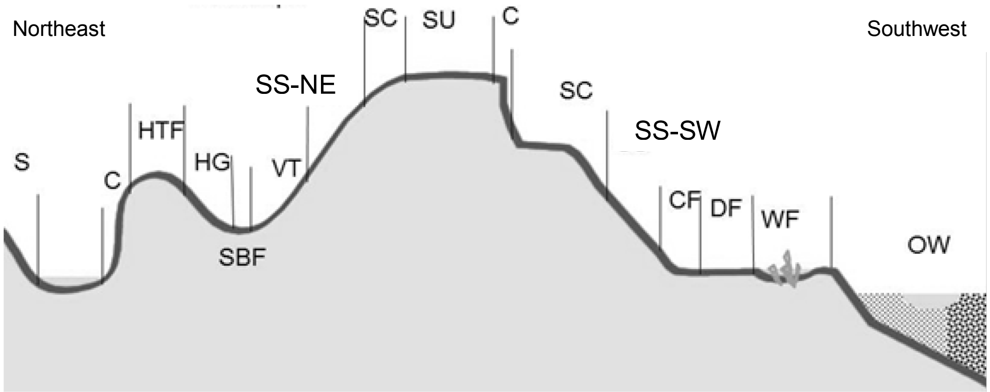
Areas with confirmed wetlands, playas lakes, or small waterbodies between 2-100 acres in size were labeled as “wet flats” in the landform model, while the remaining areas with high potential moisture but no mapped wetlands were labeled "moist flats." Wetland and water sources included Canada Agriculture and Agri-Food Canada (AAFC) "Landuse Wetlands," defined as pixels classified as wetland >2 years out of 2012-2016 period (AAFC 2012-2016), Canada Vector Waterbodies 1:50,000 (Natural Resources Canada, 2017), Alberta Merged Wetland Inventory (Alberta Environment and Parks, 2017), US National Wetland Inventory wetlands of type EM/FO/SS (USFWS 2017), US National Land Cover Database Emergent or Forested Wetlands (NLCD 2011), US National Hydrography High Resolution Waterbodies and Areas (USGS 2017), and Playa Lakes for parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma and Texas from the Playa Lakes Joint Venture (PLJV Probable Playas V.4.).

Open water bodies between 2-100 acres were put in the "wet flat" category because these small waterbodies were considered by Great Plains ecologists to be similar to playa lakes, and to be an important part of the wetland ecosystem continuum. Spatial comparison of these small waterbodies with existing NWI, wetland, and playa datasets also showed much spatial confusion and overlap between and among the wetlands, playas, and small waterbodies mapped in different sources. To address these conflicts in classification, we restricted the "open water" landform to waterbodies >100 acres, which we expect provide substantial permanent open water habitat. Smaller "open water" areas were grouped with the permanent and intermittent wetlands and small playa waterbodies in the wetland continuum. Waterbodies less than 2 acres were removed from the dataset after careful investigation indicated most of them were either errors or artificially created stock ponds or farm ponds.

The datasets for topographic position, slope, aspect, wet flats, and moist flats were combined in a structured way to create a continuous grid of landforms (Figure 3.2). For example, a south-facing side-slope was defined by land position, slope and aspect, whereas a moist flat was defined by land position, slope and moisture accumulation. The landform model can theoretically distinguish any number of units, but we used a 17-unit model that our past assessments with species/community occurrence data suggests matched recognizable environments with differing vegetation, especially in the herbaceous layer. We tested whether these 17 units were a good fit for the Great Plains by working with our Steering Committee to evaluate results at various stages using maps of familiar locations and comparisons of different site types, such as those shown in Figure 3.3.

To identify areas with the highest diversity of microclimates, we calculated the variety of landforms in a 40.4 ha (100-acre) circle surrounding every 30-m cell (Figure 3.4) using a focal variety analysis. This search area corresponds to roughly a 350-m radius around each focal cell, and was chosen because it provides the best discrepancy between cells (highest between-cell variance), and is reasonable for a wide range of species, in that it suggests local population movements could access a 40.4 ha (100-acre) neighborhood. In the count of landforms each type was given 1 point except for wet flats and open water, both of which were given 2 points if they occurred in the focal circle, bringing the total possible score to 19. Previous assessments have not given higher values to wet flats and water, but we made this change in the Great Plains to account for the importance of water in this more arid region. If for example two sites had the same total number of landform/microclimates but only one contained "wet flats" or "open water," the site with the wet microclimates would score higher.

Figure 3.1: Distribution and Definitions of Landforms.



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

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

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

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

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

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

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

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

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

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

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

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

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

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

Figure 3.2: The Underlying Slope and Land Position Model used to Map Landforms.
Adapted from Fels and Matson 1997.

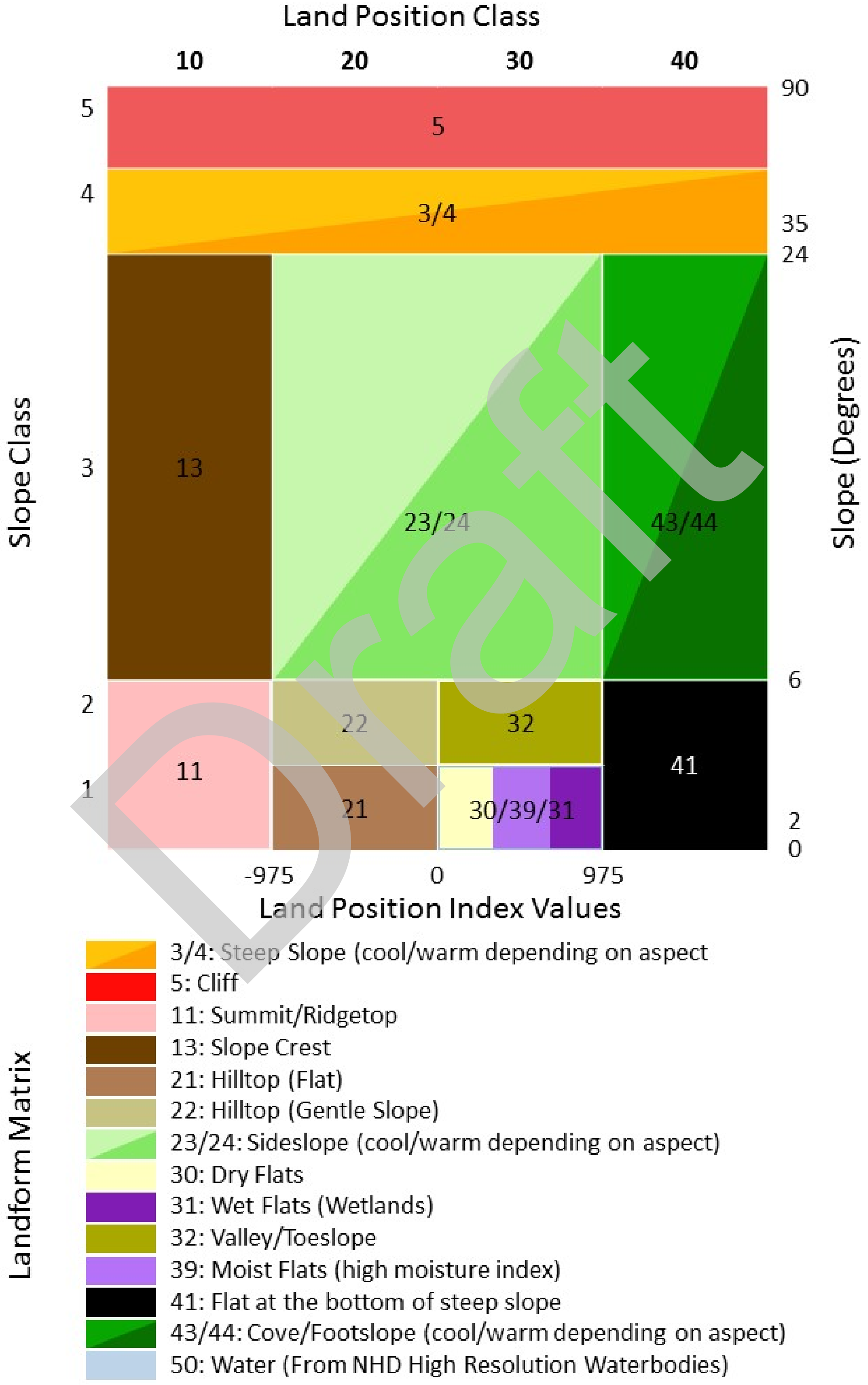


Figure 3.3: The 17-unit Landform Model. These images show how the landform model partitions the landscape based on slope, aspect, land position, and moisture accumulation using the Palo Duro Canyon, Armstrong Texas, Southern Shortgrass Prairie Ecoregion, as an example. The area includes a wide spectrum of landforms—from steep slopes, sideslopes, and coves in the canyon to flatter surrounding plains where gentle hills, dry flats, and playa wetflat areas are common. **A)** The area in shaded relief, **B)** with an overlay of the landforms. **C)** A 3-D representation.

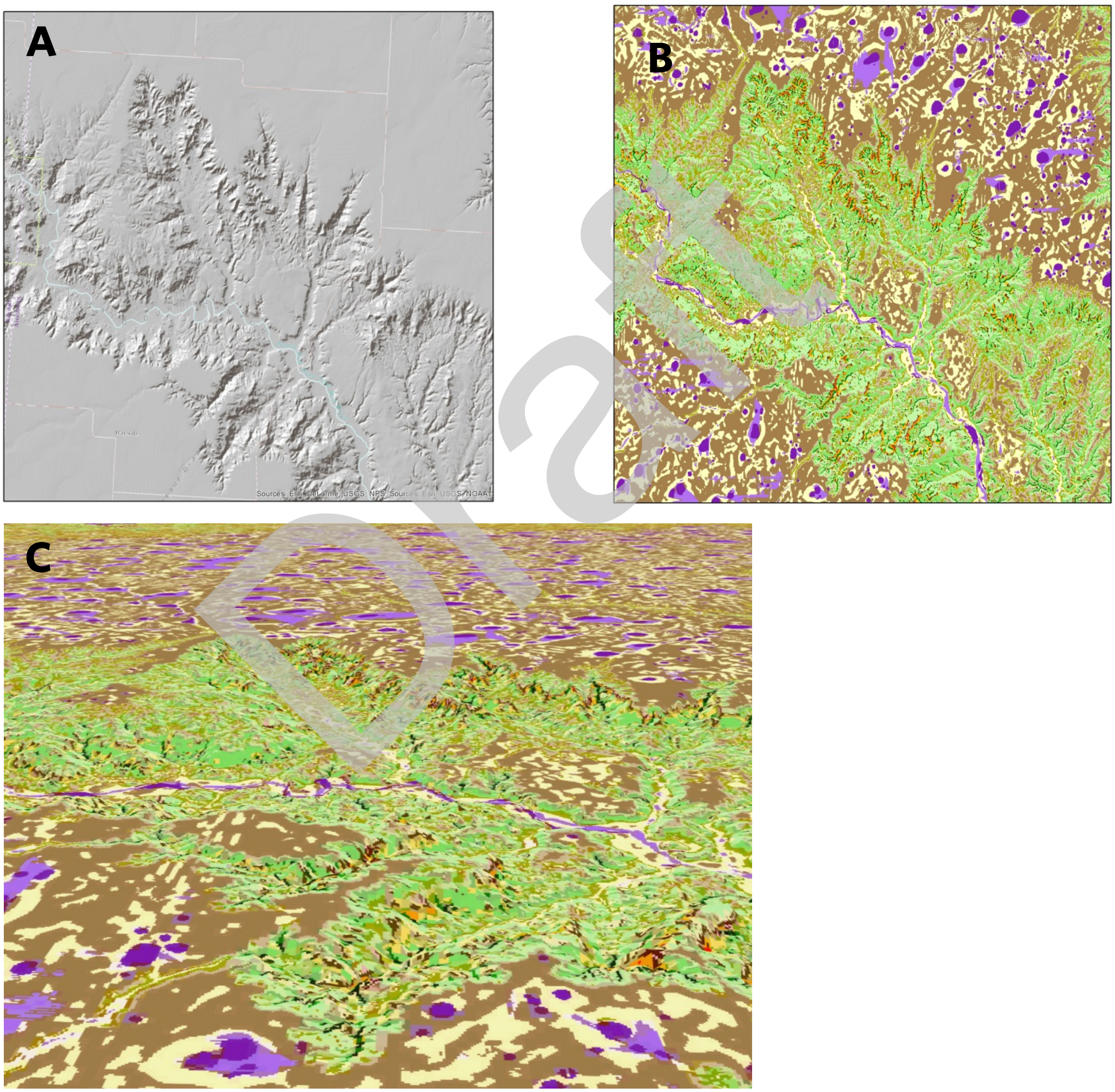


Figure 3.4: Landforms. The Great Plains focal region mapped as 17 landform types. These landforms are used to characterize the region's topography and to calculate the landform variety metric (30m cell mapping resolution).

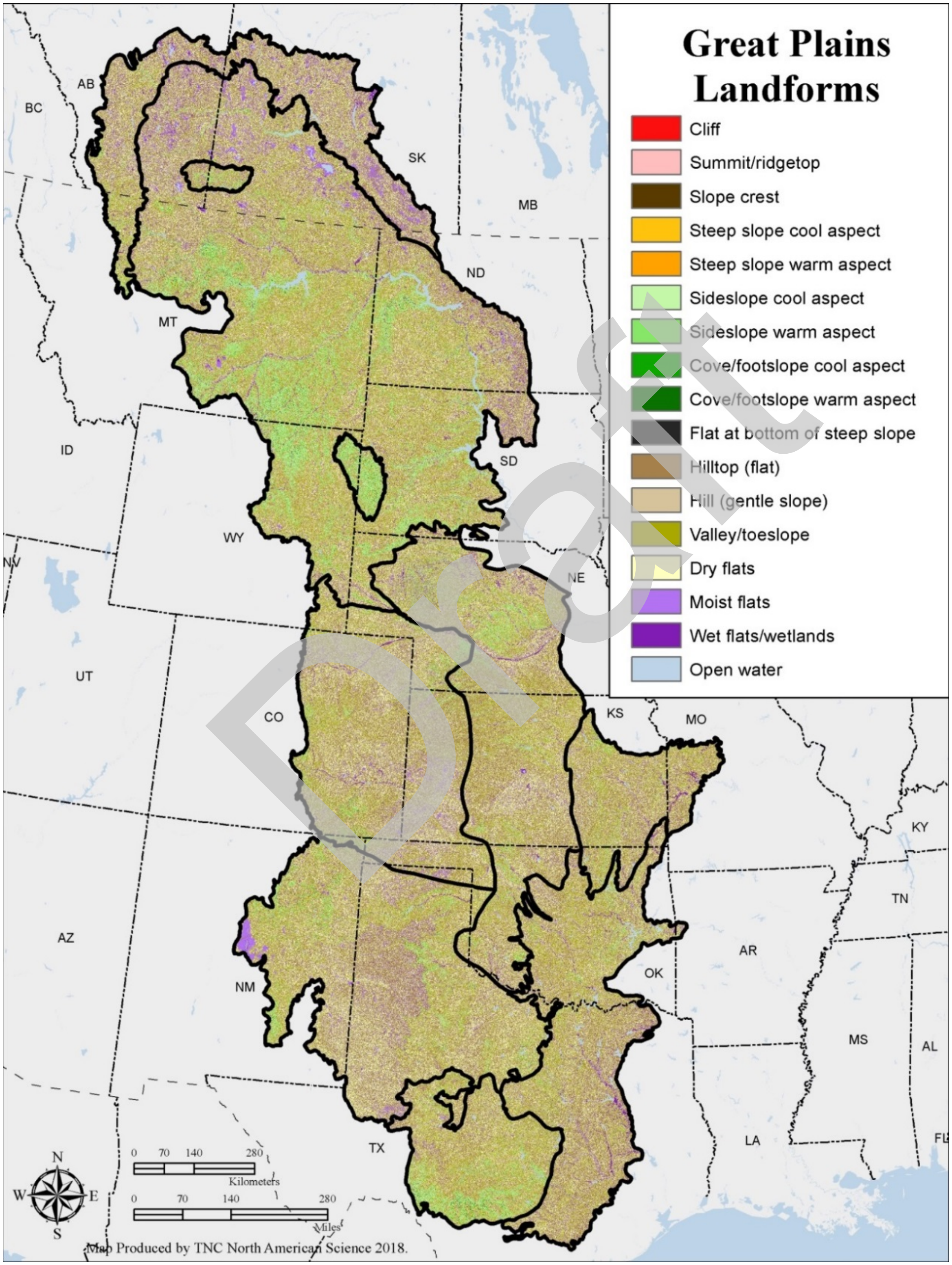
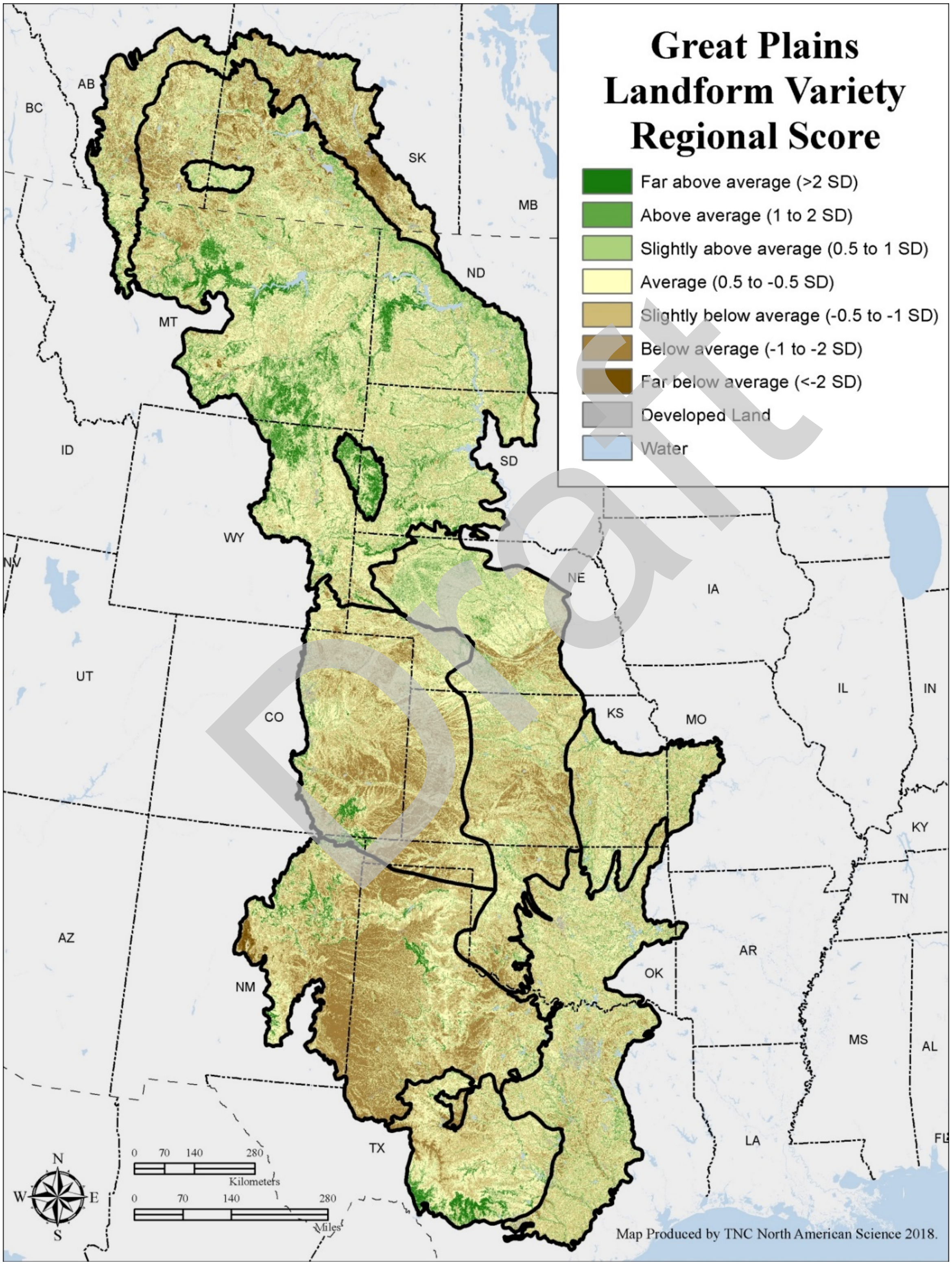


Figure 3.5: Landform Variety. The distribution of the counts of number of landforms in a 100-acre circle for the full Great Plains region. Areas with higher landform counts (more topographic variation) appear in green, and lower counts (flatter) appear brown.



Wetland Influence

In low relief areas where landform variety is inherently low, microtopographic variation determines where moisture accumulates. As the climate changes, persistent wetlands in these areas will become increasingly important because they retain soil moisture longer and preserve a mixture of organic and wetland soils. Further, wetland basins tend to have high evapotranspiration rates and play a unique role in moderating the climate and sustaining the resilience of a landscape (Geiger et al. 2003). Protecting wetlands and riparian corridors has been suggested as one of the single best actions in promoting resilience and in sustaining biodiversity (Naiman 1993, Fremier 2015).

Many areas within the Great Plains region are relatively flat, and are dry during much of the year. Wetlands are mostly small and intermittent, including the round playa lakes that hold water for short periods of time annually, and may not fill at all in some (or most) years. Because of their importance in providing water and moist microclimates we calculated a wetland density metric to identify these unique and valuable areas. Overall, our goal with the steps described in this section was to account for the importance of wetlands by calculating an independent wetland influence metric, which when combined with the estimates of microclimatic variation based on all landforms, would increase the influence of wetlands on the site resilience score (Figure 3.6).

We expect that the parts of the landscape that currently contain wetlands will continue to be important under variable climates even though the size and wetness of the areas are likely to change. Small isolated wetlands are often more vulnerable to shrinkage and disappearance than wetlands embedded in a landscape dense with other wetlands, and the wetland density metric allowed us to identify and map these dense areas.

To analyze the distribution of current wetlands, we compiled a base dataset of mapped wetlands from a variety of sources. Areas with confirmed wetlands, playas lakes, or small waterbodies 2-100 acres were included in this dataset. Wetland and water sources included:

- Canada Agriculture and Agri-Food Canada (AAFC) "Landuse Wetlands" - pixels classified as wetland >2 years out of 2012-2016 period (AAFC 2012-2016).
- Canada Vector Waterbodies 1:50,000.
- Alberta Merged Wetland Inventory (Alberta Environment and Parks, 2017).
- US National Wetland Inventory wetlands of type EM/FO/SS (USFWS 2017).
- US National Land Cover Database Emergent or Forested Wetlands (NLCD 2011).
- US National Hydrography High Resolution Waterbodies and Areas (USGS 2017).
- Playa Lakes for parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma and Texas (Playa Lakes Joint Venture 2017).

As discussed above in the landform section, water bodies 2-100 acres were added to the landform data set as "wet flats". Comparison with existing NWI, wetland, and playa datasets showed much spatial confusion and overlap between and among the wetlands, playas, and small waterbodies and lumping them together for analysis seemed to be the most reasonable approach. Our final map is shown in Figure 3.7.

We calculated a **wetland density** score using the same scale as landform variety: the percentage of wetlands within a 40.4 ha (100-acre) circle centered on each 30-m cell using a focal mean function in GIS. We based the density calculation on the portion of each circle that was land. We further weighted the score by assessing the wetland density of a larger 404 ha (1000-acre) circle around each focal cell and calculating the percentage of wetlands in this larger area. We combined this into one value for each cell, giving twice the weight to value from the smaller (closer to the focal cell) circle.

To ensure that the two scales were integrated correctly, we rank-transformed the values given their non-normal distribution and then calculated a standardized normalized score (Z score) for each scale. Areas with a wetland density of zero were assigned a Z score of -3.5 SD. We combined the standardized values from both search distances using the formula:

*Wetland Density = (2*100-acre wetland density + 1000-acre wetland density) / 3.*

The result was again transformed to Z scores using mean and SD calculated from only cells with wetland densities > 0 to yield a final wetland density score (Figure 3.8).

Final Landscape Diversity Score

To create a final map of landscape diversity, we combined the landform variety grid and the wetland density score into a single index using the transformed Z-score values to ensure they were all data were on the same scale.

For each cell, we used the maximum of the following two options as the final landscape diversity score:

1. Landform Variety Z Score
2. Landform Variety Z + Wetland Score Z) / 2

By using the maximum value, the wetland density was only incorporated in cells where it increased the base landform variety score.

Figure 3.6: Landform, Landform Variety, and Wetland Scores. These figures for Faulk County, South Dakota, illustrate how the wetland density score complements the landform variety score in places where there is little landform variation (average landform variety score) but a high density of wetlands (high wetland density score).

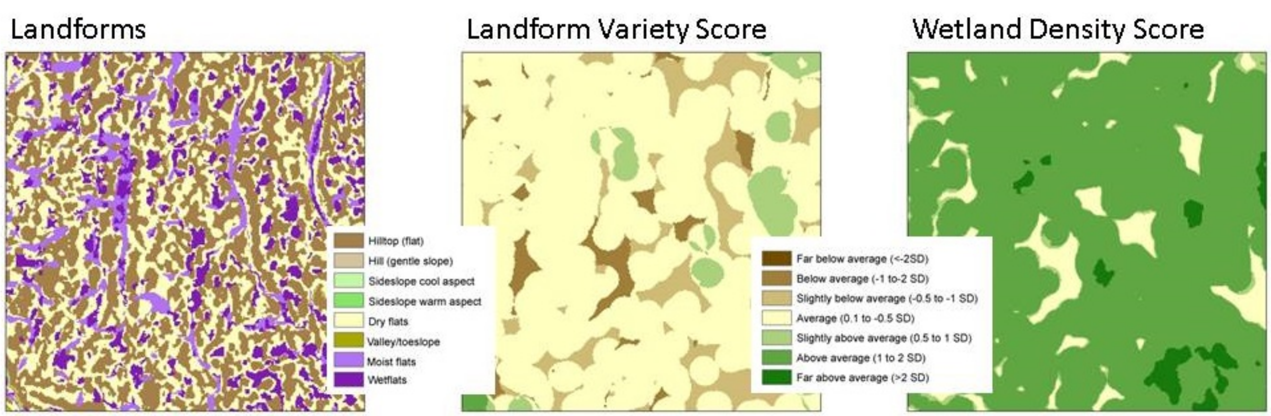


Figure 3.7: Wetlands in the Great Plains. The distribution of wetlands and small waterbodies in the region.

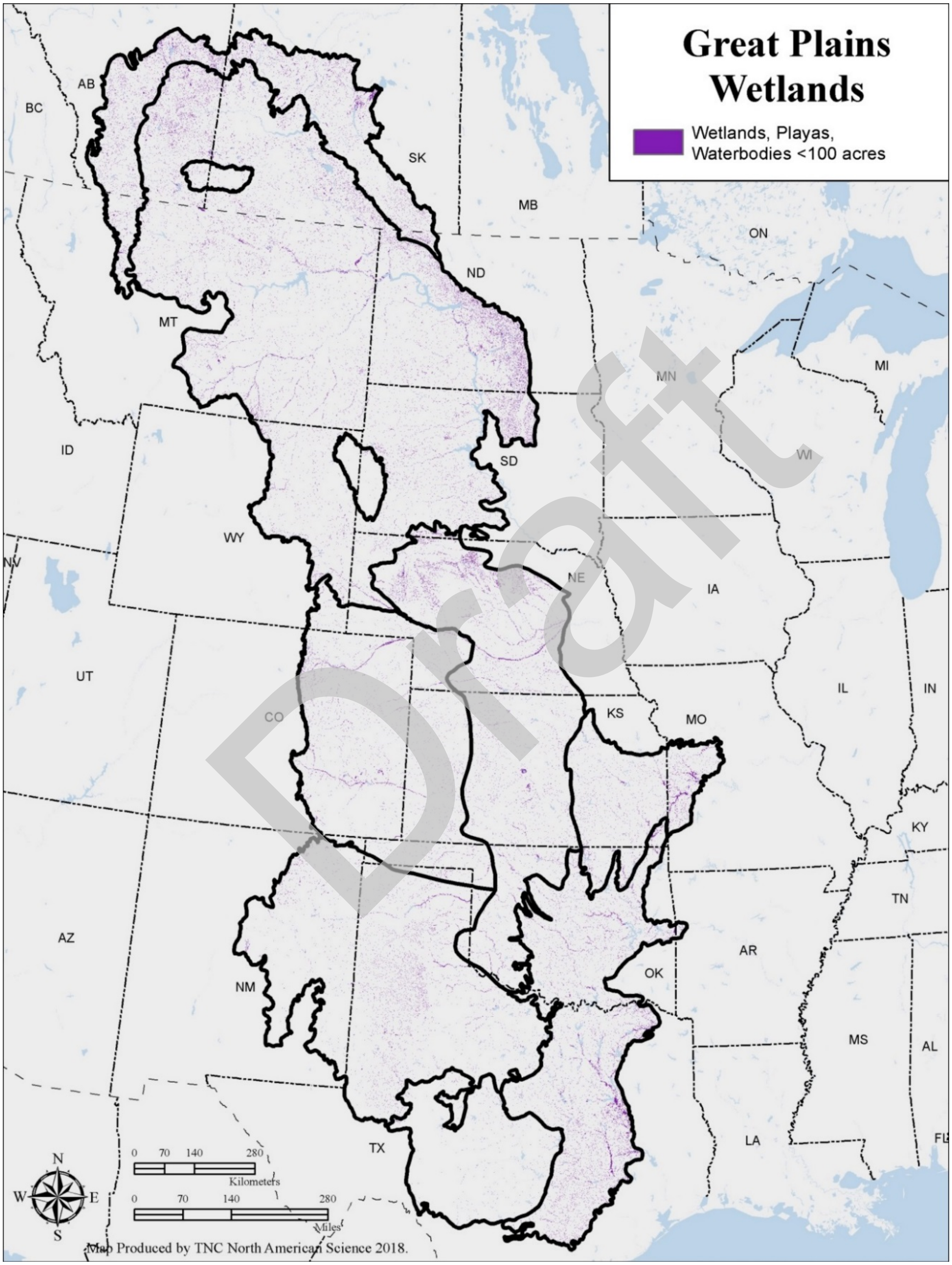


Figure 3.8: Wetland Density in the Great Plains. Weighted density of wetlands in 40- and 404-hectare circles around each central cell compared to the regional average.

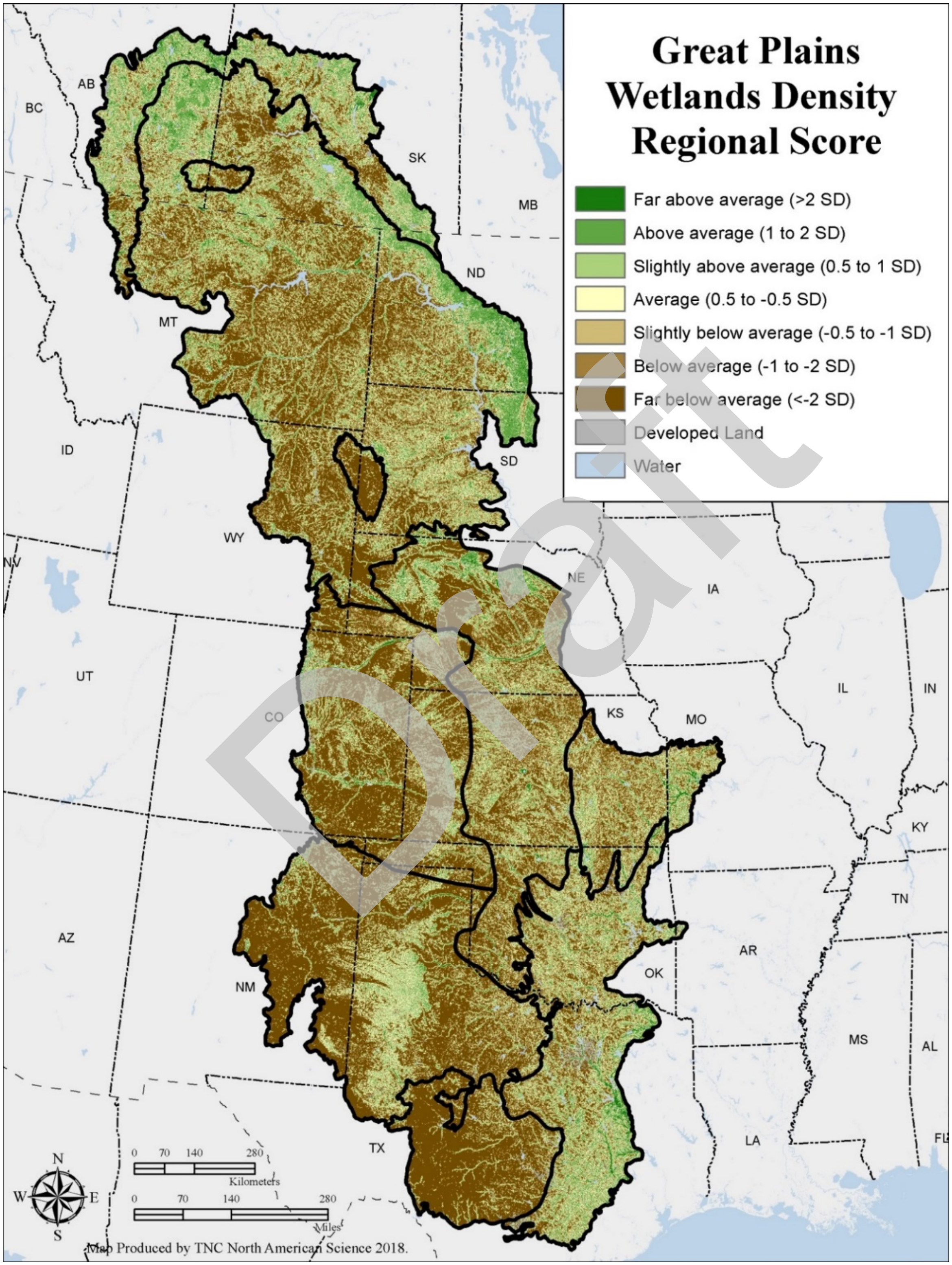
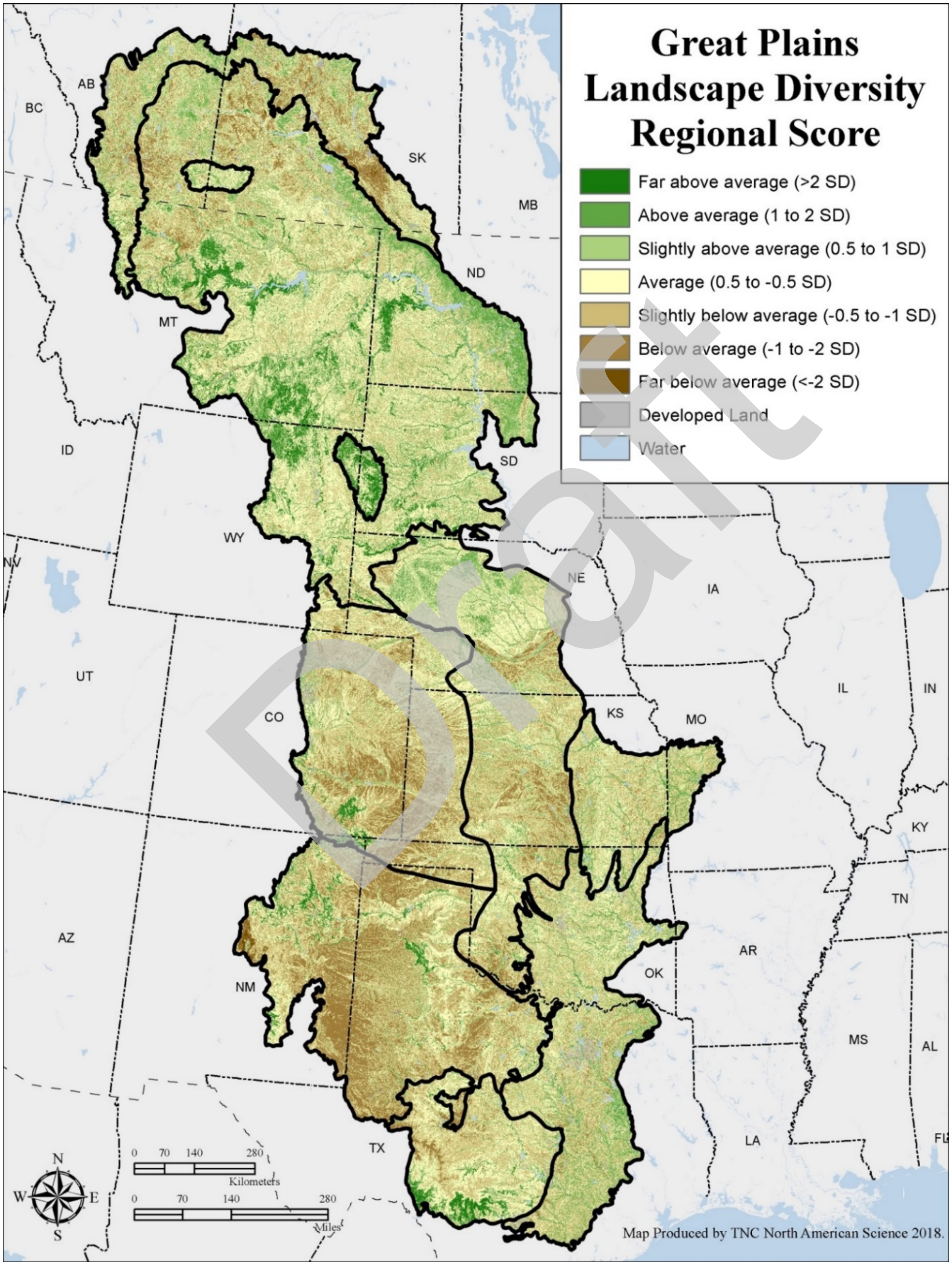


Figure 3.9: Landscape Diversity. Landscape diversity in the Great Plains based on the combined values of landform variety and wetland influence. Values are relative to the entire Great Plains region.



Section 2: Landscape Permeability

Climate change is expected to alter seasonal temperature and precipitation patterns, and intensify disturbance cycles of fire, drought, and flood. Rapid periods of climate change in the Quaternary, when the landscape was comprised of continuous natural cover, resulted in many changes to species distributions but few extinctions (Botkin et al. 2007). Now, pervasive fragmentation across the U.S. disrupts ecological processes and impedes the ability of many species to adapt to change. Industrial agriculture, development, roads, and other barriers will likely impair the ability of species populations to move, and for nature to adjust to rapid change, leading to depleted environments and less diversity. Not surprisingly, the need to maintain **connectivity** has emerged as a point of agreement among scientists researching key strategies for helping biodiversity adapt to climate change (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 resilient habitat, should facilitate the expected range shifts and community reorganization of species. Regional scale models suggest that the rate of natural migration for plants will not keep pace with the rate of climate change (Iverson et al. 1999; Iverson et al. 2004; Iverson and McKenzie 2013), highlighting the importance of microclimate buffers and refugia, and the need for species to be able to move locally to take advantage of them.

We prefer the terms '**permeability**' and **'connectedness'** over 'connectivity' because the latter is defined as the capacity of individual species to move between areas of habitat via corridors and linkage zones (Lindenmayer and Fischer 2006). Accordingly, analyses of connectivity entail identifying linkages between specific places, usually patches of good habitat or natural landscape blocks with respect to a species (Beier et al. 2011). In some studies, areas to connect have been defined by level of legal protection (e.g., Belote et al. 2016), which is particularly problematic in the Great Plains because there are few protected areas, but many large expanses of natural habitat in private ownership. Our emphasis on permeability reflects this goal of facilitating large-scale reorganization of species in response to climate change, which we suggest requires a more comprehensive and continuous analysis: all organisms, in all directions, over many years.

Landscape permeability 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). Accordingly, we developed methods that map permeability as a continuous surface, not as a set of discrete cores and linkages. Our aim was to create a surface that reveals the implications of the landscape structure with respect to the continuous flow of natural processes like dispersal, migration and recruitment.

We developed two analytical models to assess different aspects of permeability. The first, **local connectedness,** starts with a focal cell and estimates the resistance to flows outward from the cell in all directions. The second, **regional flow,** examines broad east-west and north-south flow patterns across the entire region. Both metrics estimate how flow becomes blocked, slowed, redirected, or channeled due to the spatial arrangement of human land uses and the remaining natural lands. The local connectedness metric was used in estimating the resilience of a site and the descriptions below refer to this metric. Regional flow analyses for the Great Plains will be conducted in conjunction with the Great Lakes and Tallgrass Prairie focal region and will be described in a subsequent report (early 2019).

Local Connectedness

The **local connectedness** metric estimates the resistance/permeability surrounding a focal cell if movements were to flow outward in all directions from its center point. As a component of resilience, this metric estimates how easily species can access the microclimates within their local neighborhood based on the arrangement of roads, industrial agriculture, development and other human structures that create resistance to movement by creating barriers or increasing the risk of harm.

In the local connectedness model, the permeability of two adjacent cells increases with the similarity of those cells with respect to their land cover. If adjacent landscape elements are identical (e.g., forest to forest), then there is no disruption in flow. A contrasting element (e.g., forest to developed land) creates resistance and the connection is presumed to be less permeable. Organisms can and do move across different landscape elements, but the sharper the contrast is in structure, surface texture, exposure, or chemistry, the more likely it is that movement will be altered or slowed. The degree to which a cell alters the flow arriving from an adjacent cell is its **resistance**, and the corresponding land use is assigned a **resistance weight** based on its expected resistance.

Creating a Resistance Grid

Our analysis of resistance began with a step of sorting the landscape into three basic landscape elements and assignment of general resistance weights from 1-20:

1. Natural lands (resistance weights 1-5): Landscape elements where natural processes are unconstrained and unmodified by human intervention. Examples include grasslands, wetlands, and forests.
2. Agricultural or modified lands (resistance weights 5-9): Landscape elements where natural processes are modified by direct, sustained and intentional human intervention. Nutrients are often depleted, and use by species may be constrained by management actions or chemical applications, fencing, and other barriers.
3. Developed lands (resistance weights 8-20): Landscape elements dominated by the direct conversion of physical habitat to buildings, roads, parking lots, or other infrastructure associated with human habitation and commerce. Vegetation is highly tended, manicured, or controlled.

Methods to quantify and objectively assign resistance weights have included similarity indices based on vegetation types or land cover classes (B. Compton personal communication 2009, Compton et al. 2007). Our weighting scheme was generalized with respect to vegetation types such that any natural land cover element adjacent to another natural land cover element was scored with a low resistance value assuming that dispersal and population movement requirements are less specific than those for breeding. In addition, our goal was to maintain the natural relationships and connections between all types of natural land and was not targeted towards a specific species (Hunter 2002, Ferrari and Ferrarini 2008, Forman and Godron 1986).

To create the resistance grid, we combined several datasets representing land cover, land use, roads, railroads and agriculture. For the U.S., the source data were the 30-m 2011 NLCD, which identifies each grid cell as belonging to one of 16 classes of land cover (Homer et al. 2015). For Canada, we used the Provincial land use dataset from the Agriculture and Agri-food Canada Annual Crop inventory (AAFC 2016, Fisette et al. 2014). Although both Alberta and Saskatchewan have Provincial land use datasets, after examination we found that the scale and attributes varied too far from the US 2011 NLCD to be usable in combination with this source. The AAFC data was a much closer match, as it is a 30-m, satellite derived dataset that includes information in categories that are similar to the NLCD, including water, barrens, shrublands, wetlands and forests. Waterbodies were obtained from Canada's National Hydrology Network (NHN) (Natural Resources Canada 2016), and were merged with the land use data. We created a look-up table to crosswalk the detailed Canadian classifications to our more generalized classification that were assigned resistance scores for the US (Table 3.1), as the Canadian datasets had different schema and land use categories.

Table 3.1: Resistance scores. The land cover categories from the National Landcover Classification Database (NLCD) and the corresponding resistance scores assigned to each for assessing landscape permeability in the Great Plains.

Land Cover Code (NLCD)	Land Cover Description	Resistance Score	Source
21	Developed, Open Space	8	NLCD 2011
22	Developed, Low intensity	8	NLCD 2011
23	Developed, Medium Intensity	9	NLCD 2011
24	Developed, High Intensity	20	NLCD 2011
31	Barren Land, non-natural	9	NLCD 2011
32	Barren Land, natural	1	NLCD 2011
41	Deciduous Forest	1	NLCD 2011
42	Evergreen Forest	1	NLCD 2011
43	Mixed Forest	1	NLCD 2011
52	Shrub/Scrub	1	NLCD 2011
71	Grassland/Herbaceous	1	NLCD 2011
81	Hay/Pasture	1	NLCD 2011
82	Cultivated Crops	7	NLCD 2011
90	Woody Wetlands	1	NLCD 2011
95	Emergent Herbaceous Wetlands	1	NLCD 2011

We made several upgrades to the basic land cover data that substantially improved their performance as resistance grids. These included improved mapping of:

1) Oil and gas development
2) Wind energy development
3) Natural and artificial barrens and mines
4) Wetlands and waterbodies
5) Roads and railroads
6) Energy transportation – pipelines and powerlines

Oil and Gas Development:
With over 1,750,000 active and inactive wells, the Great Plains region is the heart of oil and gas development in the US. Oil and gas development results in both direct and indirect effects on species movement. Roads and well pads fragment the landscape and the noise associated with pumping and daily vehicle traffic amplify the effect of fragmentation discouraging the movement native species and favoring invasive species. Hydraulic fracking uses large amount of water, which can exacerbate water stress in this by drought-prone region.

To accurately map the spatial effects of oil and gas development, we formed an oil and gas working group within the Steering Committee to guide our analysis approach, and review results. We collected oil and gas well data from all the states and provinces in the study area; these sources are listed in Table 3.2. Based on the Steering Committee members' observations, and discussion of existing research, we set a goal of giving the highest density oil and gas areas (>16 wells per square mile) a resistance effect similar to that associated with medium-density development. We used a two-pronged approach to accomplish this effect level, which represents a combination of the resistance score, and the typically concentrated, multi-pixel block pattern of residential development on the landscape. First, using the well locations, we calculated a point density grid based on a kernel density function in ArcGIS. To estimate the resistance of the well pads themselves, we created a 540 x 540-meter well pad area around each well point. The 540 m square was chosen because at that size, the highest density well pads (>16 wells per square mile) form a continuous coverage. We included both inactive wells and active wells in the density calculation, but inactive wells received 1/10 the weight of active wells. Second, we estimated the indirect effects of oil and gas development (traffic and noise) using a point density grid based on the individual well points (no well pads) and using a kernel density function in GIS. We used a graduated weighting so cells with a higher density of points had higher resistance (Table 3.3). The calculation of kernel density is sensitive too and often magnifies small changes in the resistance score.

Table 3.2: Oil and Gas Source Data. For each province or state, this table lists the data source, number of wells, and shows how the well classification was divided into active and inactive wells.

Alberta **344,739 Wells**	Source: https://open.alberta.ca/opendata/ahfmp **Active Wells:** Bitument (Oil Sands), Drilled and Cased, Gas, Oil, Other **Inactive Wells:** Abandoned
Saskatchewan **111,356 Wells**	Source: https://gisappl.saskatchewan.ca/Html5Ext/index.html?viewer=GeoAtlas Vertical Wells **Active Wells:** Active, Cased, Completed, Drilling, Planned **Inactive Wells:** Abandoned, Downhole Abandoned, Suspended
Montana **41,756 Wells**	Source: http://bogc.dnrc.mt.gov/WebApps/DataMiner/MontanaMap.aspx (Emailed from Brian Martin, Montana Grasslands, Conservation Director) **Active Wells**: Status: Active Injection, Completed, Domestic, Other, PA-Approved, Producing, Shut In, Temporarily Abandoned, **Inactive Wells:** Abandoned, Abandoned Unapproved, Expired, Not released, Permitted to Drill, Permitted Injection Well, Revoked Inj. Permit, Spudded, Unknown, Water Well Completed, Water Well Released
North Dakota **34,985 Wells**	Source: https://www.dmr.nd.gov/OaGIMS/viewer.htm (wells.zip) **Active Wells:** A (Active), TA (Temporarily Abandoned), TAO (Temporally abandoned – Observation), TATD (Temp Abandoned **Inactive Wells:** AB (Abandoned), Confidential, DRY (Dry Hole), EXP (Expired Permit), IA (Inactive), IAW (Inactive Well Waiver), LOC (Permitted Location to Drill), NC (Not Completed), PA (Plugged and Abandoned), PNC (Permit Now Cancelled), Drilled to Total
South Dakota **2,101 Wells**	Source: http://www.sdgs.usd.edu/SDOIL/oilgas_databases.aspx (there are also test hole drilling dat) **Active Wells:** Injecting, Producing, Shut In, Temporarily Abandoned **Inactive Wells:** Converted Fresh Water Supply, Never Drilled, Not Spudded, Plugged and Abandoned
Wyoming **55,909 wells**	Wyoming Oil and Gas –Two datasets from Holly Copeland (TNC WY), WY Active Wells, WY Plugged and Abandoned **Active** and **Inactive** Wells listed in each dataset
Nebraska **22,235 wells**	Source: http://www.nogcc.ne.gov/RBDMSDataMining/(S(zegeubimwk0x3o31m5i4bqox))/ **Active:** AI (Active Injection), AX (P&A Approved), PR (Producing), SI (Shut-IN), TA (Temporarily Abandoned) **Inactive:** DA (Dry and Abandoned), EX (Expired Permit), JA (Junked and Abandoned), PA (Plugged and Abandoned), UN (Unknown)
Colorado **114,524 wells**	Source: http://cogcc.state.co.us/data2.html#/downloads **Active:** AC-Active, CM-Commingled, DG-Drilling, DM-Domestic Well, IJ-Injecting, PR-Producing, RC-Recompleted, SI-Shut In, TA-Temporarily Abandoned, WO-Waiting on Completion, XX-Permitted Location **Inactive:** AB-Abandoned, AL-Abandoned Location, CL-Closed, DA-Dry and Abandoned, PA-Plugged and Abandoned

Kansas **480,757 wells**	Source: http://www.kgs.ku.edu/PRS/petroDB.html **Active:** CBM (produced coalbed methane), EOR (enhanced oil recovery well), GAS (produced natural gas) INJ (Salt water disposal well or other injection well), Intent – proposed well that is not yet drilled, OG – oil and gas, OG-PA, OIL – oil, SWD – salt water disposal well **Inactive:** CBM-PA (produced coal methane plugged and Abandoned), DA (never produced now plugged and abandoned), EOR-PA ((enhanced oil recovery well plugged and abandoned), GAS-PA (produced natural gas plugged and abandoned), INJ_PA ((Salt water disposal well or other injection well plugged and abandoned), LOC – well that was never actually drilled, OIL-PA (Oil plugged and abandoned), OTHER– may not be an energy well since water research wells and road construction wells may be in the database, OTHER-PA, SWD-PA (salt water disposal well plugged and abandoned)
New Mexico **117,621 wells**	Source: http://www.emnrd.state.nm.us/OCD/ocdgis.html **Active:** A (Active) **Inactive:** C (cancelled APD), H (Plugged (not released)), N (New Not Drilled/Completed), P (plugged), S (Plugged Site Released), T (approved TA – Temporarily Abandoned)
Oklahoma **11,162 Wells**	Source: Oklahoma Corporation Commission (excel database) https://www.occeweb.com/Orawebapps/OCCORaWebAppsone.html There is a field for active and inactive
Texas **1,308,669** **wells**	Source: Texas Railroad Commission - http://www.rrc.state.tx.us/about-us/resource-center/research/data-sets-available-for-purchase/digital-map-data/digital-map-data-statewide-prices/ **Active:** Brine Mining Well, Dry Hole Well, Gas Well, Horizontal Drainhole, Injection Disposal Well from Gas, Injection Disposal Well from Oil/Gas, Injection Disposal Well from Oil, Injection Disposal Well, Oil Well, Oil/Gas Well. Shut in Well (Gas), Shut in Well (Oil), Sidetrack well Surface Location, Storage Well, Water Supply from Oil, Water Supply Well. **Inactive:** Canceled Location, Core Test, Observation Well, Permitted Location, Plugged Gas Well, Plugged Oil Well, Plugged Oil/Gas Well
Louisiana **240,864 Wells**	Source: http://sonris-www.dnr.state.la.us/gis/dnld/download.html **Active:** Active – Injection Aquifer Remediation, Active Injection Community Salt Water Disposal, Action Injection ER—Injection (Water), Active Injection Produced Salt Water, Active Producing Gas, Active Producing Oil, Approval to Construct Injection Well, Permitted, Reverted to single completion No product Specified, Shut-In Dry Hole Fulture Utility No Product Specified, Shut-In productive Future Utility Gas, Shut-In productive Future Utility Oil, Temporarily Abandoned Well no product Specified **Inactive**: Orphan Well Eng Gas, Orphan Well Eng Oil, Orphan Well Injection and mining not product specified, Dry and Plugged gas, Dry and Plugged no product specified, dry and plugged oil, formation storage gas, Permit expired, plugged and Abandoned Dry Gas, plugged and Abandoned Gas, plugged and Abandoned Oil, plugged and Abandoned Dry no product specified, Plugged Back. Unable to locate.
Missouri **10,470 Wells**	Source: https://dnr.mo.gov/geology/geosrv/oilandgas.htm Has Well Status Field.

Table 3.3 Well Density Resistance Weights.

Well Density	Resistance Weight
0 – 1 wells per square mile	0
1-2 wells per square mile	0.2
2-4 wells per square mile	0.4
4-8 wells per square mile	0.6
8- 16 wells per square mile	0.8
16 wells per square mile	1.0

The well density weights (Table 3.3.) were added to the score from the NLCD. For example, an area that was natural but had 4-8 wells per square mile got a resistance value of 1 (natural) plus 0.6 (well density) = 1.6. An agricultural area that has 4-8 wells per square mile got a resistance score of 7 (agriculture) plus 0.6 (well density) = 7.6. Inactive wells were also included, but weighted 1/10 of the weight of active wells.

The final well density data layer (Figure 3.10) highlights the high density of wells in Texas, Oklahoma, and Alberta.

Wind Energy:
55% of the US's wind power capacity is in states that are in the Great Plains region (https://www.awea.org/windenergyfacts.aspx), with over 27,000 wind turbines in the Great Plains states. Although wind power is one of the cleanest and sustainable energy sources, there are a variety of environmental impacts associated with wind energy that may affect the connectedness of the area surrounding a turbine. The landcover at the base of the wind turbine is permanently disturbed, and a larger area is disturbed during construction. There are also impacts from the roads connecting the turbines. Research is ongoing on the effect of turbines on wildlife. The impact on birds and bats is the most well studies and the area of impact varies depending on the species.

To represent wind energy development in our resistance dataset, we combined the two key datasets for wind turbines in the United States. The first was the Federal Aviation Administration Digital Obstacle File (https://www.faa.gov/air_traffic/flight_info/aeronav/digital_products/dof/). The second was the U.S. Wind Turbine Database which was collected and compiled from various public and private data sources, and quality checked and position-verified from aerial imagery (https://eerscmap.usgs.gov/uswtdb/). After the two datasets were combined, duplicates were removed.

To map the impact in the local connectedness score, we used a 1-mile kernel density with the same weights as oil and gas development (Table 3.4). Due to lower impact of wind development on the habitat in this landscape for many species (though clearly not all) relative to oil and gas development, we did not inflate the area of the turbine base, as we had done with the well heads. Our final coverage for the effect of wind development is shown in Figure 3.11.

Figure 3.10: Oil and Gas Well Density. The density of oil and gas wells in the Great Plains study area based on source data from every state and province.

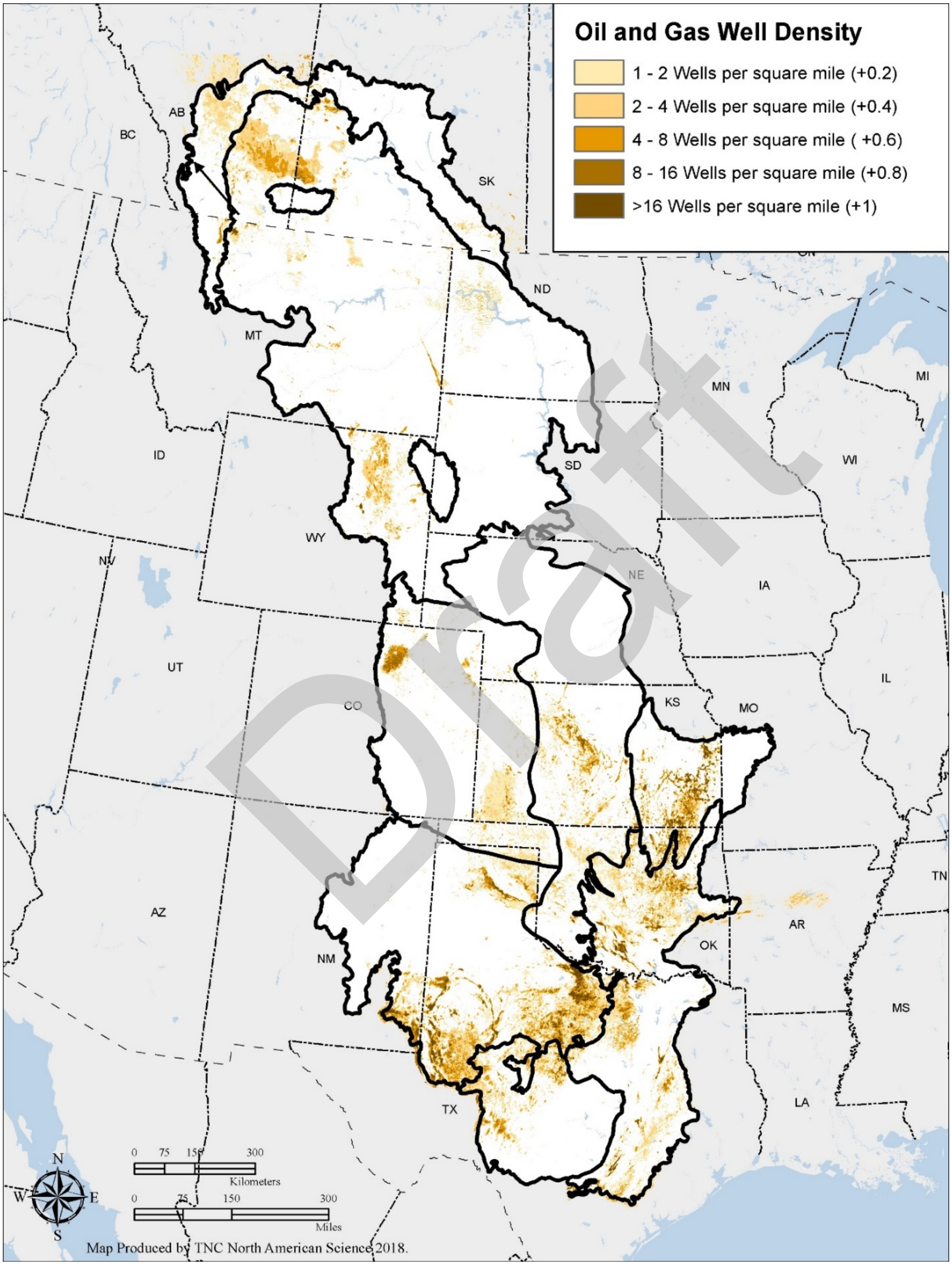
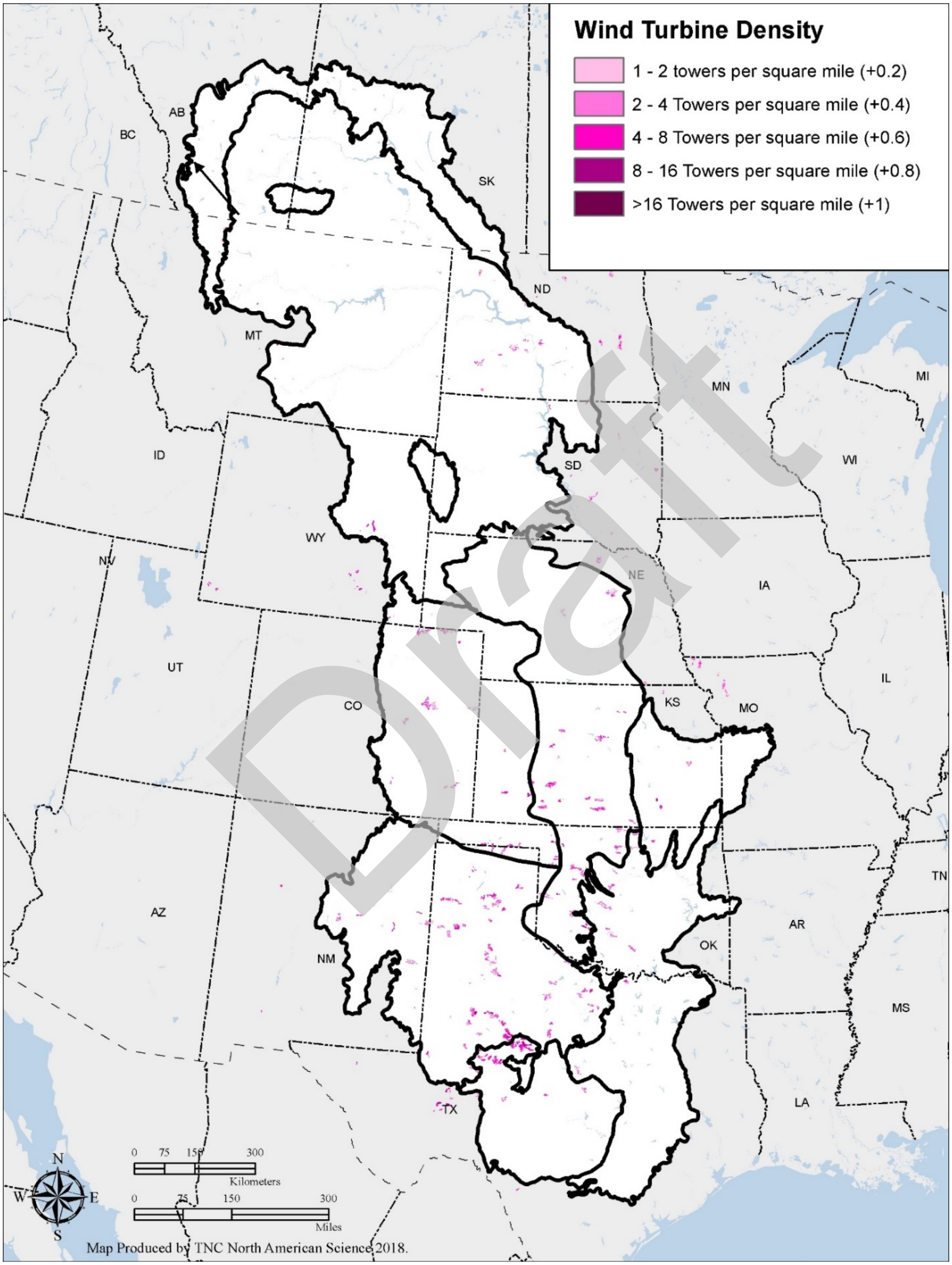


Figure 3.11: Wind Turbine Density. The density of wind turbines in the study area based on FAA Digital Obstacle data set and the US Wind Turbine database.



Barrens:
In the land cover datasets, the category "barrens" often mixes developed lands such as oil and gas wellheads with natural barrens such as blowout areas, mudflats, and summits. To distinguish between developed and natural barrens, we manually inspected all polygons of barrens larger than 50 acres and assigned them to one category or the other. For polygons less than 50 acres in size, we used decision rules based on the degree of development, agriculture and roads in the surrounding 1000 acres to classify them into natural and non-natural barrens. After these rules were applied, some areas had conflicting results, and did not get classified; these we assigned to "natural". A subset of these barrens was visually inspected, and the majority turned out to be natural, but it was not feasible to check all cases.

Some mining operations were identified using USGS's significant topographic changes in the United States Dataset (https://topochange.cr.usgs.gov/), which captures areas of topographic changes from surface mining, urban development, and landfills. Areas identified in this dataset were given a score same as "developed barrens".

Natural barrens were assigned a resistance score of "1," the same as natural cover. Developed barrens and surface mines were assigned a resistance score of "10" to reflect their highly developed and modified nature.

Waterbodies:
We adjusted the resistance score of waterbodies to reflect their size, because very large waterbodies impede the movement of terrestrial species more than small streams or ponds. To quantify the effect of waterbody size, we first created a waterbody file from the waterbodies in the landforms (see Chapter 2) and the NLCD cells classified as water. We assigned water within 200 m of a shoreline a resistance value of "1," water between 200 and 400 m of a shoreline received a resistance value of "3,"and water greater than 400 m from a shoreline was given a value of "5" to reflect a stronger barrier as the waterbody size increases (Figure 3.12). Streams and ponds that had less than 200 m of shoreline were all assigned a "1."

Roads:
The 2011 NLCD landcover data set (Homer et al. 2015) contains an embedded roads data set from the Bureau of Transportation Statistics that does not align with the newer and more accurate 2016 Tiger Road dataset (U.S. Census Bureau 2017). To correct this issue, we removed the older roads from the NLCD and replaced them with roads from the Tiger 2016 dataset. To do this, cells in the 2011 NLCD's "developed open space" class were shrunk by one pixel to remove linear road pixels but not the larger developed areas. Values for these cells were replaced with the majority value of the surrounding pixels. Next, the 2016 Tiger roads were "burned in" on top of the 2011 NLCD replacing the older road data with the more recent data. Similarly, we burned road data from the National Road Network (National Road Network 2017) into the compiled Canadian land use data, which did not contain information on roads except for major highways.

Unpaved roads, including forest management roads, are unevenly mapped in both the U.S. and Canada landcover datasets, even though they collectively constitute substantial road networks in some parts of the region. To map unpaved roads, we used data from OpenStreet Map (2017) which is an opensource global dataset built by a community of mappers that contribute and maintain data about roads and trails. We extracted roads tagged as "track" which includes roads used primarily for agriculture and forest logging (i.e., two-track roads). This class of roads is usually unpaved but may include paved roads. Trails and paths that are not wide enough for a two-track vehicle are excluded from this class. Although the quality and consistency of this dataset is not known, visual inspection suggested that it was more comprehensive than any other available dataset for mapping unpaved roads.

We assigned major roads (e.g., multi-lane interstate highways, MTFCC code S1100) a resistance score of 20 and secondary roads a resistance score of 10 (e.g. two-lane county highways) (MTFCC codes S1200, S1630, SS1780). Residential roads were assigned a score of a resistance score of a 7 (MTFCC code S1400, S1640). Cells were assigned an additional resistance point if they contained one or more unpaved roads. For example, the resistance of agriculture cells with unpaved roads increased from a "7" to a "8" (Table 3.4).

Energy Transportation – Pipelines and Powerlines:

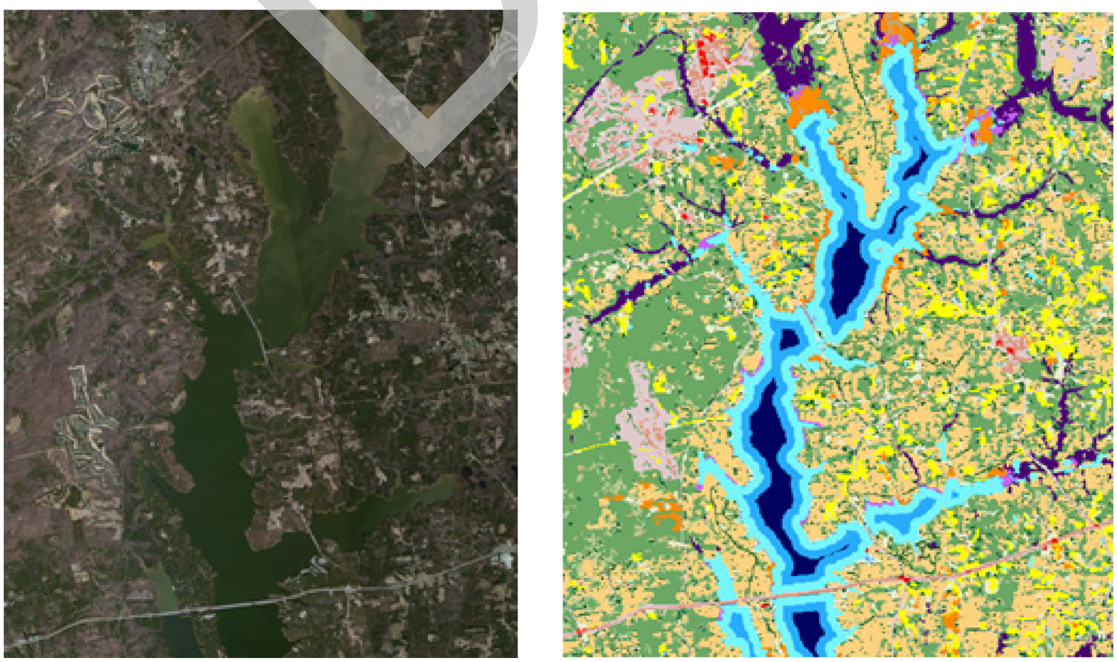
To account for the influence of energy infrastructure, we added the locations of pipelines and powerlines to the landcover datasets. To do this, we obtained power industry GIS data (Ventyx 2017, used with permission). We selected all transmission lines in service by voltage class, and all in-service natural gas pipelines. These were incorporated into the landcover dataset using power industry standard right-of-way widths: 30-m width for transmission lines <230 kilovolts, and 180-m width for lines > 230 kilovolts. All pipelines were given a 30-m width (Duke Energy 2014). Underground powerlines are occasionally in the Ventyx data and where they are specified we pulled them out in the dataset.

We assigned transmission lines a resistance of "7". If the powerlines are identified as below ground they added one additional point of resistance. Pipelines may present a more substantial barrier to movement, depending on their location and whether they are buried or above ground, and to these we assigned a resistance score of "7" (Table 3.4).

Table 3.4. Summary of Weights and Data Sources for Water, Roads and Energy Infrastructure.

Category	Resistance weight	Source
	Waterbodies: Distance to Shoreline	
<200 m	1	NLCD, NHD, NHN, ArcGIS Analysis
200 - 400 m	3	NLCD, NHD, NHN, ArcGIS Analysis
>400 m	5	NLCD, NHD, NHN, ArcGIS Analysis
	Roads & Railroads	
Major Roads	20	Tiger 2016 & National Road Network
Minor Roads	10	Tiger 2016 & National Road Network
Residential Roads	7	Tiger 2016 & National Road Network
Dirt Roads	Resistance +1	Open Street Map Tracks (US & CA) and Tiger Vehicular Trail (4WD) S1500 (US)
Railroads	9	CTS 2016
	Energy Transportation	
Transmission Lines	7	Ventyx 2017
Pipelines	7	Ventyx 2017

Figure 3.12: Waterbodies and the Zones used in the Resistance Weighting. The left panel shows a satellite image of a waterbody. The same waterbodies appear in the right panel symbolized in blue. Darker blues indicate higher resistance values at 0-200, 200-400, and 400+ m.



Resistance in the Great Plains compared to the Great Lakes/Tallgrass region:

There were several changes to the NLCD and the resistance grid that we made in other regions that we did not make in this region.

In contrast to the southern half of the Great Lakes and Tallgrass Prairie region, which is dominated by row-crop agriculture, the Great Plains is dominated by grasslands, much of which is used for rangeland and pasture. At this scale, the NLCD 2011 and the CropScape data did a poor job separating grasslands that were not actively being grazed or harvested from pasture/hay and rangeland. Further, our Steering Committee emphasized that grazing is an essential process for maintaining prairie species diversity, and that when managed well, grazed land has high biodiversity value. For these two reasons, rangelands and pasture/hay lands were assigned the same resistance value as natural lands (resistance of 1) in the Great Lakes pasture hay received a resistance score slightly higher than natural (resistance of 3).

The region does have a fair amount of agriculture, including corn and soy agriculture, but industrial agriculture was not developed to the scale that it is in the Great Lakes/Tallgrass Prairie region. Thus, we gave agriculture from the NLCD a high resistance (7, the same as in other regions of the US), but did not separate out the high intensity corn/soy agriculture as we did in the Great Lakes and Tallgrass assessment.

In previous assessments, we have increased the resistance of industrial forest relative to a "natural" system. Due to the rarity of forest in this region, we did not make this distinction. Based on a dataset of global forest change the few areas of significant forest loss or gain were because of large scale forest fires.

Mapping Local Connectedness

Connectedness refers to the connectivity of a focal cell to its ecological neighborhood when the cell is viewed as a source (Compton et al. 2007). The analysis estimates the extent to which ecological flows outward from a cell are impeded or facilitated by the surrounding landscape. In the connectedness model, 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 some maximum distance where the influence is considered zero.

We mapped local connectedness using a resistant kernel model developed by Brad Compton of the University of Massachusetts (Compton et al. 2007), who helped us run the model for the complete study region. The first step in running the model was to convert the 30-m landcover and roads data in to a "resistance" grid by coding each land cover class with the resistant weights described above (Table 3.1, 3.3, & 3.4). Next, we assigned a maximum distance of 3 km to the model (the default value recommended by the software developer) to represent the distance where the influence on the focal cell is zero. The computationally intensive model estimates the resistance around each cell based on a weighted sum of the resistance of all cells in the 3-km radius. The focal cell is then scored between 0 (least connected) and 100 (perfect connectedness). The map of all focal cell scores creates a continuous wall-to-wall estimate of local connectedness (Figures 3.13 and 3.14).

Figure 3.13: Examples of Four Resistant Kernel Cells shown with the Land Cover and Roads Map. The focal cell is the central point of each kernel and the spread, or size, of the kernel reflects the amount of constraints. The score for the focal cell is based on the area round the cell (i.e., the constraints) and is shown here in a bluish-purple color. Kernel A is the most constrained and has the lowest connectedness score, while D is the least constrained and has the highest connectedness score.

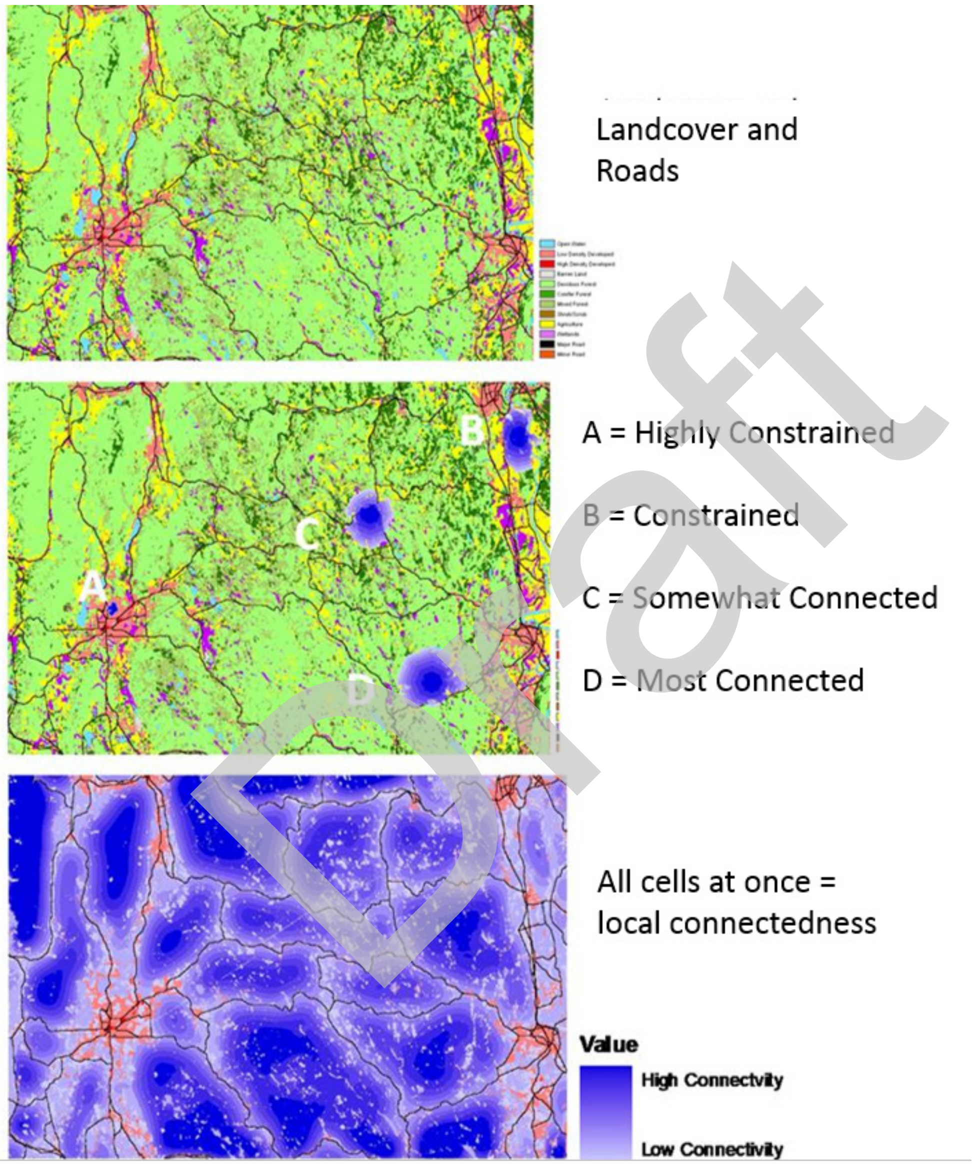
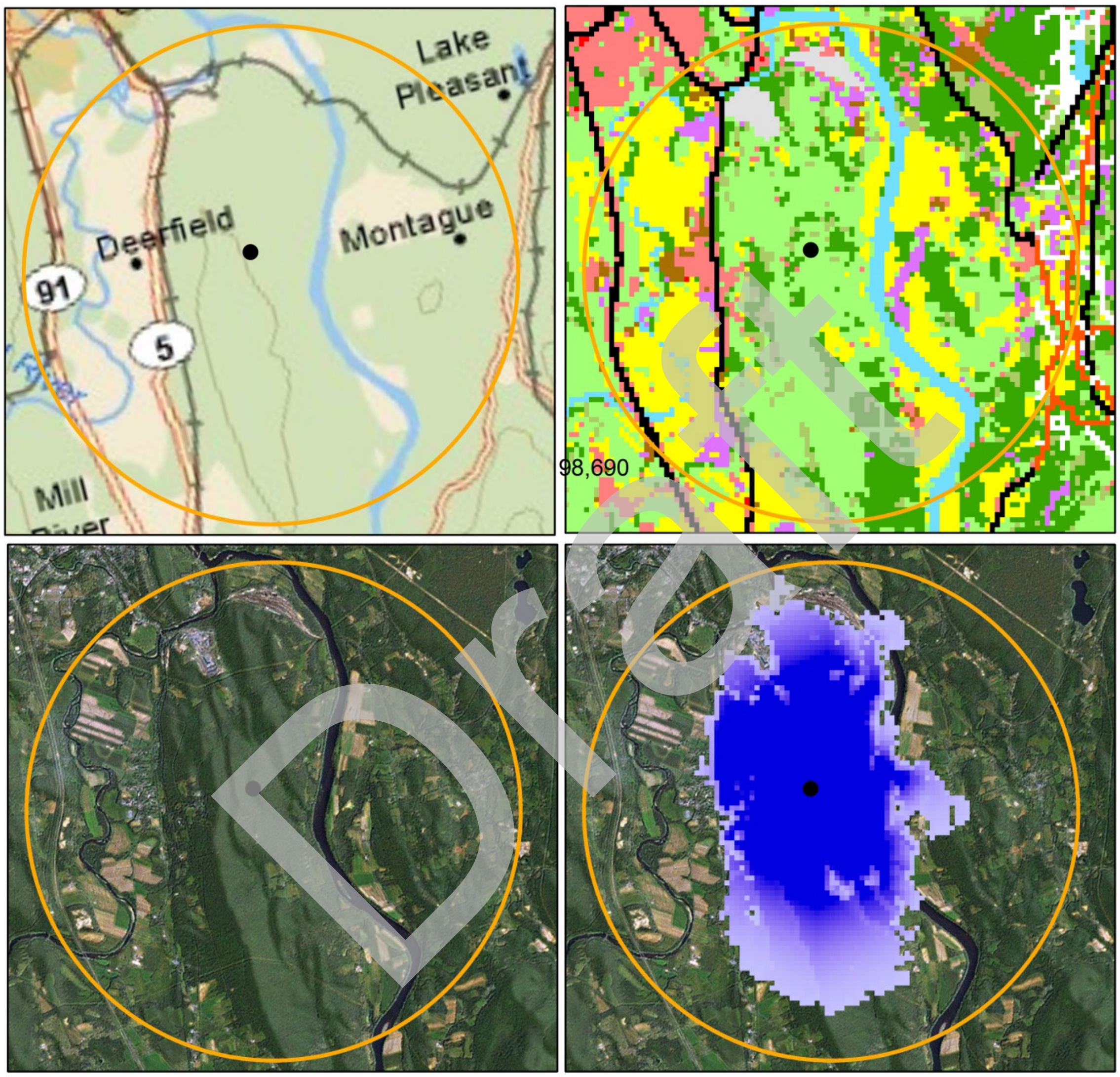


Figure 3.14: Detailed look at Kernel B in Figure 3.13. The top left image shows the topographic map. The top right image shows the land use grid details. The bottom left panel shows the aerial image with the 3-km circular resistant kernel distance outlined in orange. The bottom right box shows the kernel spread. Kernel B is constrained on the west by roads and railroads and on the east by water. The kernel can flow well through the natural landscape in the north and south direction.



The result was a grid of 30-m cells for the entire region where each cell was scored with a local connectivity value from 0 to 1. The actual scores had a mean of 0.55 and a standard deviation of 0.31 for the region. Numerical scores were transformed to Z-scores so they could be combined with the landscape diversity scores. Sample areas within the study region were visually assessed to ensure that the results accurately reflect connectedness and to understand the distribution of values (Figure 3.15). The final map of connectedness values, scored relative to the region as a whole, is shown in Figure 3.16.

Figure 3.15: A Gallery of Satellite Images and their Corresponding Local Connectedness Scores. The resistant kernel (RK) scores and regional Z-scores are based on a roughly circular site positioned at the center of each image (not shown).

RK Value = 0.017
Regional Z Score = -2.2 SD

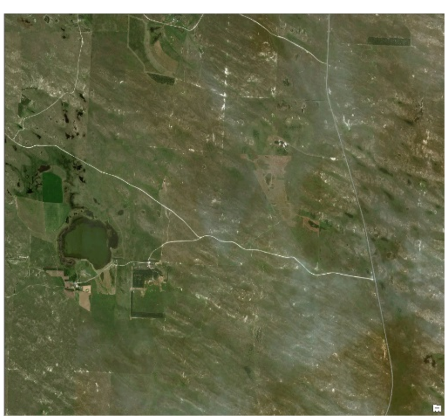
RK Value = 0.025
Regional Z Score = -1.5 SD

RK Value = 0.19
Regional Z Score = -0.63 SD

RK Value = 0.29
Regional Z Score = -0.43 SD

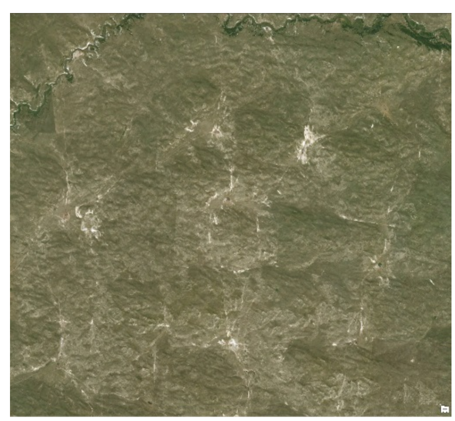
RK Value = 0.45
Regional Z Score = -0.1 SD

RK Value = 0.57
Regional Z Score = 0.79 SD



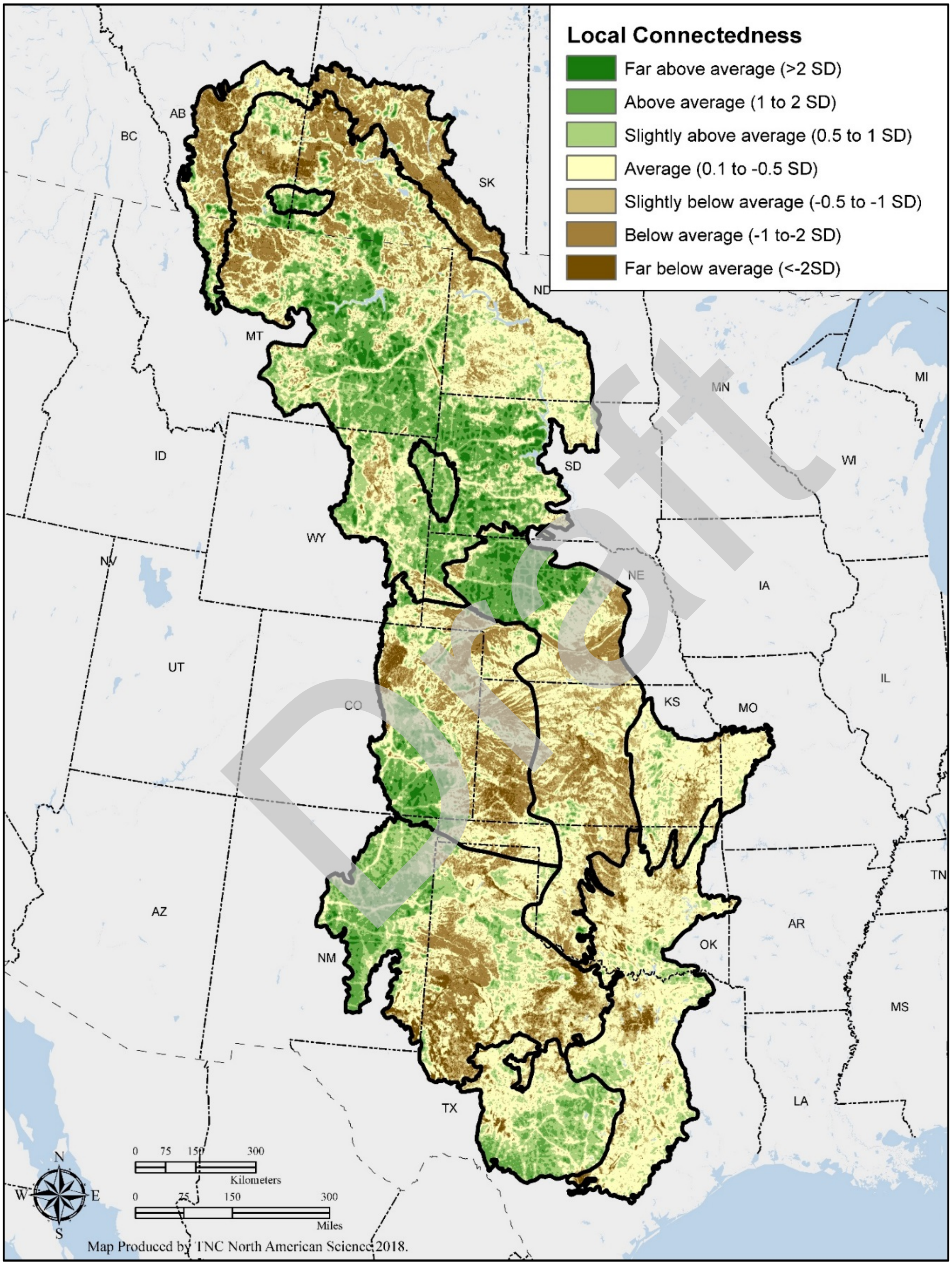
RK Value = 0.80
Regional Z Score = 0.84 SD

RK Value = 0.87
Regional Z Score = 1.5 SD



RK Value = 0.91
Regional Z Score = 3.2 SD

Figure 3.16: Local Connectedness. This map estimates the degree of connectedness of a cell with its surroundings within a 3-km radius, compared to the regional average.



Section 3: Combined Resilience Factors

We combined the landscape diversity and local connectedness scores into an integrated resilience score (Figure 3.17). 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. Although this map (Figure 3.17) accurately reflects the absolute scores, it is not the final map for this project because the study area boundaries are arbitrary. The final map repeats the process of scoring values relative to the mean for each ecological region, and then assembles the ecoregion results into a composite map (ecoregion maps are in Chapters 4, the composite map is in Chapter 5).

To ensure the two factors—landscape diversity and local connectedness— had equal weight in the integrated score, we transformed each metric to standardized normalized scores (Z-scores) so that each has a mean of 0 and a standard deviation of 1. The normalized score prevents factors with a larger mean or variance from having more influence.

A standard normal transformation (Z-score) is used throughout this project for combining datasets. The formula for calculating the Z-scores is:

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

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-m cell was equal to:

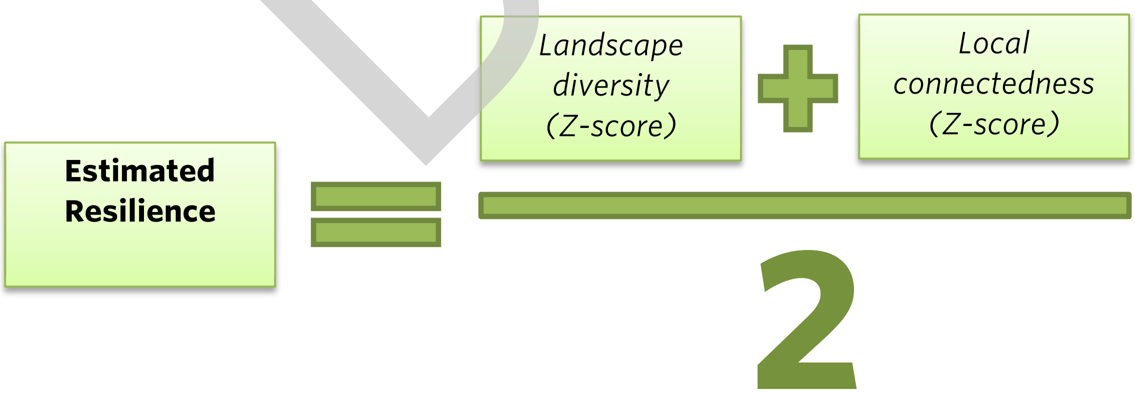
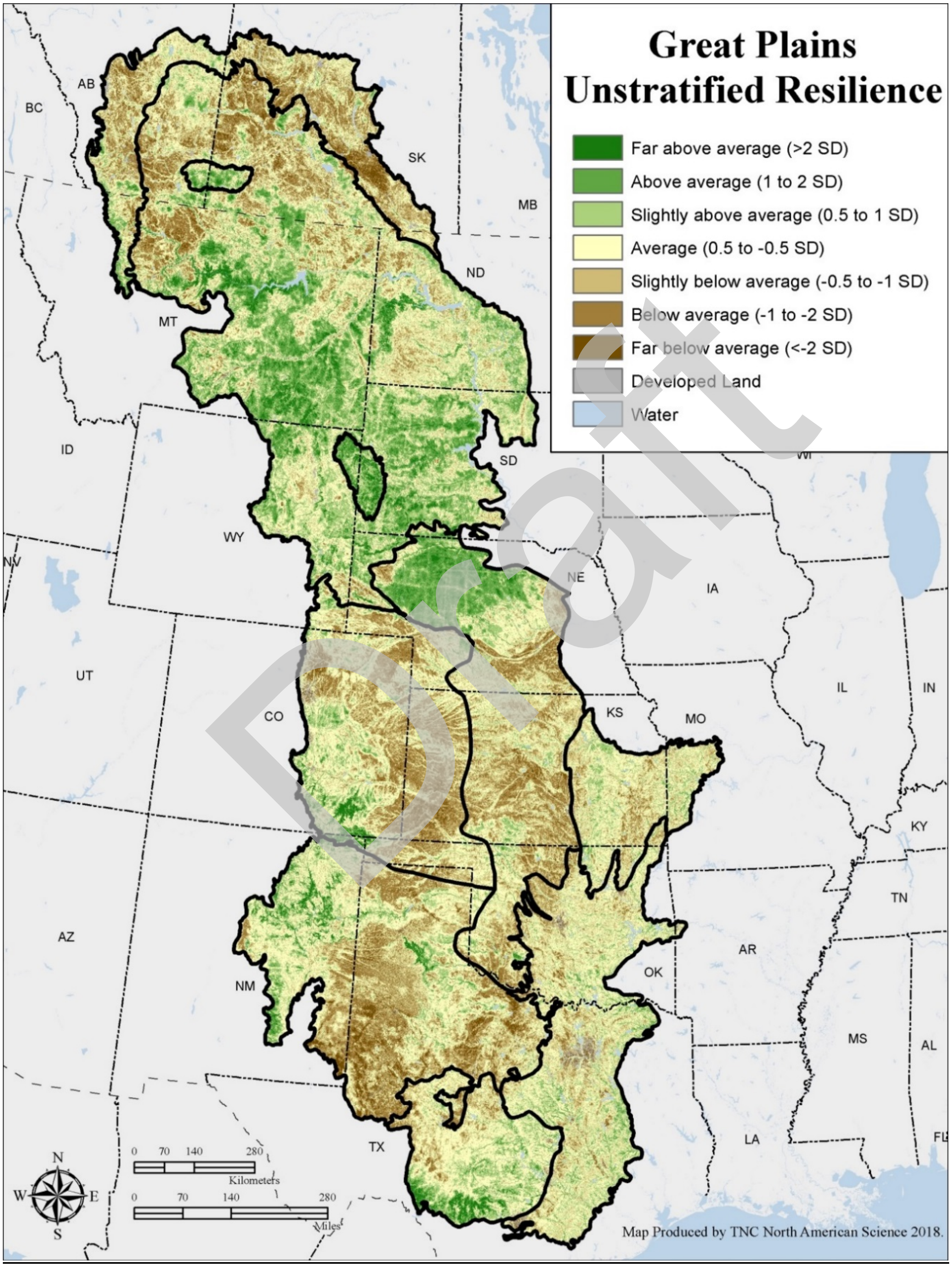


Figure 3.17: Unstratified Resilience Score. This map shows the raw cell scores for estimated resilience (landscape diversity + local connectedness) before we stratified the score by geophysical setting and ecoregion.



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ECOREGIONAL RESULTS

CHAPTER 4

In this chapter, we present site resilience results for the ten ecoregions of the Great Plains region. As described in Chapter 1, we define site resilience as "the capacity of a site to adapt to climate change while maintaining biological diversity and ecological function" (following Anderson et al. 2014b). As described in Chapters 2 and 3, in each ecoregion, we mapped the geophysical settings and identified areas with relatively higher site resilience based on their landform (microclimate) diversity and local connectedness.

The ten ecoregions (Figure 4.3) fall into three basic types in terms of their physical structure, with most characterized by large expanses of gentle topography that is dominated by grassland vegetation. Boundaries among these ecoregions reflect shifts in dominant grassland types, often related to persistent gradients in precipitation and temperature (Bragg 1995). Starting in the north, the Fescue-Mixed Grass Prairie (separated into the Moist Mixed Grasslands and Fescue Grasslands ecoregions in Canadian plans, e.g., Riley et al. 2007, Shorthouse 2010) falls between the Northern Great Plains Steppe and Aspen Parklands, which is outside of the scope of this assessment. Two small ecoregions, the Black Hills, and Cypress Uplands, delineate zones with more rugged topography and a higher range of elevation that support both grassland and forested systems. These two ecoregions are embedded within the largest ecoregion, the Northern Great Plains Steppe (referred to as the Mixed Grass ecoregion in Canadian conservation planning documents). The Northern Great Plains Steppe extends from the Rocky Mountain foothills in the west, to poorly-drained upland moraines derived from glacial till intersected by hummocky lowlands in the east. These lowlands comprise an area of extremely dense prairie pothole wetlands along the Missouri Coteau. At the southern end of the region, the Edwards Plateau is characterized by more varied topography than the prairie ecoregions, with rugged hills, and diverse geologic features including limestone cliffs and caves that support many unique species and communities. In between are three prairie ecoregions, the Central Shortgrass, Central Mixed-Grass, and Southern Shortgrass which are dominated by grasslands on gentle topography, although the two shortgrass regions have more rugged terrain along the border with the Rockies. In the southeastern section of the focal area, the Osage Plains/Flint Hills, and Crosstimbers and Southern Tallgrass Prairie ecoregions include a mix of grasslands and forests and woodlands, some of which share species with more mesic ecoregions to the east.

The Great Plains has strong variability in the amount of natural landcover across the ecoregions. The most notable shift occurs at the international border, with especially high rates of grassland conversion to agriculture in Canada (Riley et al. 2007, Gage et al. 2016). Several ecoregions show strong spatial patterns in conversion to row crops or energy development, and often these patterns can be tied to soil productivity and variation in geophysical settings. As with all the resilient site assessments, we use these ecoregions and geophysical settings as stratification factors. Therefore, scores across ecoregions and settings are not directly comparable. For example, a site that scores above-average for resilience in the flat and fragmented Fescue-Mixed Grass Prairie would likely score average or even low in the more topographically diverse and intact Black Hills. Results for the study area as a whole are presented in Chapter 5.

Resilience and Vulnerability

As we shift from describing our methods (Chapters 2 and 3) to presenting results, it is important to remember that our goal was not to predict species responses to a particular climate change scenario, but rather to identify sites within each ecoregion and on each geophysical setting, that will have accessible (i.e., locally connected) climate options which will benefit species under *many* possible scenarios. Over time, these sites will be exposed to shifts in climate patterns, which in turn are likely to promote changes in species composition, and shifts in key functions and ecological processes. As these responses occur, we expect that these more complex and connected sites will sustain higher levels of biological diversity and ecological function.

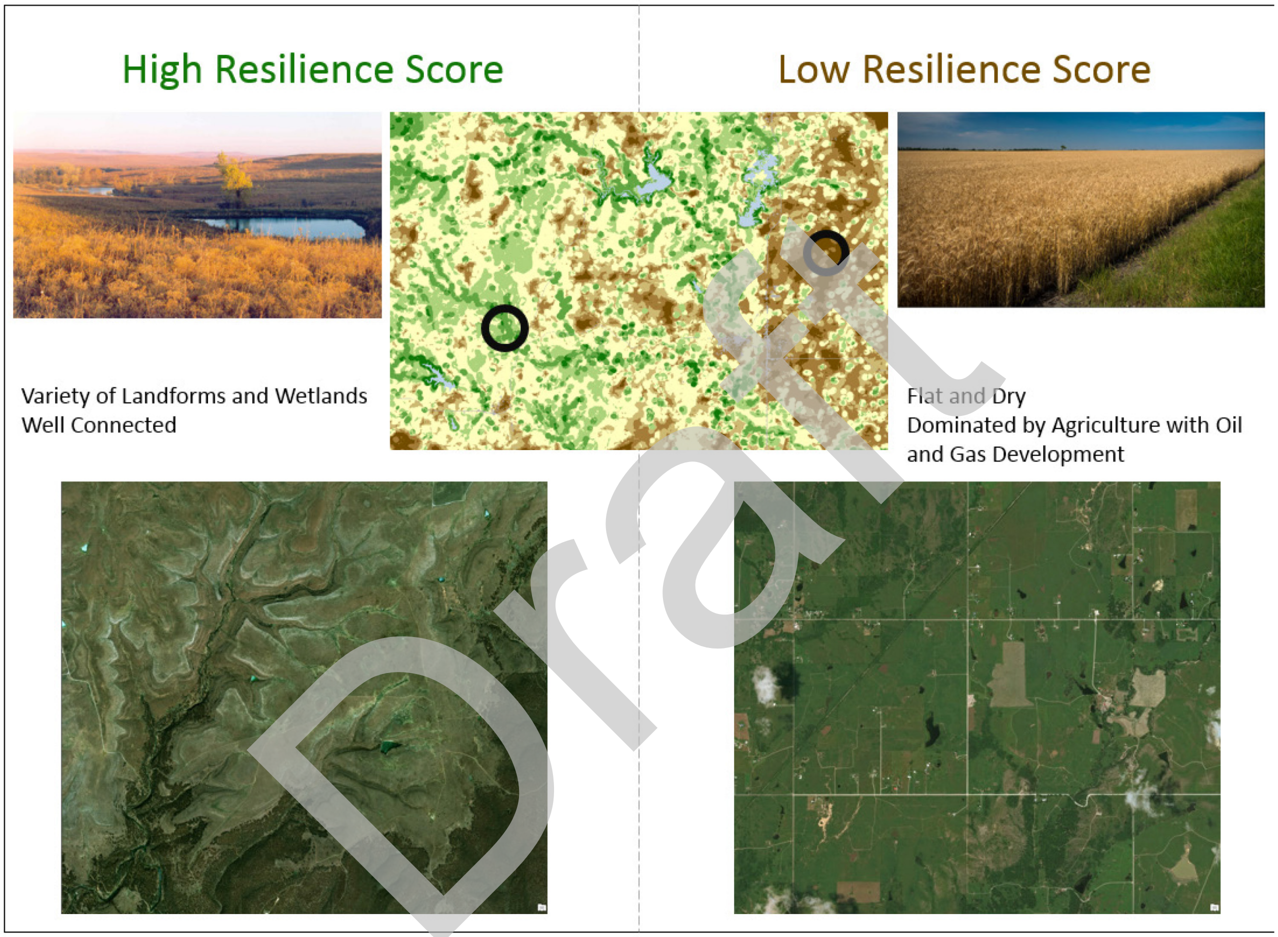
Coarse-scale climate models can provide useful estimates of the directional changes in temperature, and (with higher levels of uncertainty) project future changes in precipitation and related variables like evaporative demand. However, within the extent of a single spatial unit (a grid cell, typically about 62 miles or 100 km per side) of a mapped climate projection, we expect to see a wide range of local climate conditions (temperature and available moisture), due to the shape of the land, and characteristics of the soil and dominant vegetation (see full discussion in Chapter 3). These landscape and vegetation-based variations are relatively uncoupled from regional averages across multiple climate model grid cells, and often much larger in variance. For example, ten bogs in the Adirondacks were estimated to have an average of 128 ± 9 growing season days based on PRISM climate models, but in-situ temperature loggers found them to be much cooler and more variable (mean = 73 ± 33, Langdon in prep).

Our focus was on mapping the most persistent drivers of the local variation, the landscape characteristics, and then applying them to subsets of each ecoregion delineated by geology and surficial sediments (see Chapter 2). We cannot predict the biotic responses of species nor the interactions between species, but by identifying and conserving sites with characteristics that increase options for species and communities to adapt, we can help identify sites most likely to set the stage for nature to remain resilient.

In this study, resilience to climate change and its converse, vulnerability to climate change, are relative concepts for which we do not have absolute thresholds. We defined a resilient site as one with more of the characteristics (microclimatic buffering and connectedness) that maintain species and functions than the average site in the ecoregion. We expect that these sites will support an array of specialist and generalist species, even as the species composition and ecological processes change. In contrast, a vulnerable site was defined as one where natural connectivity is disrupted and fragmented, and there are limited options for species to shift to a more suitable microsite as the regional climate changes. We suggest that vulnerable sites may be more likely than resilient sites to show a net loss of biological diversity, and as species are lost, opportunistic "weedy" species adapted to high levels of disturbances and anthropogenic degradation may be more likely to thrive. Evidence to support this was found in the Northeast where high-scoring resilient sites contained significantly more of the known biodiversity locations (including 75% of the target species) and low-scoring vulnerable sites contained significantly less ($p < 0.0001$, Anderson et al. 2014a).

Climate change is expected to greatly exacerbate the degradation of vulnerable sites, through multiple mechanisms, including the dominance of generalist species described above. However, to the extent that a site retains natural forms of landcover, it will likely continue to perform many natural services, such as contributing to cleaner air, sequestering carbon, providing wildlife habitat and recreational opportunities, and filtering water. Without a doubt, natural but vulnerable sites have value, but relative to other comparable sites (mapped here as those sites in the same ecoregion, and on the same geophysical setting), they are places where the impact of climate change may be felt most severely, and where it may be most difficult to sustain the full suite of natural functions and species diversity that could occur on the site over time (Figure 4.1).

Figure 4.1: Estimated resilience and vulnerability. This image compares two sites (landscape photos paired with aerial overviews, and corresponding circled areas in the resilience map) in northeastern Oklahoma in the Osage Plains/Flint Hills ecoregion. The site on the left, located in the Joseph H. Williams Tallgrass Prairie Preserve, has greater landscape diversity and connectedness, and scores higher (green) for resilience. The agricultural area in the images on the right is flatter and more fragmented, contributing to lower (brown) resilience scores.



Mapping Resilience

The maps in this chapter illustrate the relative resilience of sites in relation to their geophysical setting, the ecoregion, and the larger study area. The results are intended to support conservation strategies by identifying each ecoregion's most resilient areas using objective and repeatable criteria that could be observed in the field and were not dependent on knowing the future climate. In earlier chapters, we explained the logic and evidence for this approach, and here we want to help users understand and interpret the results.

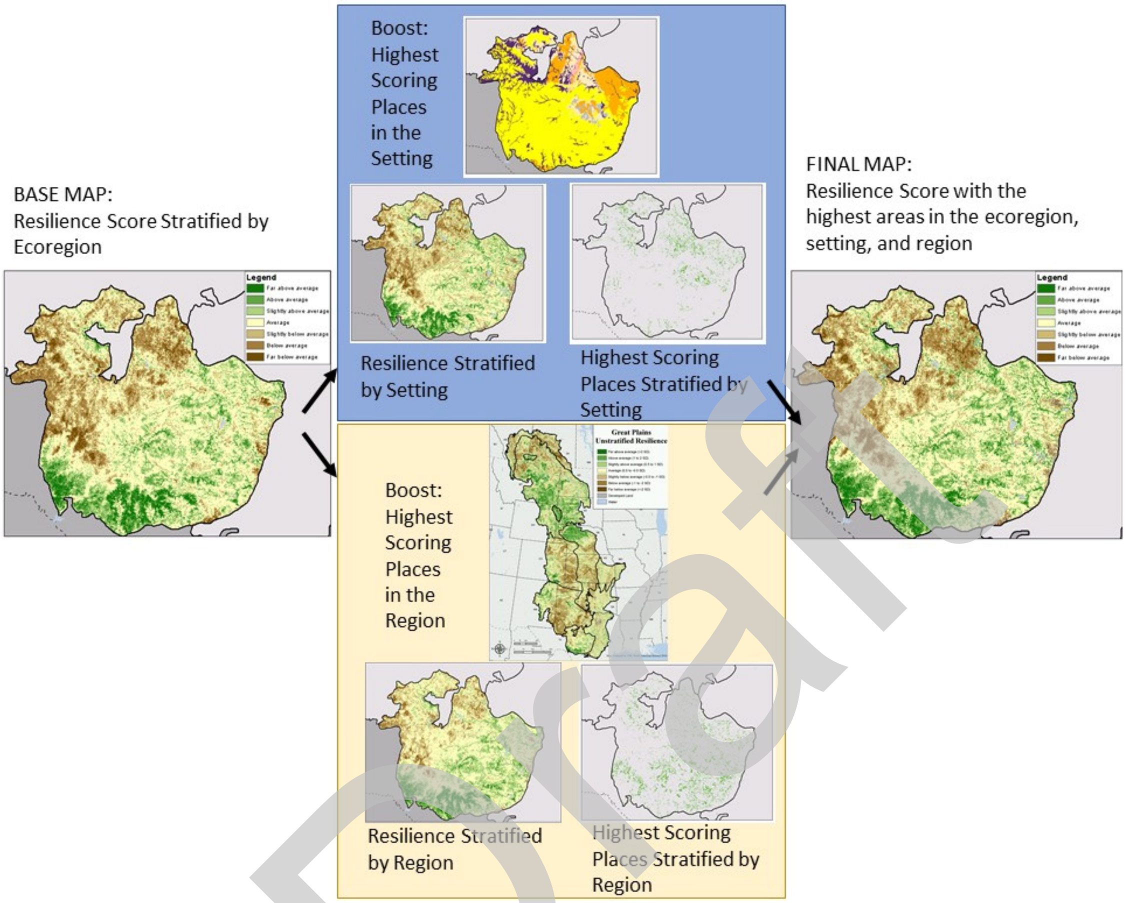
The legends for all the maps of resilience and its components are on a relative scale based on a standard normal distribution (Z-scores). This transformation converts the data to a scale where the mean is equal to 0 and each standard deviation is equal to 1. Thus, a site score of 1 SD means the site is one standard deviation above the average value of all sites in the ecoregion on the same setting. Based on a normal distribution, this translates to a score that is roughly 84% higher than other comparable sites. For example, if the site is on sand in the Central Mixed-Grass Prairie, then a score of 1 SD means the site has greater landscape diversity and local connectedness than 84% of the other sites on sand in the Central Mixed-Grass ecoregion, and thus is mapped as more resilient. All map legends reflect this scale:

Score	Numeric Value	Meaning	Interpretation
Far below average	(<-2 SD)	Below 98%	**Most Vulnerable**
Below average	(-1 to -2 SD)	Below 84%	**More Vulnerable**
Slightly below average	(-0.5 to -1 SD)	Below 69%	**Somewhat Vulnerable**
Average	(-0.5 to 0.5 SD)	Between 31-69%	**Average**
Slightly above average	(0.5 to 1 SD)	Above 69%	**Somewhat Resilient**
Above average	(1- 2 SD)	Above 84%	**More Resilient**
Far above average	(>2 SD)	Above 98%	**Most Resilient**

Use of this scheme assumed that the raw scores followed a normal distribution, i.e., that a plot of the resilience values for each 30-m cell would show a bell-shaped curve centered on the mean, with roughly two-thirds of all observations falling within one standard deviation of the mean. We examined the distribution patterns and, when necessary, transformed the data using log- or rank-based transformations to approximate a normal distribution.

Resilience values in Z-scores are always relative to some population or distribution. For example, to estimate the resilience of sites in the Central Mixed-Grass Prairie, we selected all the cells in the ecoregion, calculated their average resilience score based on landscape diversity and local connectedness, then normalized them to identify the places that were above-average. What we can say with confidence is: the high scoring sites have the greatest number of microclimates and least amount of fragmentation relative to other sites in the Central Mixed-Grass Prairie. Because different ecoregions have different average scores, what scores average in one ecoregion might score high in another.

Figure 4.2: Integration Across Stratification Levels: Edw ards Plateau Ecoregion. The resilience scores are relative to the ecoregion with boosts for certain geophysical settings or the highest scoring sites in the study area to correct for bias.



The final ecoregion site resilience map contained two modifications to boost sites that *were not* the highest in the ecoregion, but *were* the highest in their setting or in the entire study region. The method for creating the maps followed a linear progression (Figure 4.2). First, we calculated the resilience Z-scores relative to the ecoregion irrespective of geophysical setting. Next, we repeated the process, this time normalizing the resilience scores relative to each geophysical setting within the ecoregion. We compared the two scores cell-by-cell and where the geophysical setting score was both greater than 1 SD for the setting and greater than the ecoregion score, we replaced the ecoregion score with the setting score. This had the effect of boosting the score for settings that had mean scores below the ecoregion mean score, and corrected for bias caused by inequality of microclimates and connectedness across settings. Next, we added a regional override to elevate cells that scored the highest in the whole study area (Figure 4.2). For this we calculated the resilience score relative to the entire study region irrespective of ecoregion or setting. We compared the regional score cell-by-cell with both the ecoregion score and the geophysical setting score. Where the regional score was both greater than 1 SD for the region and greater than the ecoregion and setting scores, we replaced the existing score with the regional score. This had the effect of boosting the score in places where the regional score was higher than the ecoregional or setting mean.

The boosting not only corrected for differences between geophysical settings, it also ensured that by skewing the distribution slightly toward resilient and away from vulnerable we did not miss potentially resilient sites

Results Overview

For each of the ten ecoregions, we present a series of maps and figures that provide information on geophysical settings and site resilience scores. The methods underlying these results are addressed in detail elsewhere in the report (Chapters 2 and 3), although we provide a short description of each map below. Region-wide results are presented in Chapter 5.

For each ecoregion (Figure 4.3), we present the results as five maps and three charts:

1) Map of Geophysical Settings
2) Map of Landscape Diversity
3) Map of Local Connectedness
4) Map of Resilience Scores
5) Map of Resilient Examples of each Geophysical Setting
6) Chart of Land Securement and Conversion by Geophysical Setting
7) Chart of the Relative Abundance of Each Setting
8) Chart of the Distribution of Resilience Values by Geophysical Setting

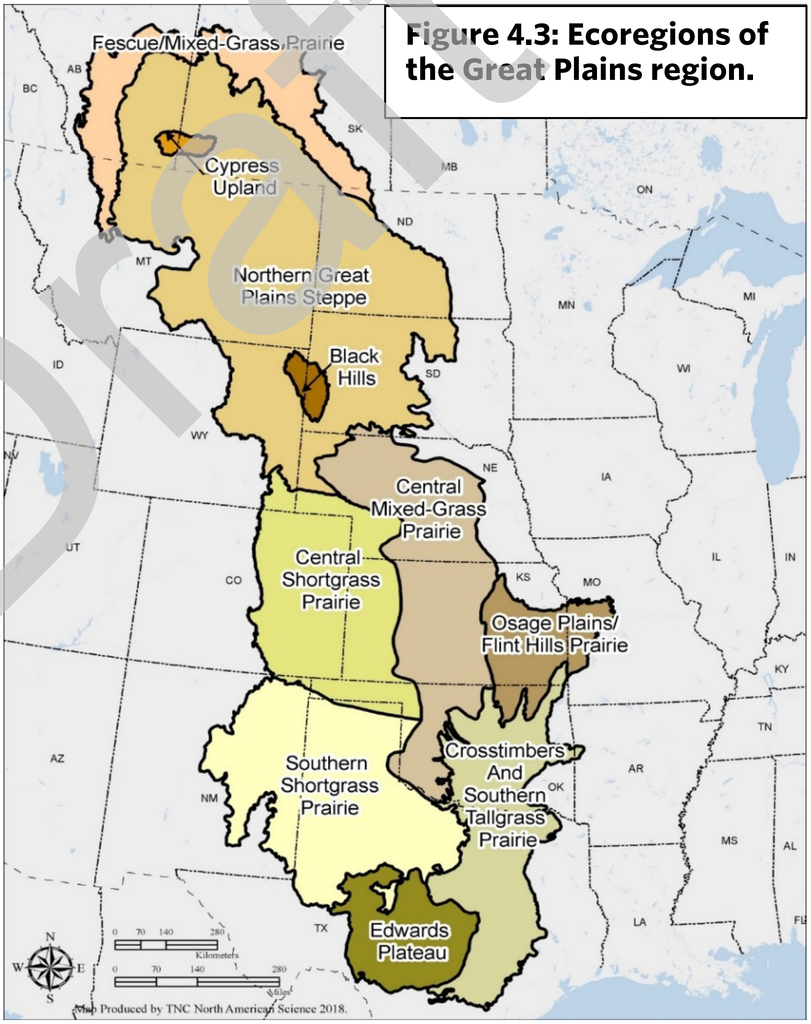


Figure 4.3: Ecoregions of the Great Plains region.

All maps show scores relative to settings within ecoregions with a regional override where appropriate. Raw scores for each geophysical setting are presented in the last chart. Explanations of each map and chart, and, in some cases, the method of mapping, are described below.

1) Map of Geophysical Settings
The geophysical settings maps show the type and distribution of surficial sediments or bedrock influenced areas in the ecoregion. Details on geophysical setting definitions and associated species and communities are in Chapter 2.

2) Map of Landscape Diversity
The landscape diversity metric evaluates the number of species-relevant landforms within a 40-ha (100-acre) moving window, and incorporates a wetland influence metric that increases the score in flat areas where wetlands are dense and topographically connected. Flat dry areas score lower and areas with more variation in topography or higher wetland density score higher.

3) Map of Local Connectedness
Local connectedness measures how intact the physical? connections are between natural ecosystems within a local (3-km) landscape. Areas in green score above-average, indicating that landcover is in a natural state (e.g., grassland, forest, etc.) conducive to movement of plant and animal populations. In contrast, below-average areas in brown are fragmented and dominated by non-natural land cover. Roads, large water bodies, and other barriers also contribute to lower local connectedness scores.

4) Map of Resilience Scores
This map shows the estimated resilience score of each cell based on its landscape diversity and local connectedness scores. Resilience scores are calculated relative to the ecoregion, with overrides for cells that are the highest scoring in its geophysical settings or the highest scoring in the whole study area (see Mapping Resilience). Areas in green are above-average and estimated to be more resilient to climate change. Areas in brown are below-average and estimated to be more vulnerable to climate change.

5) Map of Resilient Examples of each Geophysical Setting
The map shows only the grid cells that score above-average for estimated resilience based on Map 4. Each high scoring grid cell is colored with its corresponding geophysical setting to reveal the most resilient examples of each geophysical setting. These maps are useful in understanding how resilient areas correspond the underlying geophysical structure, and for identifying where conservation action could address a particularly physical habitat. For example, if deep loess is identified as underrepresented in the ecoregion's current conservation lands (described in 8, below), this map shows where the most resilient areas are for conservation.

6) Chart of the Proportional Area of Each Setting
The pie chart shows the proportional area (in %) of each geophysical setting in the ecoregion.

7) Chart of the Distribution of Resilience Values by setting type
The chart shows the average resilience score for each geophysical setting in the ecoregion calculated from the unstratified regional resilience grid. It reveals the inherent variation in resilience across the different settings. For example, in the Southern Shortgrass Prairie ecoregion (Figure 4.66) the mean and standard deviation of resilience scores for pixels on calcareous loam is almost completely below the mean

and standard deviation of those on acidic granitic settings. Thus, in this ecoregion the most resilient areas for loam have fewer microclimates and are more fragmented than most of the least resilient areas for these two bedrock settings. Interpretation should be tempered by knowing that each of these settings make up less than 5% of the ecoregion (Figure 4.65).

8) Chart of Land Securement and Conversion within each setting type
For each geophysical setting, this figure shows the percentage of land converted to development or agriculture, the percentage permanently secured for conservation (GAP 1-3), and the percentage of remaining natural land by its relative resilience (see Chapter 5 for a map of land securement).

To provide context for the results, we highlight a few key characteristics of the Great Plains ecoregions in Table 4.1. Notably, most ecoregions in this region have very low proportions of land in protection relative to other US ecoregions.

Table 4.1: The Great Plains Ecoregions – a snapshot from north to south.

Ecoregion name	Area (acres, km²)	Mean elevation & range (ft, m)	Protection category	
			% Gap 1,2	% Gap 3
Fescue/Mixed-Grass Prairie (US), Fescue Grassland & Moist Mixed Grassland (CAN)	32,000,000 130,000	2600 (1400 to 7400) 760 (440 to 2300)	1.1	3.3
Northern Great Plains Steppe (US), Mixed Grassland (CAN)	157,000,000 630,000	2900 (1200 to 7900) 890 (350 to 2400)	1.7	12.8
Cypress Uplands	2,100,000 8,000	3500 (2500-4800) 1100 (750-1500)	5.0	9.7
Black Hills	3,400,000 13,000	4800 (2940-7200) 1500 (900-2200)	5.3	40.8
Central Mixed-Grass Prairie	59,000,000 240,000	2200 (900-4700) 670(280-1400)	0.8	0.5
Central Shortgrass Prairie	56,000,000 230,000	4100 (1700-8800) 1300 (520-2700)	1.3	5.2
Osage Plains/Flint Hills Prairie	20,000,000 80,000	1100 (500-1700) 300 (160-510)	1.6	0.1
Southern Shortgrass Prairie	69,000,000 280,000	3500 (710-9400) 1064 (220-2900)	0.3	3.1
Crosstimbers and Southern Tallgrass Prairie	49,000,000 200,000	740 (75-2000) 220 (23-600)	0.7	0.5
Edwards Plateau	23,500,000 95,000	1800 (430-2900) 550 (130-900)	1.1	1.0

Fescue/Mixed-Grass Prairie

Photo credit: © Matthew Braun/Nature Conservancy of Canada

This ecoregion description was adapted from A Conservation Blueprint for Canada's Prairies and Parklands (Riley et al. 2007) and Shorthouse et al. (2010).

The northern-most ecoregion of the Great Plains, this ecoregion caps the Northern Great Plains Steppe and separates it from the Aspen Parkland ecoregion to the north. Canadian conservation plans divide this into the Moist Mixed Grassland ecoregion plus a narrow band of Fescue Grasslands along the western border.

Landforms in this ecoregion are mostly glacial in origin, consisting of level to gently rolling plains of relatively young glacial till left behind by the retreat of the Laurentide ice sheet roughly 12,000 years ago. Most of the terrain is poorly drained, and formed into upland moraines which vary from level to hummocky. At the western edge, the Fescue Grasslands occur on morainal, glaciolacustrine, and outwash deposits along the Rocky Mountain foothills. Across the ecoregion, wetlands fill the depressions among the hummocks, and are particularly prevalent along a large glacial lake plain extending from the base of Missouri Coteau to the south and west. Overall, sloughs, potholes, and streams are more common in this ecoregion than to the south.

Relative to the Northern Great Plains Steppe, the Fescue/Mixed-Grass Prairie tends to be slightly cooler, and receives about 20% more annual precipitation. The southwestern section lies in the chinook belt adjacent to the Rocky Mountain foothills, and receives more snow than the rest of the ecoregion. As the name suggests, the Fescue Grassland section along the western edge of the ecoregion is dominated by rough fescue species, a highly productive and globally-rare system type. The rest of the ecoregion supports a diverse and productive suite of grassland communities, dominated by wheat grass communities on moister sites, and blue grama communities on drier, more exposed sites. Since European settlement, this ecoregion has become one of the most productive agricultural regions in Canada, leading to very high (~80%) rates of conversion. These high rates of conversion are linked to dramatic declines in plant diversity, and wildlife populations.

Figure 4.4: Fescue/Mixed-Grass Prairie Geophysical Settings.

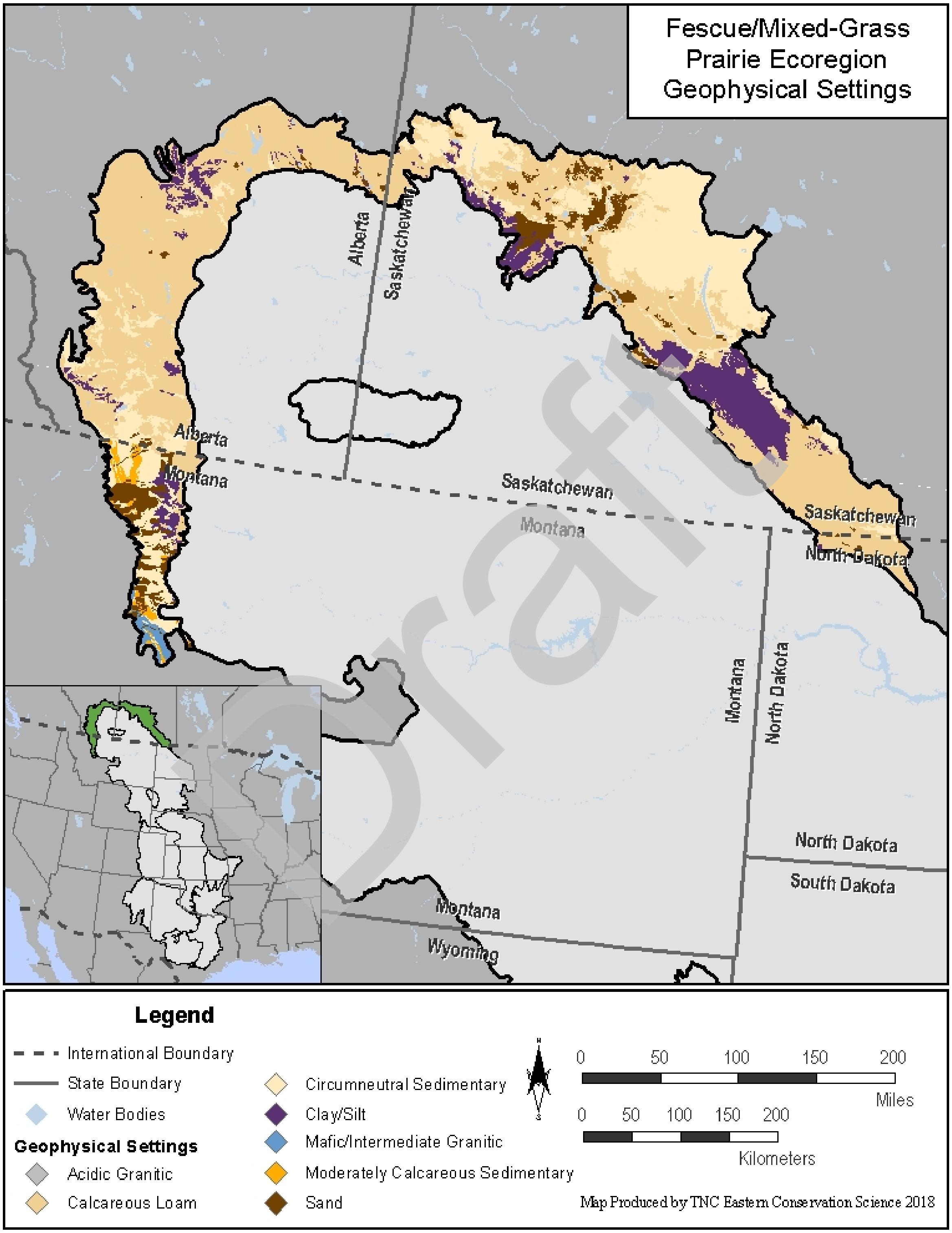


Figure 4.5: Fescue/Mixed-Grass Prairie Landscape Diversity.

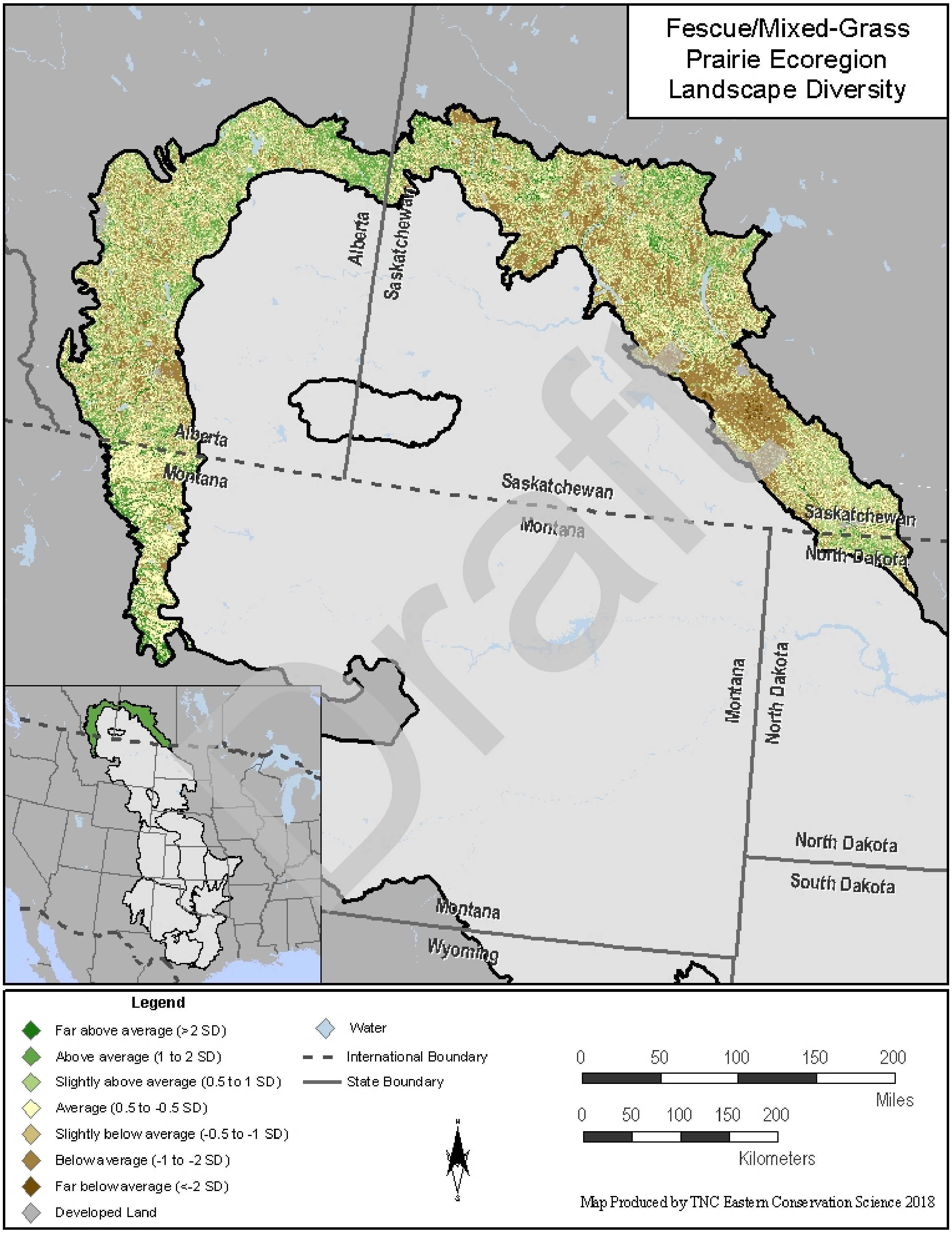


Figure 4.6: Fescue/Mixed-Grass Prairie Local Connectedness.

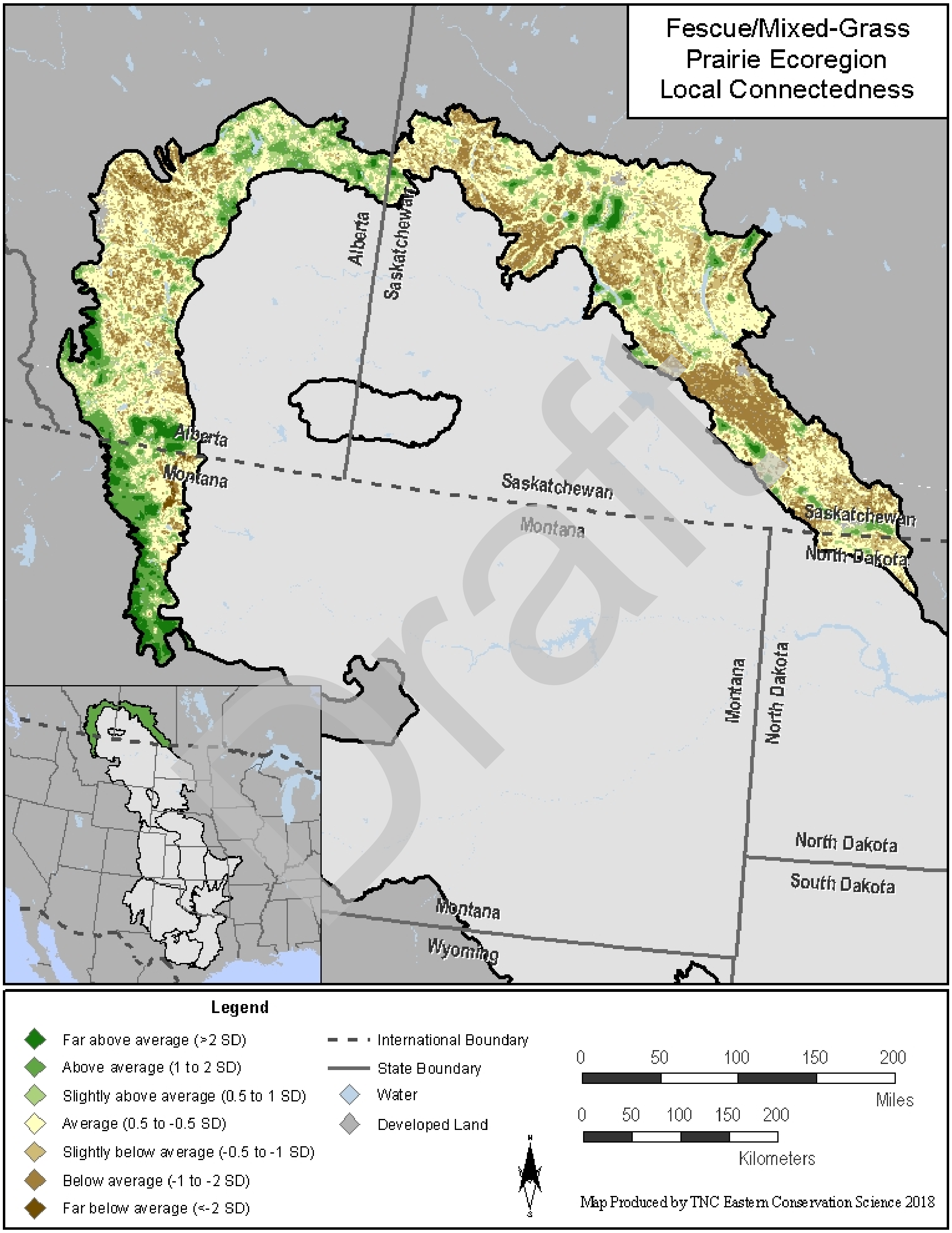


Figure 4.7: Fescue/Mixed-Grass Prairie Site Resilience Scores.

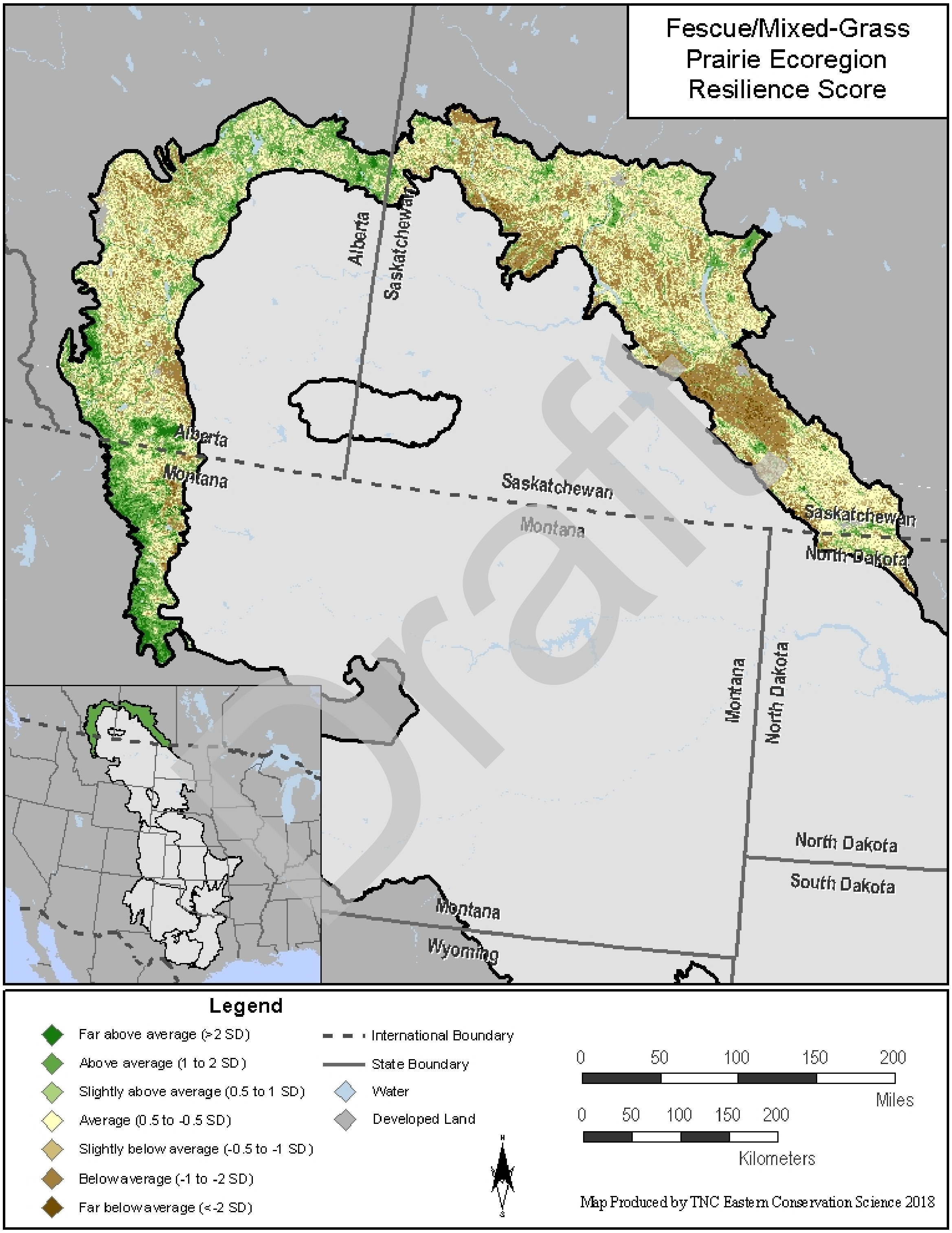


Figure 4.8: Highest Resilience Score Areas for Each Geophysical Setting Within the Fescue/Mixed-Grass Prairie Ecoregion.

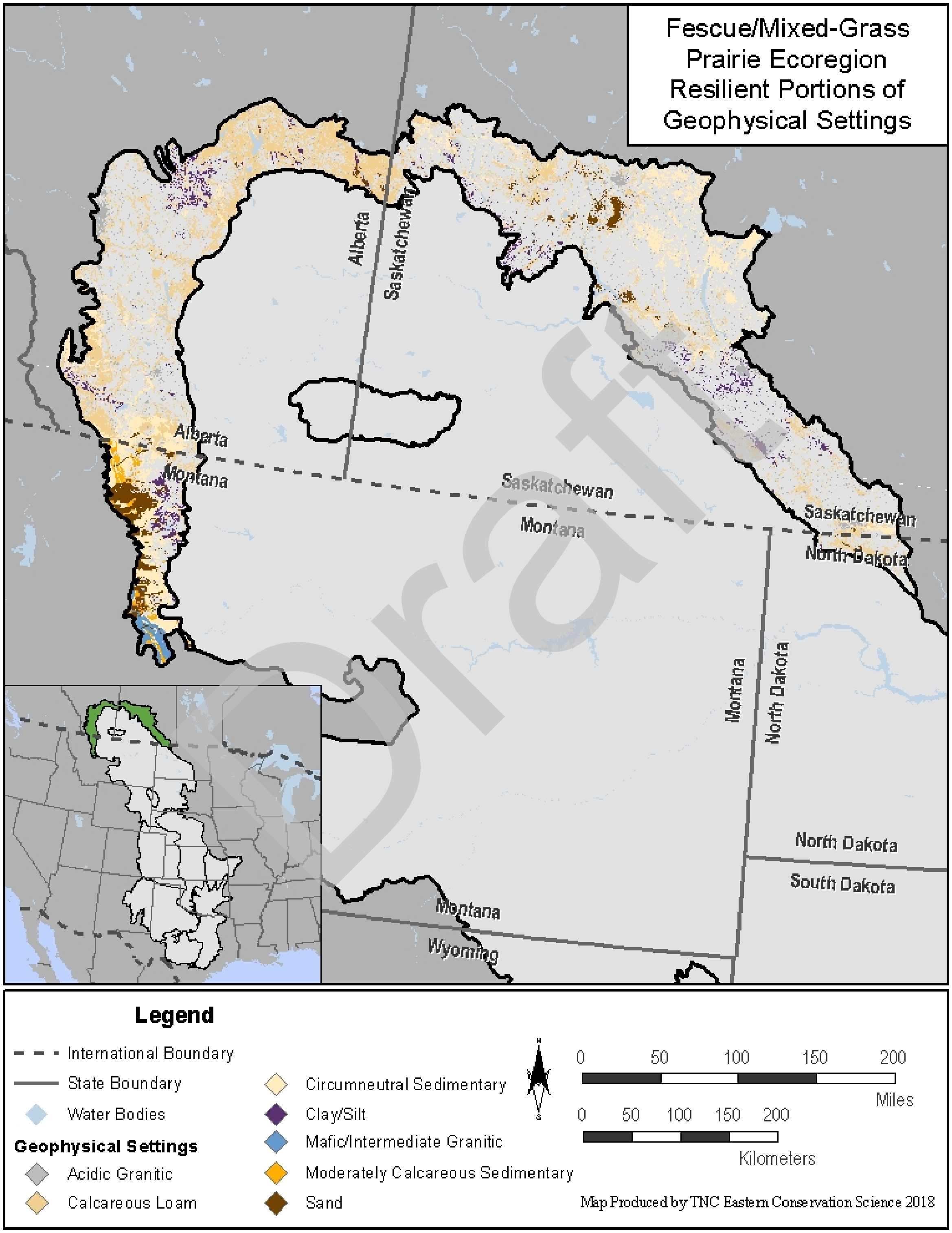


Figure 4.9: Fescue/Mixed-Grass Prairie Geophysical Settings - Proportions by Area. (Note unlabeled "utramafic" is less than 1 %)

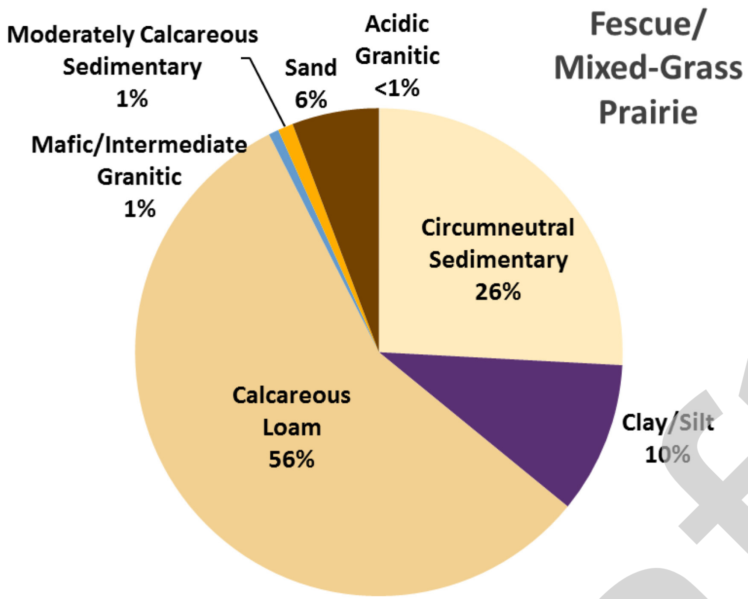
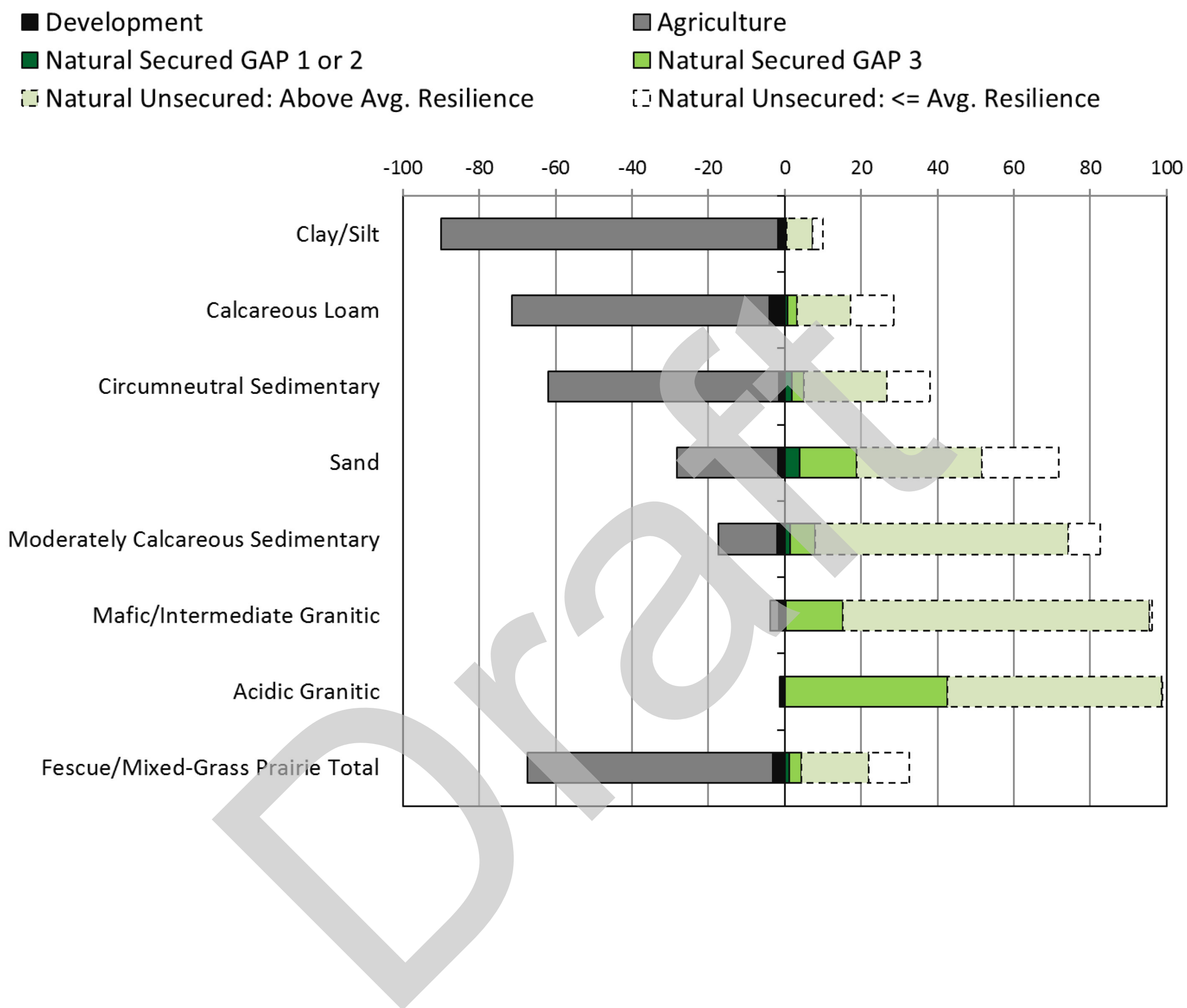


Figure 4.10: Fescue/Mixed-Grass Prairie Settings by Regional Resilience Score.

	Ultramafic	Mafic/Intermediate Granitic	Calcareous Sedimentary	Acidic Granitic	Moderately Calcareous Sedimentary	Circumneutral Sedimentary	Clay/Silt	Acidic Shale
Upper SD	1372	1218	1254	873	816	731	613	317
▲ MEAN	1021	572	372	305	165	3	-217	-356
- Lower SD	671	-74	-510	-263	-485	-724	-1047	-1030

Upper SD ▲ MEAN - Lower SD

Figure 4.11: Conversion and Securement of the Fescue/Mixed-Grass Prairie Ecoregion by Geophysical Setting. This ecoregion is 67.3% converted and 4.4% secured, a ratio of 15 to 1. Within this ecoregion, 18 % of the land (5.3 million acres) is in natural landcover, scored above average for resilience, and is not currently secured.



Northern Great Plains Steppe

Ogalala National Grasslands, NE. Photo credit: © Chris Helzer/TNC

Description adapted from A Conservation Blueprint for Canada's Prairies and Parklands (Riley et al. 2007), Ecoregional Planning in the Northern Great Plains Steppe (Northern Great Plains Steppe Ecoregional Conservation Team 1999) & Shorthouse et al. (2010).

Encompassing about one fifth of the Great Plains, the Northern Great Plains Steppe is a large, semi-arid ecoregion that spans the US-Canada border, and includes parts of two provinces and five states. The northern sections were shaped by glaciation and include large expanses of rolling topography, and kettle-kame topography, especially along the eastern prairie pothole region (the westernmost extent of these wetlands). The northern half of the ecoregion includes several isolated mountain ranges, and surrounds the Cypress Uplands ecoregion, an area with particularly high relief. The southern sections were beyond the extent of glaciation, and dominant landforms are typically gently sloping to rolling dissected plains, interspersed with scattered buttes and badlands, and a second mountainous ecoregion, the Black Hills.

Grasses and sedges are by far the dominant life form, especially in the north, where they can be 85-95% of the biomass (Shorthouse et al. 2010). Dominant communities include mid-height and short grasses such as wheat grasses, June grass, green needlegrass, blue grama, and needle-and-thread, with short-grasses tending to be on the drier sites. In northern sections, the rest of the biomass comes from forbs, sages and shrubs, while in the southern regions there are extensive areas of coniferous forest, shrub steppe, and hardwood systems along rivers and in draws.

Although human population density is low, human land use, especially conversion of prairie to agriculture, and energy development have dramatically changed system dynamics. Conversion rates have been particularly high on the northern side of the border, but losses of key grazers like bison, black-tailed prairie dogs, and disruption in other forms of disturbance (e.g., drought, insect outbreaks) have combined with habitat loss and fragmentation to put many species, such as grassland birds, at risk. Despite these losses, extensive areas of intact natural vegetation persist and play crucial roles in sustaining biodiversity, connectivity, and ecological function.

Figure 4.12: Northern Great Plains Steppe Geophysical Settings.

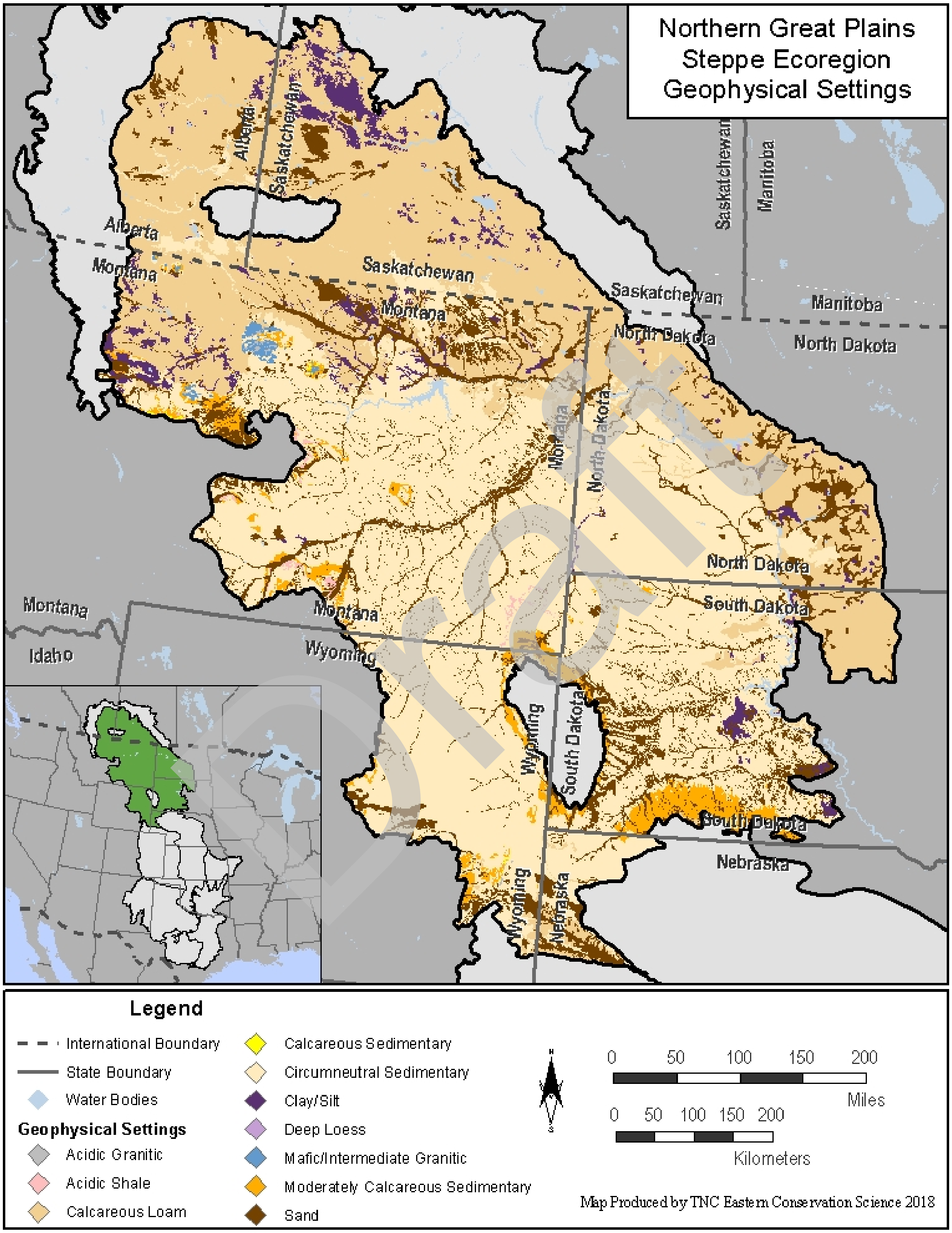


Figure 4.13: Northern Great Plains Steppe Landscape Diversity.

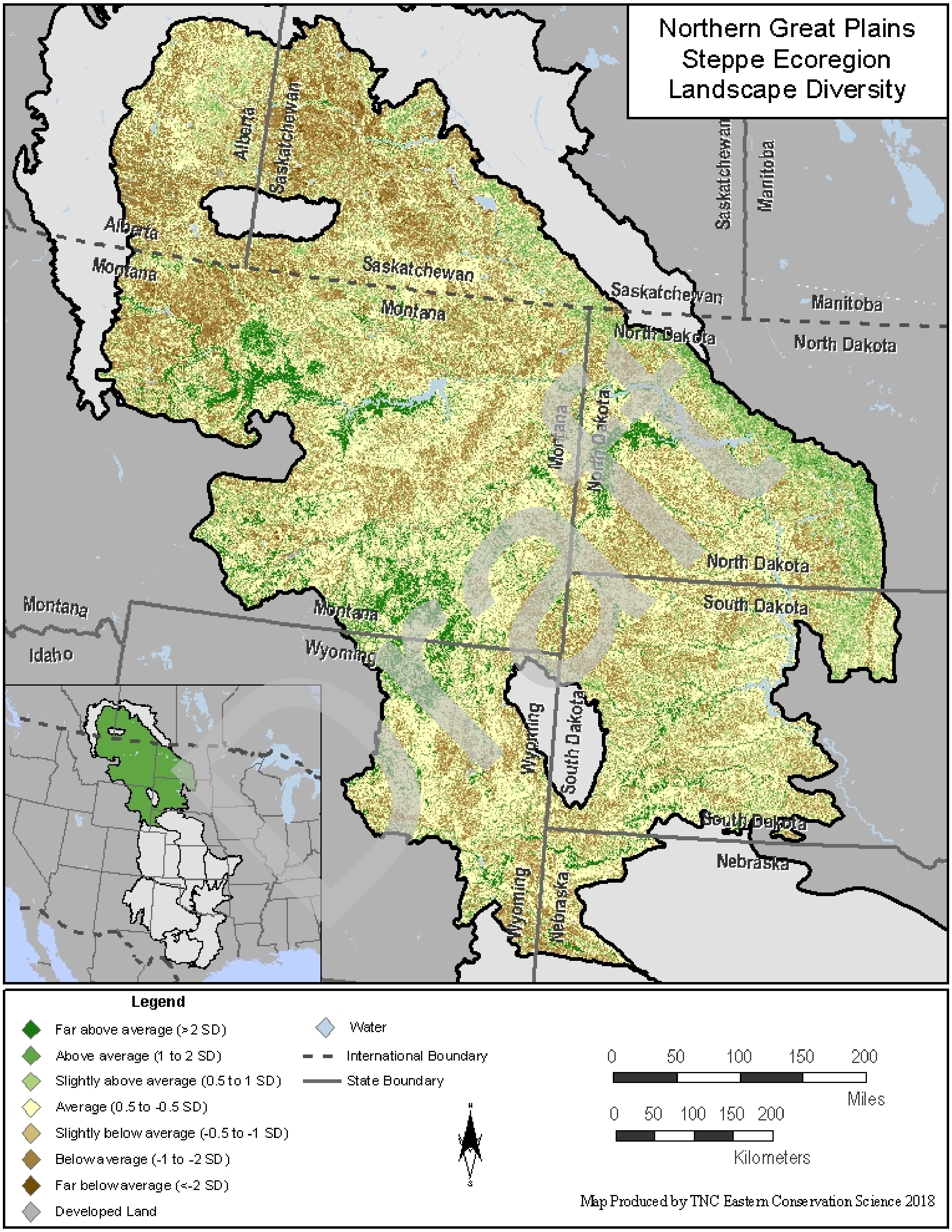


Figure 4.14: Northern Great Plains Steppe Local Connectedness.

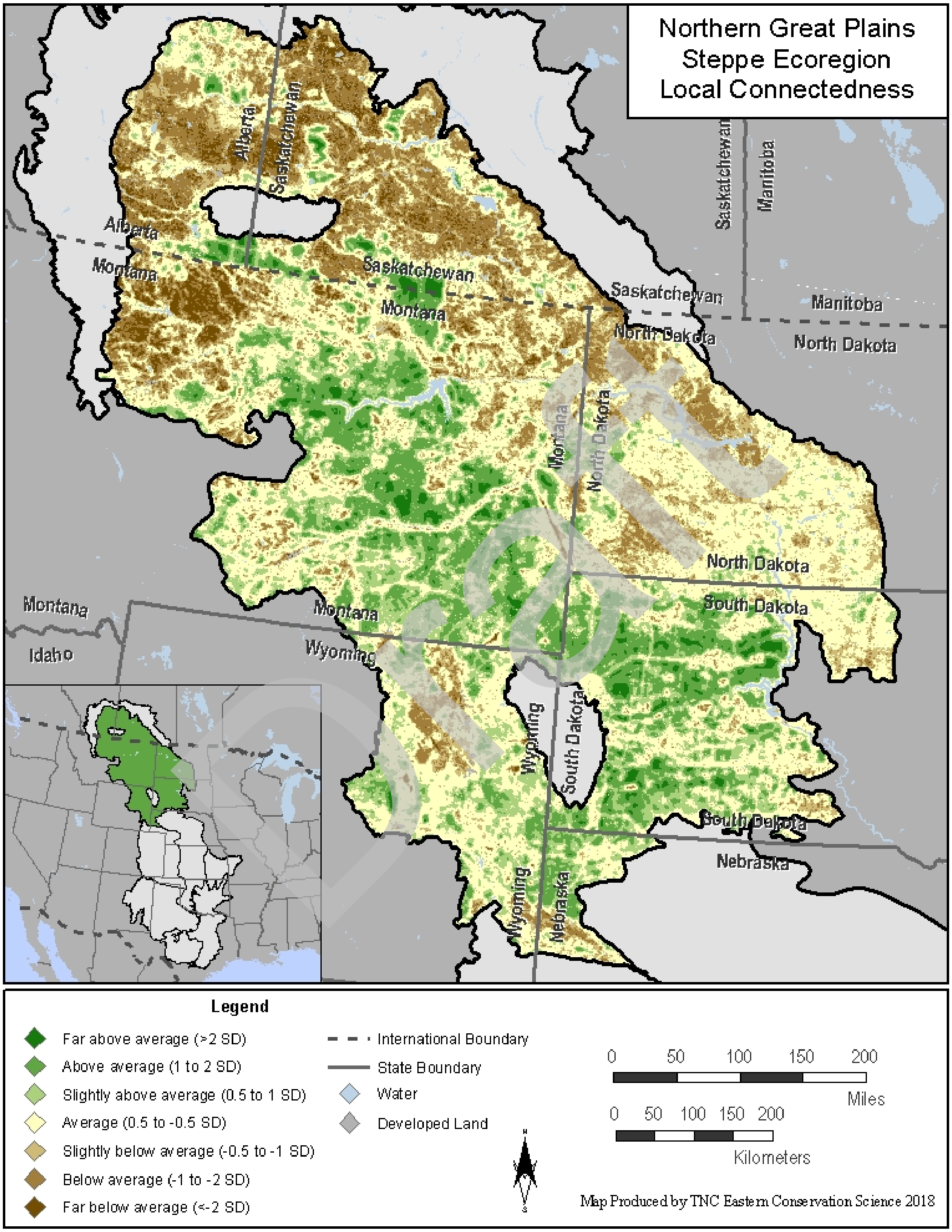


Figure 4.15: Northern Great Plains Steppe Site Resilience Scores.

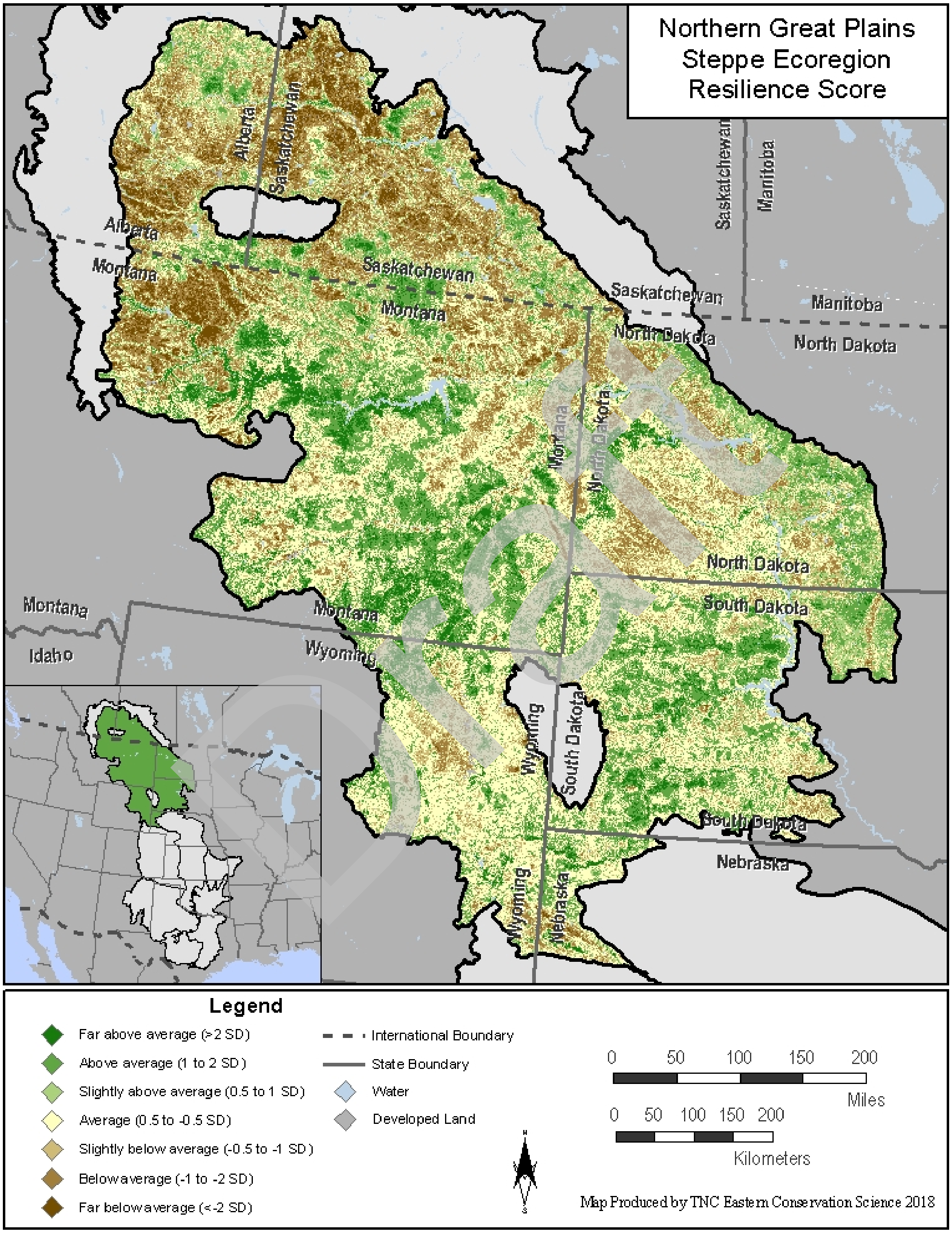


Figure 4.16: Highest Resilience Score Areas for Each Geophysical Setting Within the Northern Great Plains Steppe.

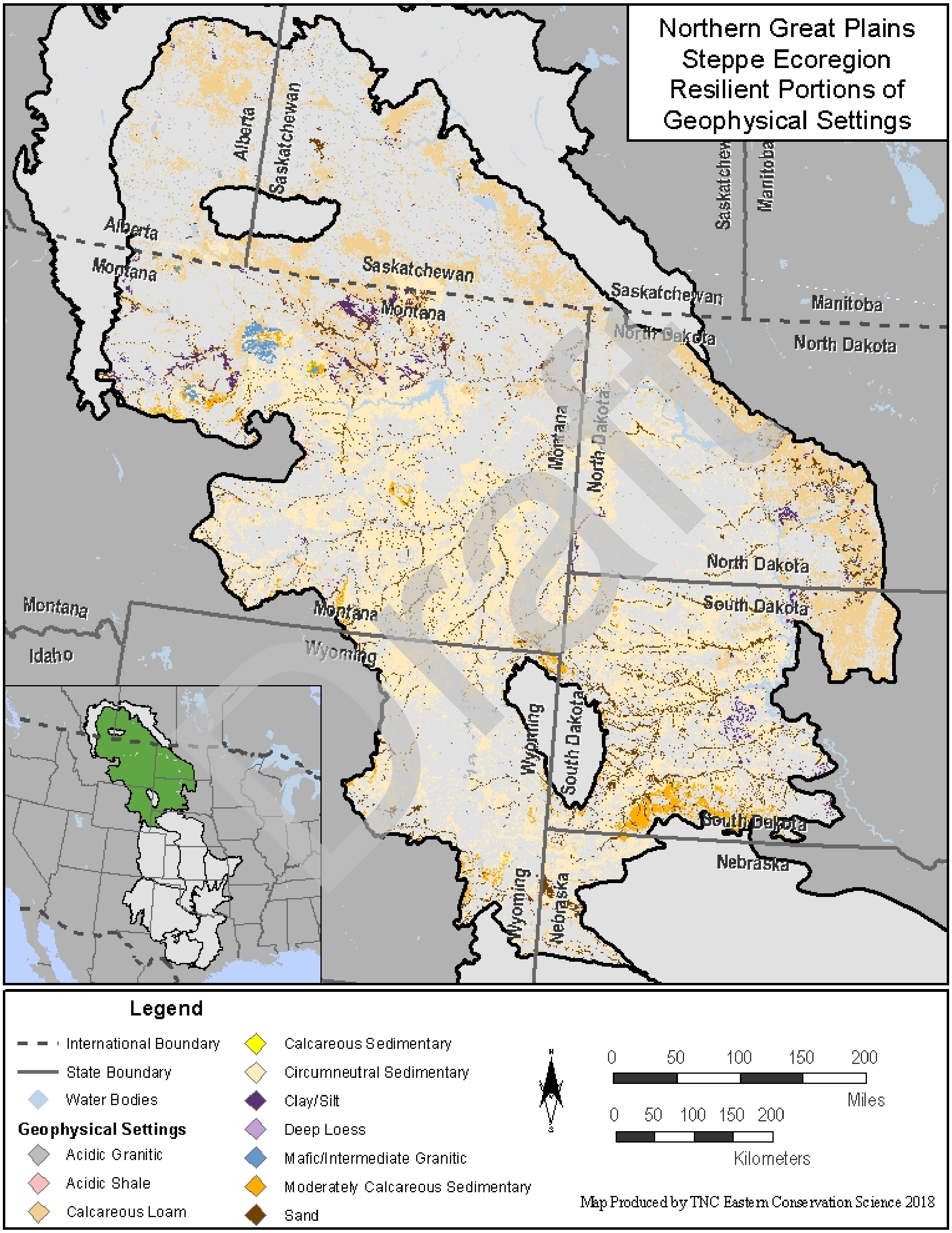


Figure 4.17: Northern Great Plains Steppe Geophysical Settings – Proportions by Area.

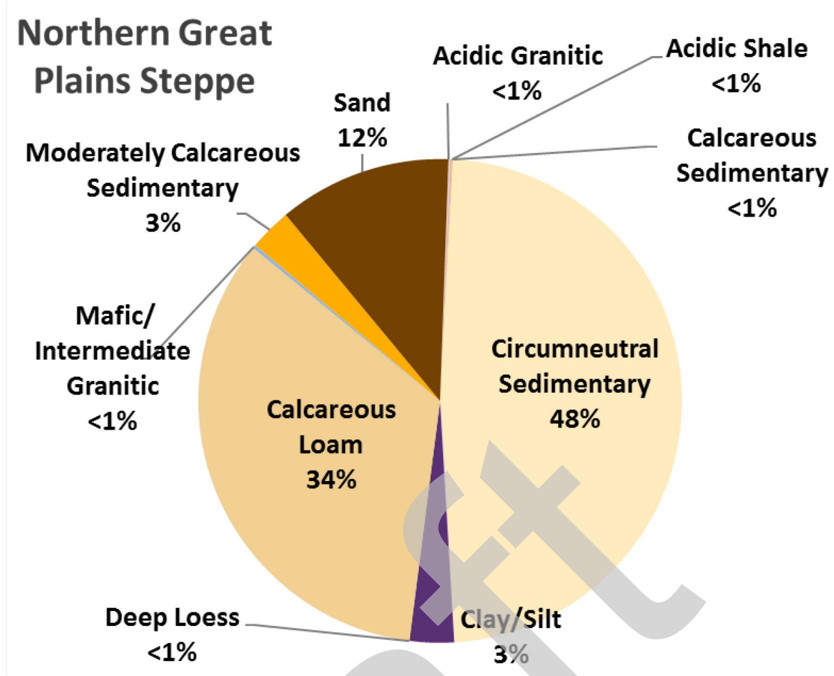
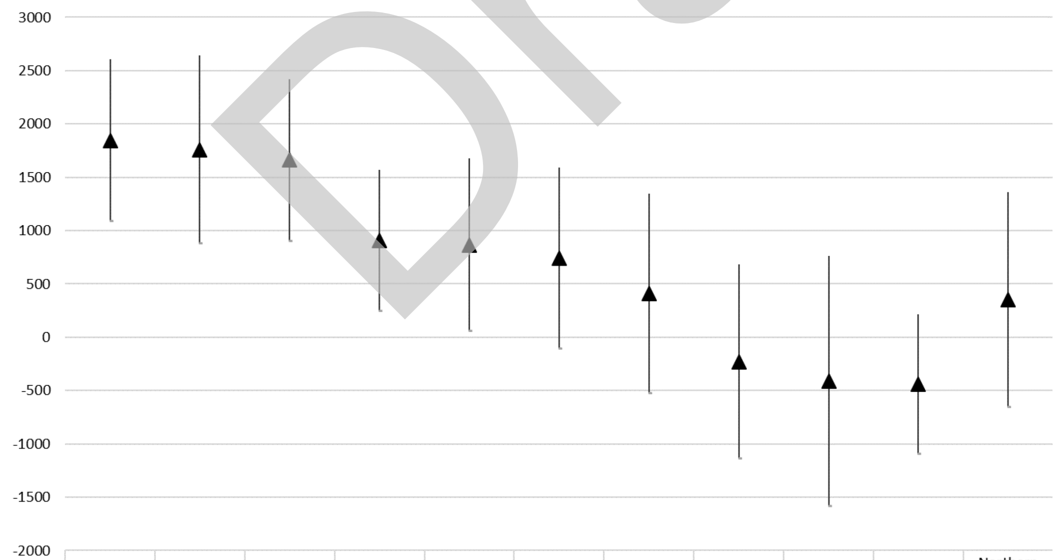


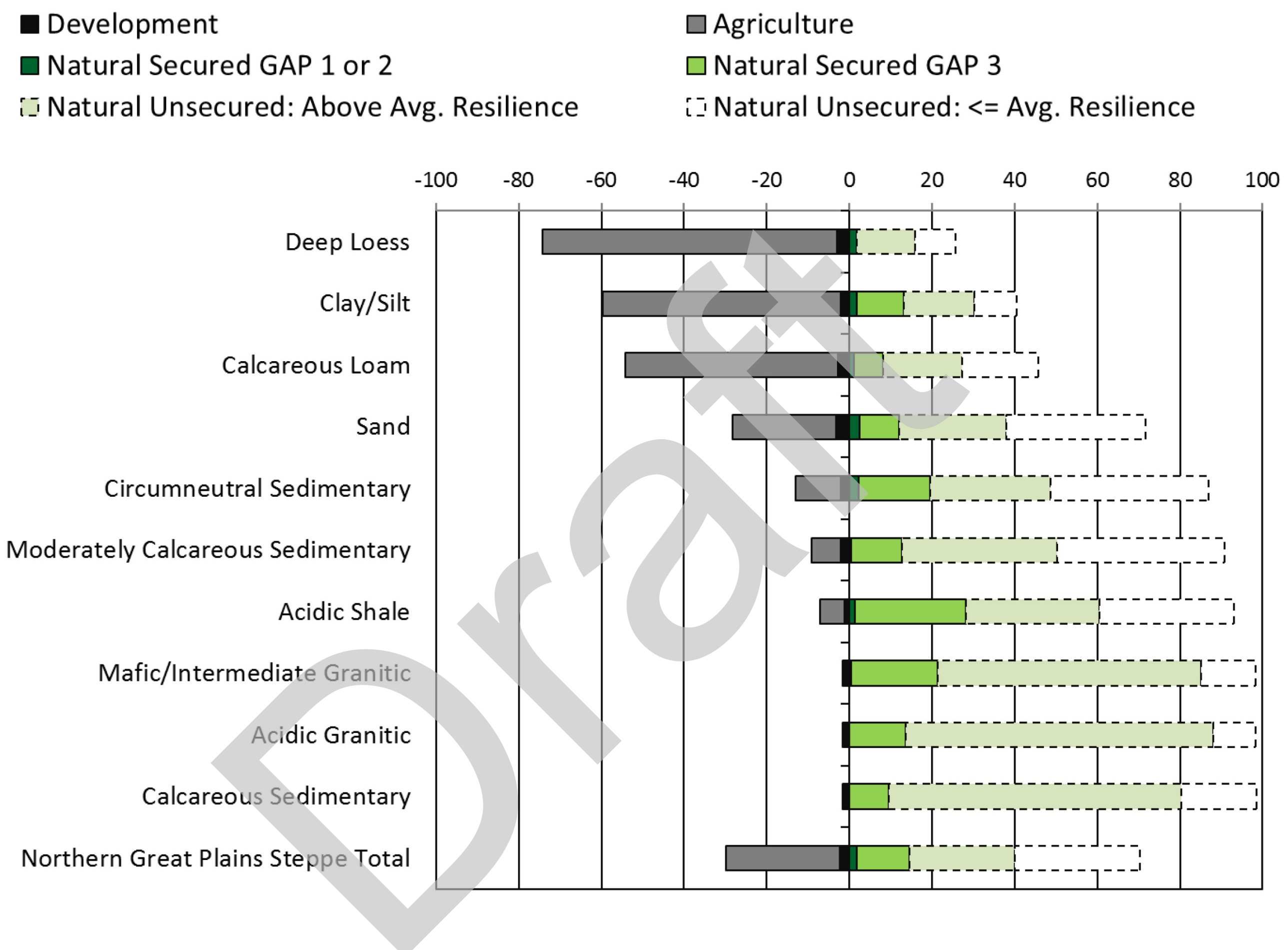
Figure 4.18: Northern Great Plains Steppe Geophysical Settings by Regional Resilience Score.



	Acidic Granitic	Calcareous Sedimentary	Mafic/Intermediate Granitic	Acidic Shale	Moderately Calcareous Sedimentary	Circumneutral Sedimentary	Sand	Calcareous Loam	Clay/Silt	Deep Loess	Northern Great Plains Steppes Ecoregion
Upper SD	2604	2640	2421	1572	1674	1590	1348	684	765	217	1357
▲MEAN	1846	1759	1662	907	867	741	411	-229	-410	-441	351
- Lower SD	1088	879	902	242	60	-108	-527	-1143	-1585	-1099	-656

Upper SD ▲MEAN - Lower SD

Figure 4.19: Conversion and Securement of the Northern Great Plains Steppe Ecoregion by Geophysical Setting. This ecoregion is 30% converted and 14.5% secured, a ratio of 2.1 to 1. Within this ecoregion, 26% of the land (39.2 million acres) is in natural landcover, scored above average for resilience, and is not currently secured.



Cypress Uplands

Cypress Hills Interprovincial Park. Photo credit: © Matthew Braun/Nature Conservancy of Canada

This ecoregion description was adapted from [A Conservation Blueprint for Canada's Prairies and Parklands] (Riley et al. 2007) and Shorthouse et al. (2010).

Embedded within the northern portion of the Northern Great Plains Steppe, the Cypress Uplands ecoregion defines a set of high elevation outliers – a set of three hills, one in Alberta, and two in Saskatchewan. These hills rise almost 2000′ (600 m) above the plains, reaching a maximum elevation of 4800′ (1465 m) on the west side, and are characterized by steeply sloping escarpments and numerous valleys. These peaks formed during the Tertiary period, and were not glaciated during the last Ice Age. They formed through millions of years of sedimentary deposition and erosion, and are defined as an erosional plateau. These higher elevations promote cooler temperatures and increased precipitation, which favors forests over prairie vegetation.

The ecoregion name comes from "cyprès," a term used by French Canadians and Métis to describe dominant conifers in the region, such as jack and lodgepole pine, and white spruce (Shorthouse et al. 2010). In addition to conifer forests this rugged terrain supports stands of aspen and balsam poplar, freshwater streams, fescue grasslands, fresh and saline marshes, meadows, and lakes. Patches of fescue grasslands, a rare ecosystem type, occur at the highest elevations, and are isolated from similar systems that occur farther west in the Rocky Mountain foothills. With this range of topography and microclimates, the Cypress Uplands supports a wide range of biodiversity, including 18 species of orchids, that is not found in the surrounding prairies.

Overall, the rocky soils have contributed to this ecoregion much less converted than other Canadian sections of the study region. Ranching, which is often compatible with sustaining grassland diversity, is a common land use. There is some oil and gas development, but this is less widespread than in neighboring areas. The Cypress Hills Interprovincial Park (shown above) is Canada's only Interprovincial Park, and include 50,500 acres (204.51 km^2) of the ecoregion.

Figure 4.20: Cypress Uplands Geophysical Settings.

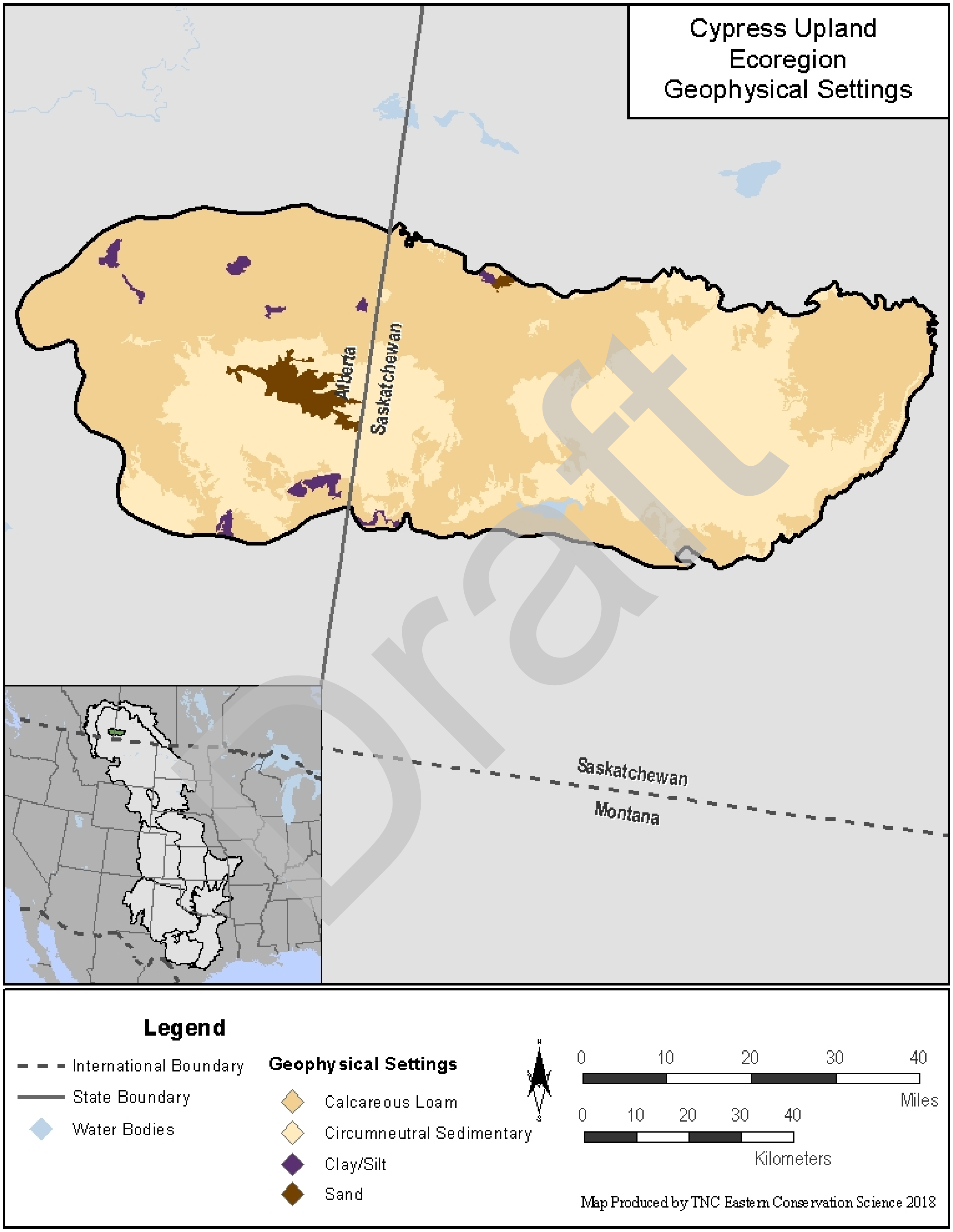


Figure 4.21: Cypress Uplands Landscape Diversity.

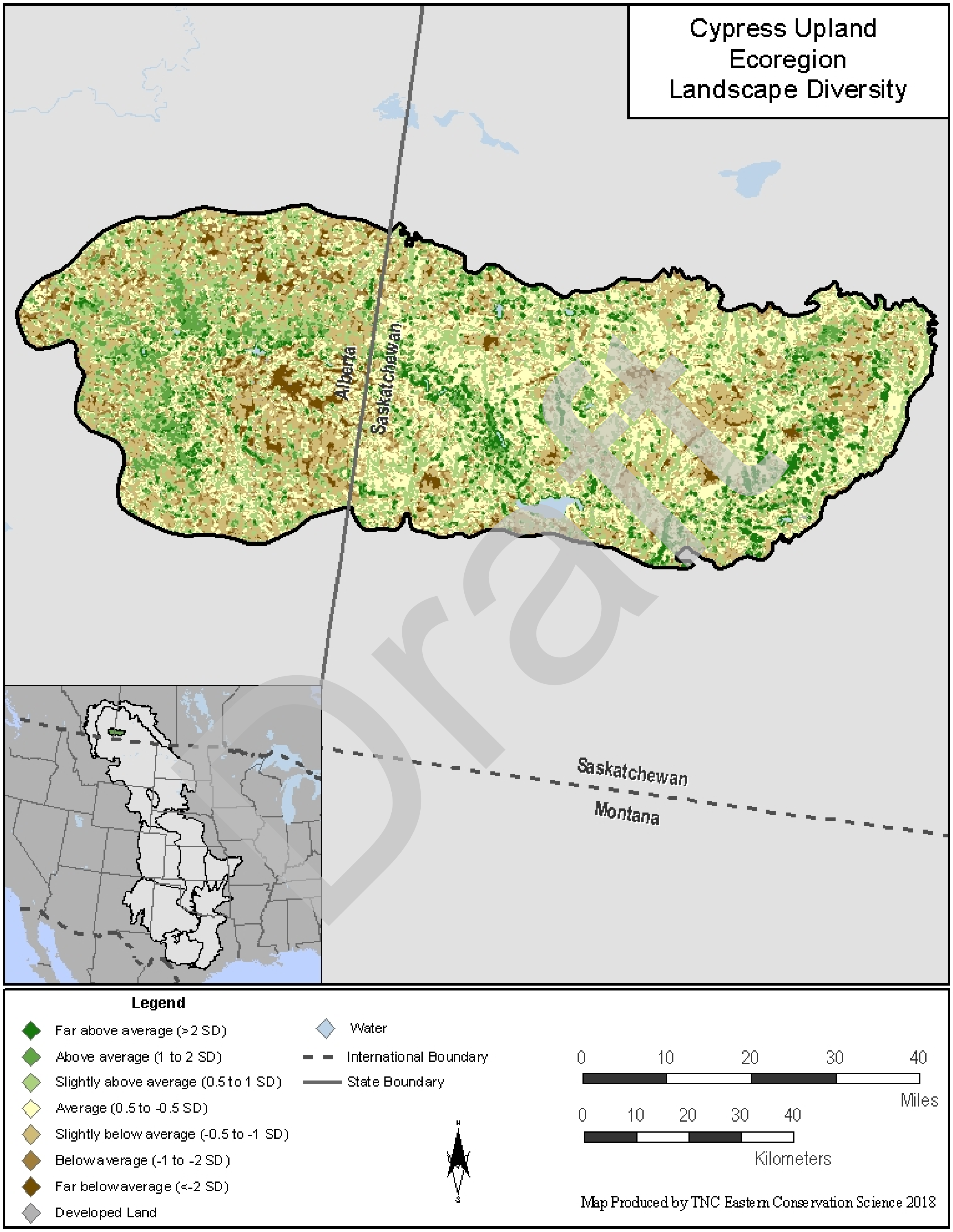


Figure 4.22: Cypress Uplands Local Connectedness.

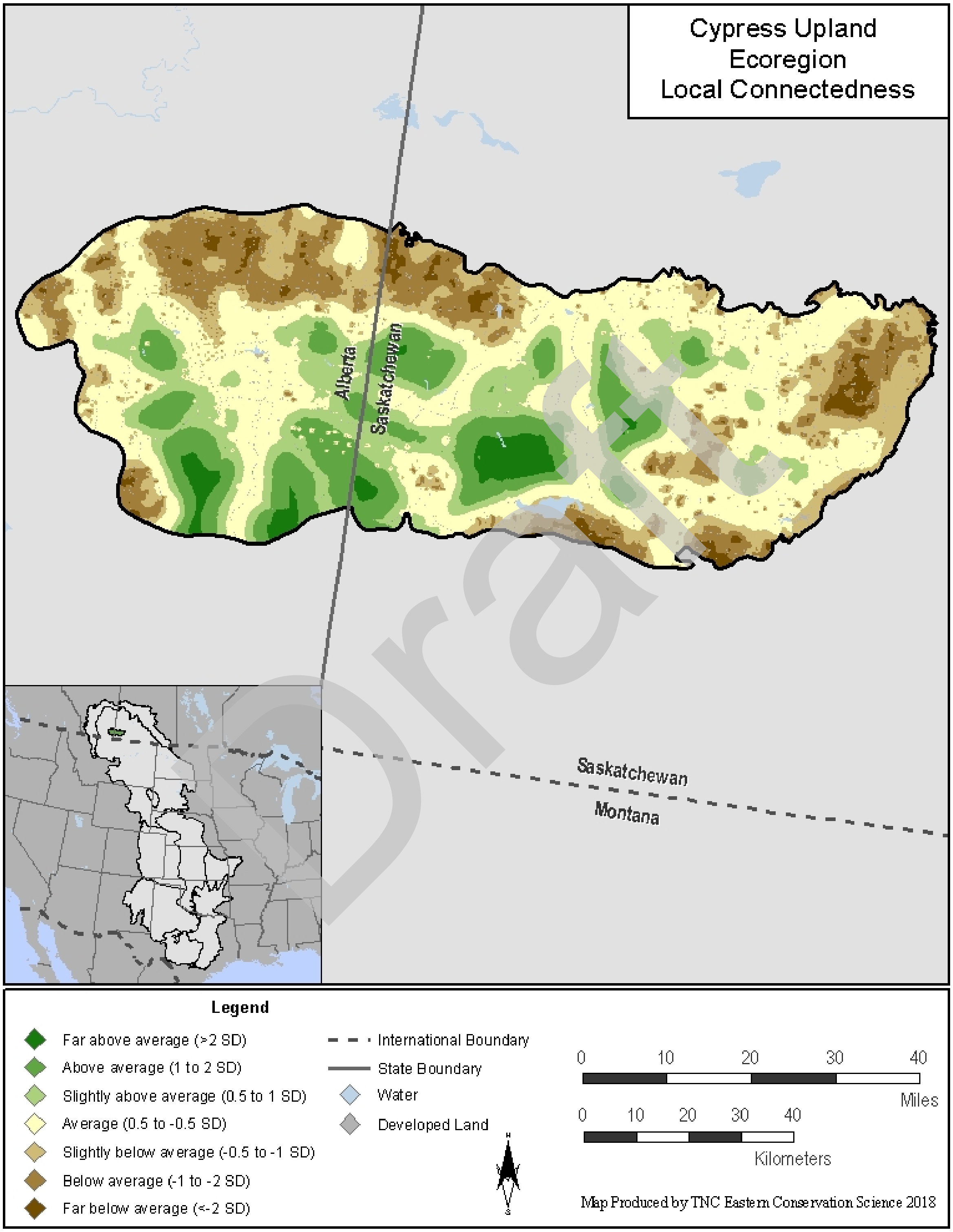


Figure 4.23: Cypress Uplands Site Resilience Scores.

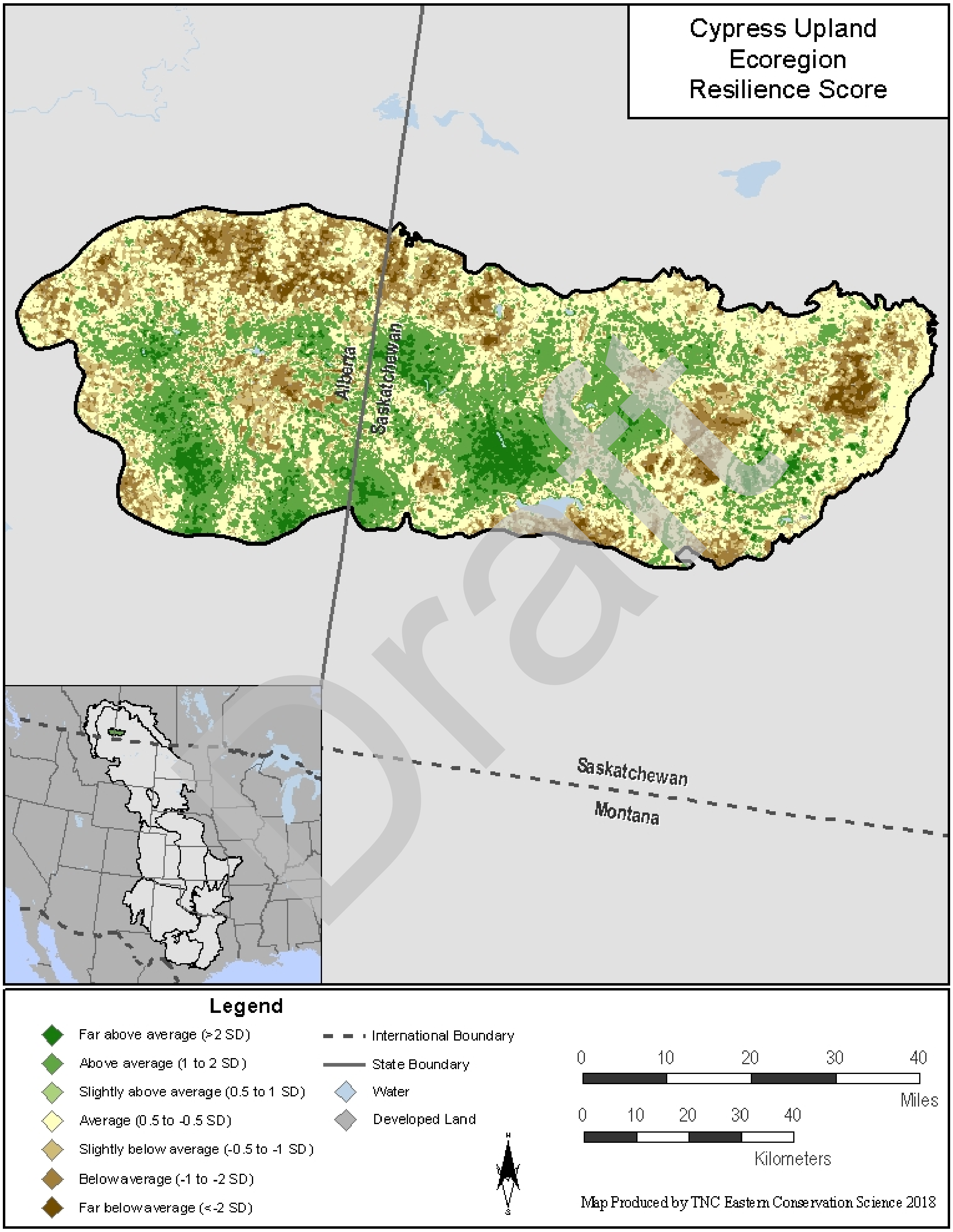


Figure 4.24: Highest Resilience Score Areas for Each Geophysical Setting Within the Cypress Uplands Ecoregion.

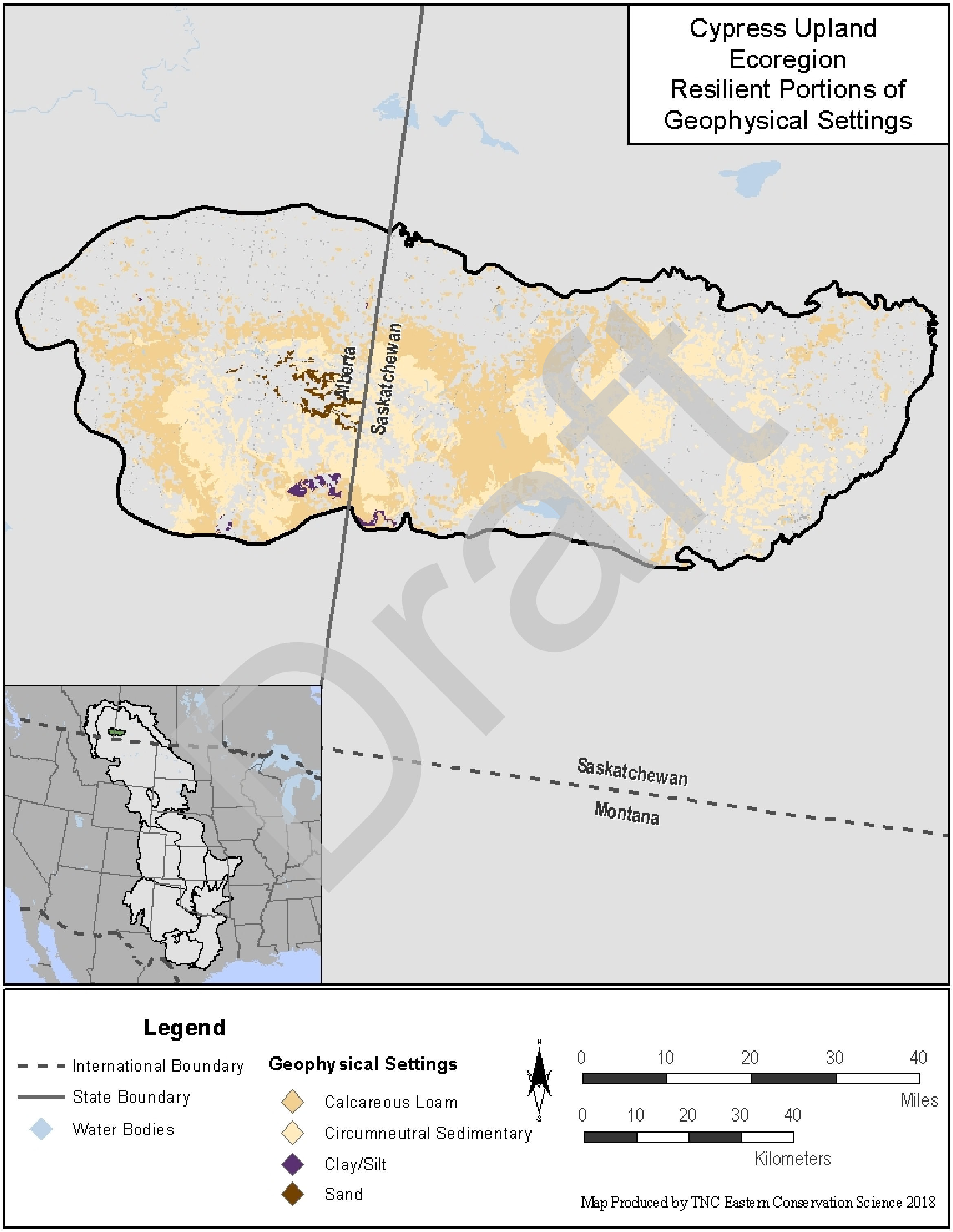


Figure 4.25: Cypress Uplands Geophysical Settings – Proportions by Area.

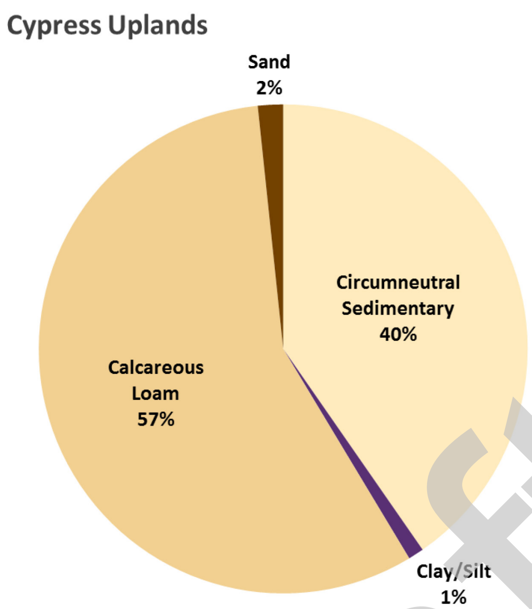
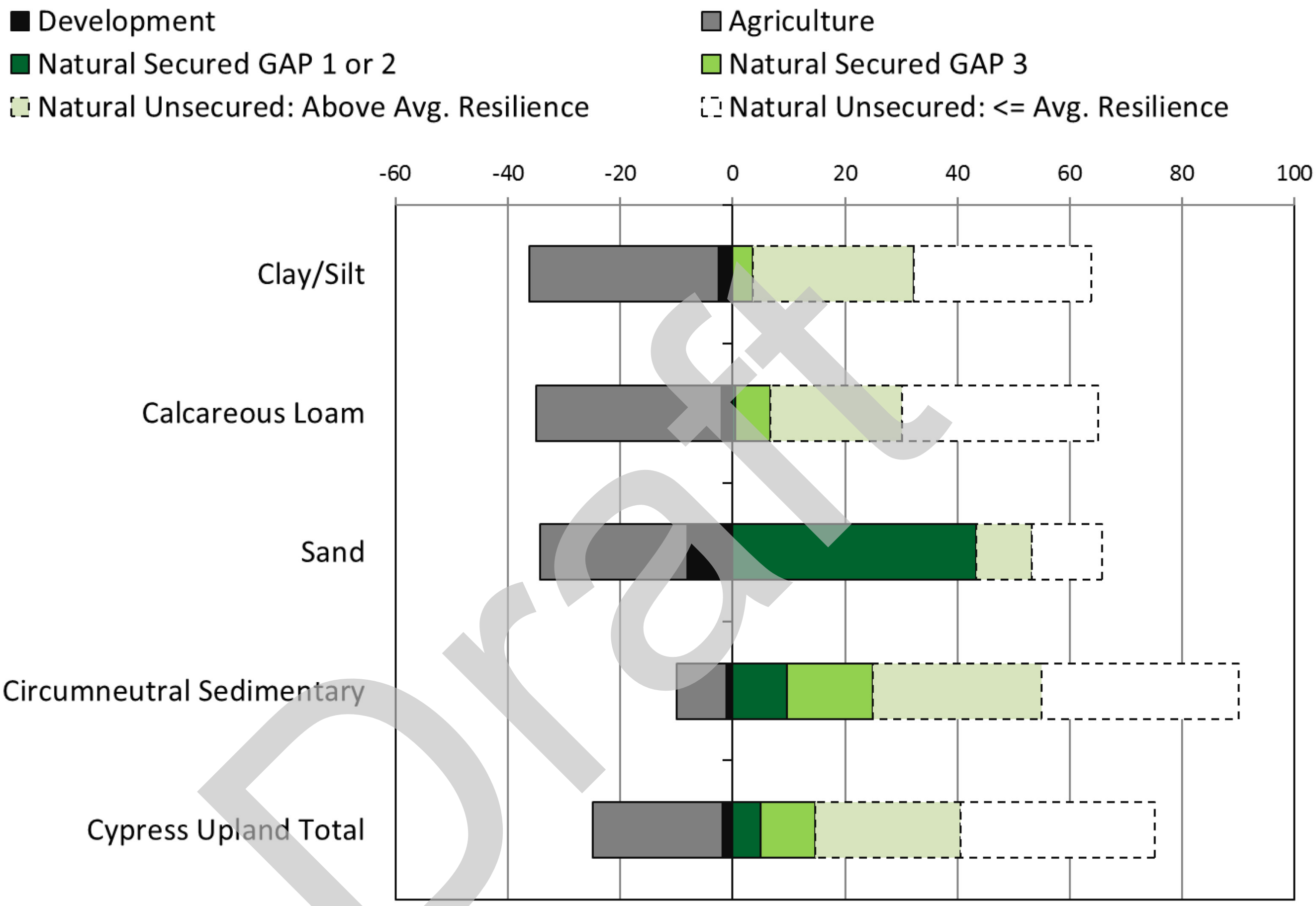


Figure 4.26: Cypress Uplands Geophysical Settings by Regional Resilience Score.

	Circumneutral Sedimentary	Calcareous Loam	Clay/Silt	Sand	Cypress Uplands Ecoregion
Upper SD	1582	1392	1370	1033	1487
▲ MEAN	927	577	509	450	716
- Lower SD	272	-238	-352	-132	-55

Upper SD ▲ MEAN - Lower SD

Figure 4.27: Conversion and Securement of the Cypress Uplands Ecoregion by Geophysical Setting. This ecoregion is 25% converted and 15% secured, a ratio of 1.7 to 1. Within this ecoregion, 26% of the land (525,000 acres) is in natural landcover, scored above average for resilience, and currently unsecured.



This ecoregion description was adapted from Ecoregional Conservation in the Black Hills (Hall et al. 2002), and Epstein & Doctor (2013).

The Black Hills ecoregion is an isolated high elevation area embedded in the Northern Great Plains Steppe ecoregion in northeastern Wyoming and western South Dakota. This small ecoregion delineates a zone of rugged mountains that extend up to 4242 ft. (1300m) above the plains, reaching a peak elevation of 7,242 ft. (2200m).

The Black Hills uplift was part of the mountain building episodes that created the Rocky Mountain ranges beginning in the early Tertiary. It is a rounded mountain range with a series of different geomorphic regions arranged concentrically around the oldest center region. The central core is the highest elevation area, and consists of granitic and metamorphic rock. This is surrounded by a limestone plateau, and then by a zone of moderately calcareous foothills and plains. Geophysical settings in these lower elevation areas include the "Red Valley" zone, a collection of red sandstones and siltstones with gypsum outcrops. Dissolution of the evaporite-karst features that comprise the surface and subsurface features has produced sinkholes, caves, springs, and breccia pipes. The outer geomorphic zone, called the Hogback Rim, is dominated by sandstones, siltstones, and shales, which form prominent hogbacks on the southern and eastern sides, and more gentle ridges and canyons to the northwest.

"Black Hills" refers to the contrasting color of ponderosa pines relative to prairie grasses, and while ponderosa pines dominate, hardwoods like aspen occur on the uplands, bur oaks are common at lower elevations, and ash, boxelder, and elms are found in riparian areas. Mixed grass prairies can be extensive in lower elevation areas, and saline and alkaline wetlands and wet meadows are common in the foothills. The variety of different types of rock outcrops also provide important habitats, i.e., for limestone-associated rare species, or gypsum specialists. In contrast to the rest of our study area, only 52% percent of the region is private land, with over 40% of the region in public ownership, mostly by the US Forest Service.

Figure 4.28: Black Hills Geophysical Settings.

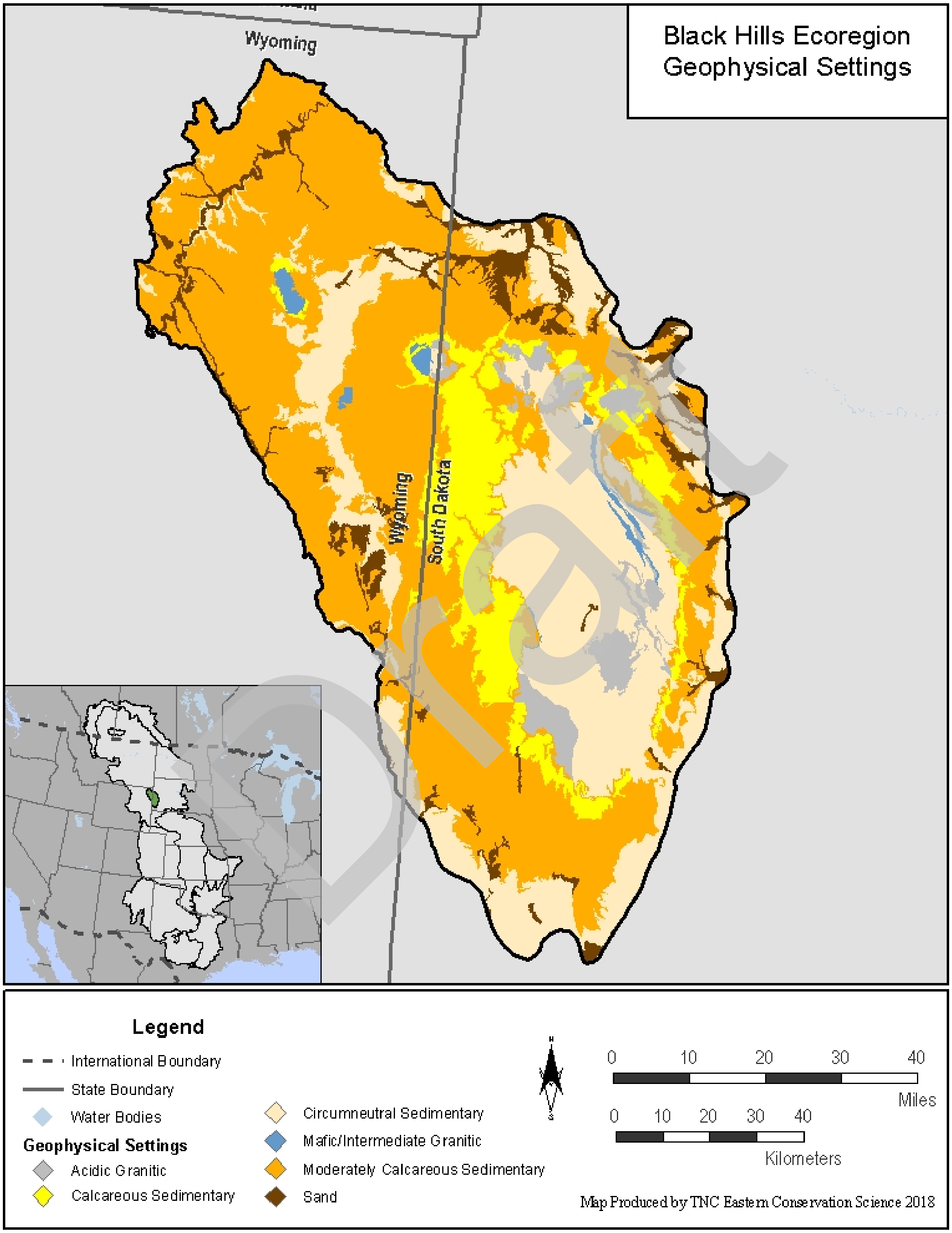


Figure 4.29: Black Hills Landscape Diversity.

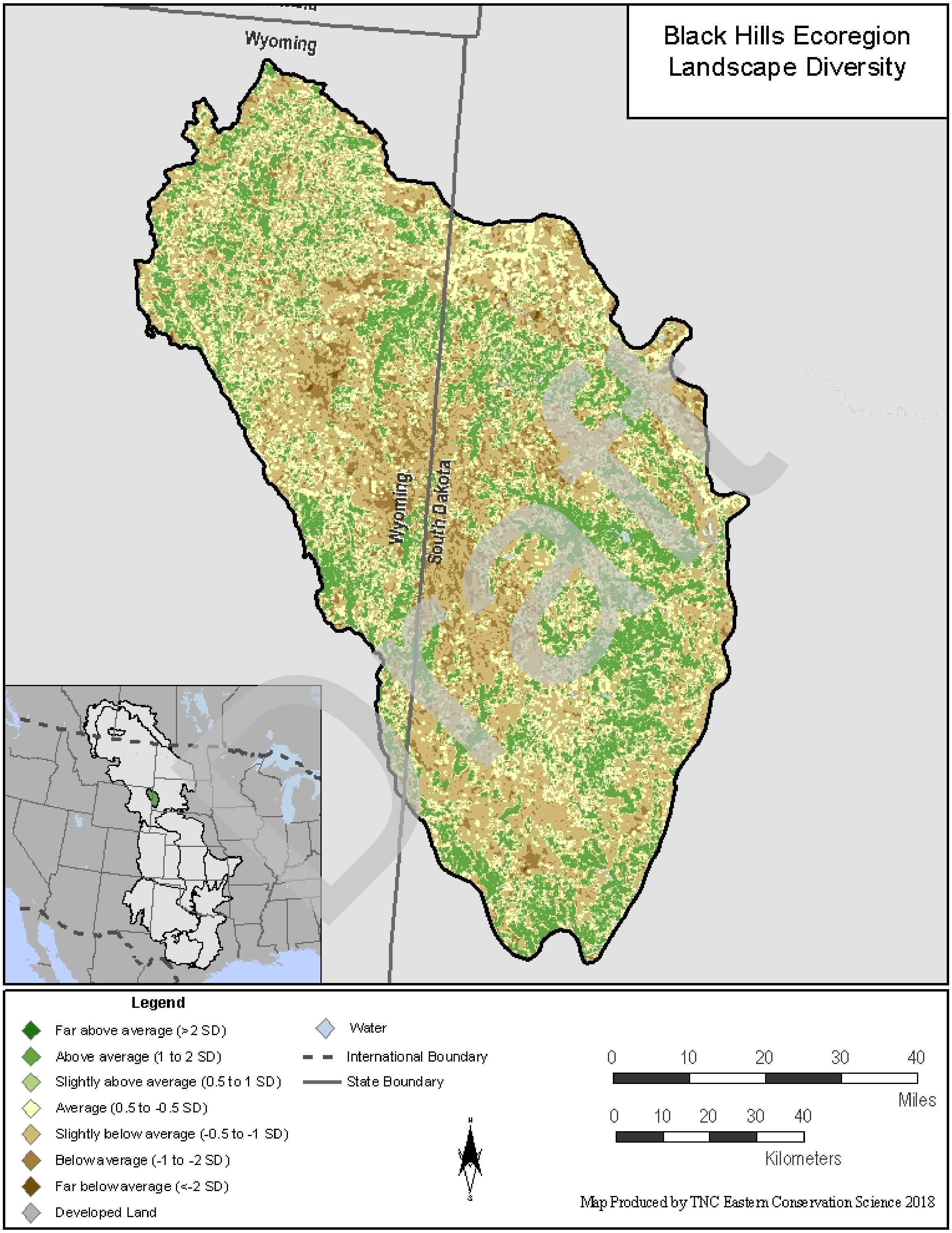


Figure 4.30: Black Hills Local Connectedness.

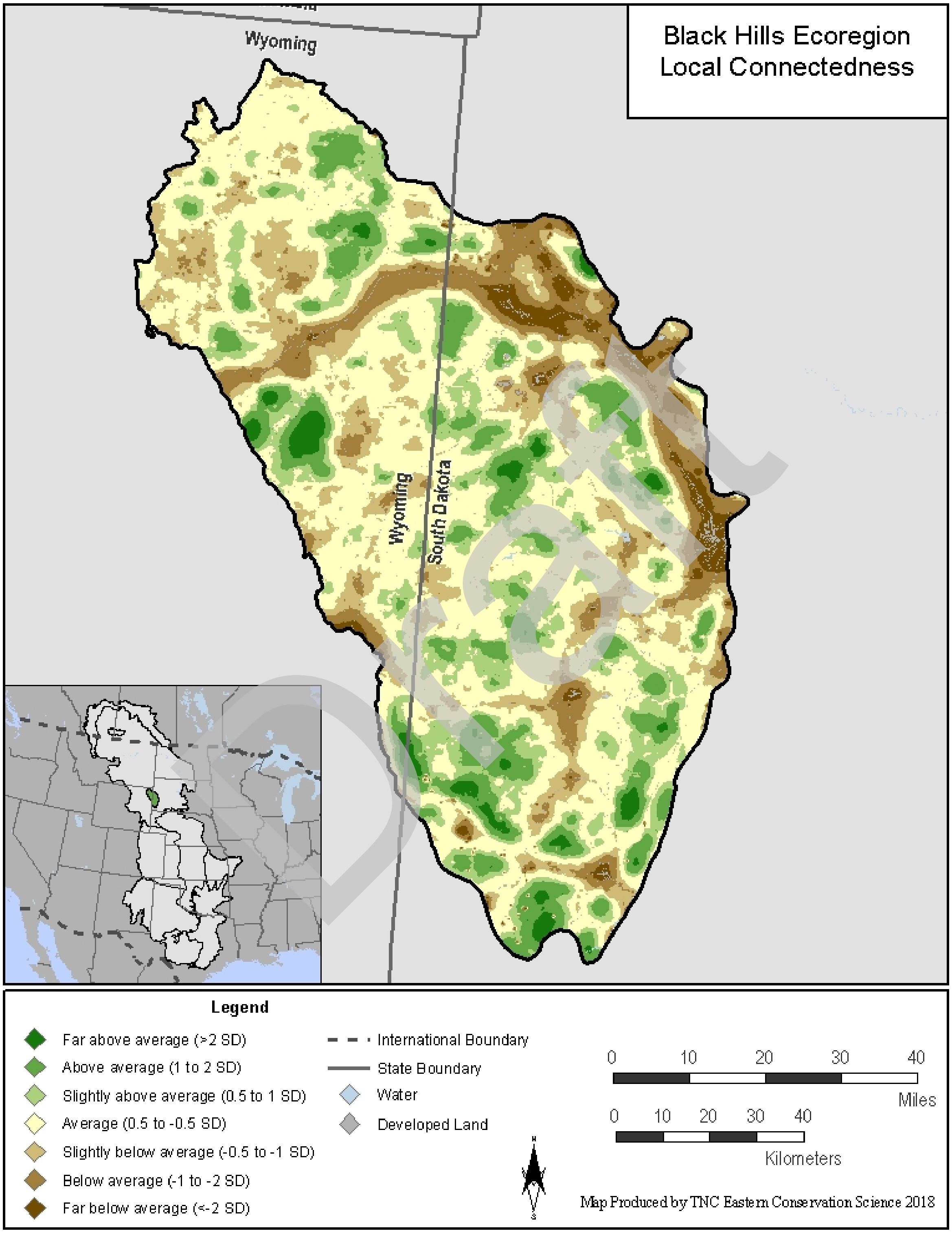


Figure 4.31: Black Hills Site Resilience Scores.

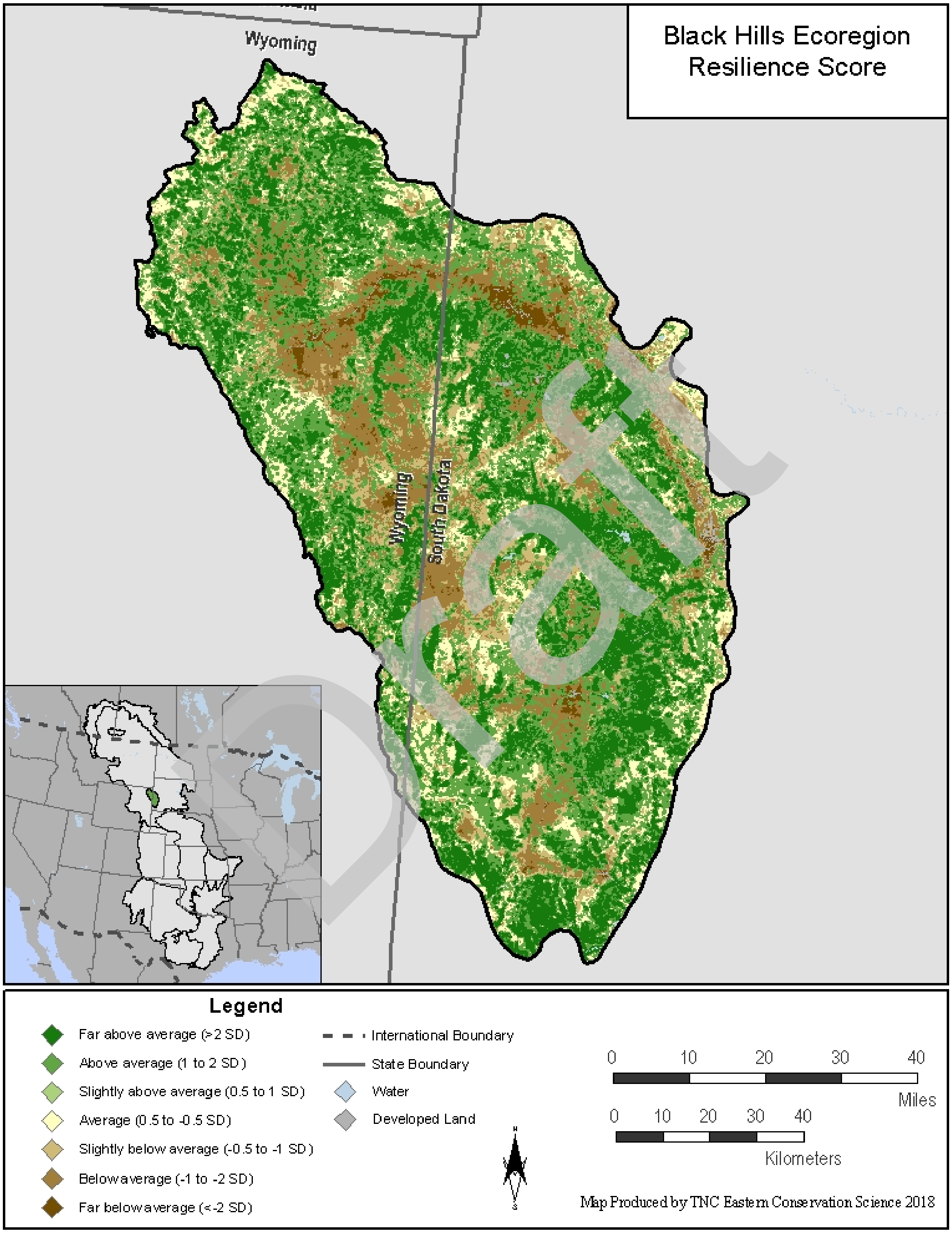


Figure 4.32: Highest Resilience Score Areas for Each Geophysical Setting Within the Black Hills.

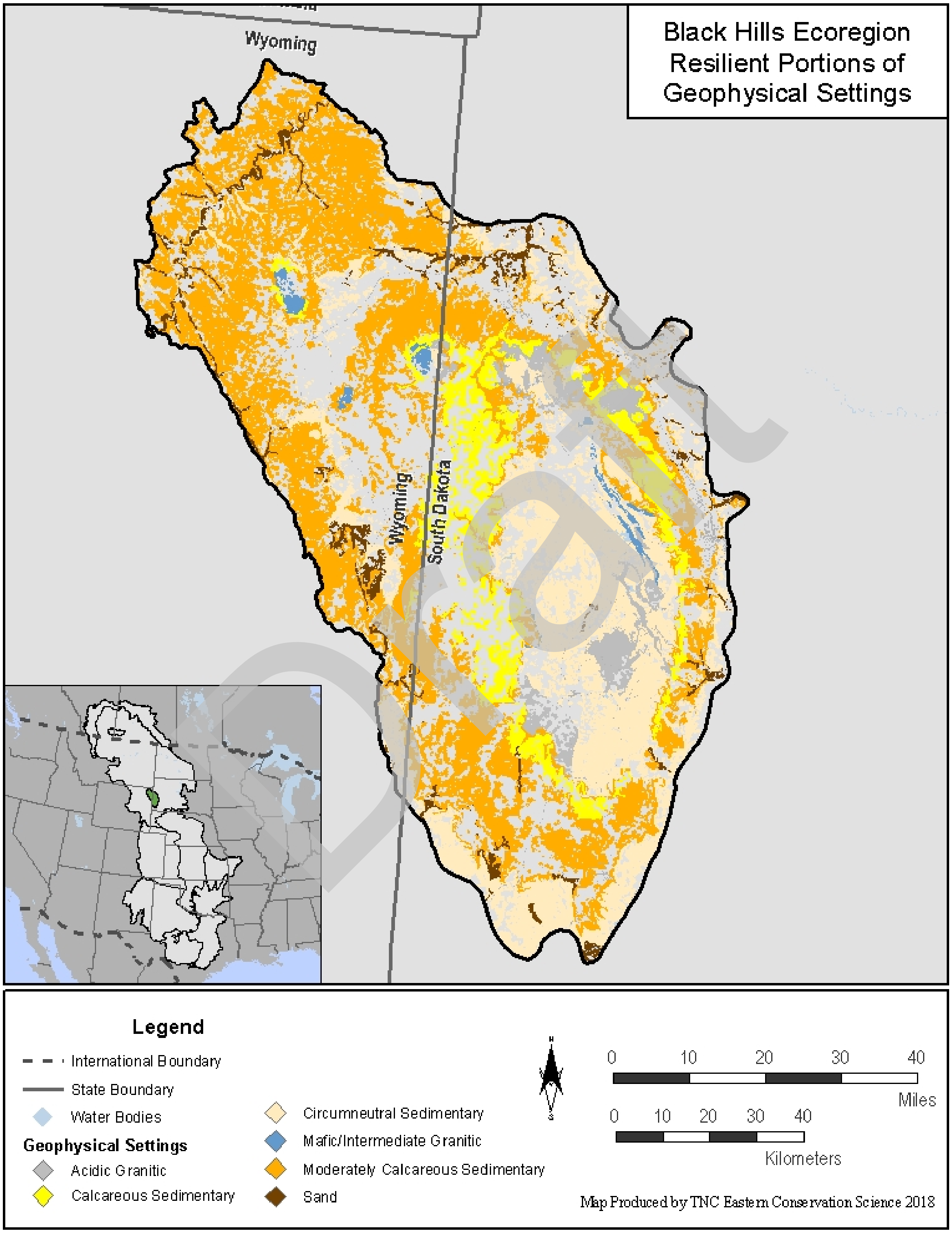


Figure 4.33: Black Hills Geophysical Settings – Proportions by Area.

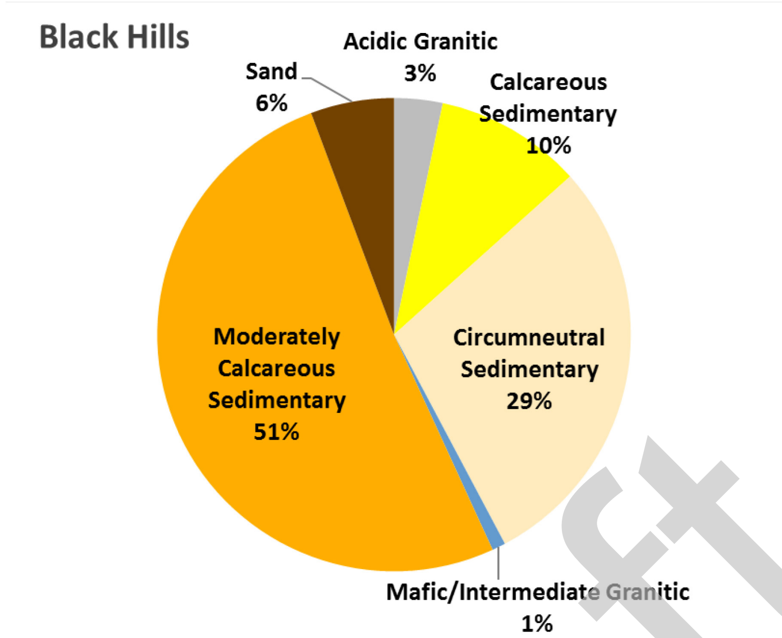
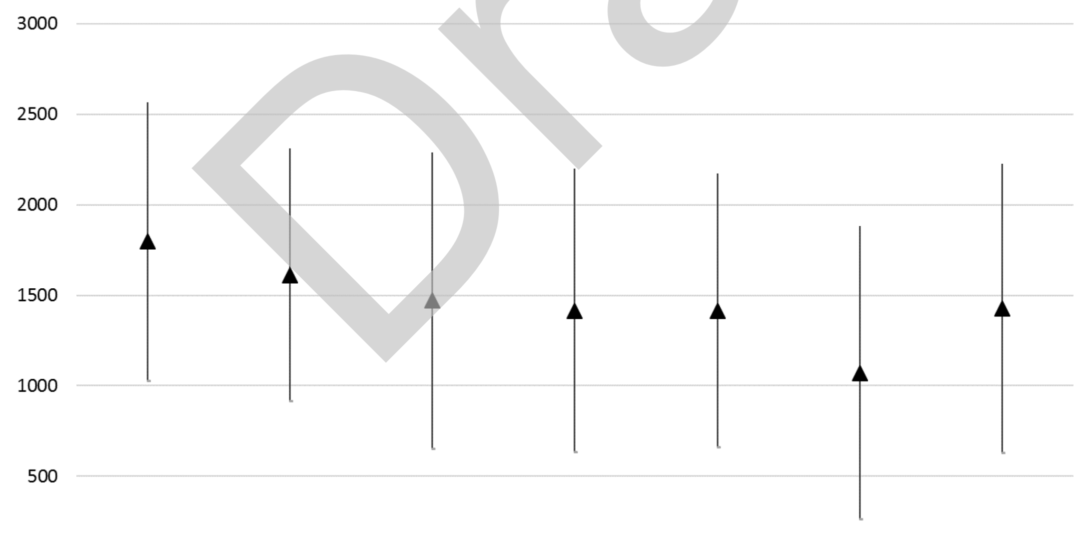


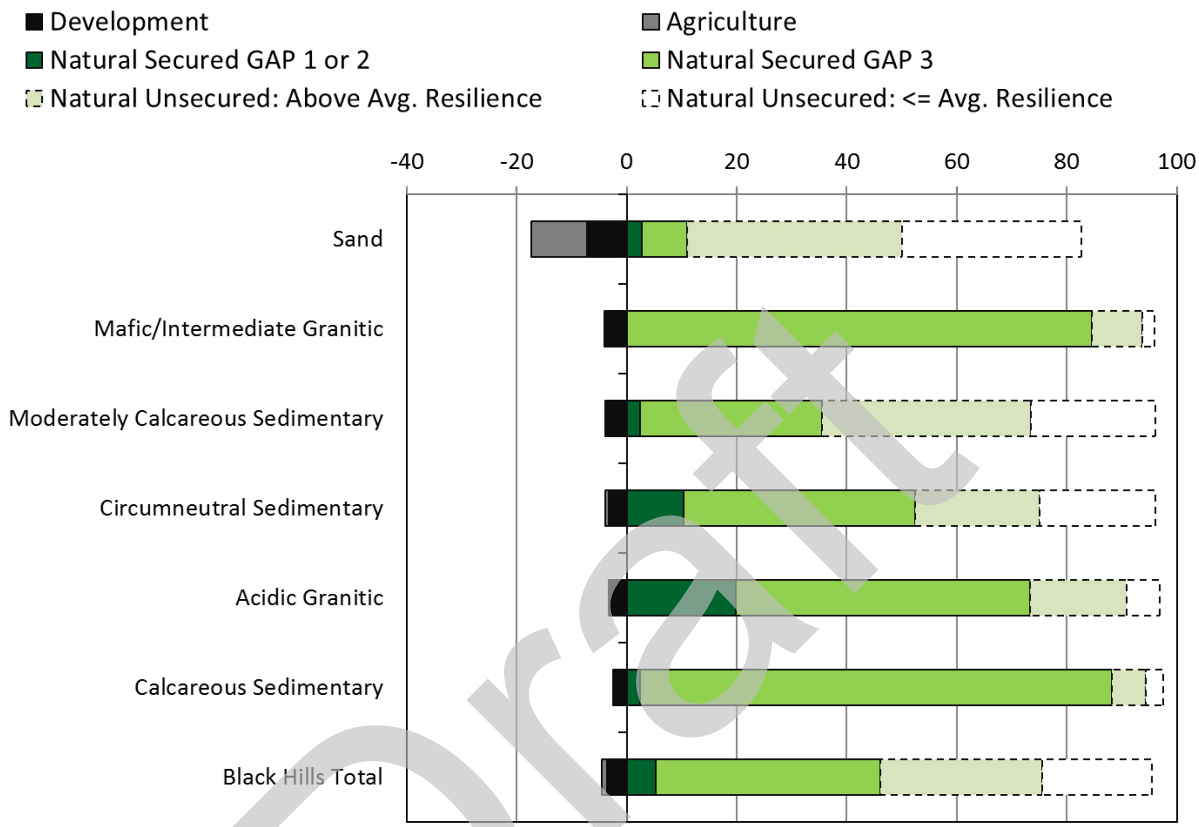
Figure 4.34: Black Hills Geophysical Settings by Regional Resilience Score.



	Acidic Granitic	Mafic/Intermed iate Granitic	Circumneutral Sedimentary	Moderately Calcareous Sedimentary	Calcareous Sedimentary	Sand	Black Hills Ecoregion
Upper SD	2568	2312	2290	2198	2173	1880	2226
▲ MEAN	1797	1612	1470	1415	1414	1070	1426
- Lower SD	1026	912	651	631	656	259	626

Upper SD ▲ MEAN - Lower SD

Figure 4.35: Conversion and Securement of the Black Hills Ecoregion by Setting. This ecoregion is 4.5% converted and 46% secured, a ratio of 0.1 to 1. Within this ecoregion, 30% of the land (958,000 acres) is in natural landcover, scored above average for resilience, and is currently unsecured.



Central Mixed-Grass Prairie

TNC's Niobrara Valley Preserve, NE. Photo credit: ©Chris Helzer

This description was adapted from Conserving the Biological Diversity of the Central Mixed-Grass Prairie: A Portfolio Designed for Conservation Action (Steuter et al. 2003).

The Central Mixed-Grass Prairie ecoregion occurs in a transition zone between tallgrass prairies to the east, and the more arid steppe and shortgrass ecoregions to the west. The dominant geophysical settings are loess, alluvial sands, and Permian shale. The northern end is dominated by the Nebraska Sandhills, a relatively mesic zone of deep sand deposits that shift over time with the wind. The center is characterized by the fertile loess plains of Kansas. Mixed alluvial plains occur along east-west river valleys such as the Niobrara at the northern edge, and the Platte, Republican, Arkansas, and Canadian further south. At the southern end in Oklahoma, soils have developed on Permian shales and sandstones, with isolated scarps and bedrock outcrops, and areas with "redbed" clays, and rugged gypsum hills and caves. The climate is semi-arid, with high seasonal and annual variability.

Historically, the dominant vegetation consisted of a mosaic of mixed-grass prairie, sand prairie, and tallgrass prairie (on loamy soils), with highly dynamic patterns of structure and species composition due to large-scale disturbance from a diverse and abundant set of mammalian grazers & browsers. Sand sage shrublands, oak woodlands, and gypsum-associated species such as mesquite, junipers, and salt-tolerant grasses and meadow associations add diversity to the region. While semi-arid, the region supports expansive wetland complexes, especially in the Sandhills, and many important riparian habitats. Today, mesquite and eastern redcedar have invaded some areas formerly dominated by mixed-grass prairie, likely due to fire suppression.

Nearly all (over 98%) of this ecoregion is privately owned and managed, with much of this land, especially the loess soils in the center of the region, in production agriculture. The ecoregional plan described only two "functional" landscapes, the Nebraska Sandhills Prairie (sand prairie, sand sage, wetlands), and the Red Hills region of Kansas and Oklahoma (mixed-grass prairie, Western Gypsum and Redbed Clay Prairie).

Figure 4.36: Central Mixed-Grass Prairie Geophysical Settings.

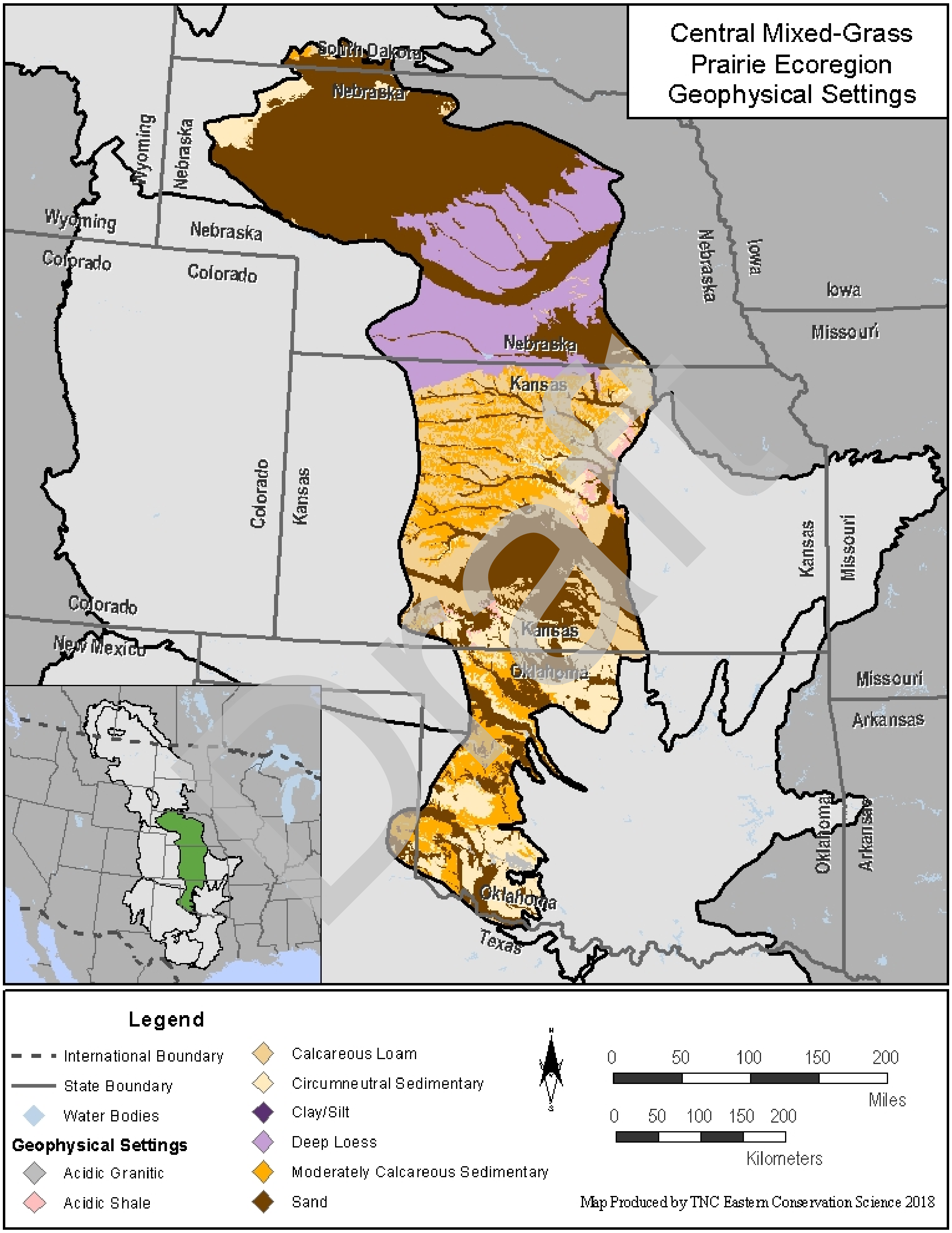


Figure 4.37: Central Mixed-Grass Prairie Landscape Diversity.

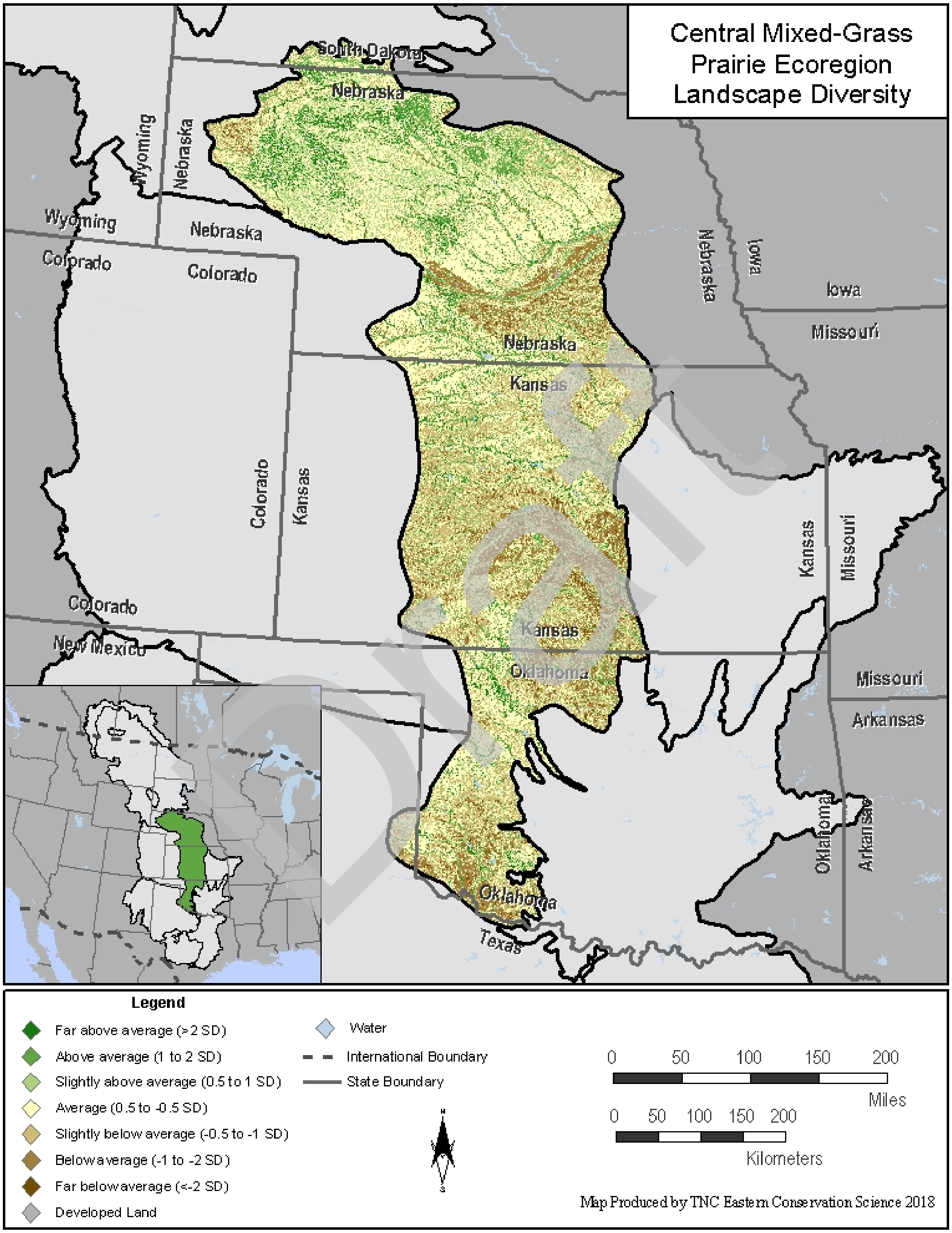


Figure 4.38: Central Mixed-Grass Prairie Local Connectedness.

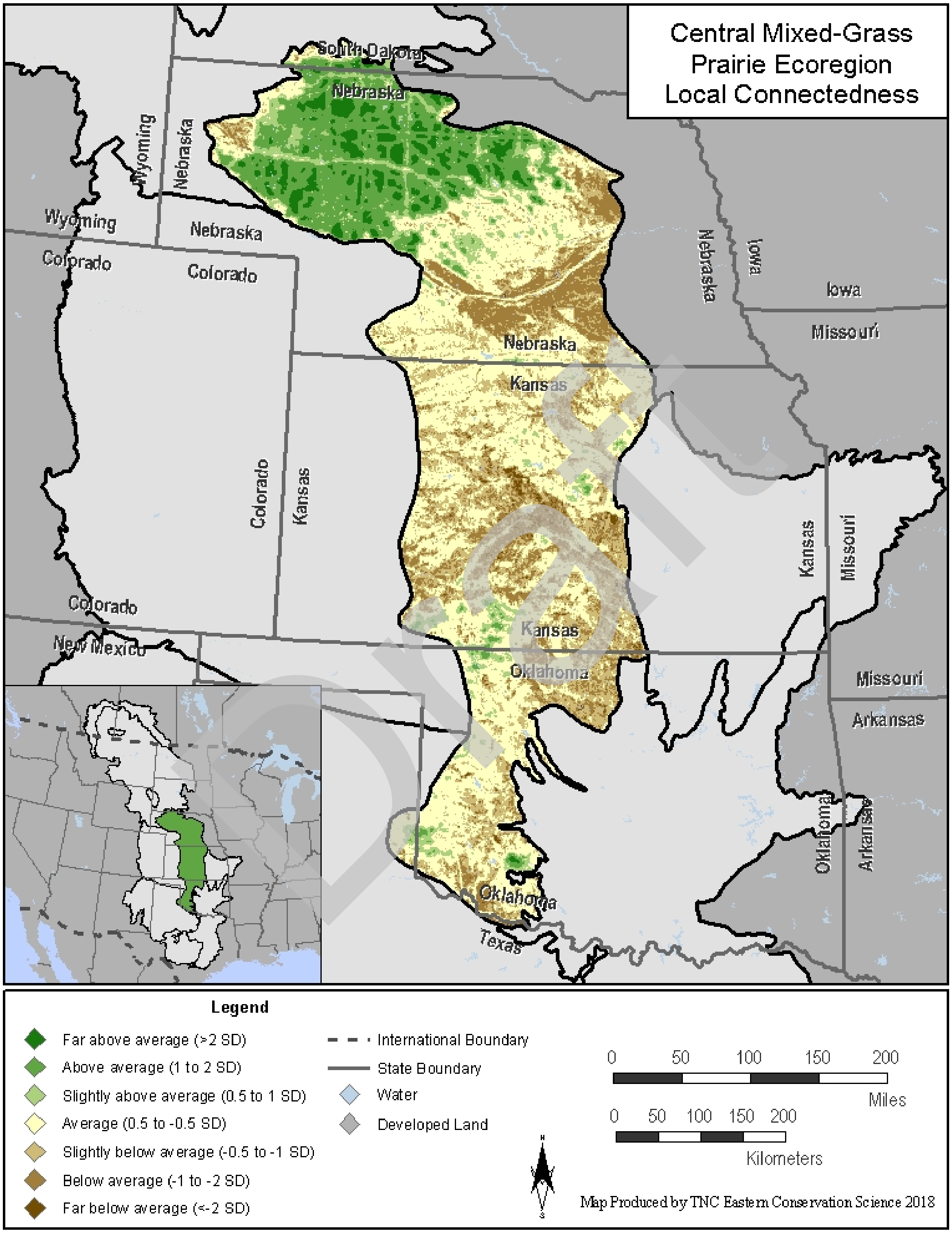


Figure 4.39: Central Mixed-Grass Prairie Site Resilience Scores.

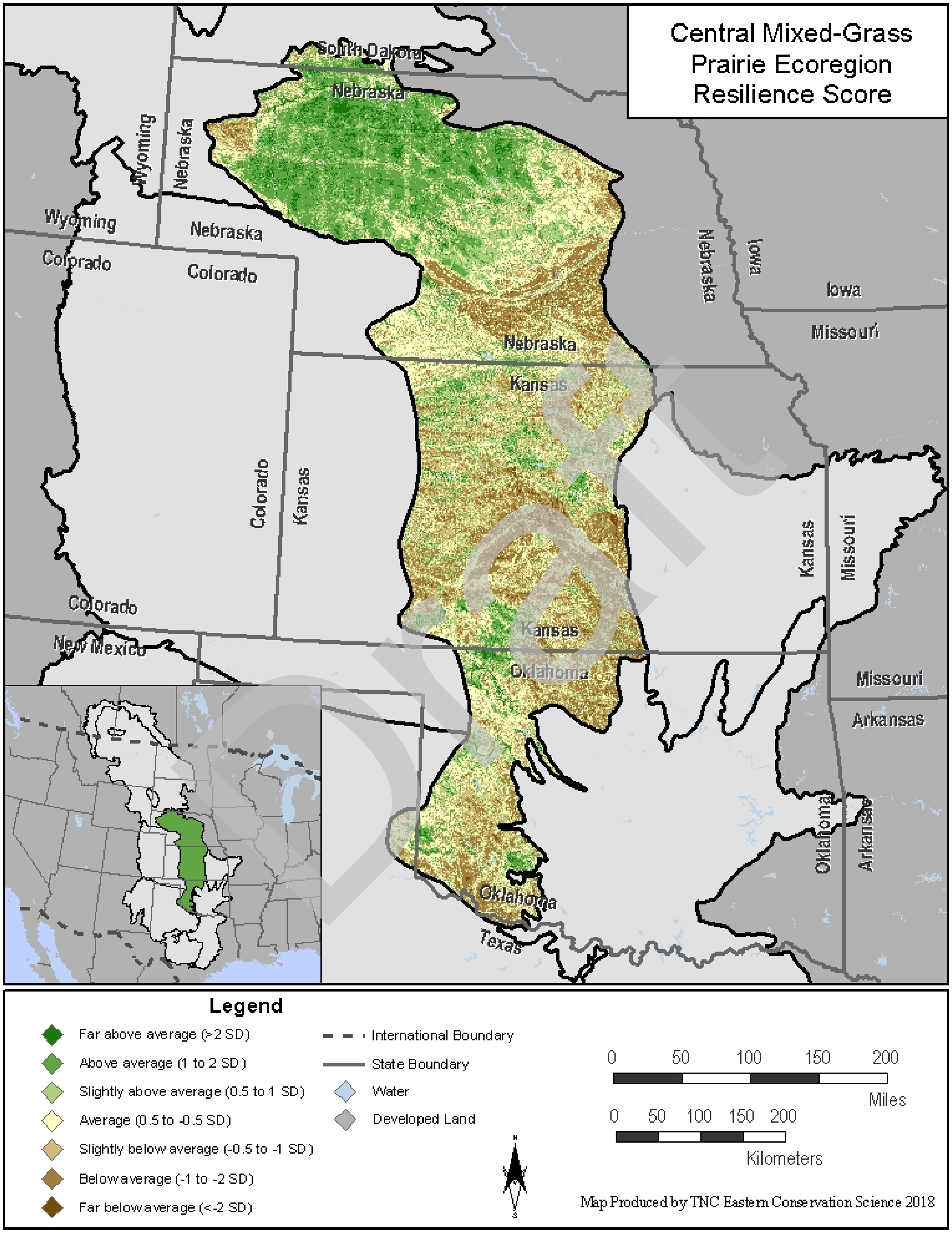


Figure 4.40: Highest Resilience Score Areas for Each Geophysical Setting Within the Central Mixed-Grass Prairie Ecoregion.

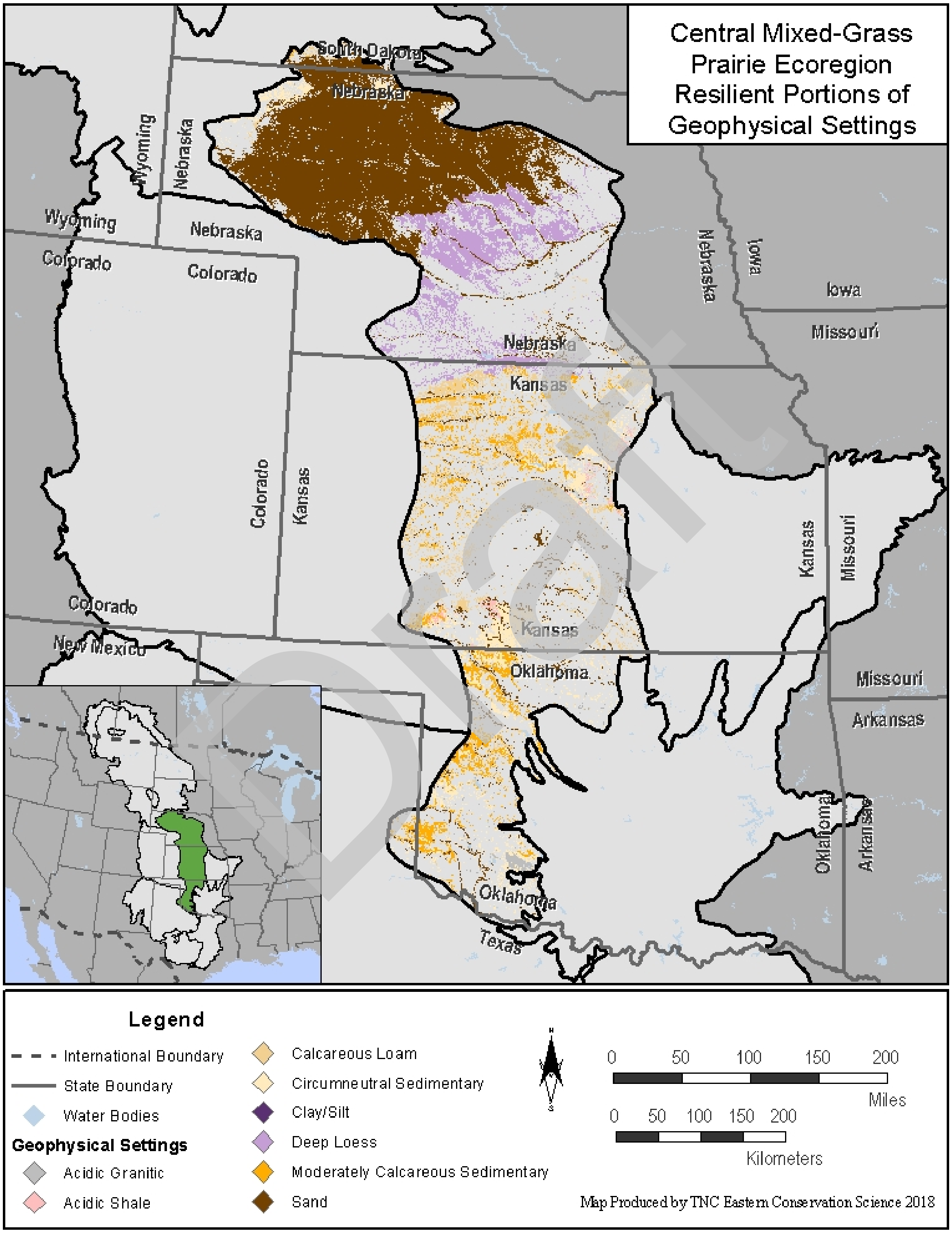


Figure 4.41: Central Mixed-Grass Prairie Geophyical Settings – Proportions by Area.

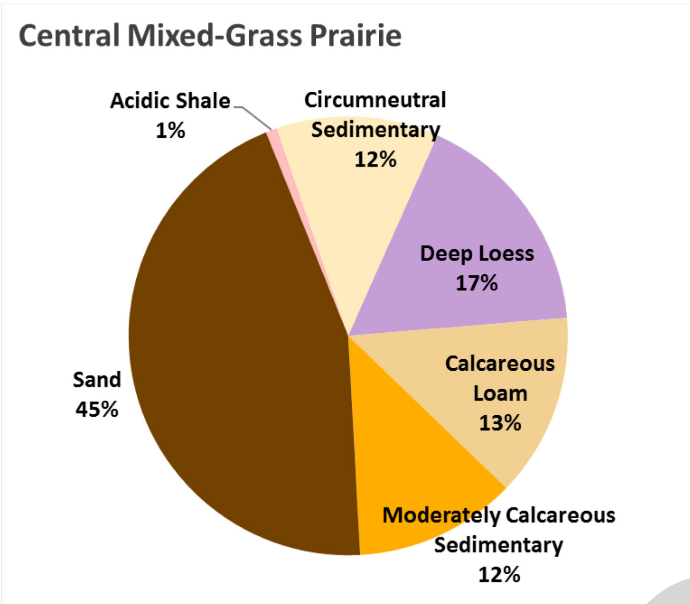
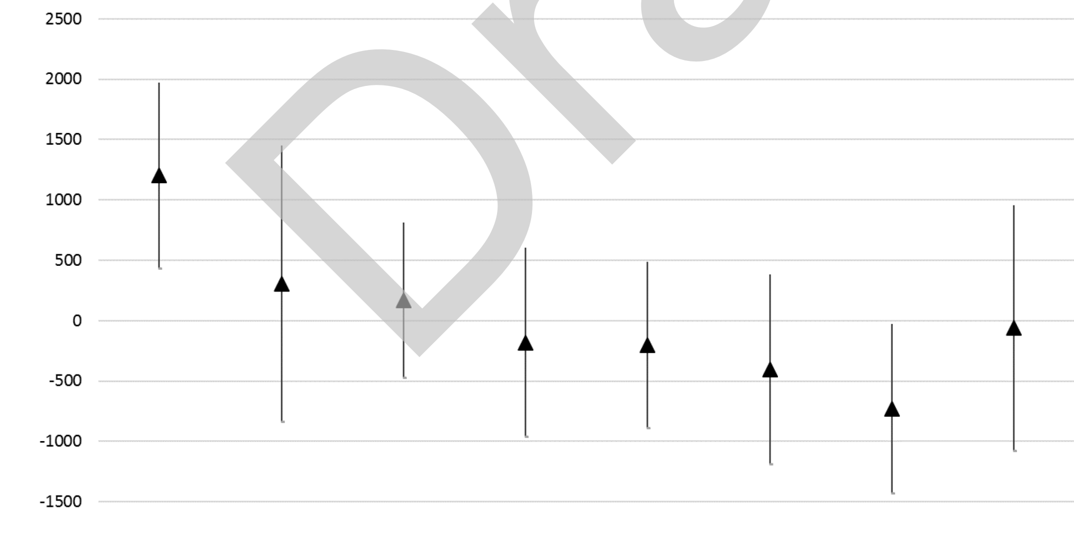


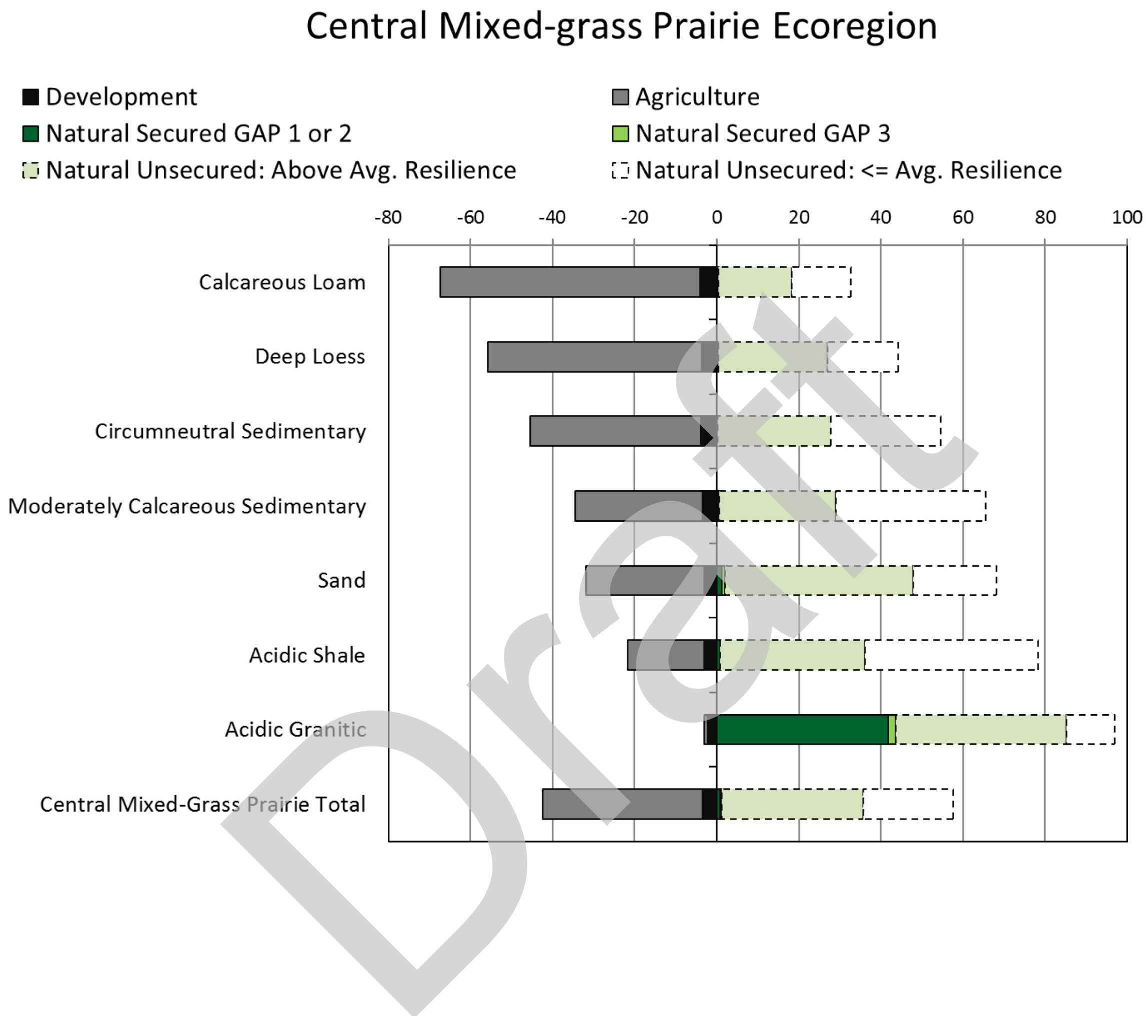
Figure 4.42: Central Mixed-Grass Prairie Geophysical Settings by Regional Resilience Score.



	Acidic Granitic	Sand	Acidic Shale	Deep Loess	Moderately Calcareous Sedimentary	Circumneutral Sedimentary	Calcareous Loam	Central Mixed-Grass Prairies Ecoregion
Upper SD	1969	1448	811	604	488	385	-25	955
▲ MEAN	1200	302	166	-181	-204	-406	-729	-63
- Lower SD	431	-844	-480	-967	-896	-1196	-1433	-1081

Upper SD ▲ MEAN - Lower SD

Figure 4.43: Conversion and Securement of the Central Mixed-grass Prairie Ecoregion by Geophysical Setting. This ecoregion is 43% converted and 1.3% secured, a ratio of 33 to 1. Within this ecoregion, 34 % of the land (20.1 million acres) is in natural landcover, scored above average for resilience, and is not currently secured.



Central Shortgrass Prairie

Pronghorn antelope at Red Top Ranch, CO. Photo credit: ©Chris Pague/TNC

This description was adapted from the *Central Shortgrass Prairie Ecoregional Assessment and Partnership Initiative* (Neely et al. 2006).

The Central Shortgrass Prairie ecoregion is located on the western edge of the Great Plains, adjacent to the Rocky Mountains and strongly influenced by their regional rain-shadow. The ecoregion is composed of the rolling plains and tablelands of eastern Colorado and western Kansas, but the edges include five additional states. It has an elevation range of 2,500-7,000 ft. (760-2130 m), which includes buttes, badlands, and canyons. The climate is semi-arid, and precipitation increases west to east; droughts and other extreme weather events (hail, blizzards) are common.

The dominant vegetation type, shortgrass prairie, occurs across a wide range of geophysical settings, including sandstone, shales and limestone, and soils derived from dune sands and loess. Buffalo grass, blue grama, and western wheatgrass are common. Sandhill shrublands dominated by sandsage, sand bluestem, and prairie sandreed are typical of sandy soils, and mixed-grass prairies occur on more mesic sites, especially on loess soils along the eastern edge of the ecoregion. Small patches of chalk barrens and salt-desert shrublands support several of the ecoregions rarest plants. Various woodlands occur along the foothills, cliffs, canyons, and riparian areas. Playa lakes and wetlands provide important habitat, but many occur in or near cultivated farmland.

Land conversion and major losses of wildlife populations, particularly grazers and browsers like bison and elk, have dramatically changed the dynamics of the dominant systems. Over 90% of the ecoregion is privately owned, and half of the overall area has been converted for human use, with extensive loss of mixed-grass prairies (about 80%) and shortgrass prairie (42%) to row-crop agriculture, and other intensive uses. This conversion has been concentrated in the more mesic eastern section of the ecoregion, and extensive areas of native shortgrass prairie persist on private lands.

Figure 4.44: Central Shortgrass Prairie Geophysical Settings.

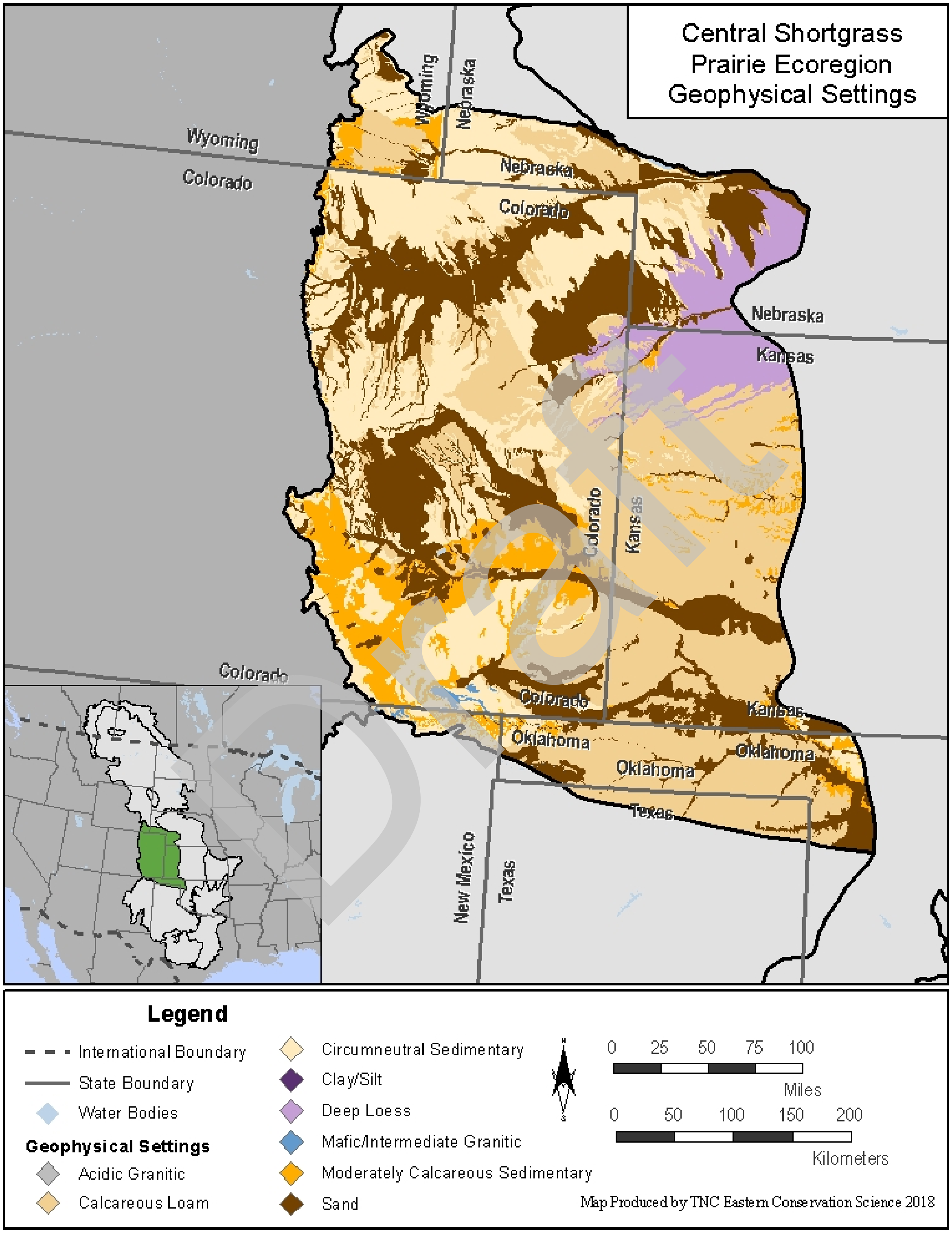


Figure 4.45: Central Shortgrass Prairie Landscape Diversity.

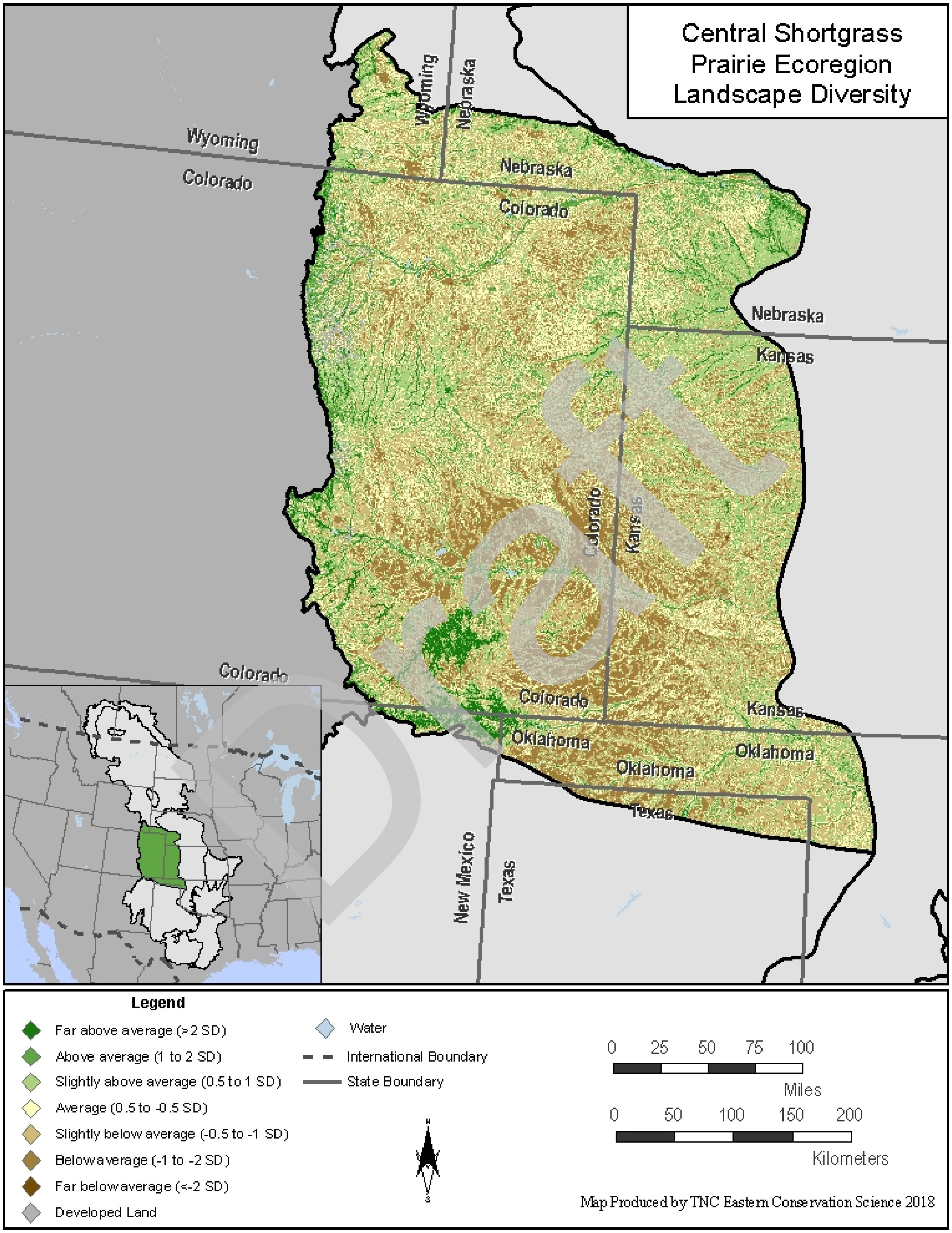


Figure 4.46: Central Shortgrass Prairie Local Connectedness.

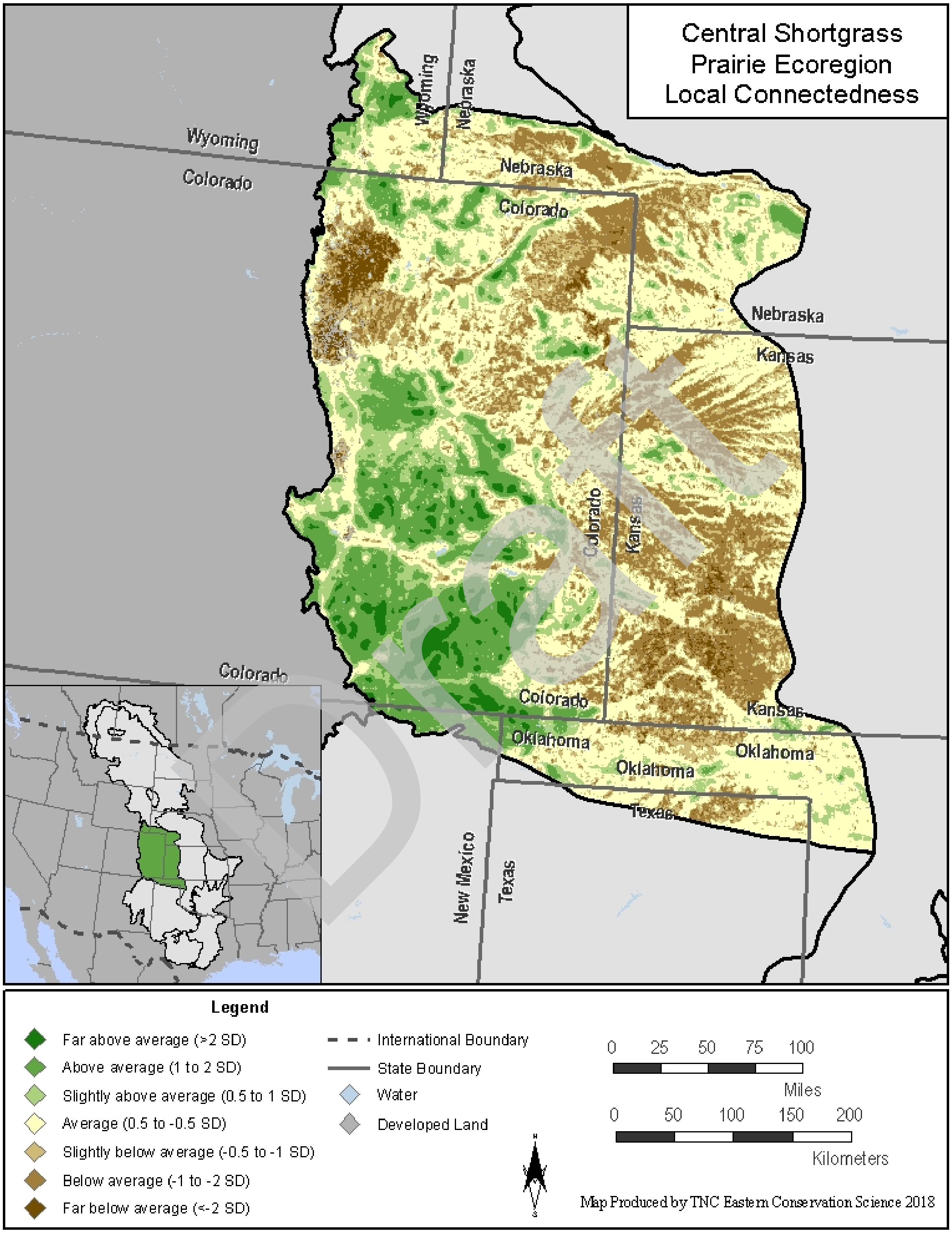


Figure 4.47: Central Shortgrass Prairie Site Resilience Scores.

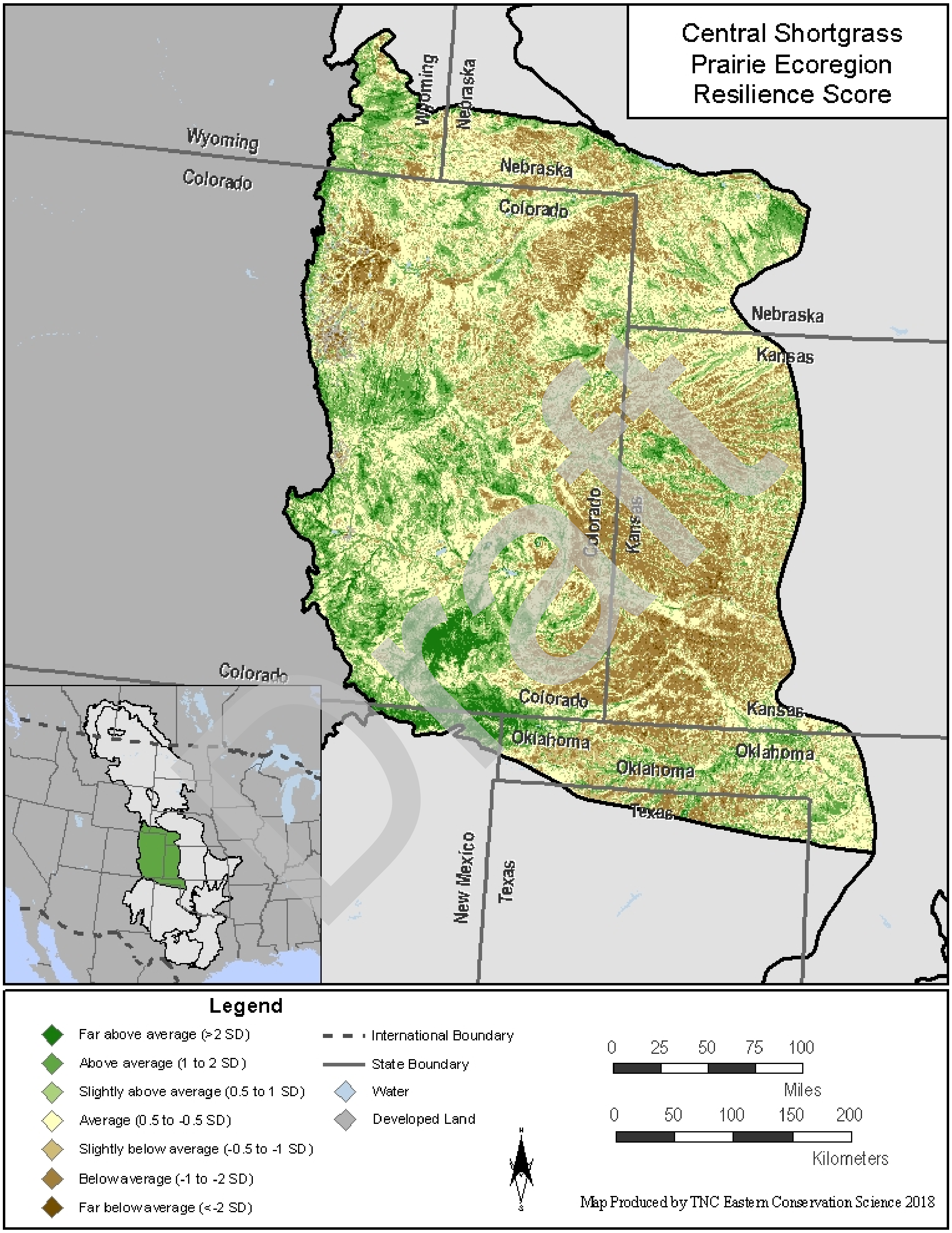


Figure 4.48: Highest Resilience Score Areas for Each Geophysical Setting in the Central Shortgrass Prairie Ecoregion.

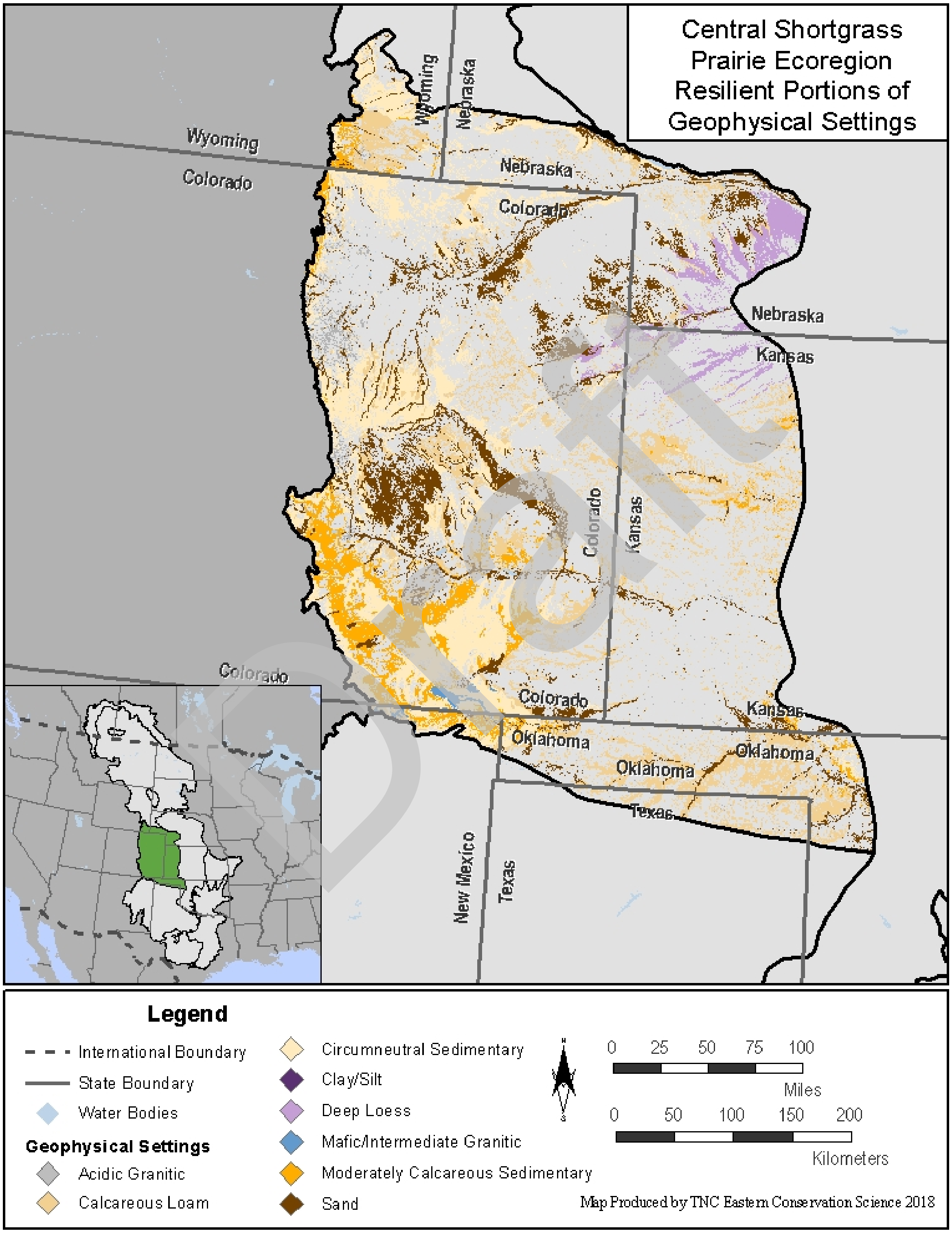


Figure 4.49: Central Shortgrass Prairie Geophysical Settings – Proportions by Area.

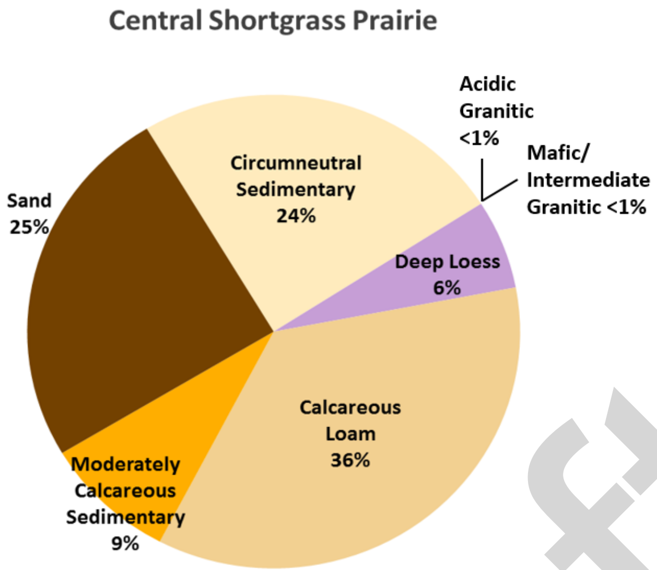
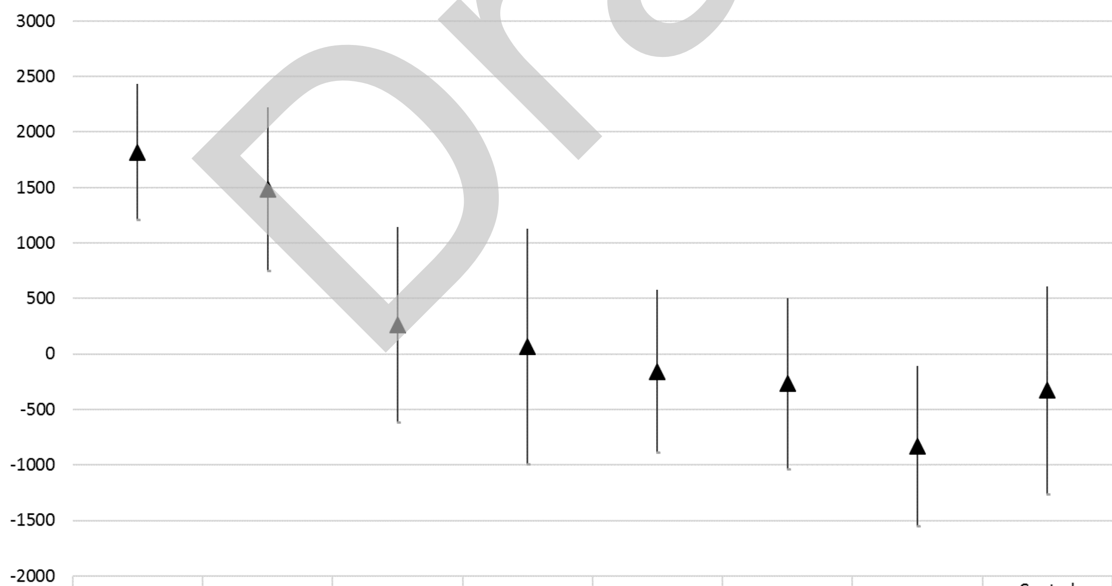


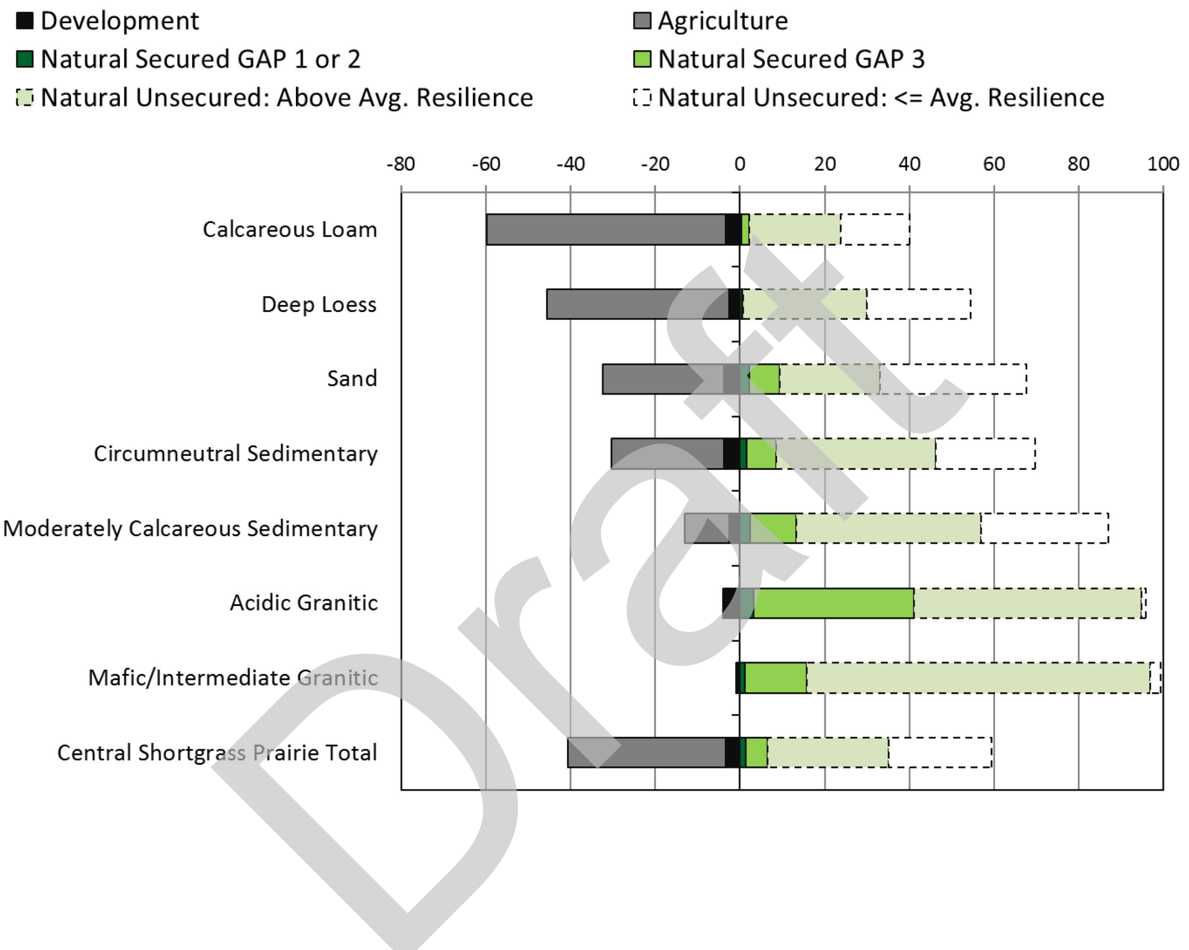
Figure 4.50: Central Shortgrass Prairie Geophysical Settings by Regional Resilience Score.

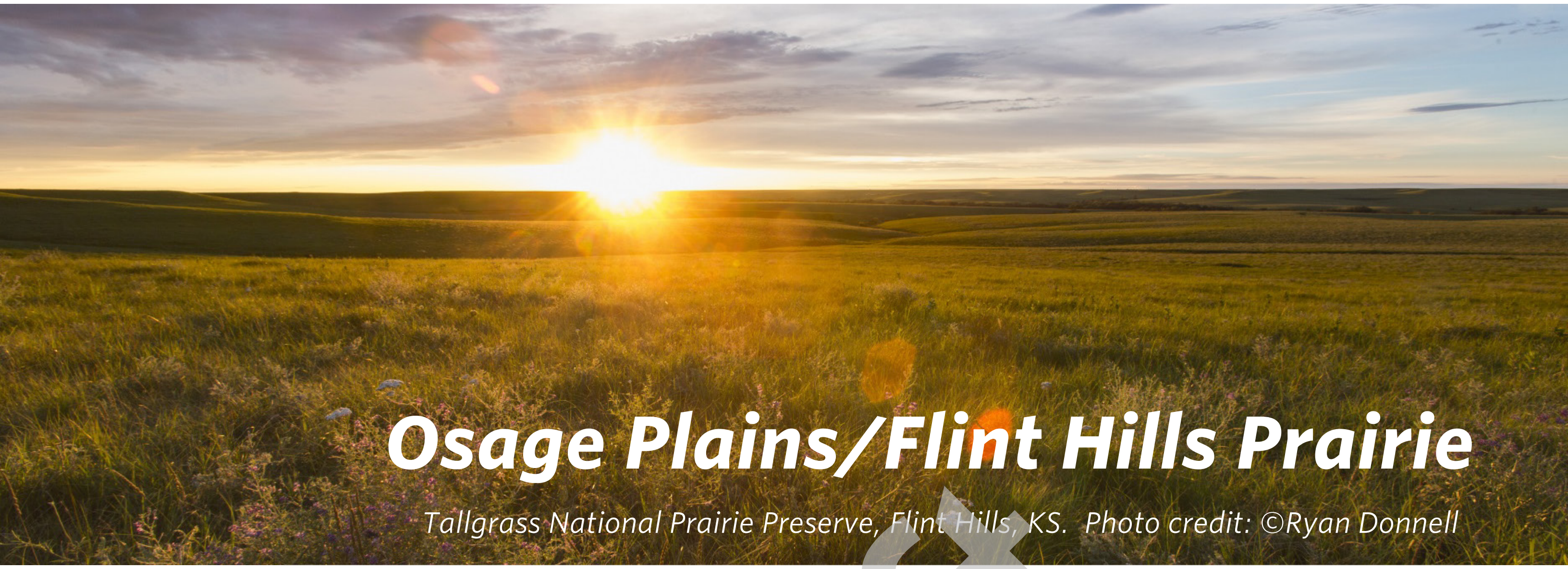


	Acidic Granitic	Mafic/Intermediate Granitic	Moderately Calcareous Sedimentary	Circumneutral Sedimentary	Deep Loess	Sand	Calcareous Loam	Central Shortgrass Prairies Ecoregion
Upper SD	2433	2220	1141	1128	577	501	-107	612
▲ MEAN	1817	1484	262	66	-159	-270	-831	-328
- Lower SD	1201	747	-618	-995	-896	-1041	-1554	-1268

Upper SD ▲ MEAN - Lower SD

Figure 4.51: Conversion and Securement of the Central Shortgrass Prairie Ecoregion by Geophysical Setting. This ecoregion is 41% converted and 6.5% secured, a ratio of 6.3 to 1. Within this ecoregion, 29% of the land (15.8 million acres) is in natural landcover, scored above average for resilience, and is not currently secured.





Tallgrass National Prairie Preserve, Flint Hills, KS. Photo credit: ©Ryan Donnell

This description was adapted from the Ecoregional Conservation in the Osage Plains/Flint Hills Prairie (Hamilton et al. 2000).

The Osage Plains/Flint Hills Prairie ecoregion is located on the southeastern edge of the study region, in west central Missouri, eastern Kansas, and northeastern Oklahoma. As the name suggests, the ecoregion encompasses two sections that differ in landform. The Flint Hills section runs along the western edge of the ecoregion, and includes about a fourth of the total area. These gently sloping hills (300-500 ft. of relief) are comprised of shale and limestone parent materials. The Osage Plains section is much larger, and while the underlying dominant geophysical setting is the same, the topography is characterized by a series of escarpments, separated by gently rolling to level plains. This ecoregion has hot summers and cool winters. Although it is within the eastern edge of the Rocky Mountain rain shadow, moisture-laden air from the Gulf of Mexico also contributes rain during the growing season.

The dominant vegetation type, tallgrass prairie, occurred in diverse forms across this range of soil types and landforms. As moisture increased from west to east, historically the importance of oak hickory forest and crosstimbers vegetation also increased in upland systems. Tallgrass prairie was especially productive in wet to moist sites that are common on the Osage Plains section, and over time these sites developed carbon rich organic soils that have been extensively converted to row-crop agriculture. Less than 10% of the pre-European settlement coverage of prairie remains in the Osage Plains section, and remnants are typically small and isolated.

In contrast, soils (typically loam) in the Flint Hills tend to be thinner, drier, and less productive, which has allowed the single largest expanse of tallgrass prairie remaining in North America to persist. While many Flint Hills landowners are engaged in management activities that are compatible with long term persistence of tallgrass, tilling within the river valleys, intensive cattle grazing, loss of native grazer/browsers (bison and elk), and changes in fire regime are likely to be impacting biodiversity and ecological processes within this critically important system.

Figure 4.52: Osage Plains/Flint Hills Prairie Geophysical Settings.

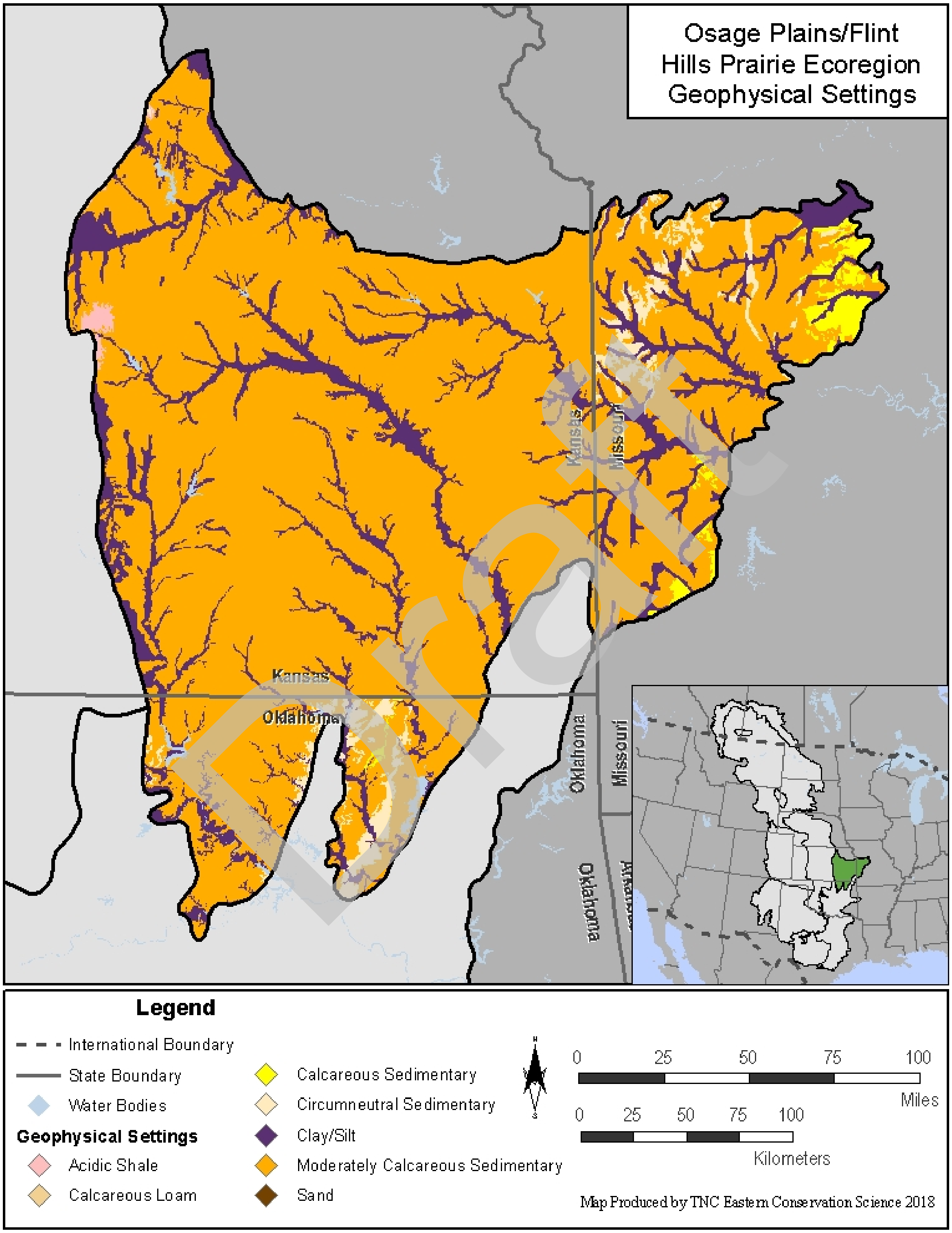


Figure 4.53: Osage Plains/Flint Hills Prairie Landscape Diversity.

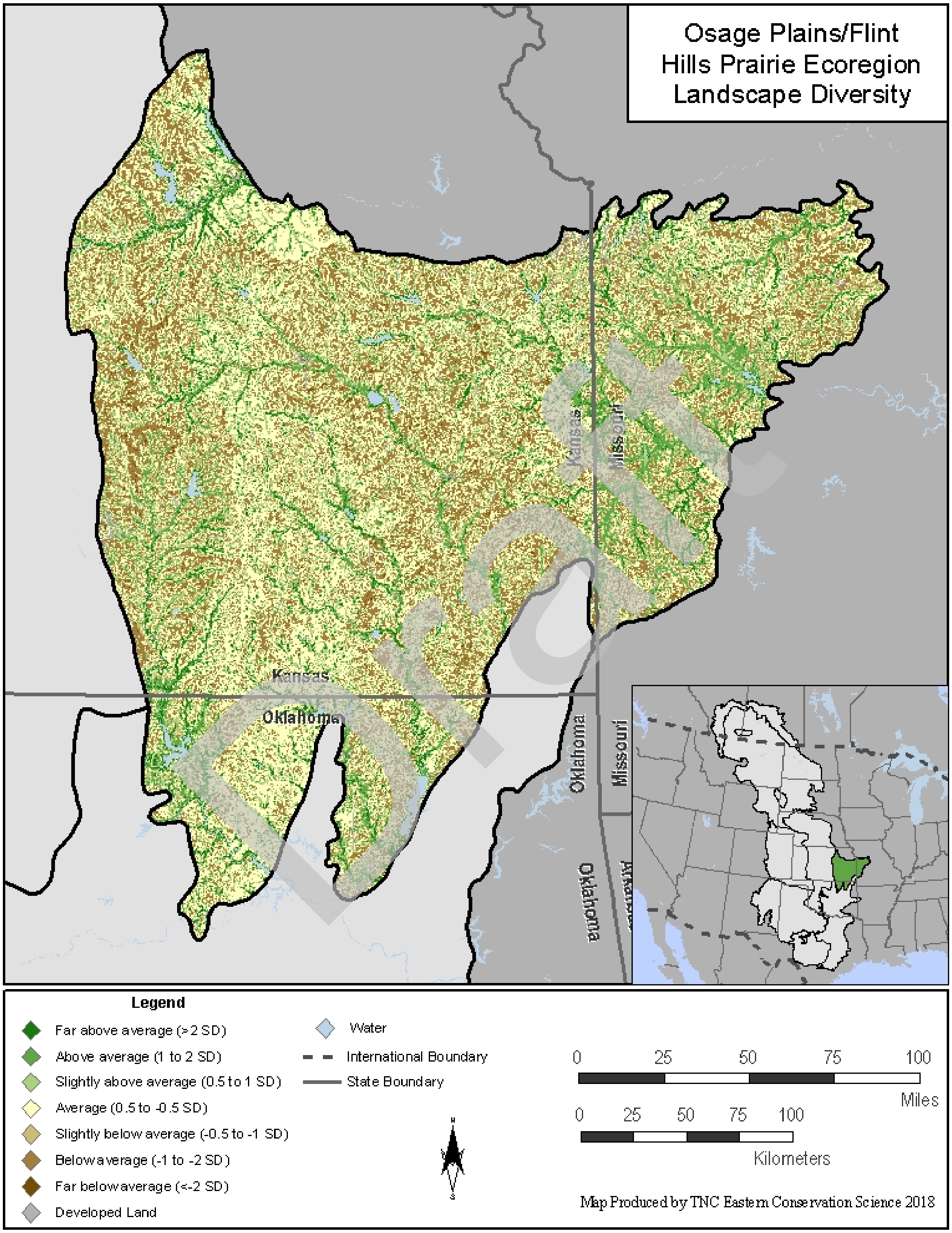


Figure 4.54: Osage Plains/Flint Hills Prairie Local Connectedness.

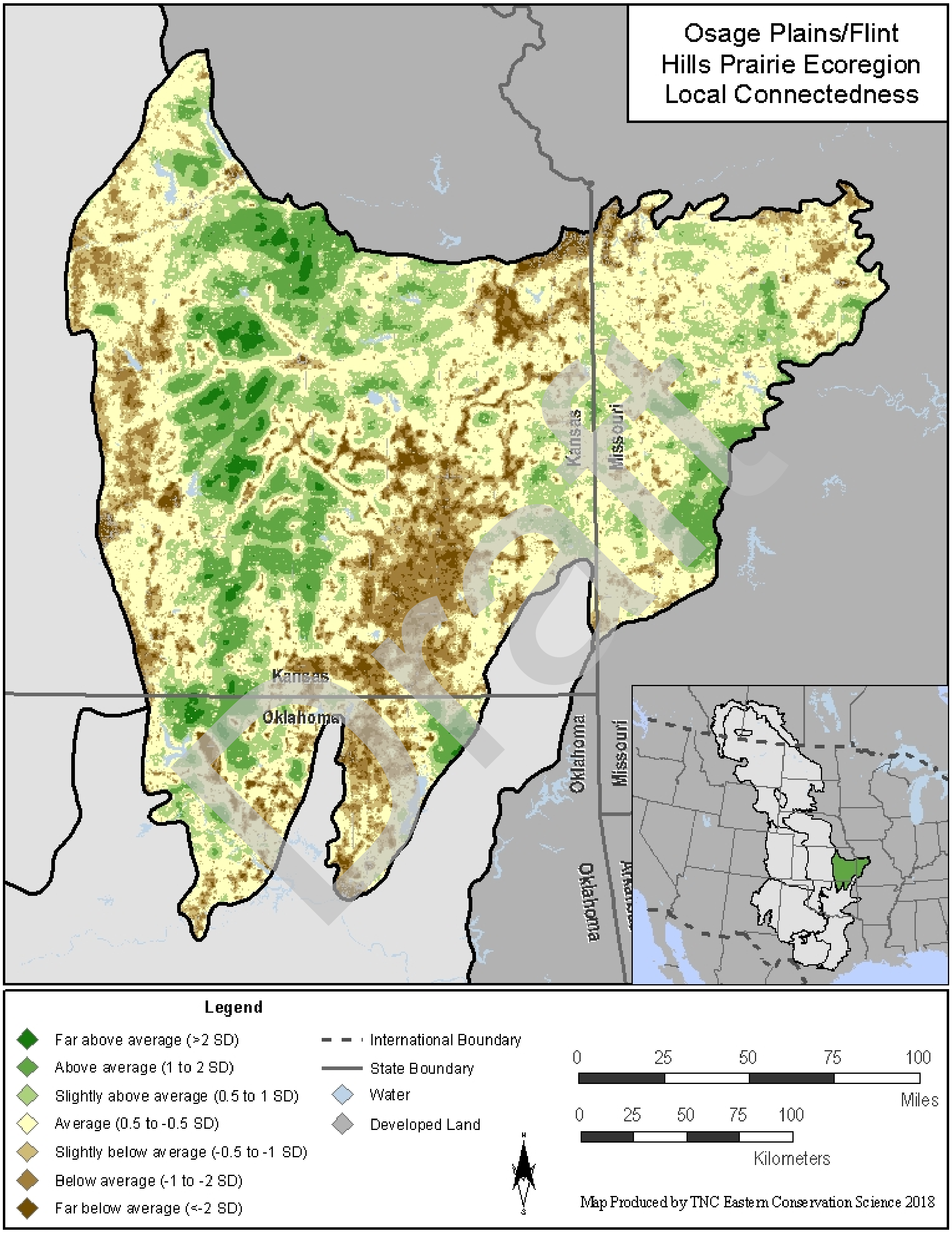


Figure 4.55: Osage Plains/Flint Hills Prairie Site Resilience Scores.

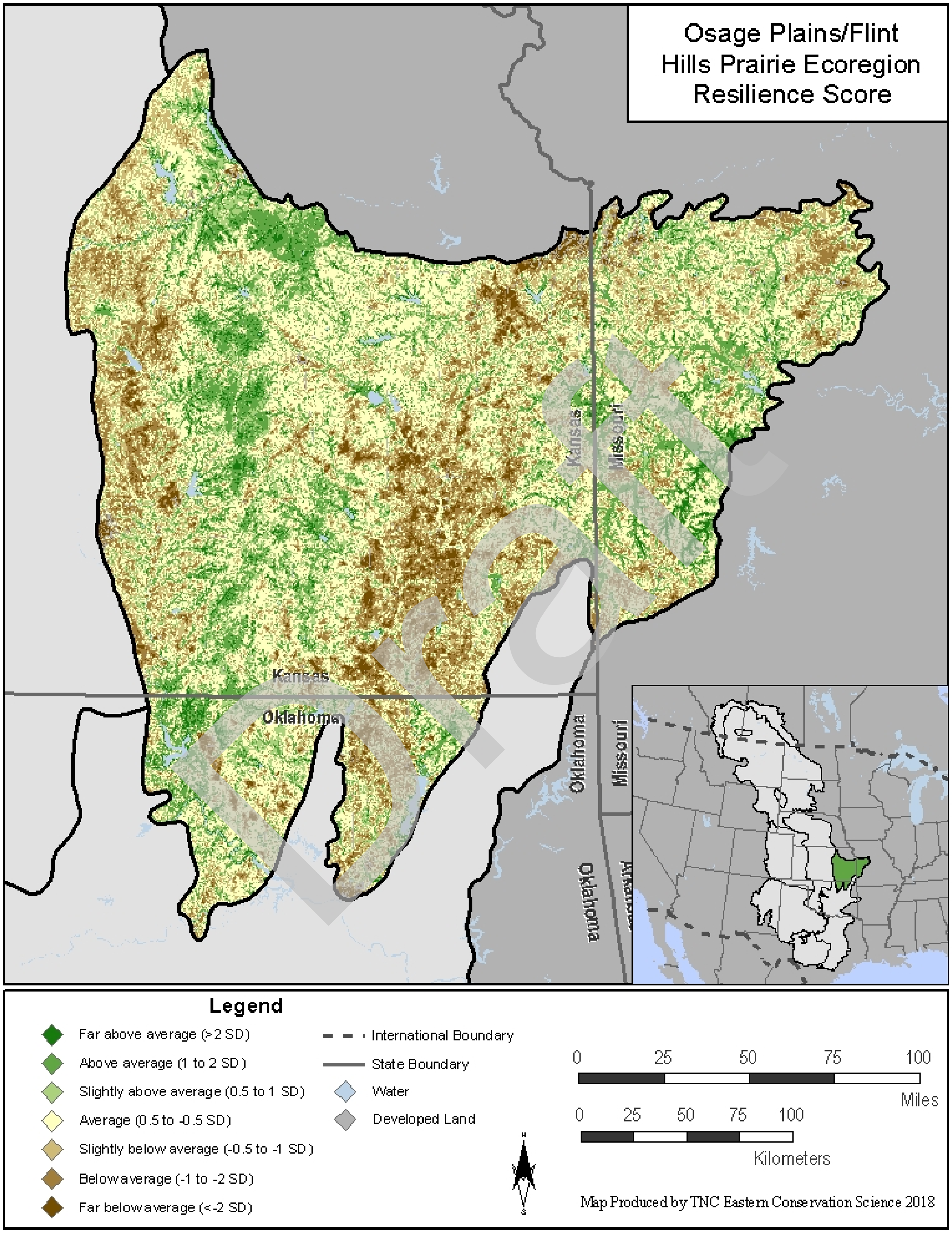


Figure 4.56: Highest Resilience Score Areas for Each Geophysical Setting in the Osage Plains/Flint Hills Prairie Ecoregion.

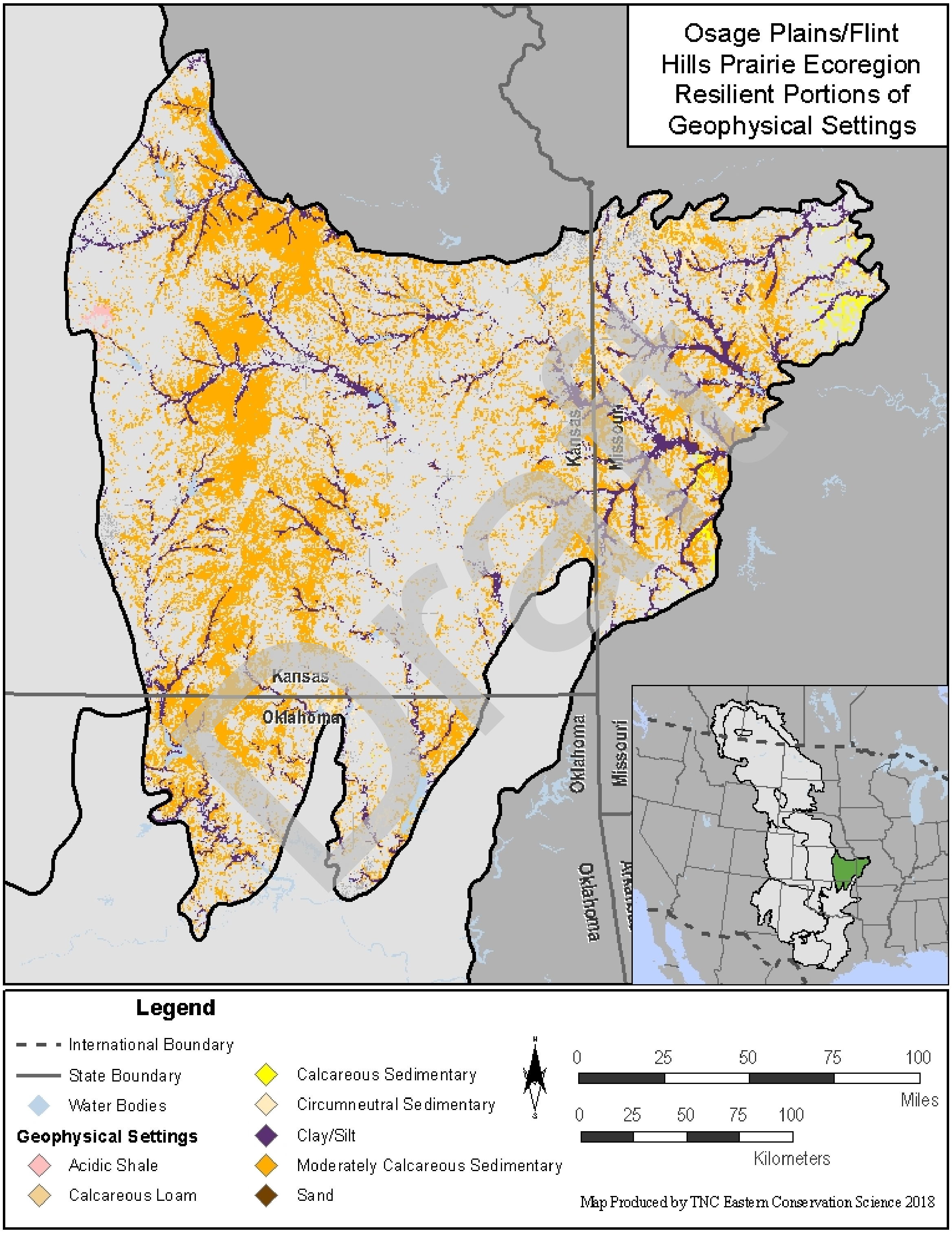


Figure 4.57: Osage Plains/Flint Hills Prairie Geophysical Settings – Proportions by Area.

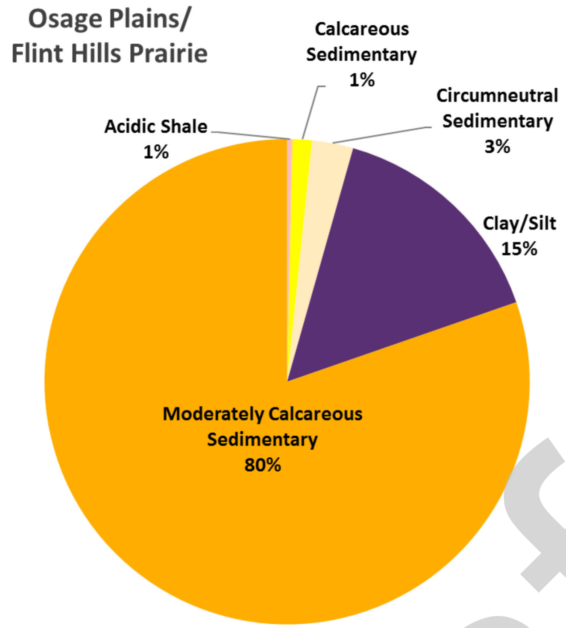
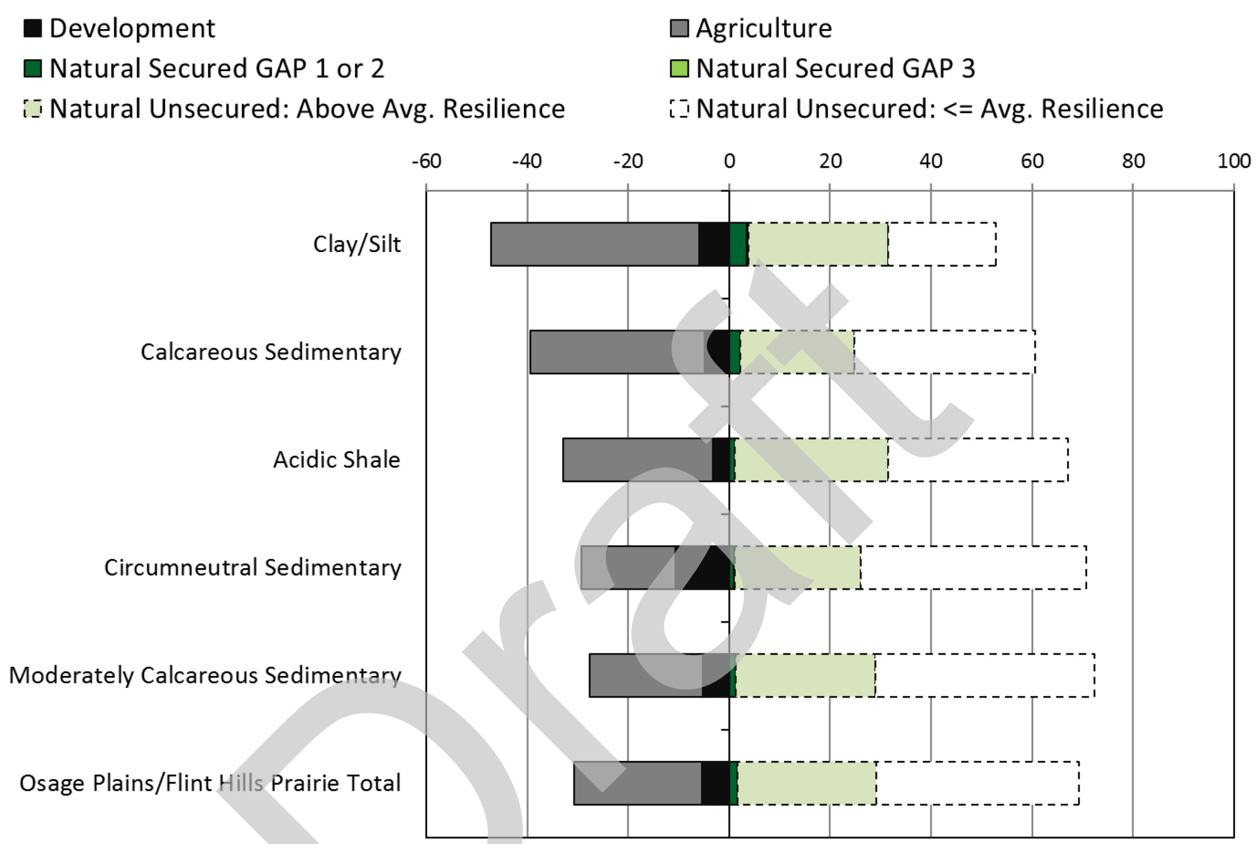


Figure 4.58: Osage Plains/Flint Hills Prairie Geophysical Settings by Regional Resilience Score.

	Clay/Silt	Moderately Calcareous Sedimentary	Calcareous Sedimentary	Acidic Shale	Circumneutral Sedimentary	Osage Plains/Flint Hills Prairies Ecoregion
Upper SD	925	540	507	382	467	602
▲ MEAN	155	-118	-121	-143	-183	-79
Lower SD	-616	-776	-750	-669	-833	-761

Figure 4.59: Conversion and Securement of the Osage Plains/Flint Hills Prairie Ecoregion by Geophysical Setting. This ecoregion is 31% converted and 1.7% secured, a ratio of 18 to 1. Within this ecoregion, 28% of the land (5.3 million acres) is in natural landcover, scored above average for resilience, and is not currently secured.



Southern Shortgrass Prairie

TNC's Four Canyon Preserve, OK – Photo credit: © Chris Hise

This description was adapted from *A Biodiversity and Conservation Assessment of the Southern Shortgrass Prairie Ecoregion* (The Nature Conservancy 2007).

The Southern Shortgrass Prairie ecoregion is located along the southwestern edge of the Great Plains, east of the southern Rockies and the Arizona-New Mexico Mountains ecoregions. Like the Central Shortgrass Prairie to the north, this ecoregion has a semi-arid climate, high temperature variability, and annual precipitation that increases from west to east. Flat to rolling plains typify the ecoregion, especially the south-central sections of dry, gently sloping mesas called the Llano Estacado. To the east and west, the plains are dissected by escarpments and canyons, with highest elevations (more than 8200 ft., or 2,500 m) associated with isolated volcanic peaks. The geology includes basalts, granite, shales, and sandstones, as well as red clay, sand and gravel beds and shallow loess deposits on the Llano Estacado.

Historically, the dominant vegetation type was vast expanses of shortgrass prairie, which occurred in a diverse range of community types reflecting variations in topography and soils. Blue grama and buffalograss are common. Sandy areas support sand-adapted species, like sand bluestem, as well as woody cover like sand sage and shinnery oak. The southwestern portion is the most arid, and supports species characteristic of desert grasslands. Mixed-grass prairie becomes dominant in the more mesic eastern sections, while pinyon and pinyon-juniper woodlands occur along breaks and canyons. Canyon breaks and wide river floodplains are important areas for biodiversity. Depressional basins that support playa lakes are common, and saline wetlands and lakes provide habitat for many specialized species.

Much of the former shortgrass and mixed-grass prairie in the ecoregion has been converted to other lands uses. The llano Estacado of Texas is one of the most extensively cultivated regions in North America. As with all the other ecoregions in the plains, the loss of key herbivores and browsers, fragmentation, and changes in fire regime have altered the processes and species diversity in the systems that remain.

Figure 4.60: Southern Shortgrass Prairie Geophysical Settings.

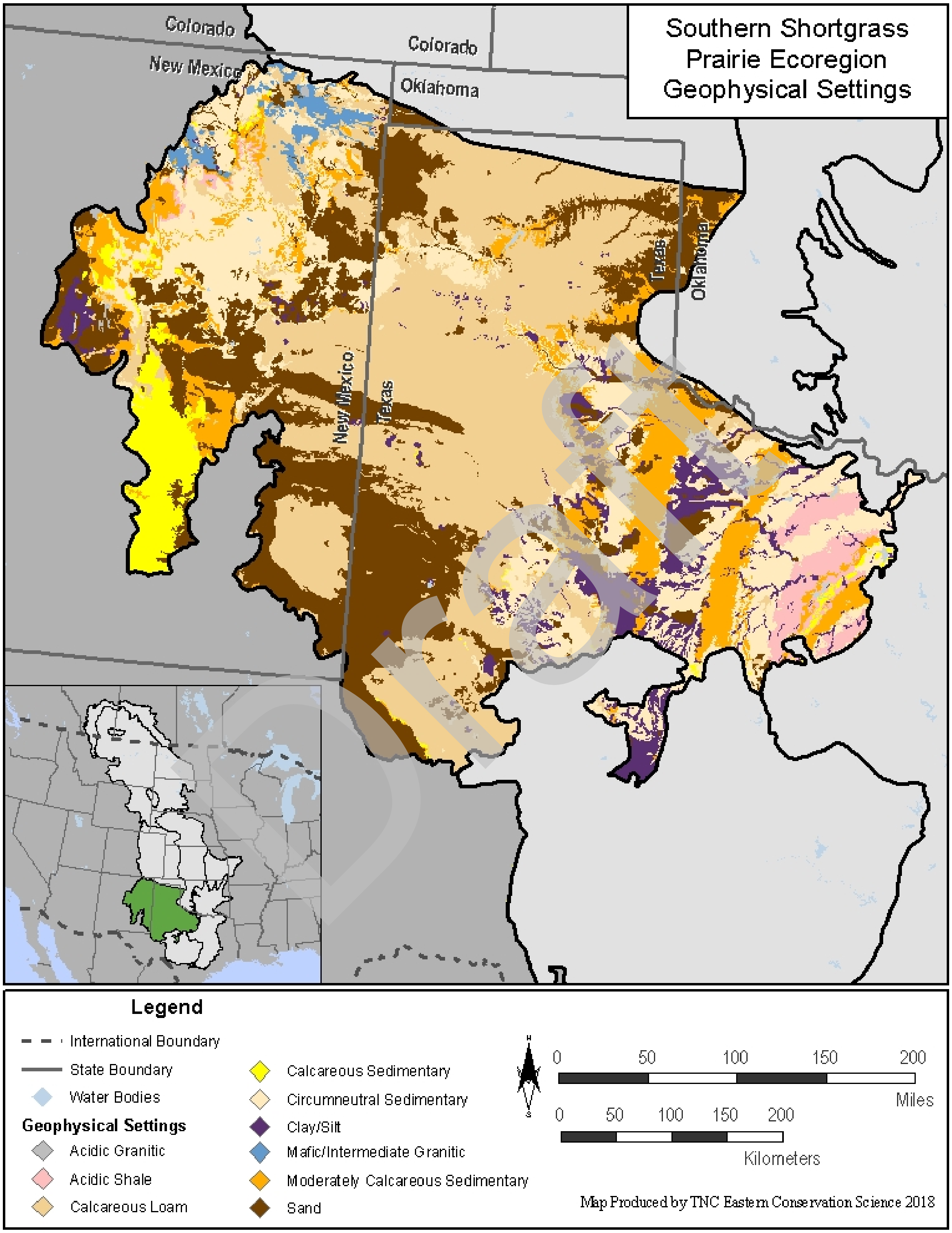


Figure 4.61: Southern Shortgrass Prairie Landscape Diversity.

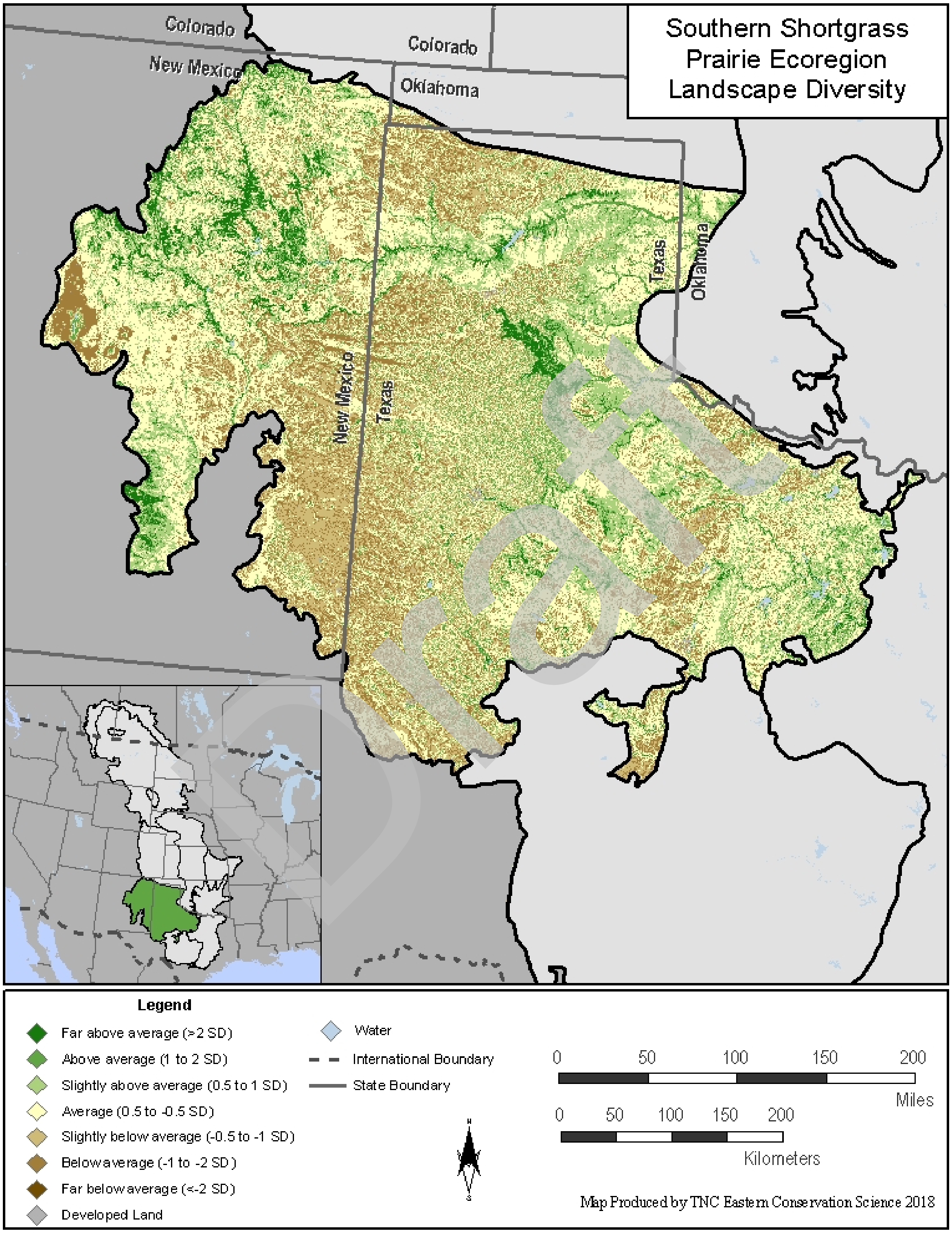


Figure 4.62: Southern Shortgrass Prairie Local Connectedness.

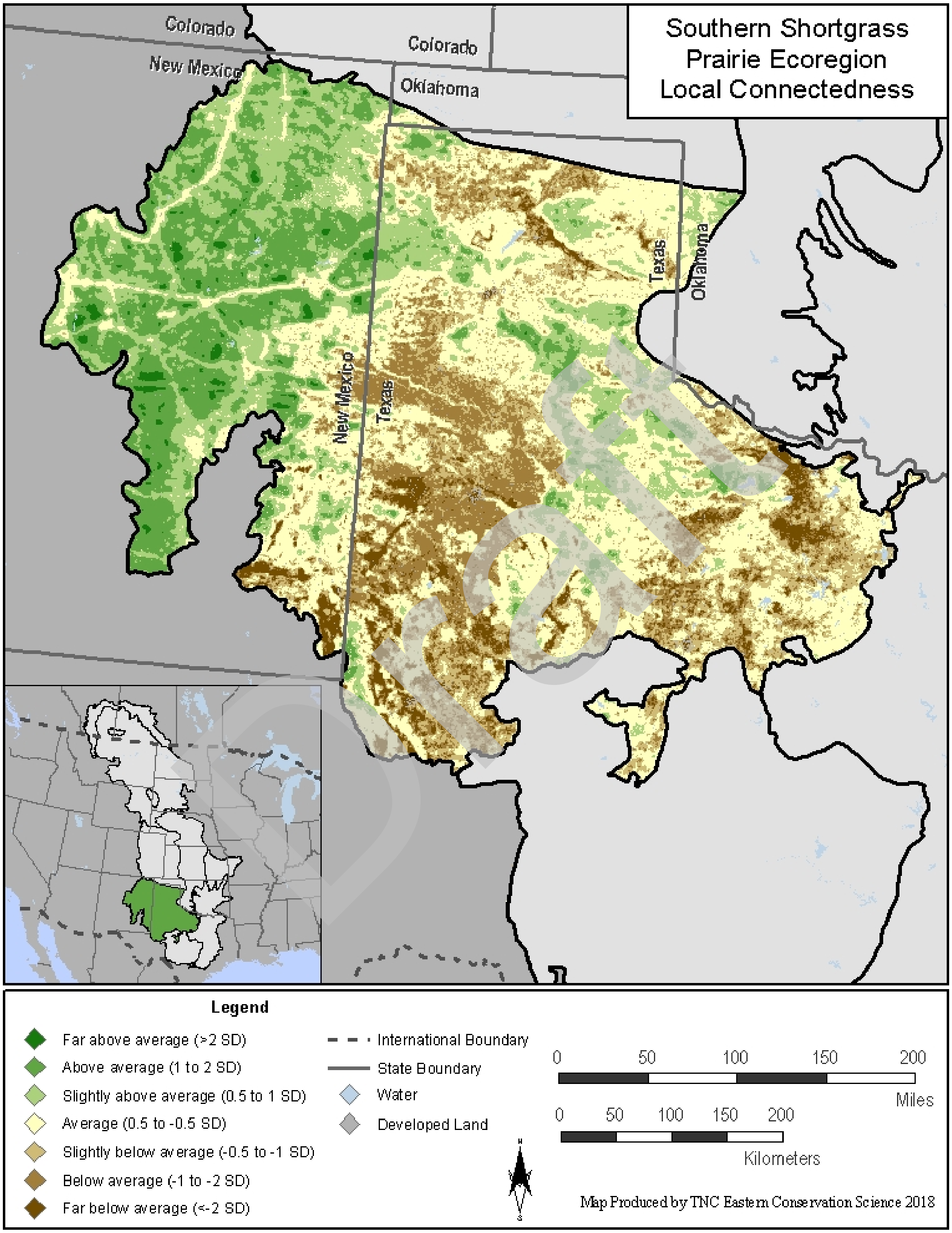


Figure 4.63: Southern Shortgrass Prairie Site Resilience Scores.

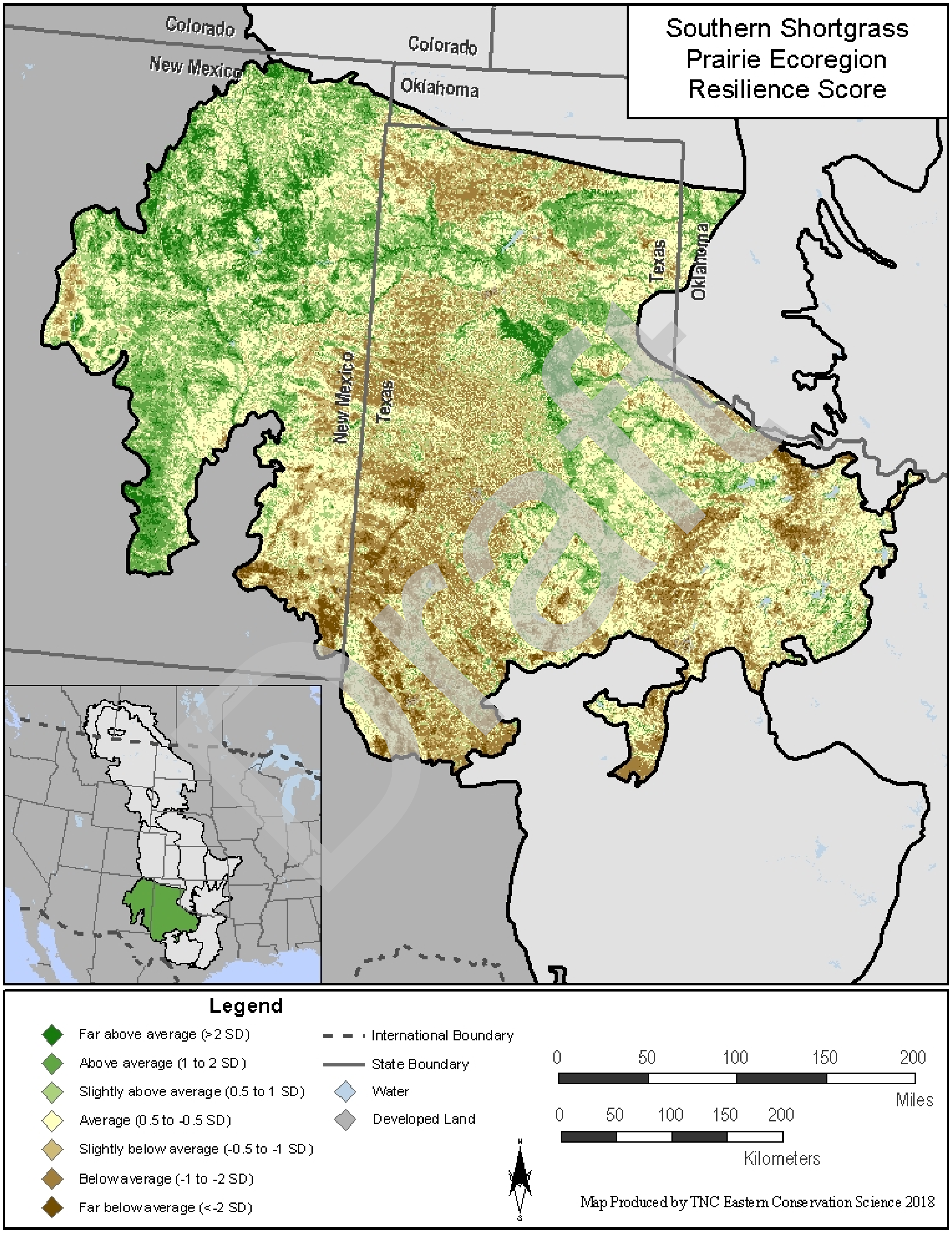


Figure 4.64: Highest Resilience Score Areas for Each Geophysical Setting in the Southern Shortgrass Prairie Ecoregion.

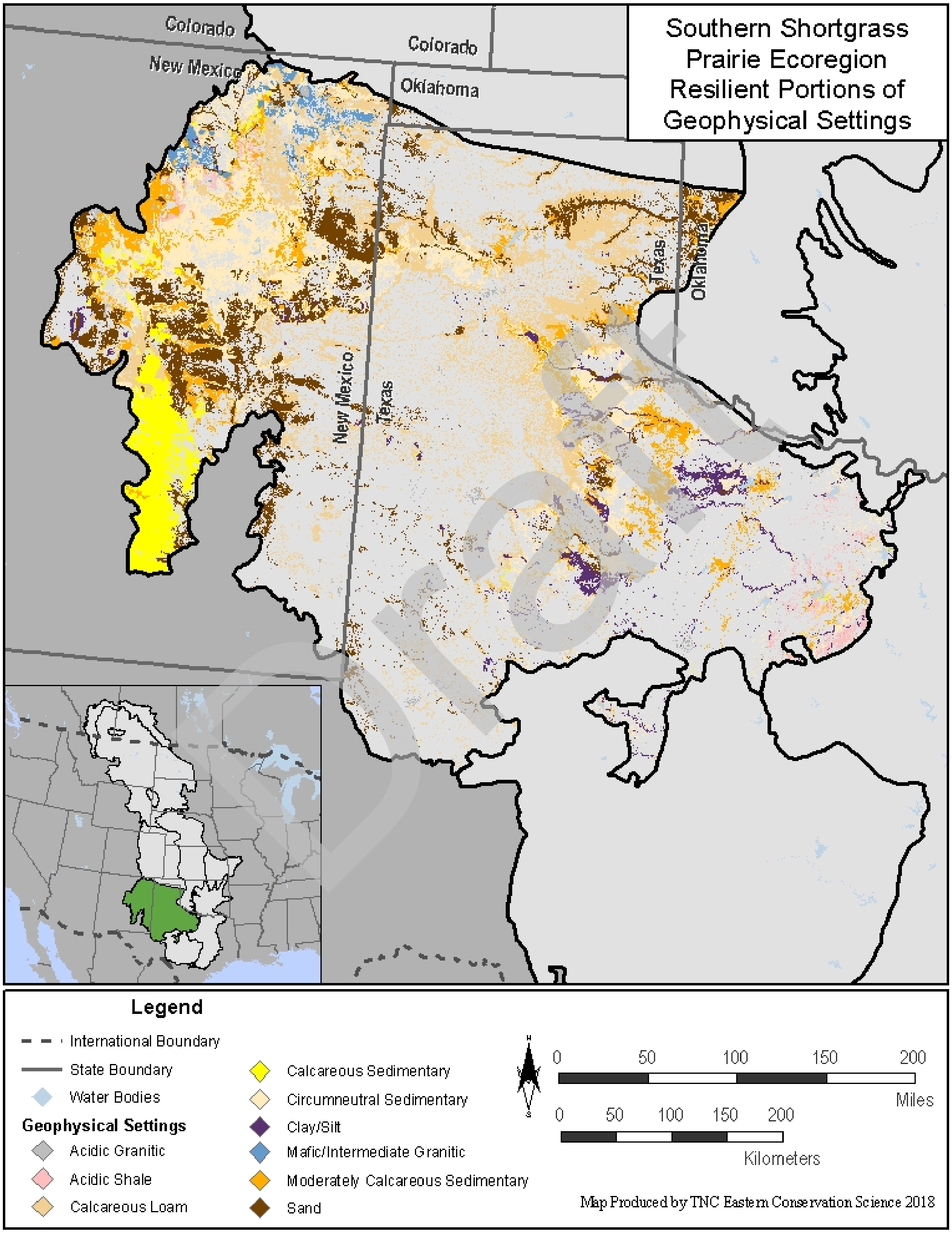


Figure 4.65: Southern Shortgrass Prairie Geophysical Settings – Proportions by Area.

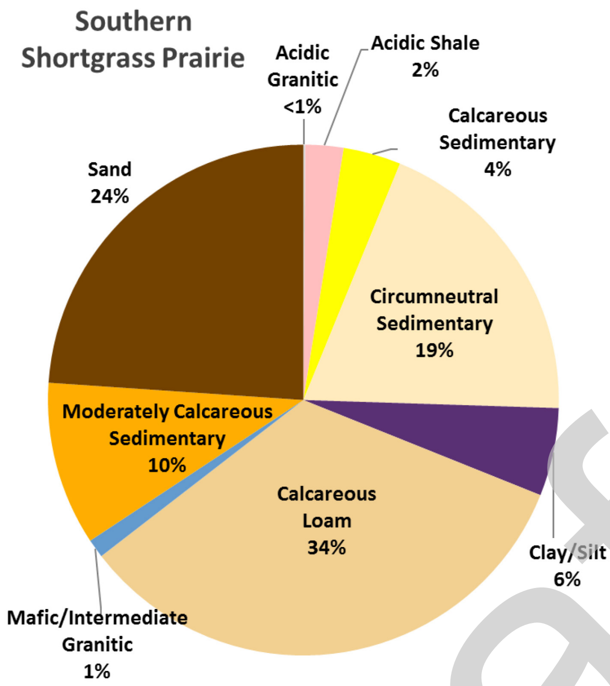
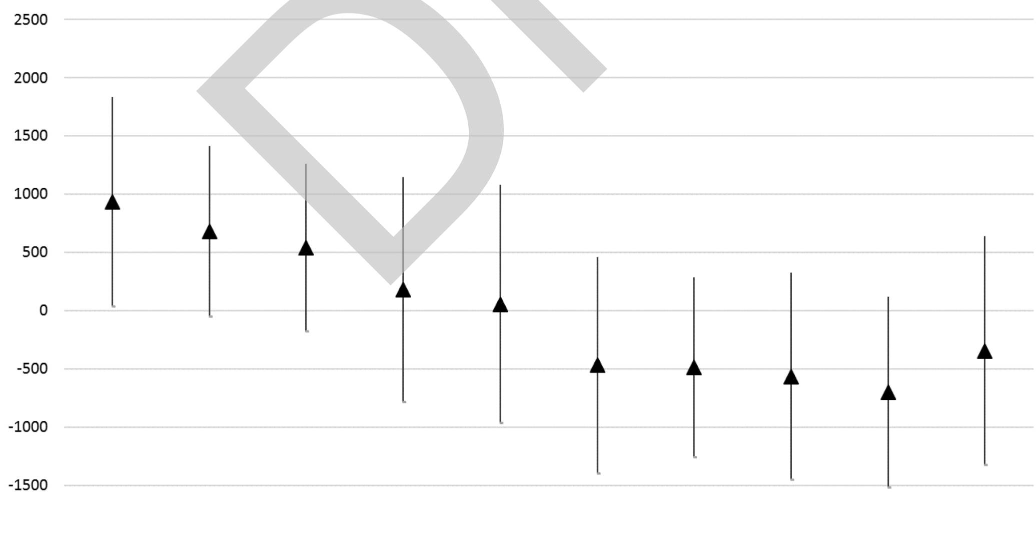


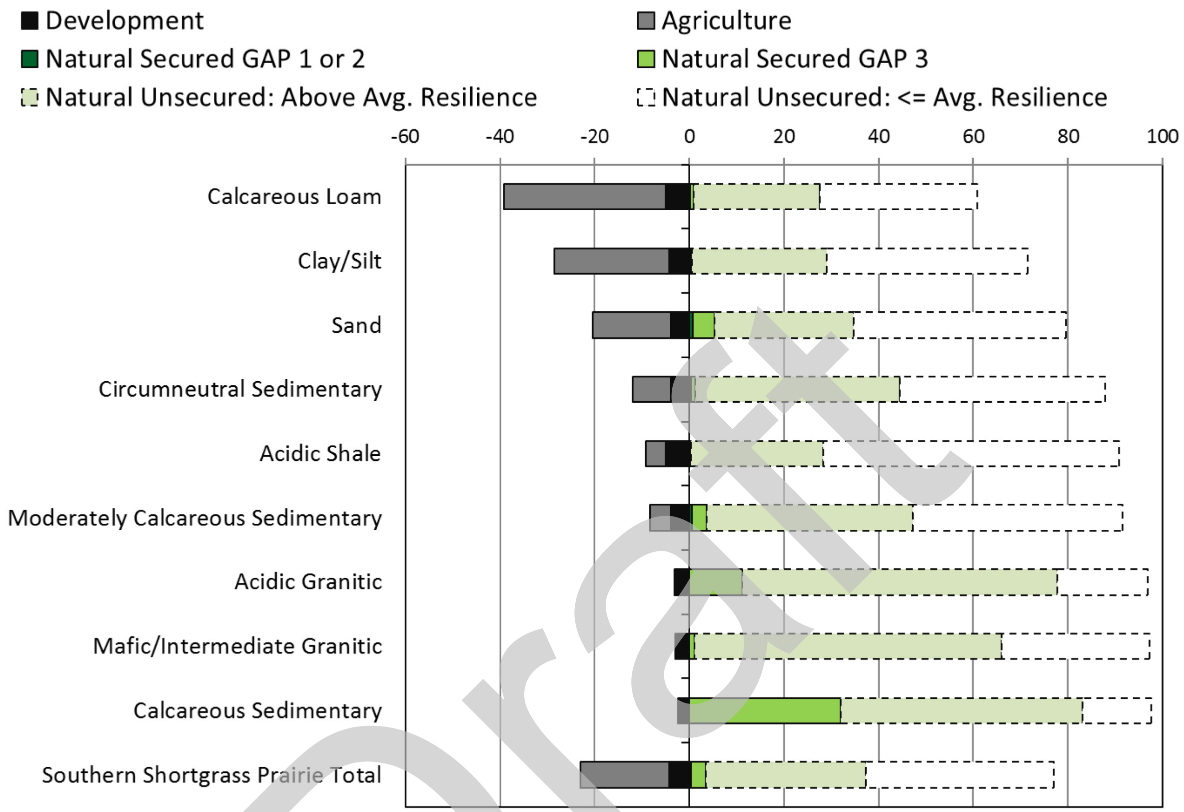
Figure 4.66: Southern Shortgrass Prairie Geophysical Settings by Regional Resilience Score.



	Acidic Granitic	Calcareous Sedimentary	Mafic/Intermediate Granitic	Moderately Calcareous Sedimentary	Circumneutral Sedimentary	Clay/Silt	Acidic Shale	Sand	Calcareous Loam	Southern Shortgrass Prairies Ecoregion
Upper SD	1835	1411	1258	1148	1082	461	283	324	116	638
▲ MEAN	933	677	539	179	55	-470	-490	-567	-704	-347
- Lower SD	31	-58	-179	-790	-972	-1401	-1263	-1459	-1525	-1333

Upper SD ▲ MEAN - Lower SD

Figure 4.67: Conversion and Securement of the Southern Shortgrass Prairie Ecoregion by Geophysical Setting. This ecoregion is 23% converted and 3.4% secured, a ratio of 7 to 1. Within this ecoregion, 34% of the land (23.2 million acres) is in natural landcover, scored above average for resilience, and is not currently secured.



Crosstimbers and Southern Tallgrass Prairie

TNC's Clymer Meadow Preserve, TX. Photo credit: © Lynn McBride

This description was adapted from the A Conservation Blueprint for the Crosstimbers & Southern Tallgrass Prairie Ecoregion (The Nature Conservancy 2009).

The Crosstimbers and Southern Tallgrass Prairie ecoregion extends from the edge of the Flint Hills in southern Kansas, through most of eastern Oklahoma, and terminates at the edge of the Tamaulipan Thornscrub ecoregion in southeastern Texas. The pattern of geophysical settings is diverse and complex, with eight settings represented, often in nearly longitudinal bands extending from the southwest to northeast, crossed by bands of alluvial silts and clays. Overall the topography is level to rolling, though sandstone ridges in Oklahoma and parts of northwestern Texas, and the Arbuckle uplift (limestone and granitic) in south central Oklahoma provide topographic variation.

The mosaic of geophysical settings that make up this ecoregion occur along the transition zone between the drier prairie ecoregions, and the wetter, forest-dominated ecoregions to the east. Historically, natural communities reflected this diversity of site conditions, with forests, woodlands, savannas, and grasslands intermingling in complex patterns on the landscape. Several types of tallgrass prairie are found in Texas and Oklahoma, typically associated with limestone-derived clay soils. Prairie species diversity is particularly high in Texas Blackland Prairie, in part due to micro-topographic variation from gilgai (depressions that form ephemeral lakes & wetlands) and mima mounds associated with expanding/contracting clay soils. Mixed-grass prairie is found in more arid sites along the western edge. Small patches of Carrizo sand in Texas are biodiversity hotspots, supporting more than a dozen common endemic plants. Large floodplains throughout the region are also important for biodiversity, supporting bottomland hardwoods, wet meadows, and unvegetated flats.

Unlike most of the Great Plains, the Crosstimbers and Southern Tallgrass ecoregion is densely populated; it includes several large metropolitan areas in Texas and Oklahoma. Over 97% of the ecoregion is privately owned, and conversion rates, especially on arable soils, are very high. Much of the land is used for forage production for cattle, although oil and gas exploration and wind farms are common and increasing rapidly, leading to further loss and fragmentation of natural systems.

Figure 4.68: Crosstimbers and Southern Tallgrass Prairie Geophysical Settings.

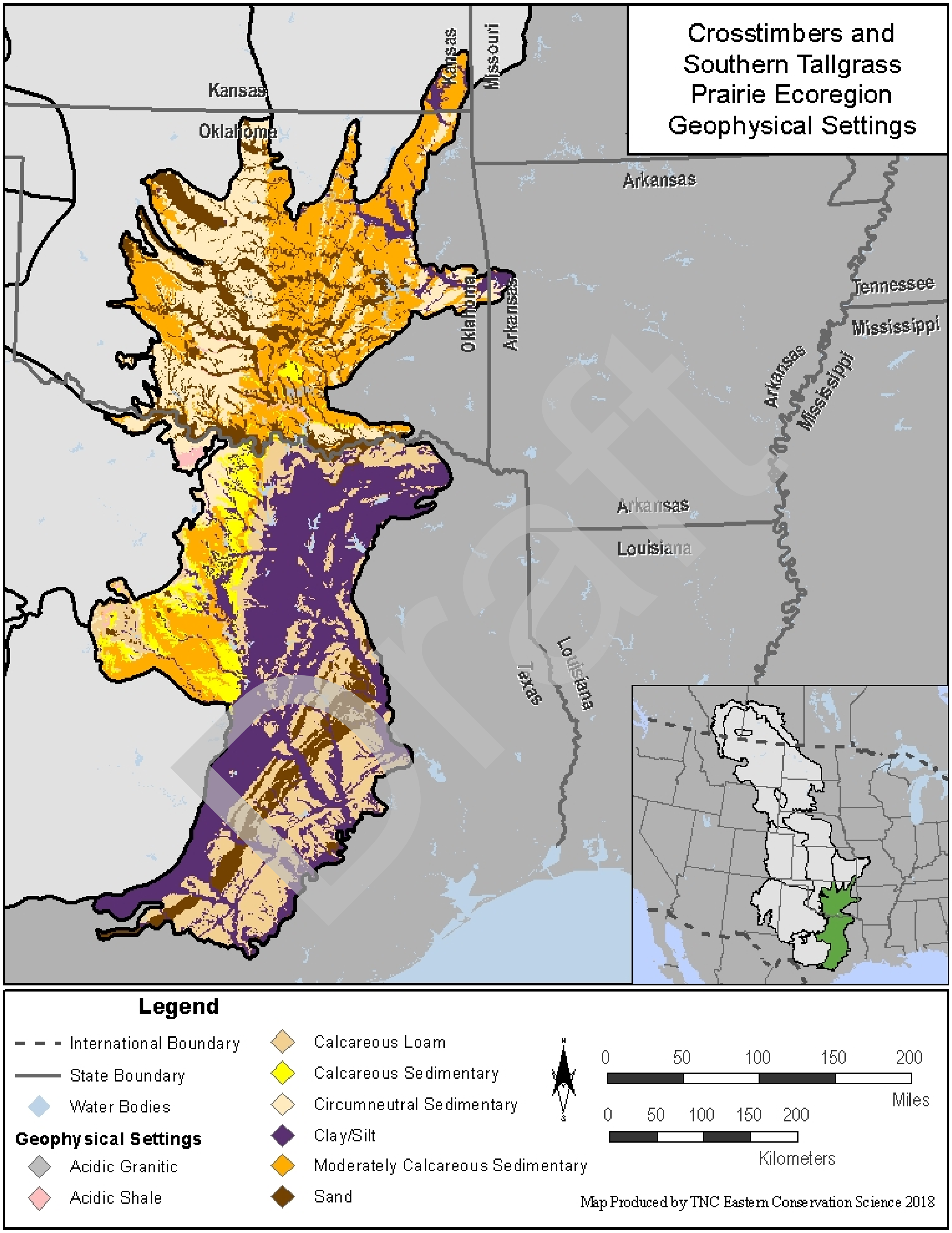


Figure 4.69: Crosstimbers and Southern Tallgrass Prairie Landscape Diversity.

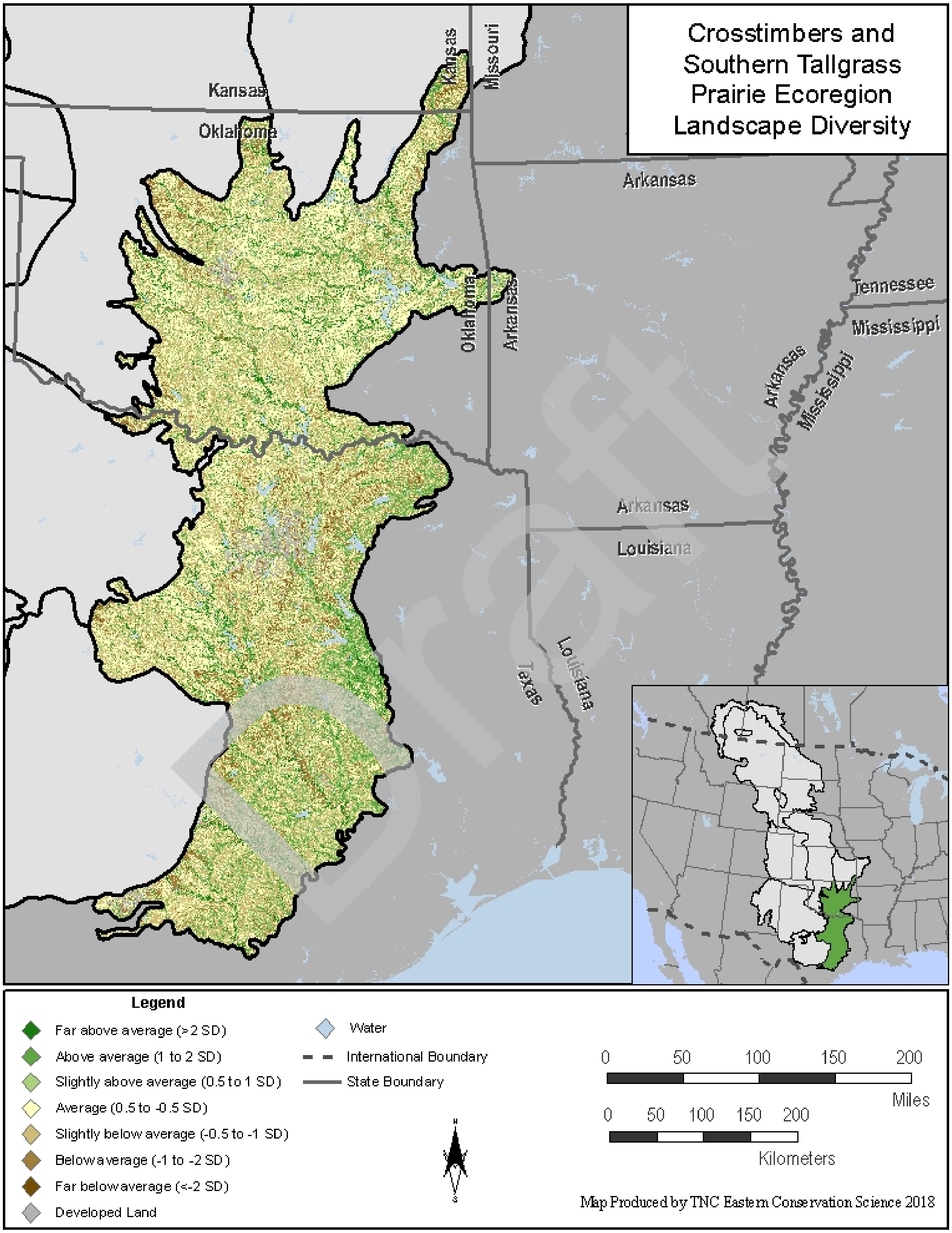


Figure 4.70: Crosstimbers and Southern Tallgrass Prairie Local Connectedness.

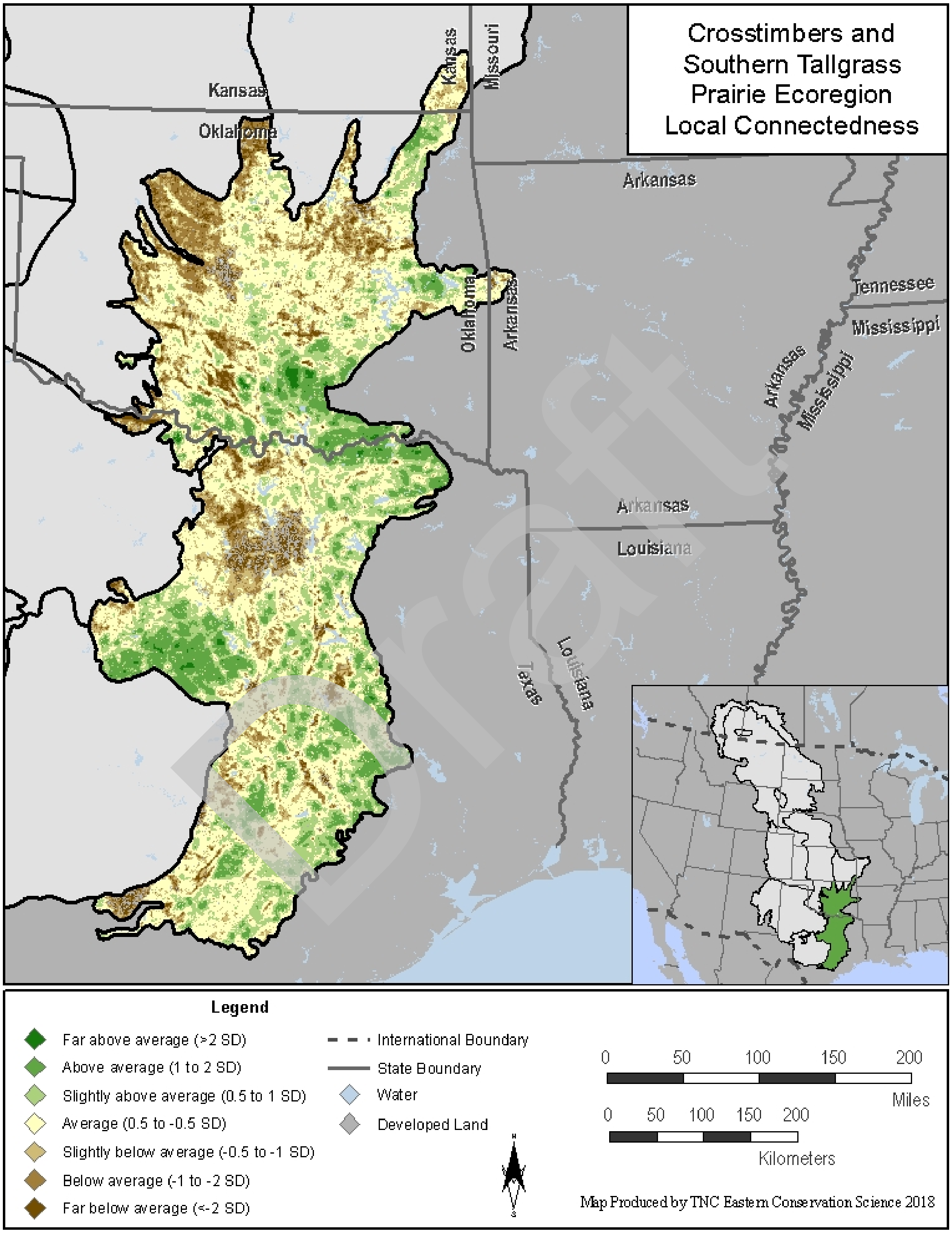


Figure 4.71: Crosstimbers and Southern Tallgrass Prairie Site Resilience Scores.

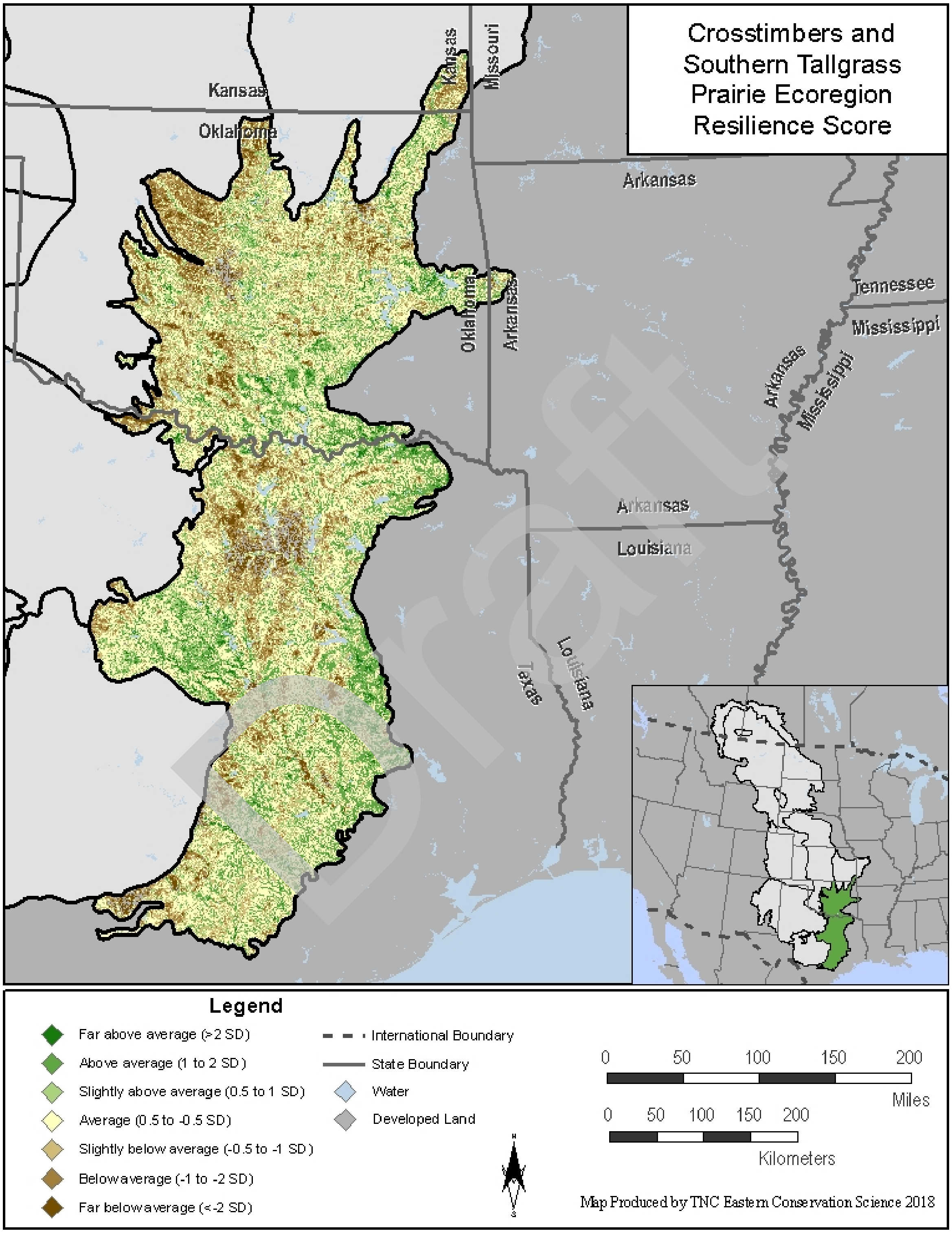


Figure 4.72: Highest Resilience Score Areas for Each Geophysical Setting in the Crosstimbers and Southern Tallgrass Prairie Ecoregion.

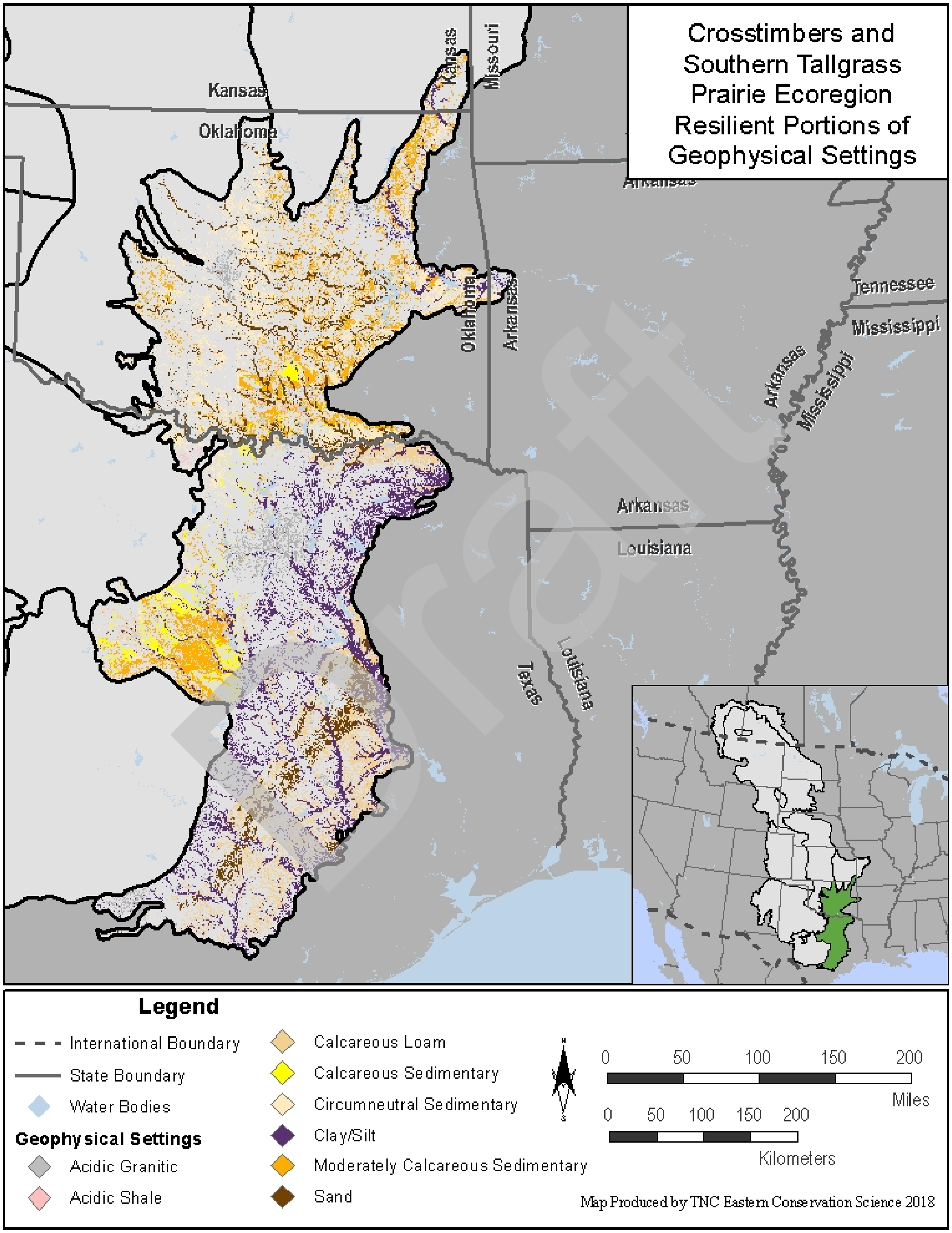


Figure 4.73: Crosstimbers and Southern Tallgrass Prairie Geophysical Settings – Proportions by Area.

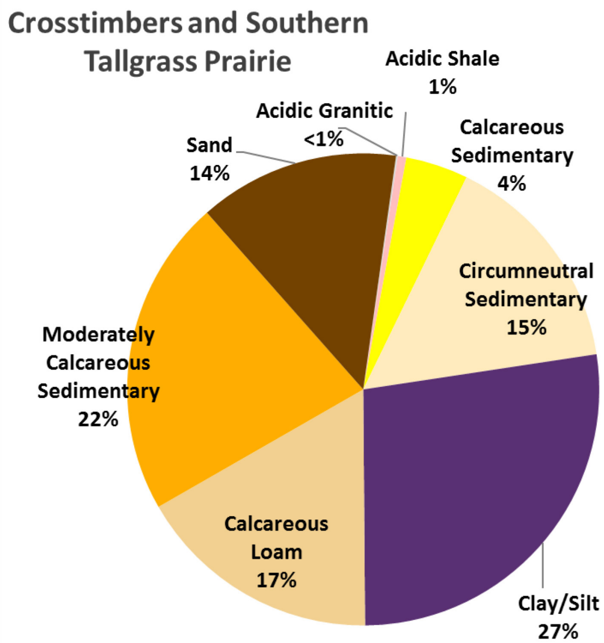
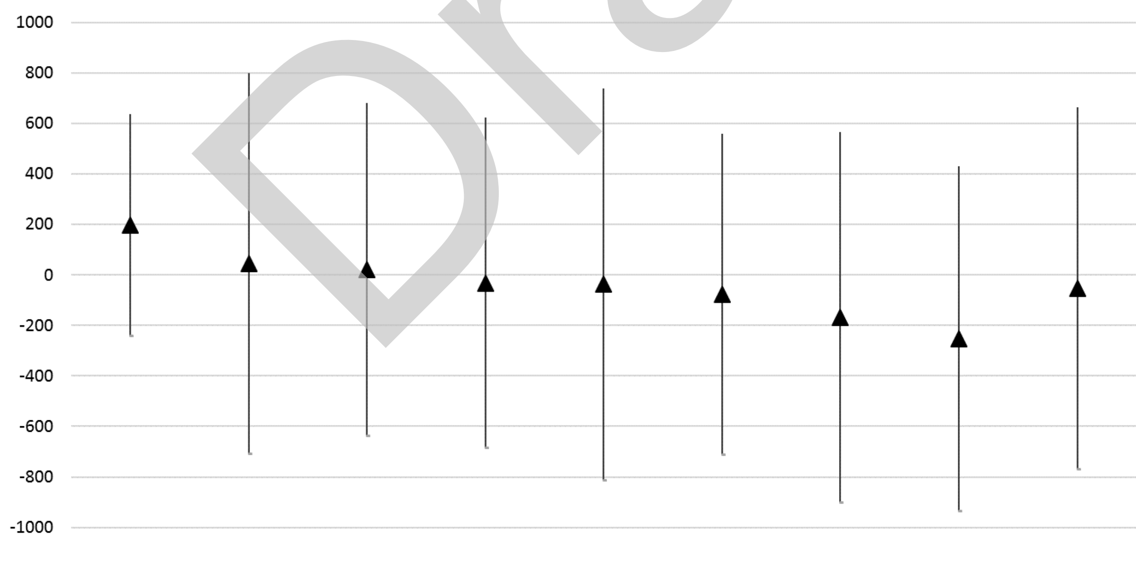


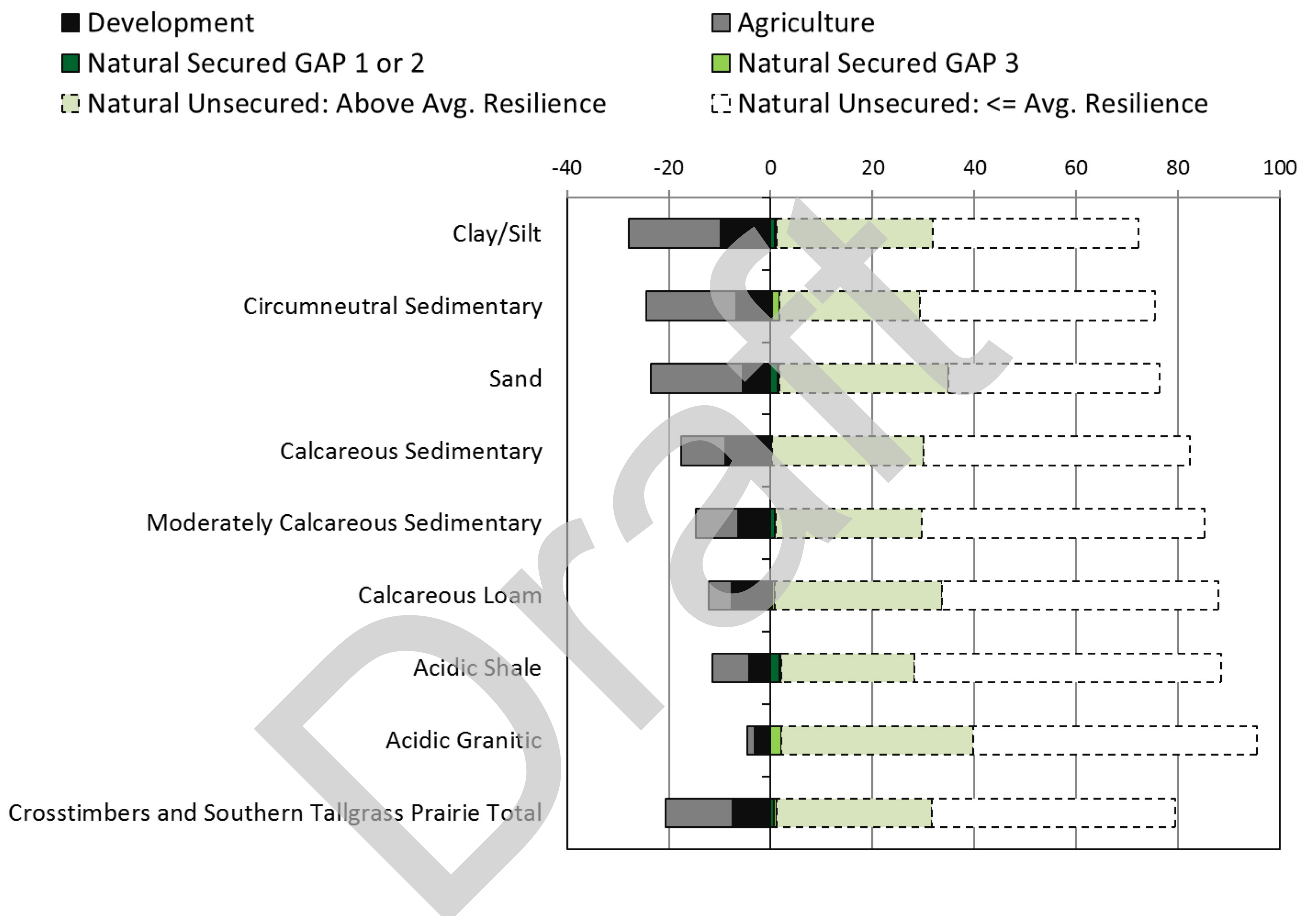
Figure 4.74: Crosstimbers and Southern Tallgrass Prairie Geophysical Settings by Regional Resilience Score.



	Acidic Granitic	Sand	Calcareous Loam	Moderately Calcareous Sedimentary	Clay/Silt	Acidic Shale	Calcareous Sedimentary	Circumneutral Sedimentary	Crosstimbers And Southern Tallgrass Prairies Ecoregion
Upper SD	638	800	681	623	739	560	567	430	663
▲ MEAN	198	45	21	-32	-37	-77	-169	-253	-55
- Lower SD	-242	-709	-639	-687	-814	-714	-905	-936	-773

Upper SD ▲ MEAN - Lower SD

Figure 4.75: Conversion and Securement of the Crosstimbers and Southern Tallgrass Prairie Ecoregion by Geophysical Setting. This ecoregion is 21% converted and 1.2% secured, a ratio of 17 to 1. Within this ecoregion, 30.4% of the land (14.3 million acres) is in natural landcover, scored above average for resilience, and is not currently secured.



Edwards Plateau

Barton Creek Habitat Preserve, Texas. Photo credit: © Lynn Mc Bride

This description was adapted from [A Biodiversity and Conservation Assessment of the Edwards Plateau Ecoregion] (The Nature Conservancy 2004).

The Edwards Plateau is located at the southern end of the Great Plains, in central Texas. As this location suggests, the region includes grasslands and wooded areas that are similar to other regions in the Great Plains, as well as sites with local climates and topographic features that more closely resemble ecoregions outside of our focal geography. The ecoregional plan divided the ecoregion into five regions – the eastern and western Edwards Plateau, broad, flatter areas; the eastern and southern Balcones Escarpment, characterized by steep limestone hillsides and canyons; and the more centrally located Llano uplift, a granitic setting with rugged topography.

These variations in geology and topography contribute to very high species diversity. The "hill country" of east Texas is within the Balcones Escarpment. In this eastern part of the ecoregion, mixed-grass prairie systems more similar to the neighboring Southern Tallgrass ecoregion transition quickly to oak and juniper woodlands of the Balcones Canyonlands. From east to west within the ecoregion, the vegetation shows a strong transition from these open woodlands, to oak and mesquite savannas, to xeric shubland communities that are more similar to Chihuahuan desert flora. The limestone of the Balcones Escarpment also has formed caves and crevices that support unique invertebrates, some of which inhabit only one or a few caves.

Threats to the biodiversity and ecosystem functions of the Edwards Plateau include pressures from a rapidly growing human population, including the risk of depletion of the Edwards Aquifer, a resource that is dependent on recharge from functional ecosystems. Overgrazing, altered fire regimes, species invasions, and related impacts of habitat loss and fragmentation are key management challenges in this almost entirely privately-owned ecoregion.

Figure 4.76: Edwards Plateau Geophysical Settings.

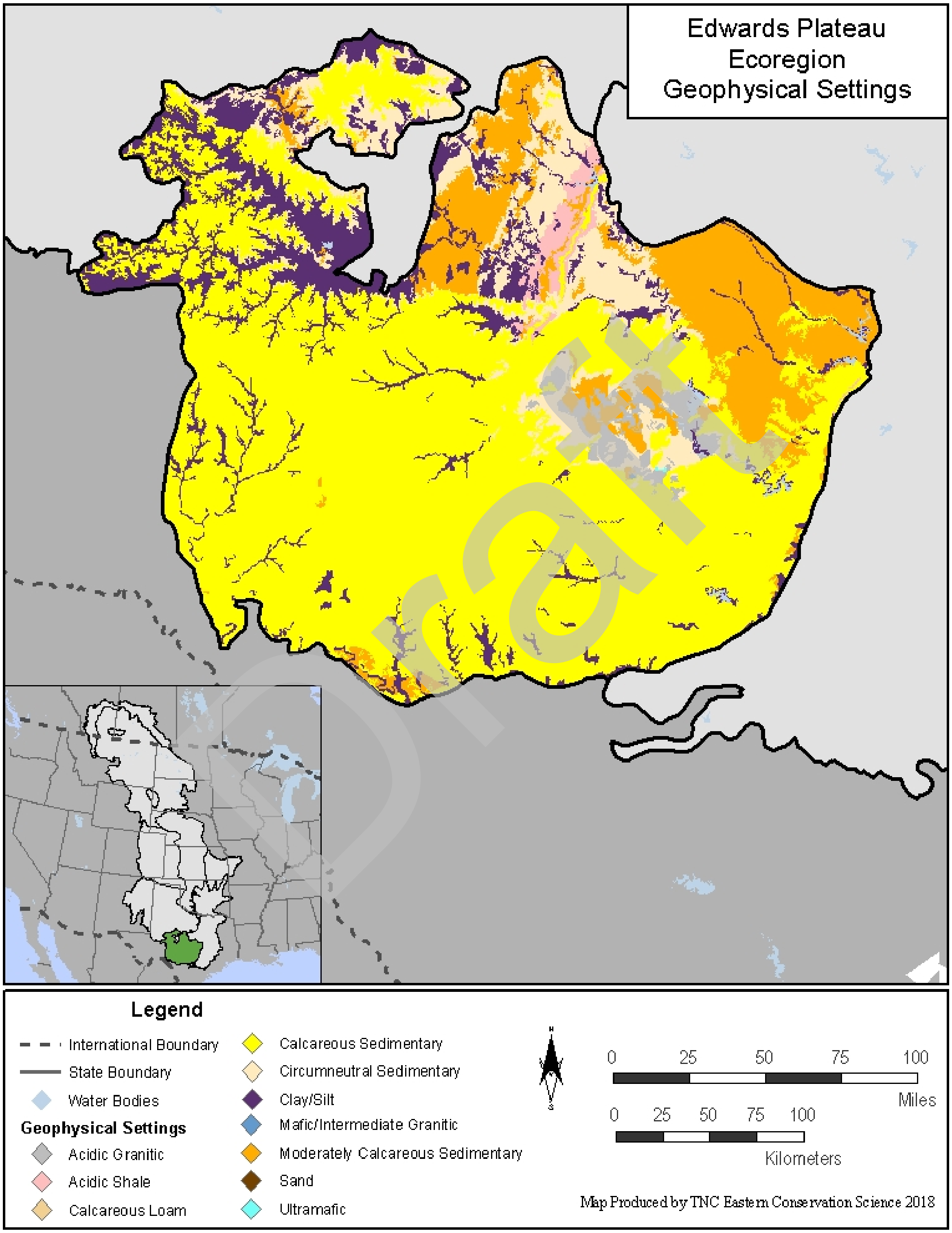


Figure 4.77: Edwards Plateau Landscape Diversity.

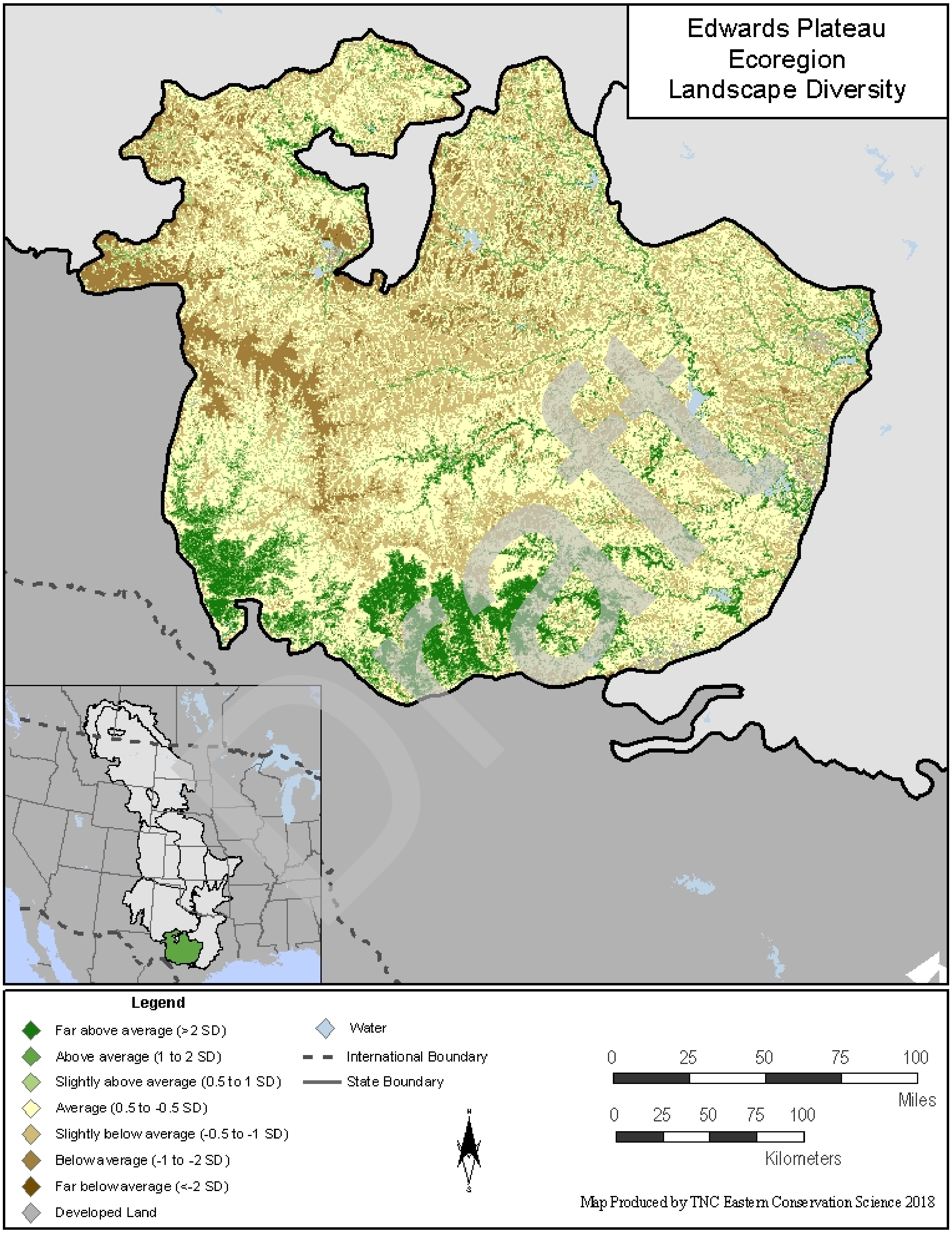


Figure 4.78: Edwards Plateau Local Connectedness.

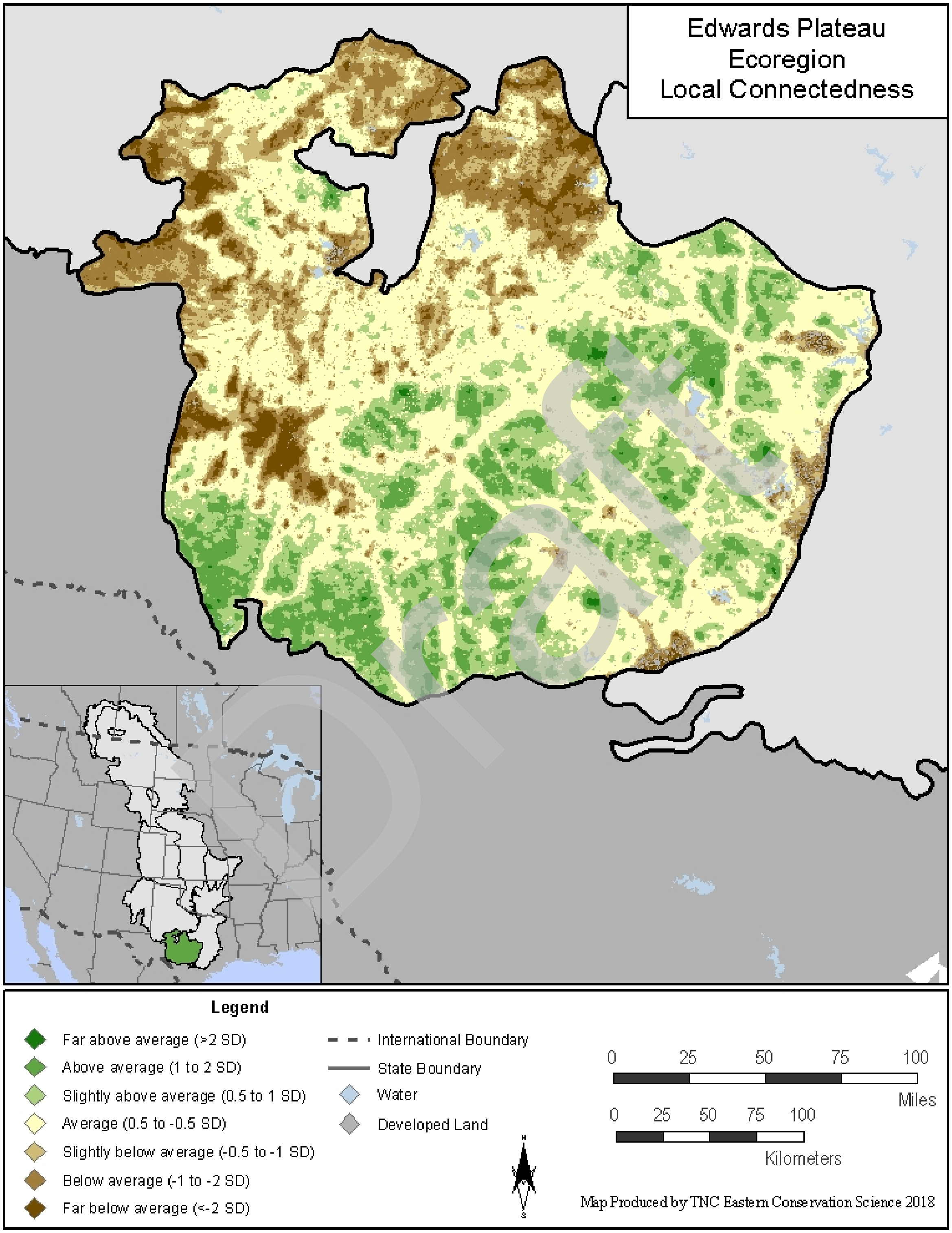


Figure 4.79: Edwards Plateau Site Resilience Scores.

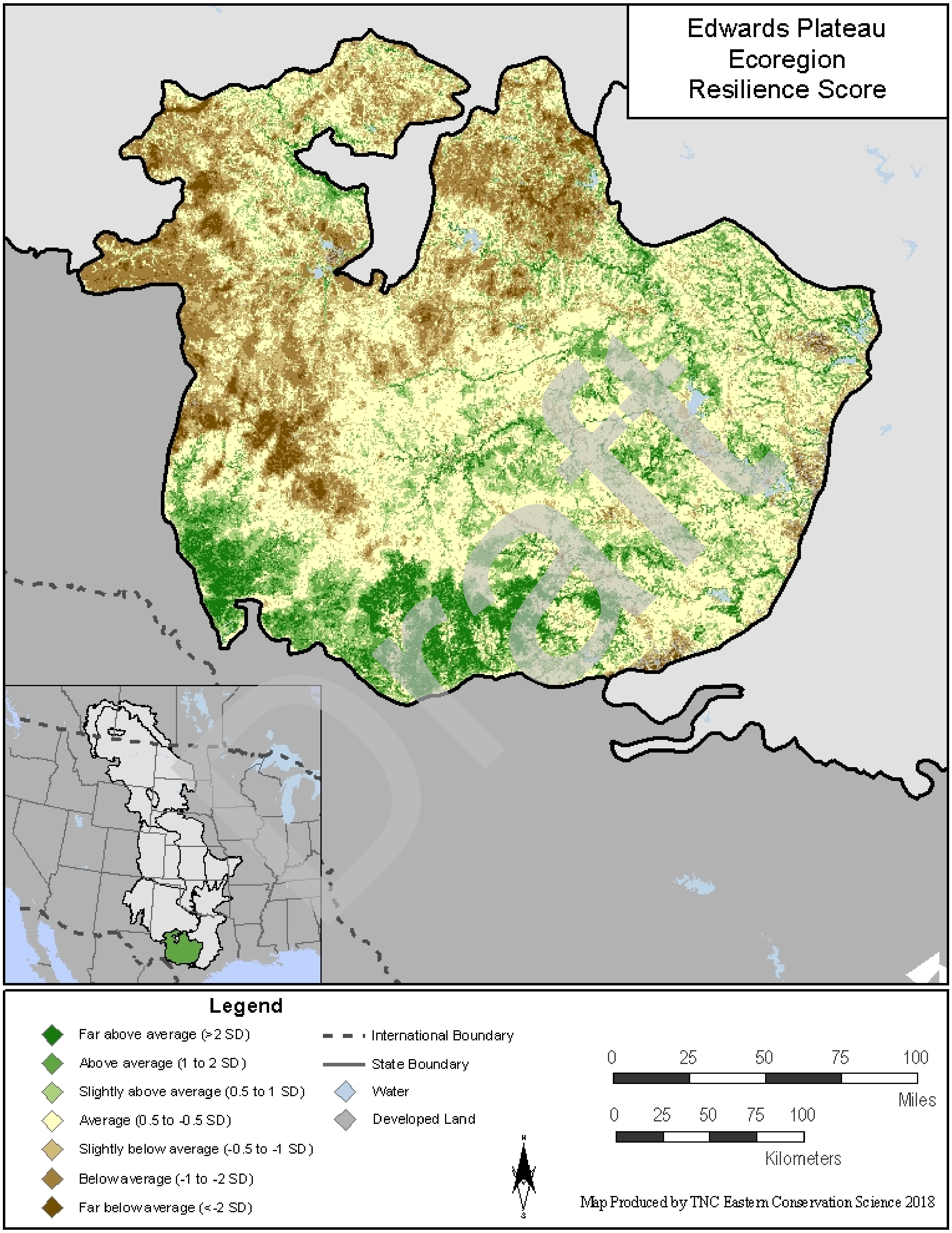


Figure 4.80: Highest Resilience Score Areas for Each Geophysical Setting in the Edwards Plateau.

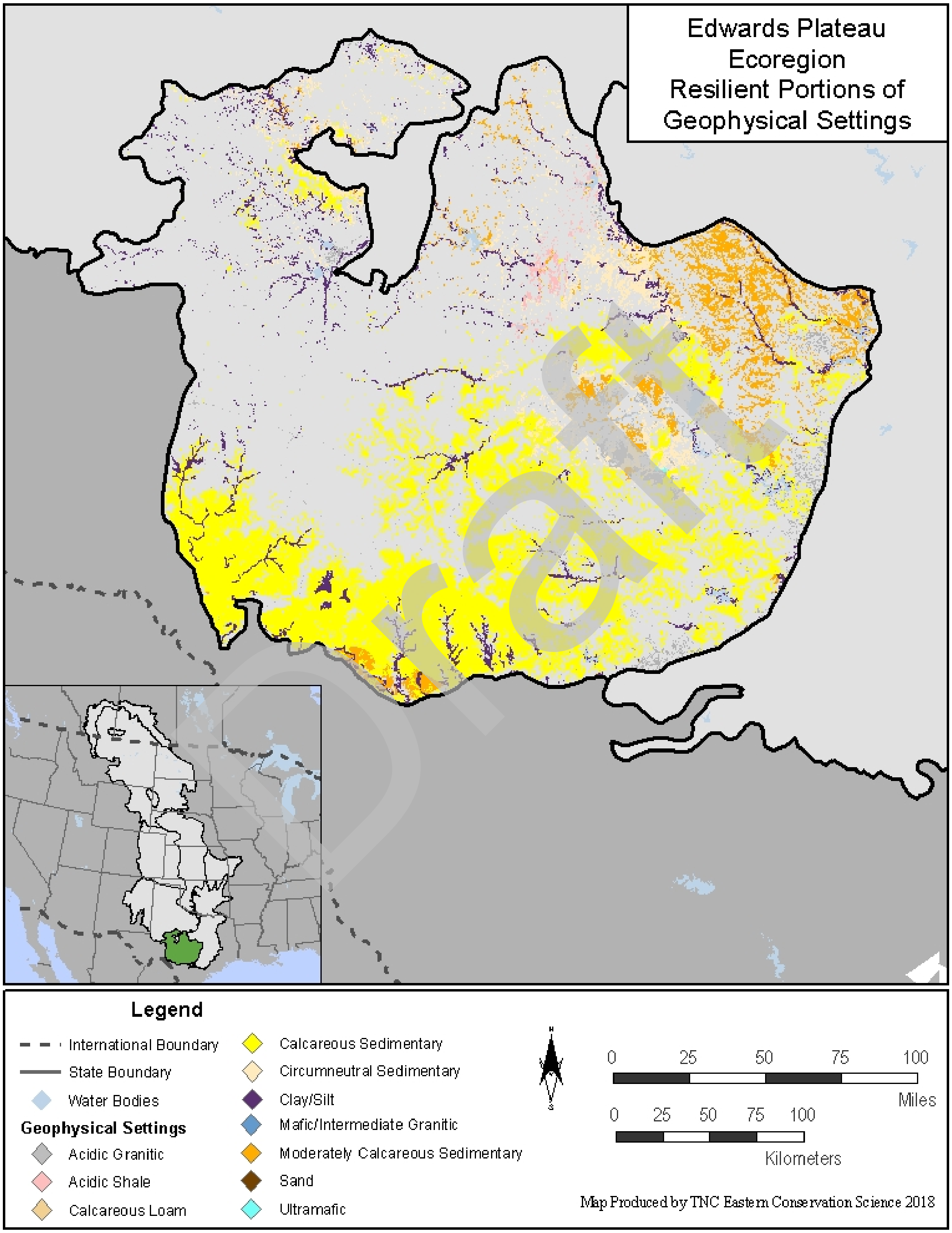


Figure 4.81: Edwards Plateau Geophysical Settings – Proportions by Area.

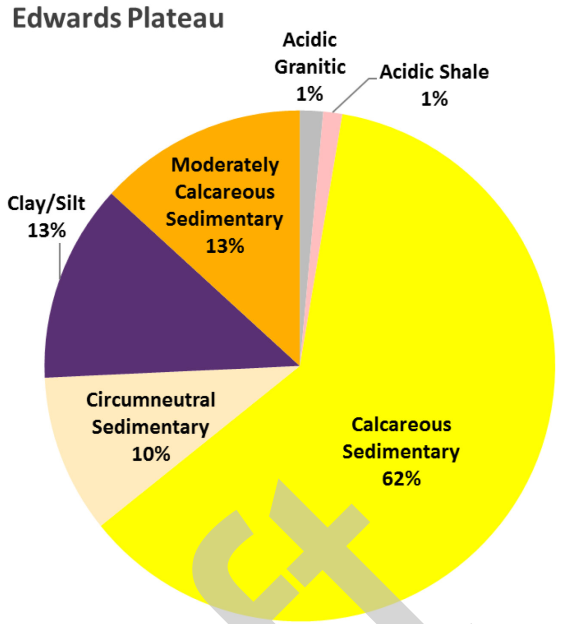
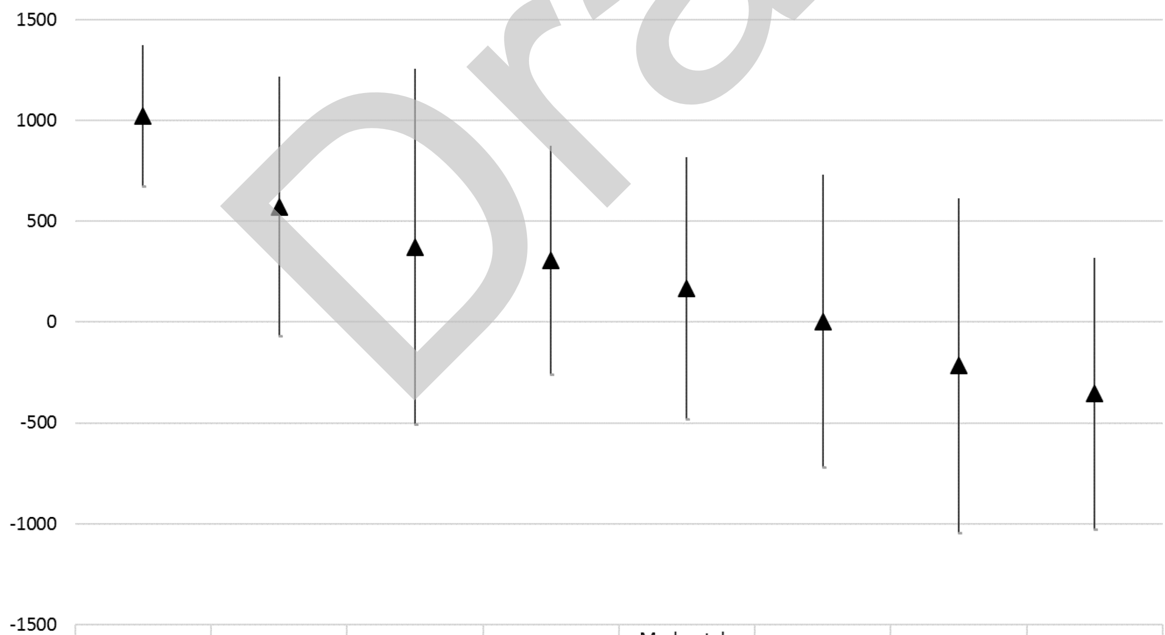


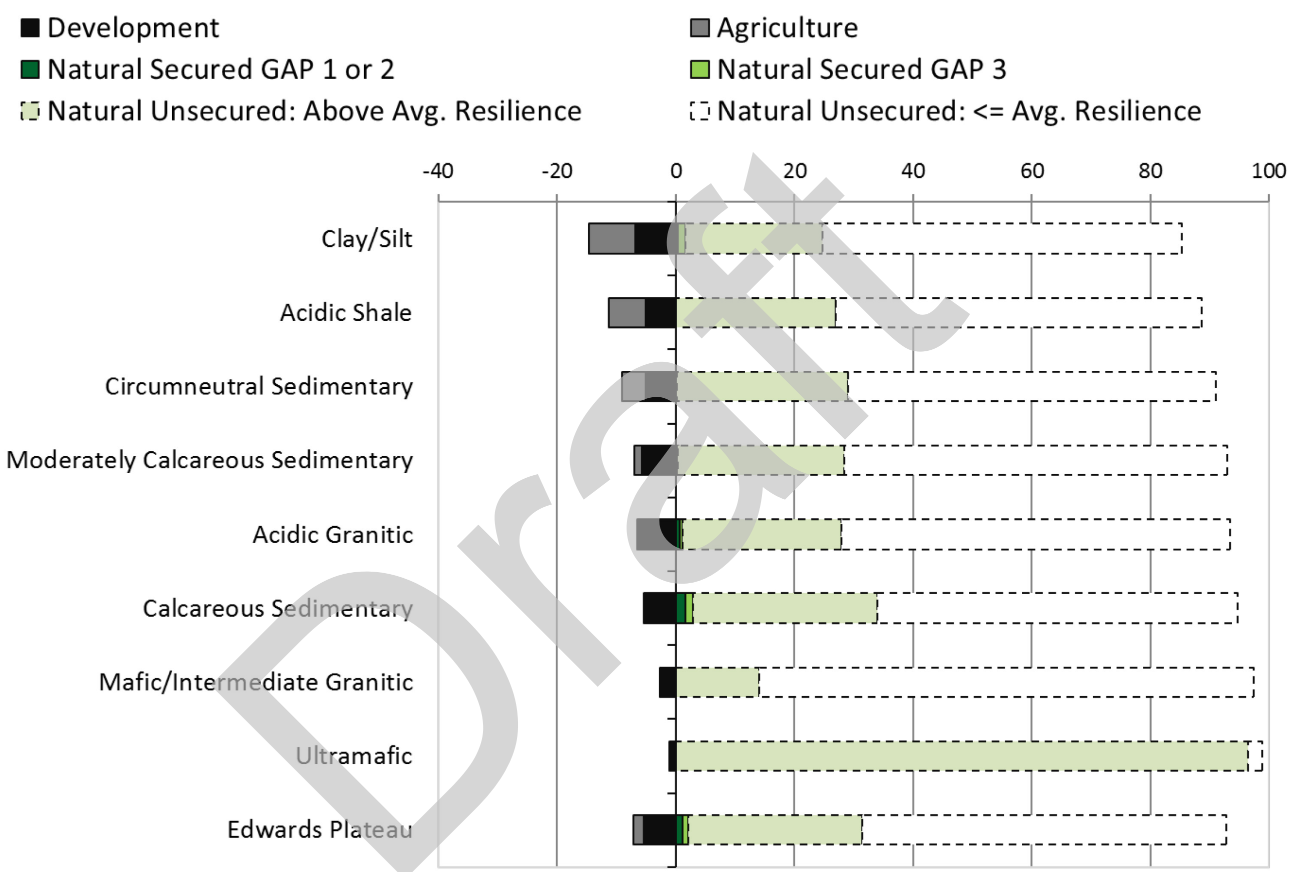
Figure 4.82: Edwards Plateau Geophysical Settings by Regional Resilience Score.



	Ultramafic	Mafic/Intermediate Granitic	Calcareous Sedimentary	Acidic Granitic	Moderately Calcareous Sedimentary	Circumneutral Sedimentary	Clay/Silt	Acidic Shale
Upper SD	1372	1218	1254	873	816	731	613	317
▲ MEAN	1021	572	372	305	165	3	-217	-356
- Lower SD	671	-74	-510	-263	-485	-724	-1047	-1030

Upper SD ▲ MEAN - Lower SD

Figure 4.83: Conversion and Securement of the Edwards Plateau Tallgrass Prairie Ecoregion by Geophysical Setting. This ecoregion is 7.2% converted and 2.1% secured, a ratio of 3.4 to 1. Within this ecoregion, 29.3% of the land (6.8 million acres) is in natural landcover and scored above average for resilience, but is not currently secured (is not in a GAP 1-3 protection category). The bar at the bottom shows percent conversion and securement, etc., for all settings combined.



CHAPTER

5

REGIONAL RESULTS

In the previous chapters, we described the rationale and methods behind Conserving Nature's Stage (introduced in Chapter 1), including how we defined geophysical settings (Chapter 2), and assessed the components of site resilience (Chapter 3). In Chapter 4, we presented the ecoregion-by-ecoregion results. In Chapter 5, we combine the ecoregion results into a composite final map for the whole Great Plains region.

In this chapter, we analyze the regional map in three ways: first, we view the results relative to different scales (region, ecoregion, and geophysical setting); second, we examine the extent to which each geophysical setting is currently conserved within the Great Plains region's protected lands; and third, we compare the results with the portfolio of biodiversity sites resulting from The Nature Conservancy's ecoregional planning efforts.

Site Resilience across Multiple Scales

To create a final site resilience map for the study region we rolled up the individual ecoregion maps presented in Chapter 4 into one composite map (Figure 5.1) and replaced the ecoregion score with the regional score in places where the regional score was higher (Figure 5.2). The latter step, which we called applying a "regional override," ensures that the highest-scoring sites in the Great Plains study area retain their high regional score. This override is needed when a high proportion of an ecoregion is relatively resilient (i.e. the Black Hills ecoregion, which as a whole is topographically diverse and relatively unfragmented), and thus the "average" for the ecoregion is much higher than the average for the entire set of ecoregions. The final site resilience map also incorporates a smoothing algorithm that is applied at the ecoregion boundaries to decrease any artificially sharp contrasts at the ecoregion edges. Details on implementing the regional override and smoothing algorithm are given below in "Methods for Creating the Regional Resilience Map".

The final resilient site map (Figure 5.2) is a compact way to display all the resilience information in a single map, but users should remember that the scores are relative to each ecoregion. For example, a resilience score of 2 SD (two standard deviations above the mean) in the relatively fragmented Southern Shortgrass Prairie, is not equivalent in an absolute sense to a resilience score of 2 SD in the relatively intact Black Hills, because the mean score of the latter ecoregion is higher. We intentionally used this relative scale so we could identify resilient areas across the full spectrum of geophysical settings and ecoregions, and by association support conservation planning that captures the full spectrum of biological diversity. If biological diversity were concentrated only in thin granitic soils, for example, then it would be easy to conserve diversity simply by focusing on this one geophysical setting. However, that approach would miss all the inherent diversity of the Sandhills, the eroded flinty limestones of the Flint Hills prairie region, and the sandstone grasslands of the Central Shortgrass Prairie. The differences in soils and topography that drive biological diversity also underlie the differences in land use patterns, contributing to differences in degree of protection.

Figure 5.1: Site resilience results for each ecoregion are combined to make the regional map.

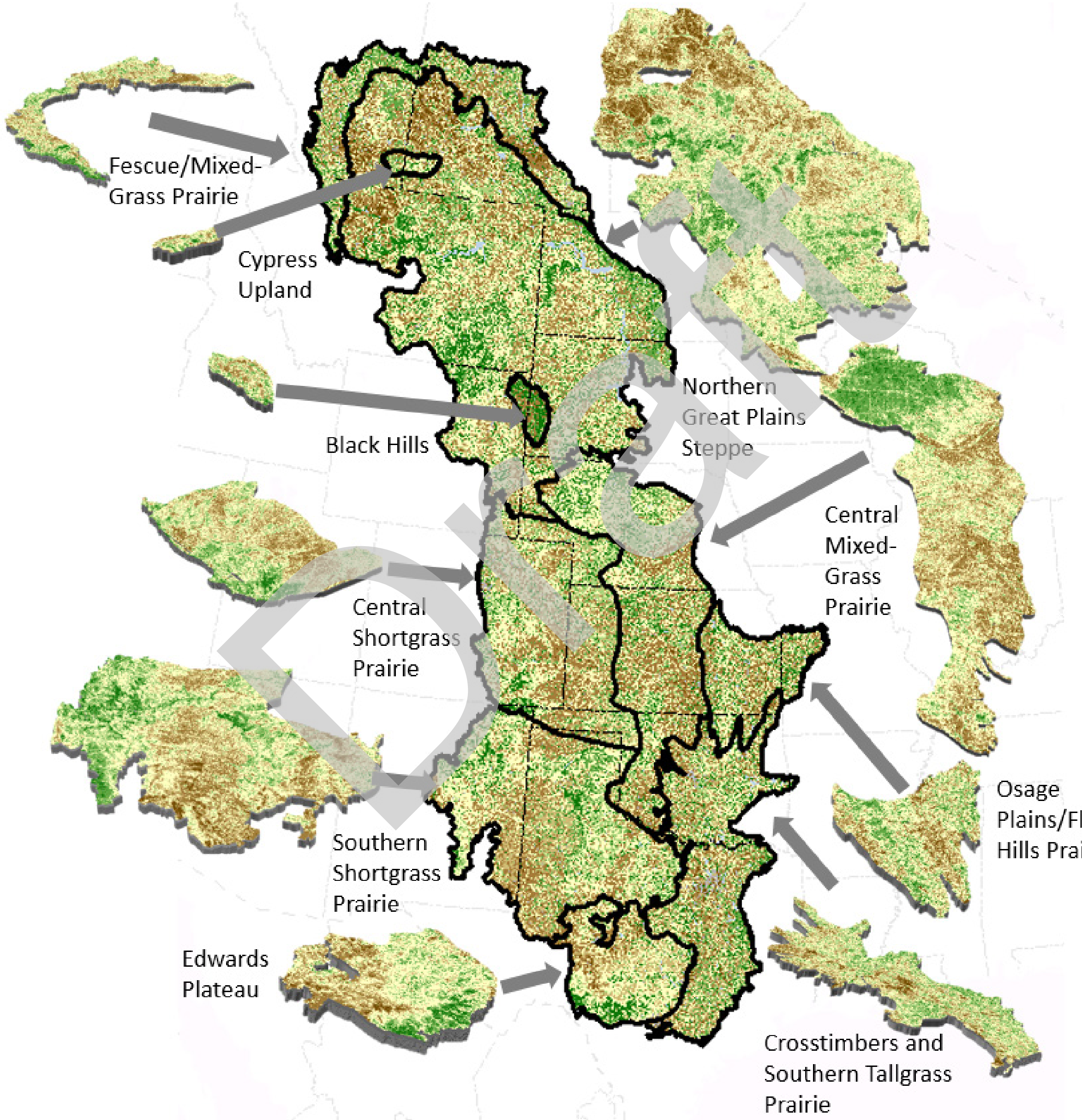
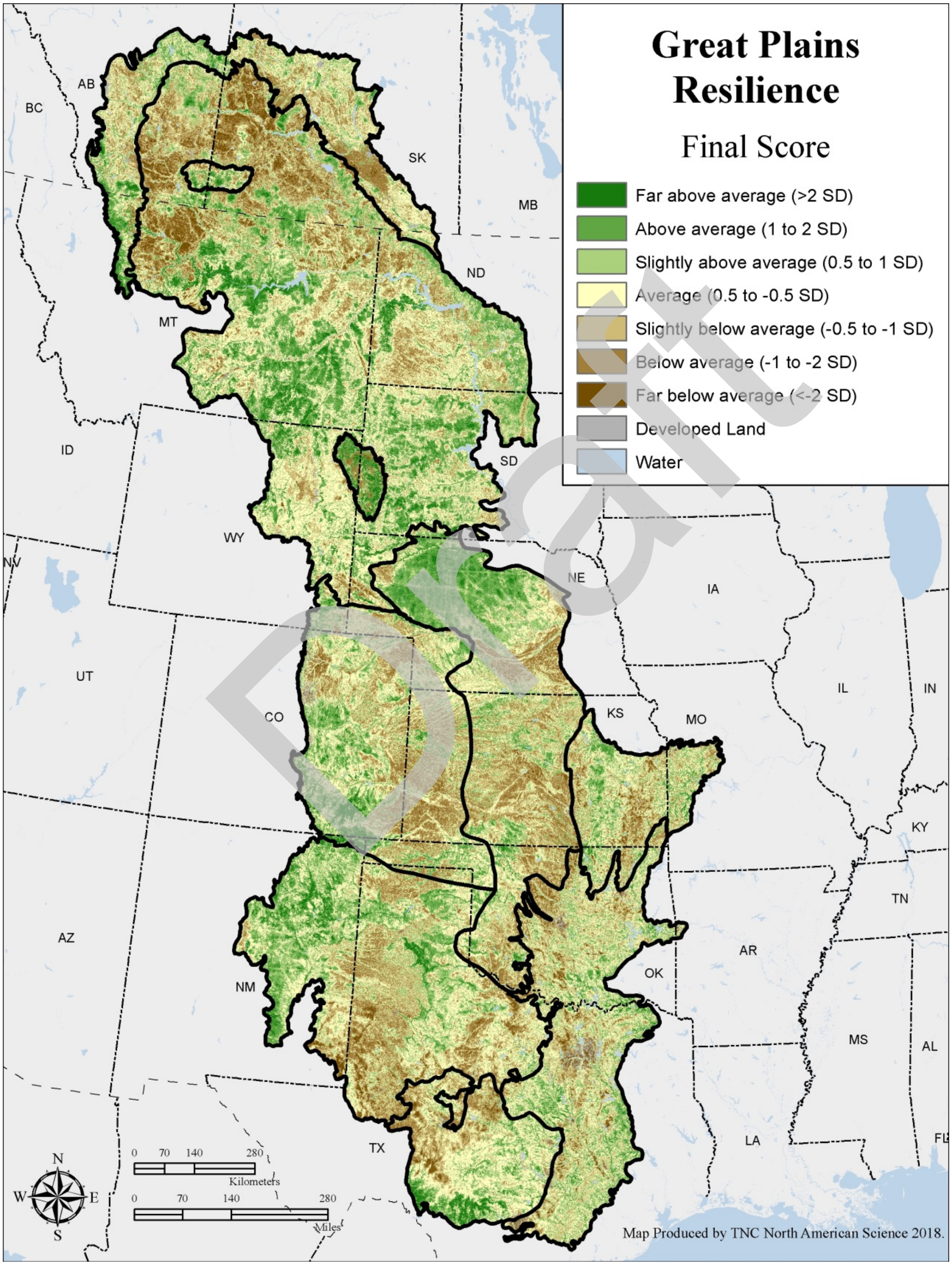


Figure 5.2: Final Regional Site Resilience Map. Areas in green score above average and are estimated to be more resilient to climate change relative to comparable geophysical settings in the same ecoregion. Areas in brown are below average and are considered more vulnerable to climate change.



To develop effective conservation strategies, it can be informative to examine the resilience scores across various scales, and the datasets we have developed allow for extensive exploration. The final regional site resilience map (Figure 5.2) incorporates the results from three queries, which are mapped in Figures 5.3-5.5.

Site resilience relative to Setting and Ecoregion (Figure 5.3). This map shows the resilience scores for each geophysical setting within each ecoregion. This is the composite (or "roll up") map of the site resilience maps for each ecoregion that includes the high resilience value sites for each setting from Chapter 4 without the application of the regional override.

Site resilience relative to Ecoregion only (Figure 5.4). This map shows the resilience scores for each ecoregion, displaying the score without the influence of the geophysical settings. In most ecoregions, the highest-scoring areas are bedrock settings, as they typically have more topographic variation (higher landform diversity) and are less fragmented than deep soil settings.

Site resilience relative to Region only (Figure 5.5) This map shows the highest-scoring sites in the entire study region. We used this query to create the regional override in the final regional map by selecting all cells greater than 1 SD above the regional mean. The highest scoring sites in the study area are in the Nebraska Sandhills (northern end of the Central Mixed-grass Prairie ecoregion), the Black Hills, the Powder River Basin of the Northern Great Plains Steppe and the southern end of the Edwards Plateau.

Resilience at Multiple Scales (Figure 5.6). This map shows the highest scoring sites across all three scales—region, ecoregion, setting—in all combinations. Two combinations identify sites that are resilient at multiple scales: the dark green areas show places with high site resilience scores at every scale, and the purple areas show sites with the highest scores at the two smaller scales, the ecoregion and the setting.

It is also useful to look at the individual components of resilience—landscape diversity and local connectedness—at the scale of the whole region. Like the final regional map, we created component maps that were composites of the individual ecoregions. The landscape diversity map (Figure 5.7) shows the areas within each ecoregion that have the most microclimates relative to the various geophysical settings. The local connectedness map (Figure 5.8) highlights the areas in each ecoregion that are the most intact and connected by natural land cover relative to each geophysical setting. Although we gave the two components equal value (weight) in the resilience score, depending on location, either component may have a stronger influence.

For example, in the Fescue Mixed-Grass Prairie and Canadian portion of the Northern Great Plains Steppe ecoregion, site resilience scores are influenced mostly by variation in landscape diversity. However, within the Cypress Uplands ecoregion, which is embedded in the Great Plains Steppe, variation in local connectedness has a greater influence on site resilience scores (Figure 5.9).

Figure 5.3: Site Resilience Relative to Setting and Ecoregion (no regional override).

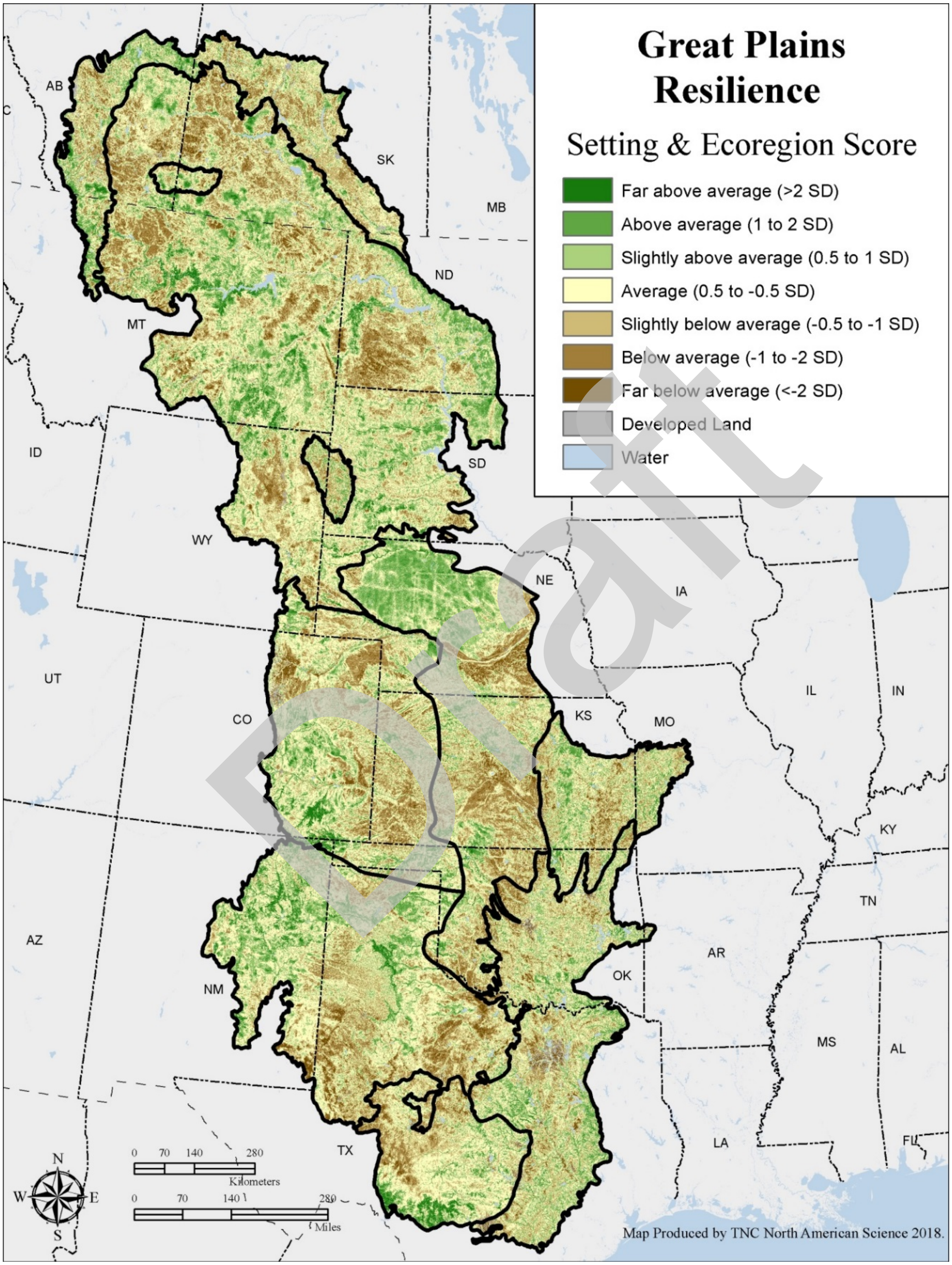


Figure 5.4: Site Resilience Relative to Ecoregion only (not the full region or settings).

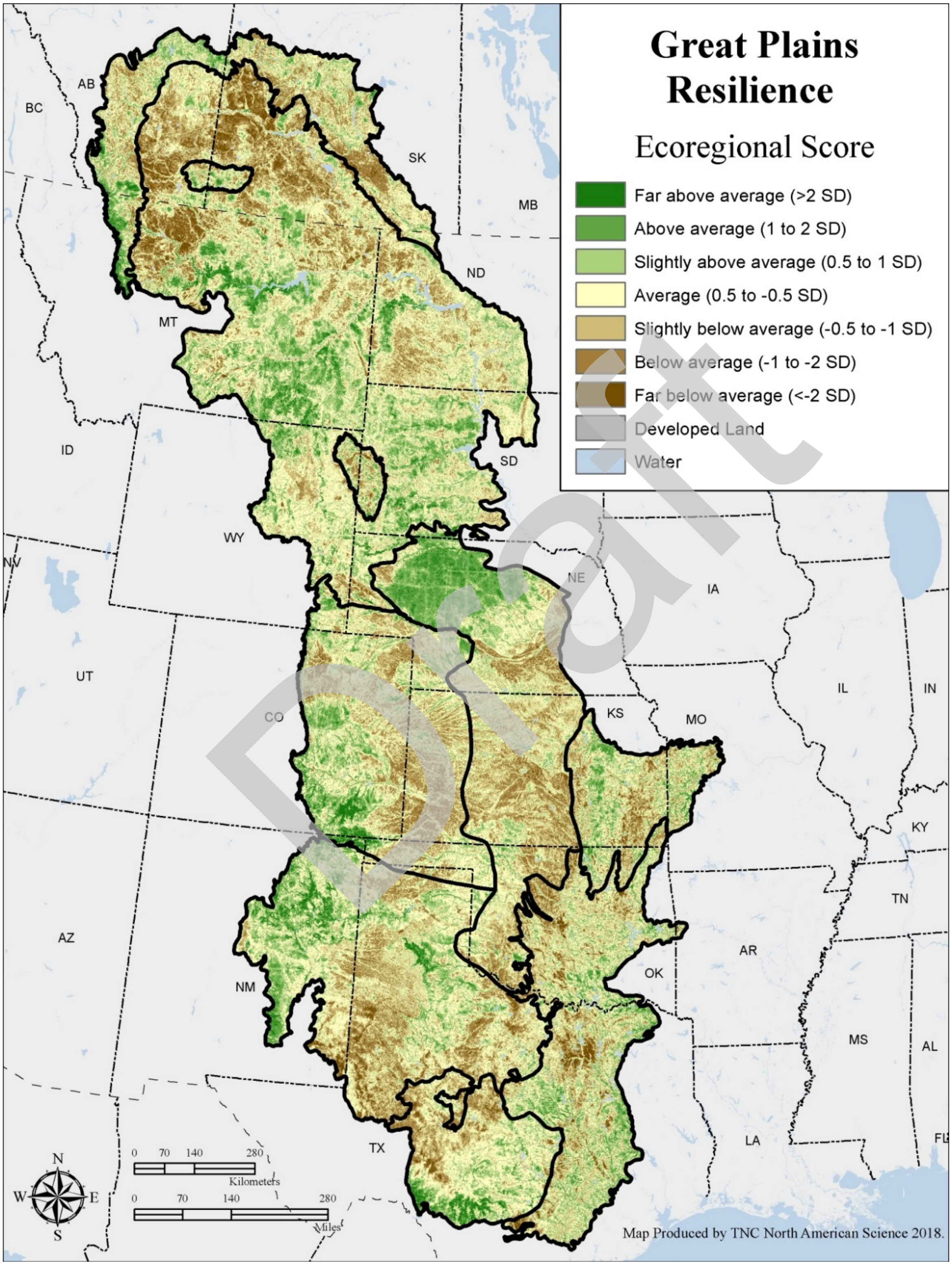


Figure 5.5: Site Resilience Relative to Region only (not settings or ecoregions).

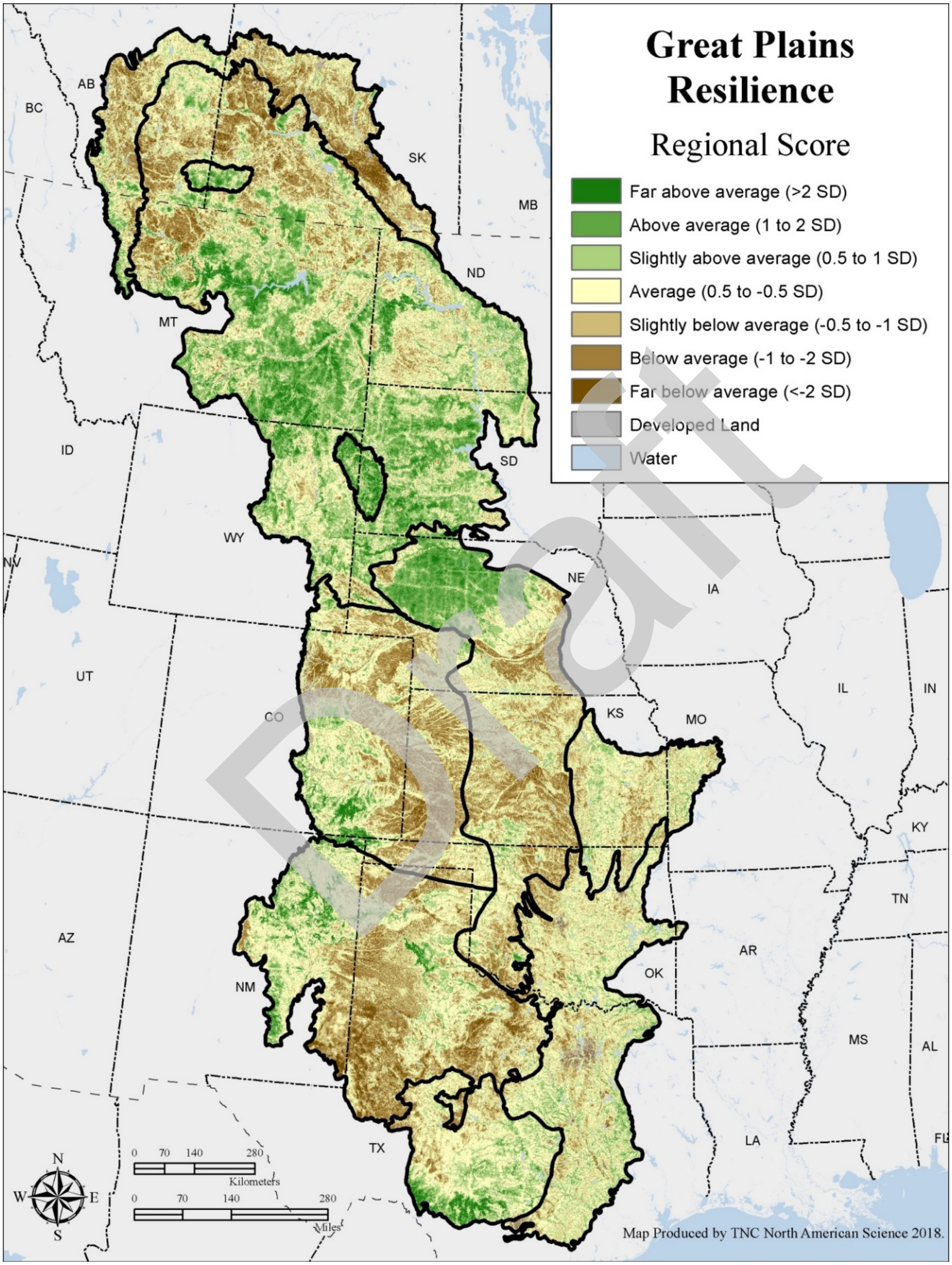


Figure 5.6: Site Resilience at Multiple Scales. This map shows the above average (>0.5 SD) scoring sites across all three scales—region, ecoregion, setting—in all combinations.

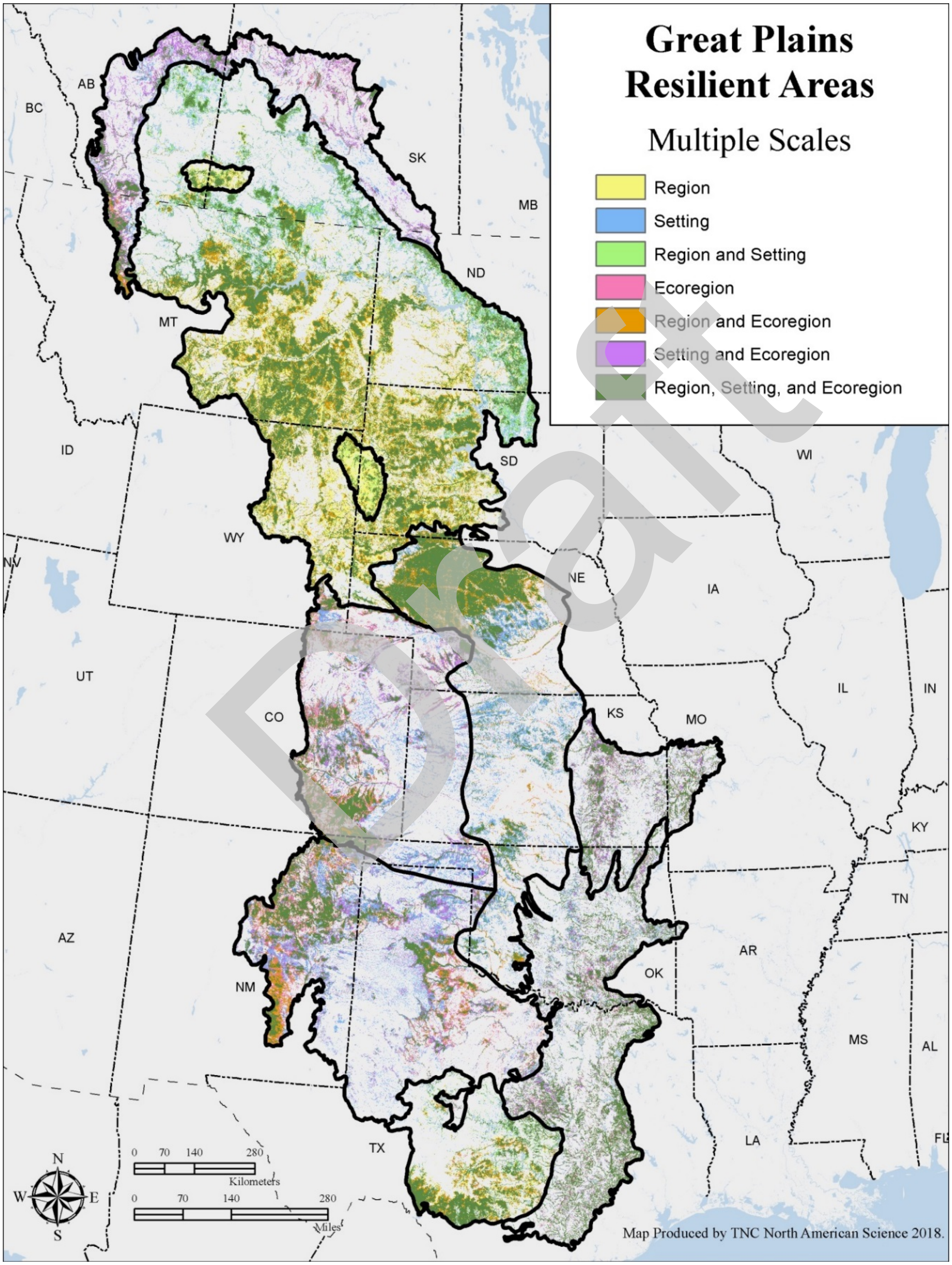


Figure 5.7: Landscape Diversity by Ecoregion and Setting with Overrides.

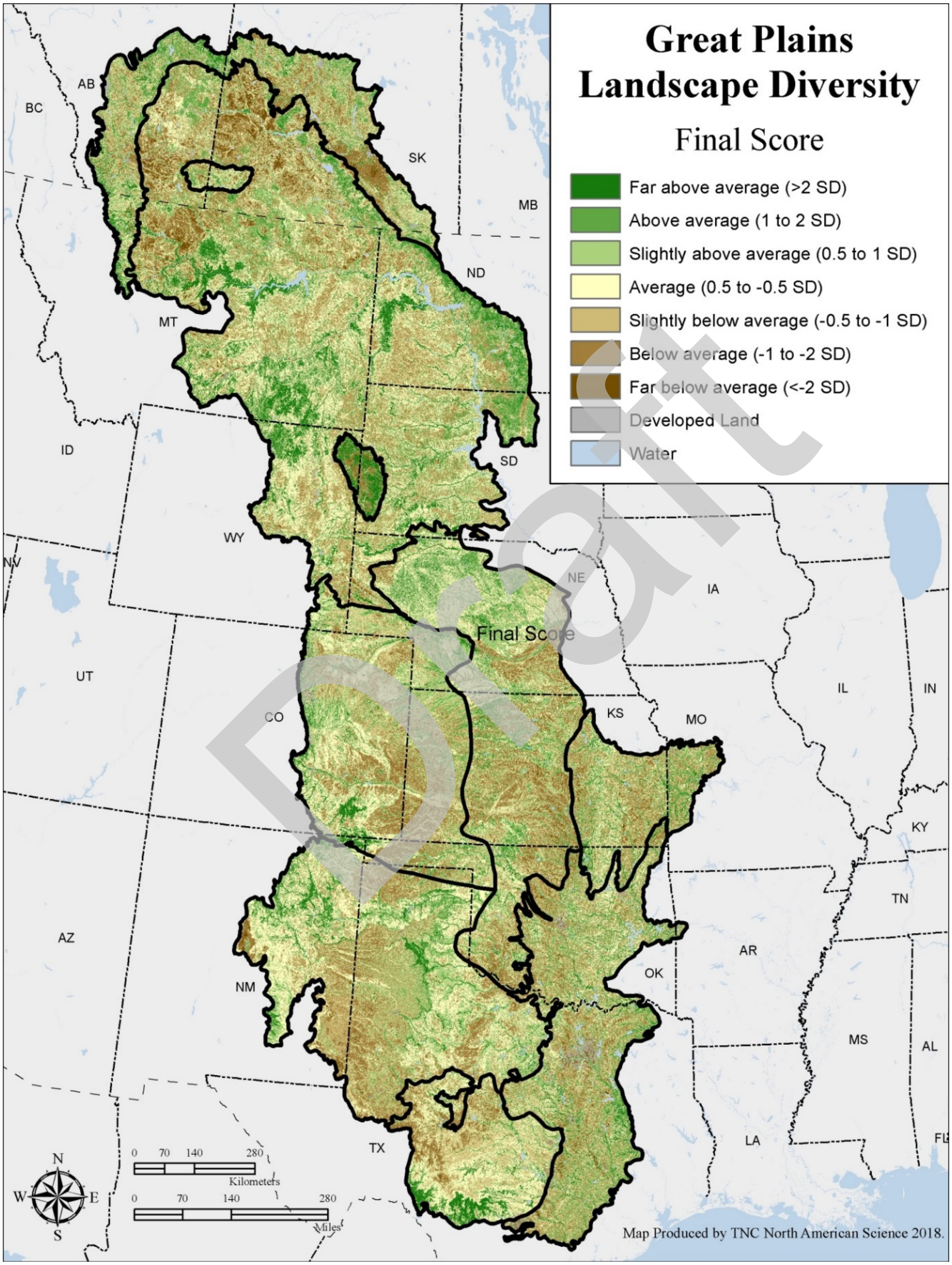


Figure 5.8: Local Connectedness by Ecoregion and Setting with Overrides.

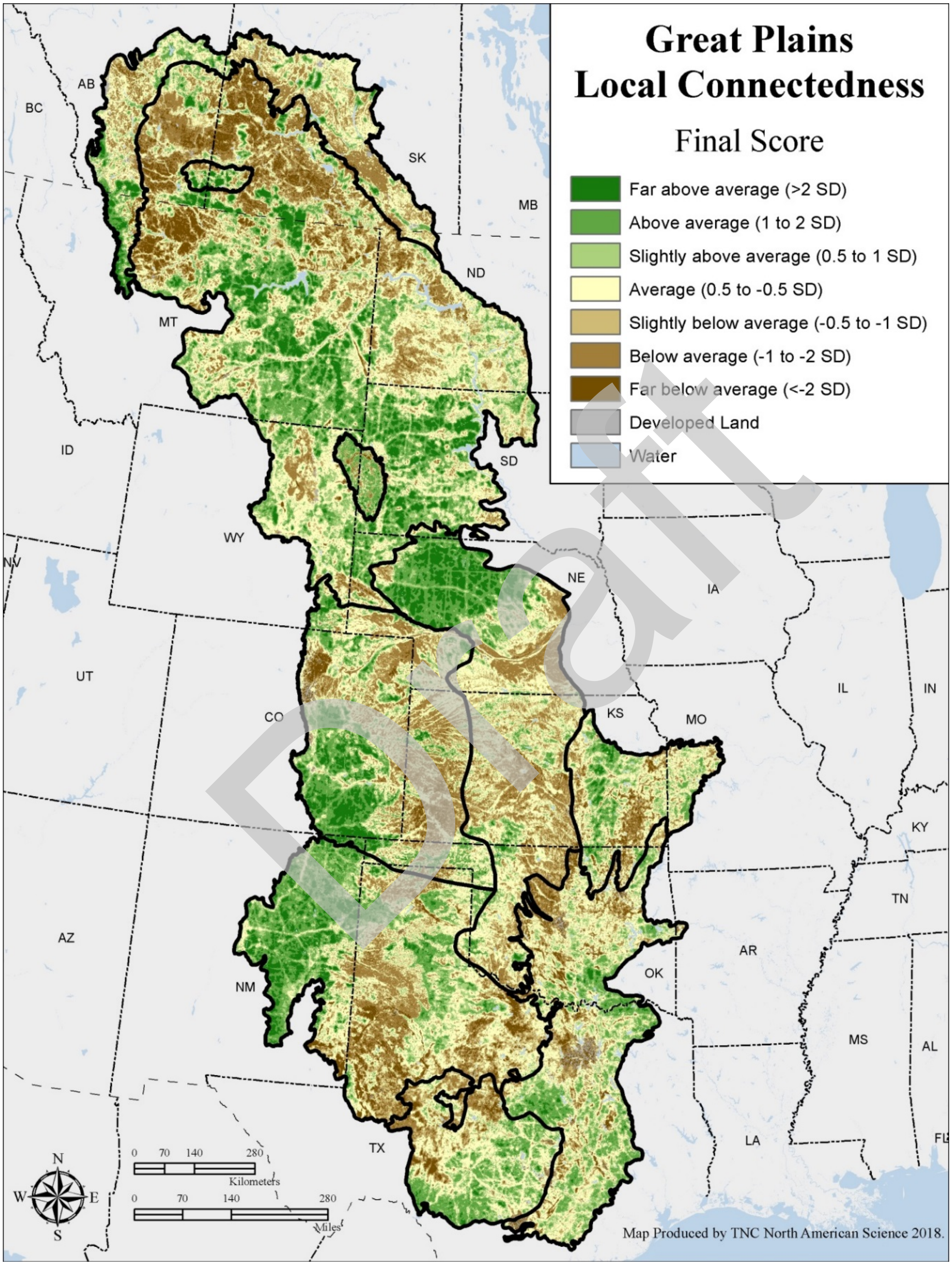
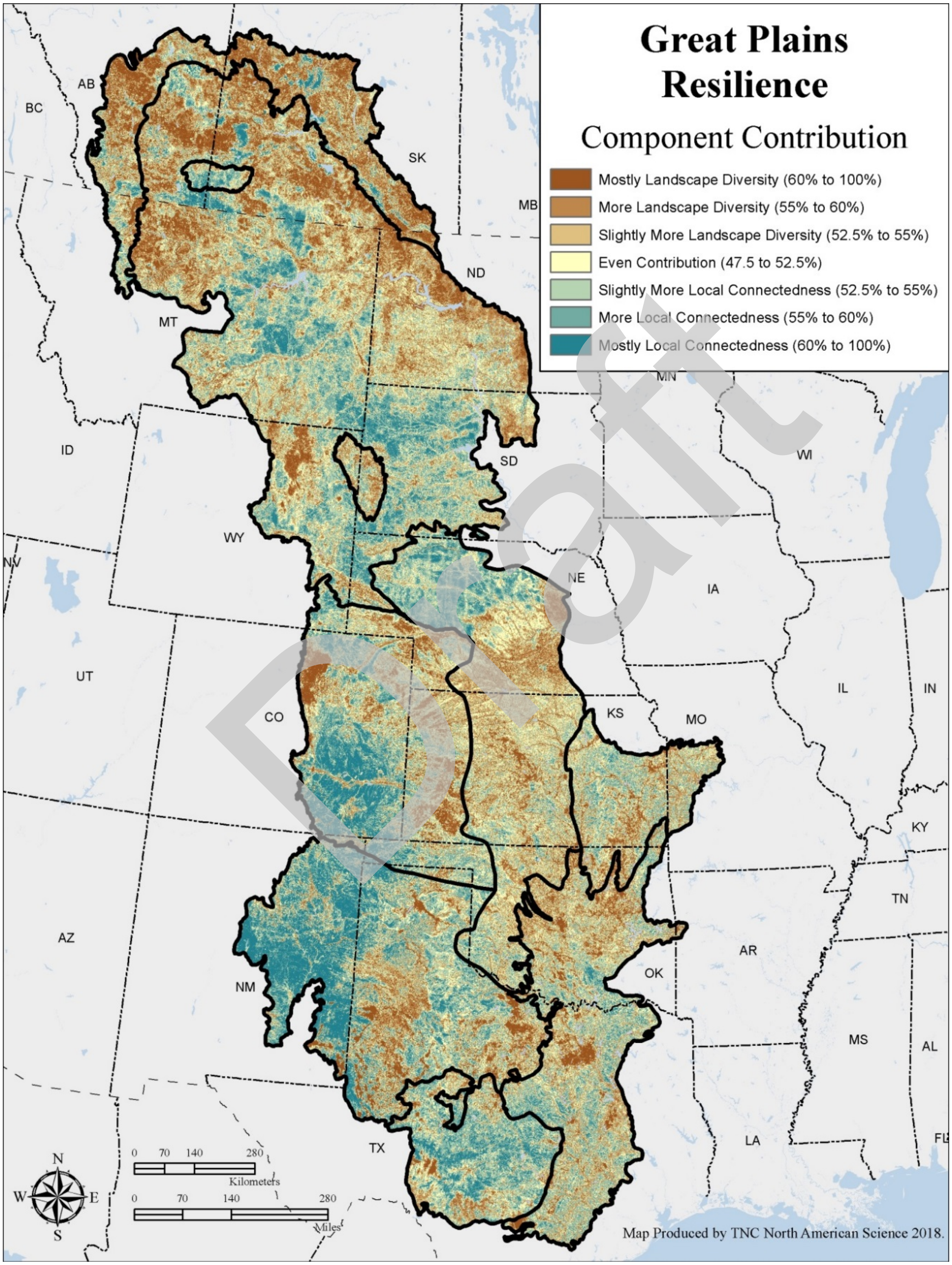


Figure 5.9: Comparision of Score Contribution. Resilience scores for sites (cells) shown in blue were more influenced by local connectedness, while scores for sites shown in brown were more influenced by landscape diversity.



Methods for Creating the Regional Resilience Map

The final regional resilience map (Figure 5.2) is a composite of the ecoregion maps (illustrated in Figure 5.1) to which we have applied an override that maintains high resilience values for the highest-scoring places in the full study area. This map was created using a set of stratification grids and by applying a smoothing algorithm to address sharp distinctions in ecoregion boundaries. The details behind these override, stratification, and smoothing steps are described here.

First, we created a grid of the raw (absolute) site resilience scores for the entire study area and stratified it by ecoregion. Stratifying the score means we calculated the mean and variance for each ecoregion, then transformed the values to Z-scores, which are units of standard deviations relative to the ecoregional mean. For example, a cell with a score of +2 SD in Northern Great Plains Steppe means the cell is two standard deviations above the mean resilience score for the Northern Great Plains Steppe.

Second, we repeated the process, this time stratifying the raw resilience score by geophysical setting within ecoregion, and calculating the mean score for each setting within each ecoregion. For example, a cell with a score of +2 SD for sand in the Northern Great Plains Steppe means the cell score was two standard deviations above the average score for all the sand cells in the Northern Great Plains Steppe ecoregion. We compared the two scores for each cell in the ecoregion, and if the setting score was greater than +1 SD and greater than the ecoregion score, we replaced the ecoregion score with the setting score. This step had the effect of boosting the resilience score for higher scoring sites in settings that had mean scores below the ecoregion mean score. The intent of this step is to correct biases in final scores that are caused by difference in topographic variety (number of microclimates) and connectedness that are inherent to or typical of different setting types. Otherwise, bedrock settings with high relief and lower land conversion rates would almost always have higher scores than surficial settings like loess, loam, and sand.

Third, we repeated the review process one more time, this time focusing on the mean and distribution of raw resilience scores at the scale of the entire study region. We compared the regional site resilience score (Figure 5.5) cell-by-cell with both the ecoregion (Figure 5.4) and the setting by ecoregion score (Figure 5.3), and if the regional score was greater than +1 SD and greater than the other scores, we used that value for the regional score in the final map. This had the effect of boosting the score in places where the regional score was higher than the ecoregional or setting mean.

Smoothing the Ecoregion Boundaries

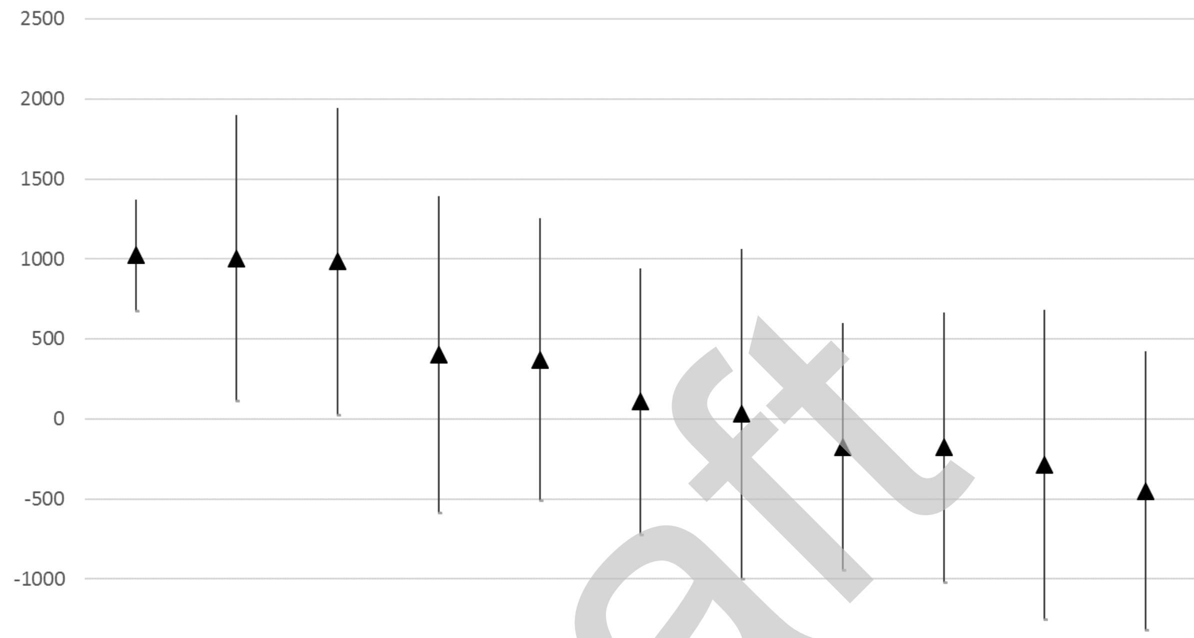
To create a more cohesive final map, we corrected sharp edge effects that occurred when adjacent ecoregions and settings had wide differences between their means, leading to strong differences in resilience scores. These strong differences in neighboring scores typically occurred in situations where two adjacent ecoregions had relatively strong differences in mean landform complexity or local connectedness values. In these cases, cells on either side of an ecoregional boundary often had roughly equivalent raw resilience scores, but after the values were stratified by ecoregion and setting, the relativized scores were quite different due to differences across the ecoregions as a whole. This appearance of a high contrast in scores was artificial because ecoregional boundaries are gradual in nature and do not change exactly at the edge of a 30-m cell. To reduce this effect in our maps, we developed a method to create a gradual transition around the boundary line which we called an "ecoregional fade." The ecoregional fade uses a distance-weighted average of the cell values near the ecoregion boundary, so that the scores of cells near the boundary reflect the relative scales of both ecoregions in proportion to the distance of the cell from the boundary. For instance, a cell directly on the boundary receives 50% of its score from each ecoregion, but a cell closer to the center of one ecoregion receives a higher proportion of its relativized score from that ecoregion. The script was applied within a 20-km buffer around the ecoregional boundary. We examined other buffer distances to verify that the smoothing effect was limited to the buffer area and did not distort scores for areas more than 20 km from ecoregional boundaries. To ensure that the component maps added up to the final resilience score, we implemented the ecoregional fade three times, once for landscape diversity, once for local connectivity, and then for the final resilience map.

Resilience by Geophysical Setting

Differences among geophysical settings in relationship to soil fertility, structural properties of bedrock, and the hydrologic cycle of groundwater flow have been recognized for centuries. Most human settlement has occurred in gentle landscapes with productive soils, and not surprisingly, most conservation areas are located on poor soils with steep slopes (Anderson et al. 2014b). As a result, fertile settings like this region's loess and calcareous loams are not only less topographically complex, but also more fragmented by human use. This pattern is reflected in the overall means of the regional resilience scores (i.e., z-scores calculated for the entire study region, Figure 5.5). For example, ultramafic, mafic and acidic granitic settings, which are associated with rough topography, remote locations, and thin soils, have the highest mean resilience score. In contrast and the fertile clay/silt and calcareous loams settings have the lowest mean resilience in the region (Figure 5.10).

These differences in the landforms and land use associated with various settings emphasize the importance of carrying the highest scoring sites for each setting type through to the final map. Ensuring that high resilience sites for each setting type are shown is an essential part of supporting the goal of providing a tool that helps us to capture the full spectrum of biodiversity in our conservation lands. However due to these inherent differences across settings, maintaining and restoring resilience in some settings will take more effort and attention than in other settings, even when working at sites with the highest estimated resilience.

Figure 5.10: Regional Resilience Scores by Geophysical Settings. The average regional resilience score for each geophysical setting in standard normal units (z-scores). For example, the average score for the mafic bedrock setting is +1.0 SD higher than the regional mean.



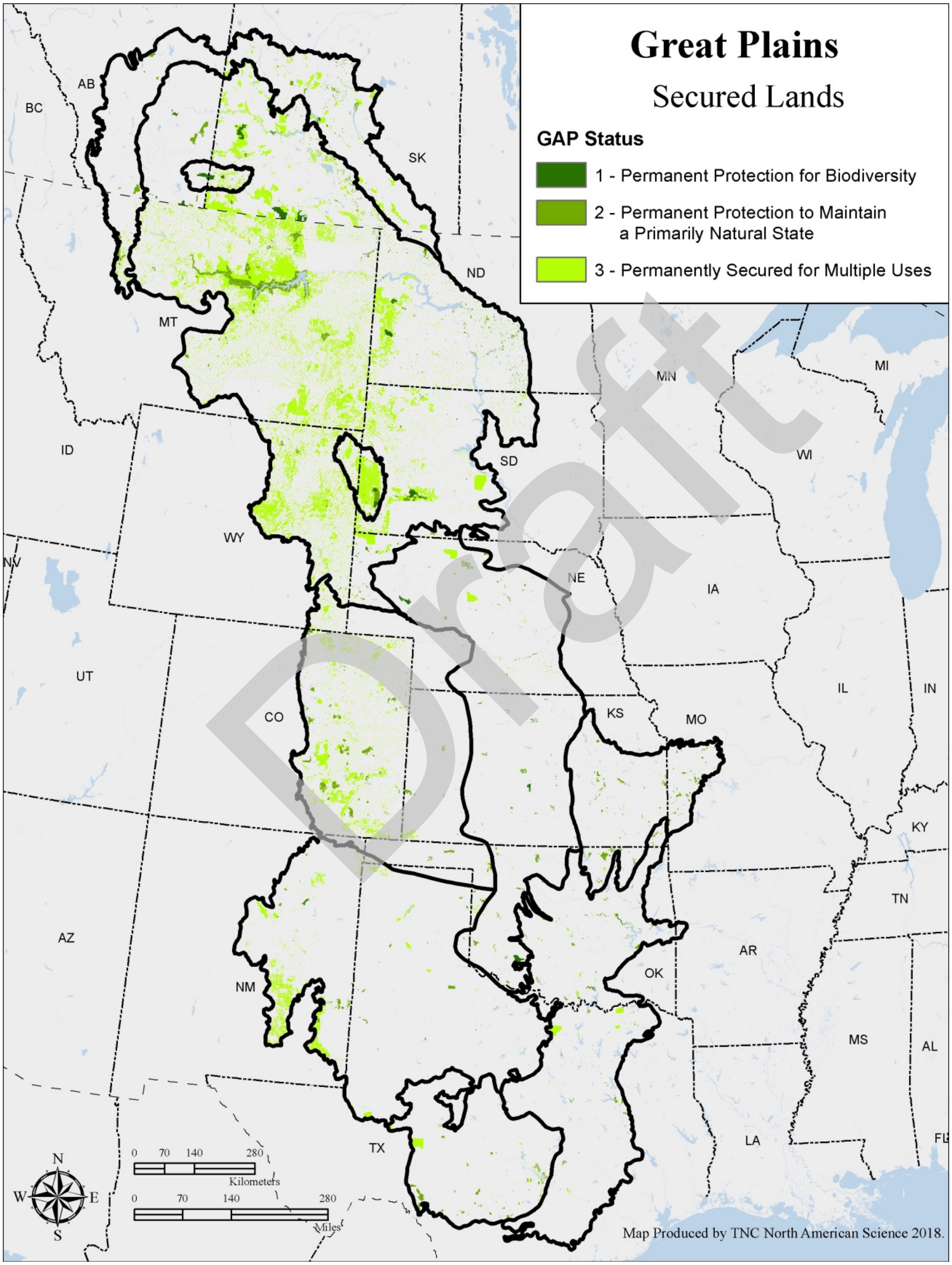
	Ultramafic	Mafic/Intermediate Granitic	Acidic Granitic	Circumneutral Sedimentary	Calcareous Sedimentary	Moderately Calcareous Sedimentary	Sand	Deep Loess	Acidic Shale	Clay/Silt	Calcareous Loam
Upper SD	1372	1899	1946	1391	1255	939	1065	597	664	683	423
▲ MEAN	1021	1003	984	400	370	107	30	-176	-180	-286	-452
- Lower SD	671	107	22	-591	-516	-726	-1006	-950	-1024	-1256	-1326

Upper SD ▲ MEAN - Lower SD

Resilience and Conservation Lands

Patterns in land securement and conversion are useful for understanding which geophysical settings are well protected and which ones are underrepresented in the current set of conservation areas. We evaluated this discrepancy by overlaying the compiled dataset of lands permanently secured against conversion (PADUS 2016, NCED 2017, TNC 2018) on the resilience and geophysical setting layers. Overall, only 7% of the land in this region is permanently secured against conversion, and 32% is converted to development or agriculture. Land securement is concentrated in the Northern Great Plains Steppe and Black Hills ecoregions with very little securement in the southeastern ecoregions such as the Central Mixed-grass Prairie, Osage Plains/Flint Hills Prairie, Cross Timbers and Southern Tallgrass and Edwards Plateau (Figure 5.11). Land securement corresponds closely with soil type. The fertile calcareous loams and deep loess of the prairie regions are both over 50% converted, with only 4% of the loam and only 0.5% of the loess secured from conversion. In contrast, the thin granitic bedrock soils are only 4% converted and are 21% secured from conversion (Table 5.1).

Figure 5.11: Secured Lands. Distribution of conservation lands that are permanently secured against conversion displayed by GAP status. (Data Source: multiple sources available at end of chapter)



The ratio of conversion to securement—the conservation risk index—can provide an idea of the relative vulnerability of a setting to the threat of conversion. We calculated these ratios and found that deep loess had the highest risk (102 to 1), followed by clay/silt (Table 5.1, Figure 5.12). We also examined how much of the remaining unconverted land was climate-resilient (> +0.5 SD) or climate-vulnerable (< -0.5 SD) and found that roughly 50% of the remaining unconverted deep loess setting scored high for resilience and could theoretically be secured. Overall, settings with relatively fertile soils (e.g., deep loess, clay/silt, calcareous loam) had the highest risk, while acidic settings (e.g. acidic granitic, mafic/intermediate granitic) were less converted and more secured. By studying the locations of resilient unsecured lands (Figure 5.13), conservation practitioners can focus attention on at-risk settings and begin to address disparities in conservation coverage.

Resilience and The Nature Conservancy Portfolio

The Nature Conservancy maintains information on critical sites for biodiversity conservation developed over the last 20 years through ecoregional assessments. The assessments identify targets relative to rare species and exemplary natural communities and map a portfolio of sites that if conserved would protect habitat using multiple representative examples of each target. For the most part, climate change was not considered in TNC's ecoregional assessment process, which focused largely on the size and quality of the target occurrences. Here we compare the spatial correspondence between the TNC portfolio (TNC Ecoregional Rollup 2012) and the regional resilience map to highlight place that score high both for resilience and current biodiversity (Figure 5.14). Results indicate that 88% of the TNC portfolio occurs on land that scores average or above for resilience, including 58% that scores above average and 30% that scores average (-0.5 to +0.5 SD). Only 12% occurs on vulnerable land that scores below average for resilience (<-0.5 SD). The map also identifies 100 million acres of resilient land that is currently outside TNC's portfolio including Canadian areas of the Fescue/Mixed-Grass Prairie where there was no TNC portfolio.

Table 5.1: Geophysical Settings: Conversion and Securement. Summary for each geophysical setting of the total number of acres, percent converted to either development or agriculture and percent "secured" in protected status. The table is sorted by the Conservation Risk Index, the ratio of converted to secured lands.

Geophysical Settings	Total Acres of Land	% of Acres Converted	% of Acres Secured	Conservation Risk Index
Deep Loess	13,379,688	53.3	0.5	102.1
Clay/Silt	29,637,010	39.8	3.1	12.8
Calcareous Loam	128,213,853	52.7	4.4	12.1
Sand	82,164,084	28.1	6.5	4.4
Moderately Calcareous Sedimentary	54,505,149	18.8	4.5	4.2
Acidic Shale	3,087,570	11.9	3.5	3.4
Circumneutral Sedimentary	128,308,604	20.1	13.3	1.5
Calcareous Sedimentary	19,509,671	6.6	7.8	0.9
Mafic/Intermediate Granitic	1,539,703	2.6	10.5	0.2
Acidic Granitic	912,376	4.3	21.2	0.2
Ultramafic	2,136	1.1	0.0	NA
Great Plains Total	461,259,842	31.9	7.3	4.4

Figure 5.12: Conservation Risk Index of each Geophysical Setting. The proportion of conversion to securement for each setting, further divided by the type of conversion and the resilience score of the remaining unsecured natural land.

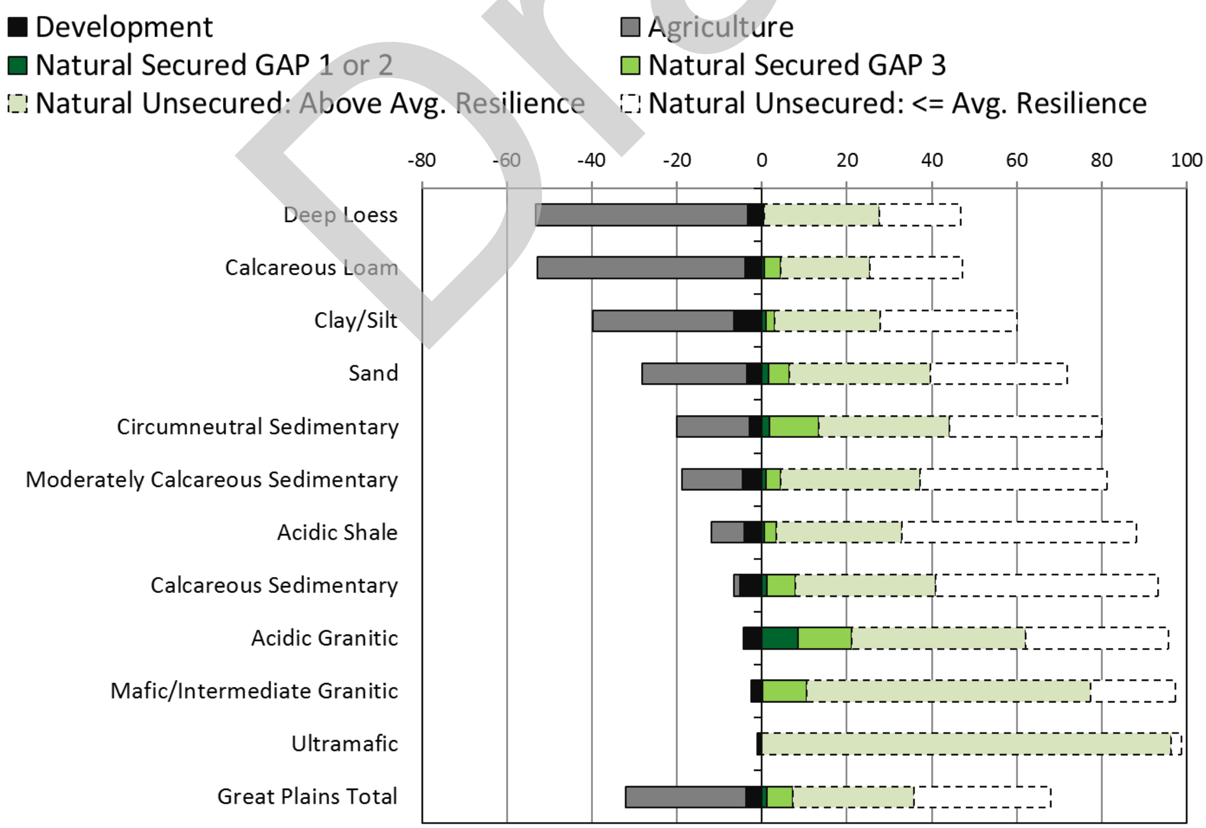


Figure 5.13: Resilient Areas and Secured Lands.

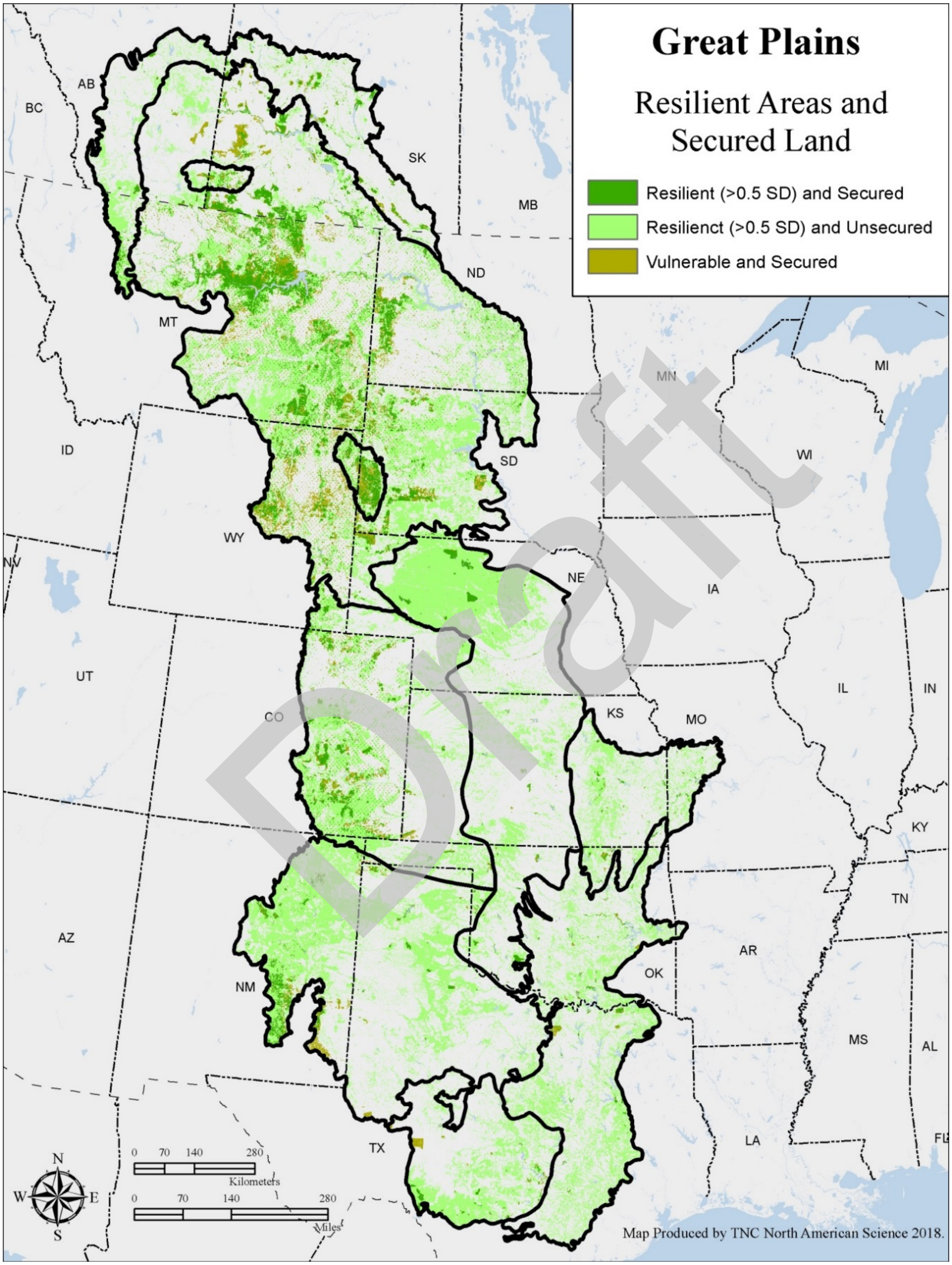
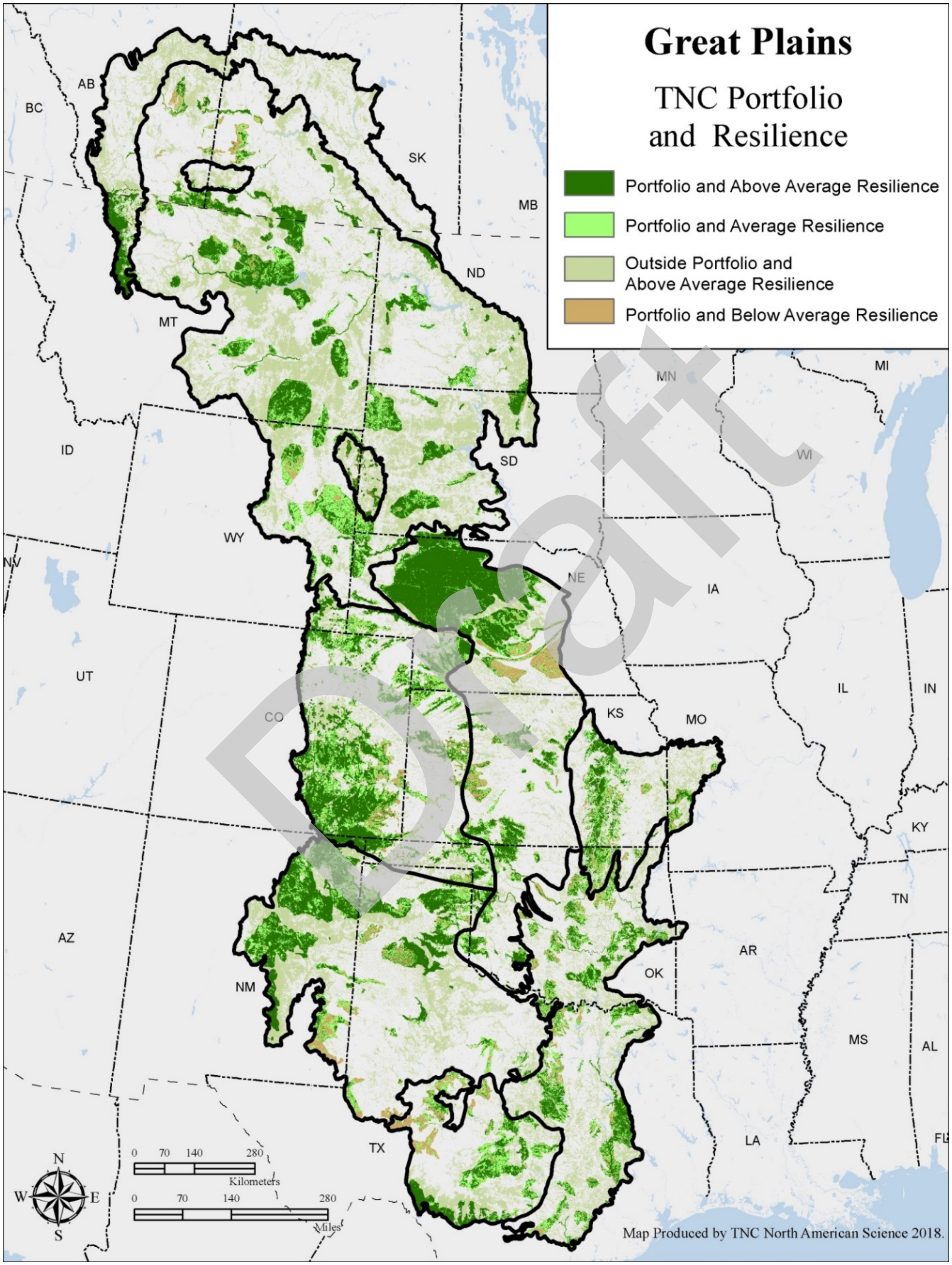


Figure 5.14. Resilient Areas and Existing TNC Conservation Portfolio. (Data Source: TNC Ecoregional Rollup, 2012)



Discussion

This project assessed 461 million acres of land across the Great Plains region to identify the areas with the highest estimated resilience relative to each of 10 ecoregions and 11 geophysical settings. Our analysis was based on estimates of microclimate diversity and local connectedness, two attributes that appear to be predictive of site resilience to climate change, and that could be mapped at a regional scale. By balancing our protection efforts across the full spectrum of geophysical settings and using site resilience criteria to select places for conservation action, conservationists can make sound decisions about where to commit the resources needed to sustain diversity under a changing climate, even as species distributions change and ecological communities reorganize.

Our emphasis on enduring land characteristics that influence the distribution of the biota and their sustaining resources implies a long-term perspective. These tools are thus well-suited for informing choices on where to invest in land protection, or implement restoration strategies. They can also help inform site-scale adaptation strategies where variation in a site's resilience factors suggest higher or lower vulnerability, which can be addressed through specific management tactics and monitoring plans. Further, the maps and assessments in this report allowed us to see the sites and landscapes we seek to protect through a new lens, expanding our focus from the many readily-apparent drivers of current species loss to envisioning how we can help nature adjust to a rapidly changing world - with a goal of sustaining a dynamic and diverse natural world capable of adapting to continued climate change.

An advantage of our approach is that it is robust to the uncertainty inherent in predictions of climate change based on regional scale models. Climate models are invaluable for understanding the general direction and magnitude of change. However, the ability of most climate models to forecast fine-scale species responses has been critiqued because they do not account for biotic interactions, dispersal limits, topographic influence, or the large variation around each estimate of temperature or precipitation (Beal et al. 2008, Araujo and Peterson 2012). Instead of selecting places for conservation based on predicted climate exposure or a future scenario derived from an ensemble of climate models as in most climate vulnerability studies, we identified places that would be resilient to many different climate scenarios because of the temperature and moisture variability inherent in the physical structure of the sites. Landscape-based climatic variation has been demonstrated to be on par with or larger than expected regional changes over the next century, and is more relevant to plants and animals that experience climate at very local scales (Chapter 3).

We place a considerable emphasis on the role of microclimates in sustaining local biodiversity, the evidence for which is substantial and growing (Chapter 3). Understanding microclimates, topoclimates and climatic microrefugia is now a hot-topic of research, and some suggest it may revolutionize climate change biology (Hannah et al. 2014). Species populations use microclimates in multiple ways: to persist for a limited time under deteriorating climatic conditions (holdouts), to facilitate range shifts (stepping stones) or to persist through a long period of unfavorable climates (microrefugia). Conservation strategies built around holdouts and stepping stones make logical sense under a rapidly changing climate (Hannah et al. 2014), although microrefugia have clearly played a needed role in past climatic events (Rull 2009, Keppel and Wardell-Johnson 2015). From the perspective of sites, areas with high microclimate diversity may serve all these functions, but more studies quantifying the climatic differences among microclimates, and how species exploit these differences, would greatly improve our ability to predict site resilience.

Current research is also reinforcing the value of connectivity in facilitating adaptation and has strong historical evidence and widespread agreement among the scientific community (Chapter 3). Improving the local connectedness of a site is an achievable strategy in many places, and much more feasible than increasing topographic diversity at a meaningful scale. The final maps and datasets of local connectedness and landscape diversity may prove useful for conservationists investigating the independent influence of each of these factors on a site. For example, users of this analysis can identify places where increasing local connectivity could significantly improve the current resilience score or areas where the resilience score is more limited by the inherent low landscape diversity. It is also important to remember that the type of species and system that have evolved to occupy sites differ, even across sites with similar topography. Our approach does not consider these differences, but native prairies that have evolved under the often extreme range of climate variability found in the Great Plains are likely to be much more climate-resilient **ecological systems** than most, a fact that should be considered when these maps are used as part of a toolbox for identifying conservation and protection strategies. Along with these patterns of ecological system resilience and vulnerability, we suggest users also consider other aspects of condition such as past or current land uses, and incorporate their own local information, such as fine scale species studies, habitat quality information, or assessments of risk and feasibility, when using this analysis to make decisions.

It is worth repeating that this study does not predict what the future will look like in terms of vegetation structure or species composition. The places identified will likely be important strongholds for diversity in the future because of their enduring geophysical characteristics, and they can provide the framework for a network of conservation lands aimed at sustaining diversity and ecological services. However, sustaining the natural diversity of this region will require many other actions, and elements of this work may help inform a variety of current conservation activities. For example, land managers seeking to prioritize areas for invasive tree removals could use the resilience and landscape diversity maps to determine what areas would be most likely to benefit from increased connectivity, or where these removals could favor potential grassland expansion into more topographically diverse areas.

With the help of our steering committee, we tried to make our analysis as transparent, consistent, and verifiable as possible. However, we necessarily approached site resilience as a relative concept because there are no known absolute thresholds. Within an ecoregion, we could confidently say that one area had more topoclimatic variation and was more connected than another area, but how completely those characteristics buffer the site from climate change varies greatly across ecoregions. Despite the relatively gentle topography across most of the region, some ecoregions had very high proportions of natural landcover and other ecoregions had only fragments of natural landcover left (see Chapter 4). For example, a high scoring site in the mostly converted Crosstimbers and Southern Tallgrass Prairie ecoregion may be less resilient and need more management than a site with an equivalent score in the Northern Great Plains Steppe. This relativity was necessary because we were as interested in conserving tallgrass prairies and playas as we were in conserving mixed-grass prairies, forests and canyons, but these natural systems occurred in fundamentally different ecological contexts. Thus, the resilient areas may provide the best physical sites for sustaining biodiversity and ecological functions, but in some ecoregions, they will still require considerable management and restoration to sustain the desired properties.

This report is a revision and integration of four previous studies on identifying resilient sites for terrestrial conservation in the Northeast (Anderson et al. 2012), Southeast (Anderson et al. 2014a), Great Lakes and Tallgrass Prairie (Anderson et al. 2018) and the Pacific Northwest (Buttrick et al 2015). This new study combines and (we hope) improves on methods to make a unified map for the North Central United States and Canada. We received extensive feedback on previous versions, and most of it came from conservationists thoughtfully applying the results to places that they knew well. This ground testing was largely reassuring, but it also revealed important ecological variations that we had missed (surficial soils in the Crosstimbers region) or problems in the datasets (one-cell stock ponds mapped as wetlands). We have done our best to incorporate all the good suggestions into this latest study, but certainly there will still be discrepancies. Our intention is to continue to work with our Steering Committee members to develop additional outreach products and examples that facilitate exploration of these rich data products, and we encourage feedback and suggestions from our peers on how we can continue to improve the approach, and can correct specific problems.

As with previous studies in other geographies we found a high correspondence between sites identified for climate resilience based on their geophysical characteristics and those selected for the high quality of their biodiversity features in The Nature Conservancy ecoregional portfolio. Portfolio sites overlapped 58% with above-average and 30% with average site resilience cells, but these sites are not all protected. We also found strong biases in the conservation lands, with the ratio of conversion to securement (conservation risk index) strongly skewed against fertile settings like deep loess (102 to 1), clay/silt (13 to 1) and calcareous loam (12 to 1). These settings were also among the lowest in raw resilience score (Figure 5.10). Because our method identified relatively resilient sites for every geophysical setting, this study identifies places for future conservation that could correct the bias in current secured lands. We encourage conservationists to explore opportunities to expand protection in these underrepresented settings.

Our method also identified low-scoring, vulnerable sites, places where biodiversity may be depleted following conversion, fragmentation and disruption of natural processes. We expect that these sites will increasingly favor opportunistic or generalist species adapted to high levels of disturbance and anthropogenic degradation. Although climate change is expected to exacerbate the degradation of vulnerable sites, this does not necessarily mean that conservation and proactive management are not important. Less resilient sites may still perform many natural services, such as buffering storm effects or filtering water, and may provide connectivity for some taxa. Through comparing and contrasting scores with locally compiled GIS information (or with our on-line tool: http://maps.tnc.org/resilientland/), underlying resilience patterns will become clearer, and will provide new insights into risks, strongholds, and action areas. We know our own understanding of this remarkable region has been greatly improved through studying these patterns with our steering committee as we performed this study.

Given the immediacy of climate change, we hope our approach and these products provides new and useful guidance for conservation planning.

DATA SOURCES

Secured Lands:

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URL: http://www.ccea.org/download-carts-data/. Date Downloaded: January 30, 2018

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PADUS – Conservation Biology Institute. Conservation Biology Institute. September 1, 2016. Protected Areas Database of the US, PAD-US (CBI Edition), version 2.1.
URL: https://consbio.org/products/projects/pad-us-cbi-edition. Date Downloaded: February 12, 2018

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