Prospect refugia: constructing climate change resilient ecosystems

by

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Abstract

“Prospect Refugia: Constructing Climate Change Resistant Ecosystems” is a landscape design playbook developed to inform and prepare landscape architects and land planners about the changing climatic threats facing the world and how to mitigate ecosystem degradation caused by climatic forces. The ecosystem construction playbook acknowledges global and national trends while proposing regional and site-specific design strategies. Regional and site-specific focuses help maximize the protection of native high-taxa biodiversity and high-risk species from extinction and extirpation due to climate change. While design of refugia is the focus of this document, connectivity of individual refugium and remnant habitats is paramount to success of a greater refugia system. Borrowing principles from Grose (2017), Forman & Godron (1981), and Forman (1995; 2008) my work builds upon existing foundations of landscape connectivity and novel ecosystem construction for climate change resilience. Development of region-specific climate refugia allows for shifting native species associations and adaptive ecosystem continuities to mitigate rapid climate change across the Midwest, the United States, and world at large.

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Abstract

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Key Terms

1. **Analog-based Macrorefugia:** Contiguous & large-patch interior habitat.
2. **Backward Velocity Index:** Areas of end of century climatic suitability to the nearest area of current climatic suitability (Stralberg et al. 2018)
3. **Catena:** A connected series or chain of soils from hilltop to valley floor
4. **Long-Tailing**: Series of small-scale interconnected design interventions phased over time that work off of Short-head catalyst.
5. **Novel Ecosystems:** "A new species combination that arises spontaneously and irreversibly in response to anthropogenic land-use changes, species introductions, and climate change without correspondence to any historic ecosystems."
1. **Refugia:** Areas in which a population of organisms can survive through a period of unfavorable conditions.
   a. events.
   b. **Ex Situ** - off-site refugia away from native range.
   a. **Glacial** - area of refugia from climatic cooling
   b. **In Situ** - On-site refugia near native habitat.
   c. **Interglacial** - area of refugia from climatic warming events.
   d. **Macro** - Large expanse of refugia.
   e. **Micro** - Small microclimates with refugia capabilities.

Refugium: Single patches of habitat of that are pieces

Introduction:

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Dilemma

Without significant and immediate course correction, life will struggle to survive the heat, drought, polluted air, and increasingly frequent natural disasters of an ever-likely inhospitable future (Wallace-Wells 2019). Climate change will create many environmental challenges for flora and fauna as they experience needs to shift their habitat ranges (Anderson 2016a; Grose 2017). As global temperatures rise, the alteration of entire ecosystems will force species of flora and fauna out of current locations in search of more sustainable environments (Kunkle et al. 2013). Mass migrations will create conflicts for people and wildlife alike in the face of this rapid and unprecedented change (Warner et al. 2009). Yet, the speed of these ecosystem migrations will be significantly outpaced by the climate changes expected in many parts of the United States and abroad. Without a habitable area to persist long-term, many species will die out and biodiversity of entire regions will be greatly reduced causing major detriments to people and wildlife alike,

Purpose

Climate refugia and connectivity are being explored by researchers in select areas across the United States due to the existing biodiversity and unique geographic features of specific states and regions. Places like the Pacific Northwest, California, and Appalachia are being explored to develop a climate refugia system for mitigating loss in biodiversity through an uncertain climate future. Yet, the need for protecting ecosystems in regions outside those most likely to persist or successfully migrate, are arguably the greatest in need of protection. The Great Plains of the Midwest are recognized as having some of the most disconnected ecosystems in North America (McGuire et al. 2016). The impacts of climate change will exacerbate the existing disconnectivity as native flora and fauna attempt to shift their habitat ranges within the Great Plains region. Finding ways to mitigate climatic effects are necessary to maintain biodiversity and reduce extirpation and extinction. Concurrently and because of this, the living components of ecosystems will seek to relocate to more habitable climates through their passive and active migration, which can be seen in Figure 1 (Appleton 1975; Van Der Geest 2018). Range shifting of various species will require a degree of facilitation from land planners, landscape ecologist, and biologists to mitigate loss of biodiversity and maintain ecosystem resilience. Together, the creation of new and existing migration passageways can promote climate resilience in migration connectivity by mitigating barriers en-route to constructing a resilient climate refugia (Anderson 2016; Grose 2017).

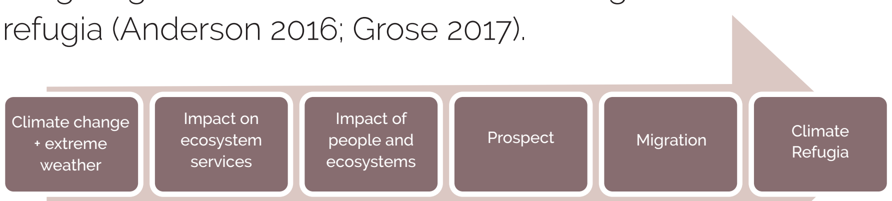

Figure 1: Prospect Refuge relationship diagram adapted from Appleton (1975) and Van Der Geest (2016)

Research Question

As the climate changes, how will the Great Plains Region adapt or change and to what extent can landscape architecture facilitate ecosystem migrations in order to mitigate the resulting ecological effects?

To reveal the best way to facilitate ecosystem migration and mitigate biodiversity loss in the Great Plains region, analysis of existing climate refugia studies will aid in understanding effective strategies for Eastern Kansas. The precedents that are outlined in later chapters identify climate refugia sites and accompanying migration corridors for different ecosystems across a variety of scales. The analysis of precedents informed a best management practice playbook to apply to a design for rural and urban refugia within the project region of Eastern Kansas. Different site scales with different contexts were chosen because any design strategies will require varying levels of compromise for what can be achieved where and to what extent. By borrowing ecological design principles from Grose (2017), Forman & Godron (1981), and Forman (1995; 2008) this work builds upon existing foundations of landscape connectivity and novel ecosystem construction for climate change persistence.

Literature Review:

Literature Review:

Environmental Changes

Air Pollution
Increased Temperatures
Sea-Level Rise
Drought & Flooding
Wildfires
Food Production/Insecurity

Great Plains Ecosystem Migration

Paleoecology

Climatic Maximums
Prairie Peninsula

Modern Ecology

Extirpation & Extinction
Sprawl & Ecosystem Degradation

Future Ecology & Predictive Models

Extirpation & Extinction
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Climate Refugia

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Refugia As Constructed Ecologies

Types of Constructed Ecologies
Prairie Peninsula

Environmental Changes

Natural disasters have displaced people and wildlife for millennia (Dort 1970). Natural disasters and major weather events brought about naturally and due to human activity have and will continue to displace life-forms at greater rates as the effects of climate change worsen. The short- and long-term impacts of these displacement events will alter the way communities are shaped and how they function within environmental systems.

Air Pollution

Much of the scholarship addressing the state of the world and urban conditions through the lens of future climate projections have yielded mixed results of how extreme the conditions will be (Crate & Nutall 2016; Wallace-Wells 2019). Yet nearly all have indicated major impacts are inevitable or increasingly likely while some have even suggested end-times are already upon us (Crate & Nuttall 2016; Romm 2018; and Wallace-Wells 2019). Romm (2018) implores change through a prophesied "doomsday" scenario backed by sound science and peer review (IPCC 2018). "A rolling death smog that suffocates millions" might seem hyperbolic but literature on predictive air quality studies suggest such a future is possible and already affecting cities around the world (Romm 2018; Wallace-Wells 2019). If fossil fuel burning continues into the future at the same degree, generations of urban dwellers will be adversely impacted through a variety of respiratory diseases and increased air pollution mortality (Crate & Nuttall 2016). There have even been linkages suggesting a strong correlation between mothers living in areas of greater air pollution and children being born with developmental disorders and genetic abnormalities (Crate & Nuttall 2016). Air pollution and proliferation of greenhouse gases also correlate to global temperature increases, which does not bode well for the livability of urban conditions that are already exacerbated by urban heat island effects (Wuebbles 2017).

Temperature Fluctuation

Wallace-Wells (2019) warns of the "Baharaining of New York City," referring to the Big Apple's transformation into what is currently the hottest location in the world. This climate transformation will be a death sentence for those unable to afford air conditioning (Romm 2018; Wallace-Wells 2019). Industrial human activity has contributed to a projected average global temperature increase of 1.5˚ Celsius equating to 2.7˚ Fahrenheit while post-industrial society is on track to double it and even surpass that (IPCC 2018). An average increase of 6˚ F above present global levels would put everybody in the country east of the Rockies under more heat stress than anyone, anywhere, in the world today (Wallace-Wells 2019), something that is capable of occurring in just a few decades (IPCC 2018). To ground these predictions further, in 2020, Pheonix, Arizona experienced 144 days of temperatures of at least 100˚F, shattering historic records (USDA Forestry Service 2020). In Midwest and Southern cities where high humidity percentages are normal, average temperatures of 105˚ F can be lethal and thousands of deaths a day due to heat stress will become normalized in summer months (Romm 2018; Wallace Wells 2019). As temperatures increase, the effects to global water systems will vary regionally (IPCC 2018).

Sea-level Rise

Many of the United States major cities have become prosperous due to their adjacency to water bodies like oceans and rivers because of their accessibility. However, those water bodies that helped facilitate the growth of these cities now threaten to sink them. As global temperatures rise, polar ice caps are melting to a greater degree throughout the summer months than they can refreeze in the winter months contributing to the continued rise in sea-levels (IPCC 2018). Landlocked cities along major rivers might not be sinking into the ocean, but studies indicate they will still be greatly affected by flash flooding due to extreme rainfall events in the midst of extended drought conditions (Kahn 2015). Literature suggests that the Midwest is expected to see longer periods of extended drought despite the region predicting to see more rain than today (Kahn 2015).

Drought & Flooding

Cook et al. (2016) calls the 21st century the age of the "Megadrought." Cook et al. (2020) found that between 2000 and 2018, the United States has experienced the greatest period of extended drought since the 1500's and the second longest since 800 CE. While it may be surprising considering the rampant flooding that has occurred in parts of the country during this period, these trends relate to soil moisture levels and relative depth across the country. When storms do break the drought seal, they will be monumental in scale and the water will be unable to infiltrate fast enough and will most likely result in flash flooding (Kahn 2015; Cook et al. 2020). The flooding will be extensive but relatively short-term. Once high temperatures aid in long-term flood abatement through evaporation, the depth of soil moisture will remain relatively shallow and will lead to further decay of soil organic matter and therefore desertification of the soil (Kahn 2015; cook et al. 2020). While the dust storm that the Midwest saw in the summer of 2020 was Saharan in origin, as remarkable as that is, the next dust storm the great plains region sees is likely to originate from within the region (Thompson 2020). In the 1930's, the loss of organic matter that led to the Dust Bowl was as much the product of drought as it was poor agricultural practices. Yet in the coming decades, as temperatures continue to rise and drought worsens, the tall and shortgrass prairies will disappear from their current range as well as the anchors their root systems provide. As organic matter is depleted, the loose and arid soils will be swept up by the strong Midwest winds once again. High temperatures, drought, and strong winds will also worsen wildfires, something that is already occurring in arid conditions elsewhere in the country.

Wildfires

As drought lingers, the forest fire season does as well. The USDA Forest Service (2020) and National Interagency of Fire Center has noted that the forest fire season has extended 78 days since 1970 (Wallace-Wells 2019; Thompson 2020). The USFS predicts that by 2050, wildfires will be twice as destructive as they are today; in some places, the area burned could grow fivefold. The NIFC (2020) released a report indicating that over 8 million acres of developed land have been burned due to rampant wildfires across the Western United States. Thompson (2020) also reports that 40 million acres of total land has been lost to such wildfires this year and due to increasingly persistent periods of drought, could continue to grow further displacing people and wildlife. While these forest fire zones are different from the grassland ecosystems of the Great Plains, an increased frequency of fires can disrupt the resilience of native systems.

Food Production & Insecurity

Agriculture will be among the industries most impacted by a changing climate. Plant hardiness and heat stress zones will change and plants that could once grow in certain parts of the country most likely will not survive there any longer (Kunkle et al. 2013; Kahn 2015). Agricultural literature on the subject shows that the Midwest, among other regions, will experience a shifting in ranges of productive agricultural lands (Warner et al. 2010). The resulting loss in produce and feed grain for livestock has the potential to result in greater food insecurity at local, regional, and national scales. Rural communities built on agriculture will experience the same food insecurity but the added detriment of financial hardship as well (Warner et al. 2010; Abrams et al. 2012). Areas fortunate to avoid long periods of drought might face issues stemming from too much rain instead (Islam et al. 2012).
Due to agricultural dependency on soil fertility and water availability, agriculture often finds itself within floodplains of river valleys. Extreme rainfall events and flooding will also impact these agricultural yields reducing the overall area of productive lands even further (Warner et al. 2010; Islam et al. 2012). Extreme weather and natural disasters will continue to affect rural and urban communities to greater extents as the climate continues to change. Paleoclimatologists have found that these future predictions seem to mirror past interglacial climatic conditions. These climatic conditions also induced significant ecosystem changes that caused organism adaptations, migrations, and extinctions.

Great Plains Ecosystem Migration
Paleoecology

The Earth's climate has fluctuated at various rates and intensities due to geologic, ecologic, and atmospheric forces for millions of years to the point that change is the one constant. Pardi and Smith (2012) among other researchers in paleoecological studies have found movement was a near-universal response to past changes in climate (Anderson et al. 2016). Yet the movement among individual species occurs at different rates due to varying levels of mobility as well as the availability of food, water, and shelter (Pardi and Smith 2012). The individualized nature of species migration is why literature on ecosystem migration is limited. Understanding the relationships and migration patterns across all individual species in any given ecosystem requires an unrealistic amount of work for information that is purely projective and subject to change. Compiling an exhaustive compendium in the overall trends of ecosystem migrations is beyond laborious and likely why such literature on how entire systems is non-existent. This can be attributed to why prehistorical precedent is essential in developing predictive models. By understanding the processes and forces that contributed of past ecosystem and specific keystone species migrations, it is possible to learn how to better facilitate future migrations and mitigate losses in biodiversity.

Paleoecology: Prehistorically Recent Climatic Maxima

The Holocene was the most recent epoch prior to the Anthropocene in which we currently live. The Holocene represents the last 11,000 thousand years up until 1950 and during that period, the world went through a series of climatic oscillations that affected the equilibrium of the biosphere and its component systems (Dort & Jones 1970). The beginning of the Holocene marks the end of the Ice Age that saw numerous climatic disruptions (Dort & Jones 1970). During this epoch, the climatic changes that occurred were largely periods of warming that converged on a climatic optimum or terminus 6,000 years ago that researchers have provided different coinages for (Wells 1965; Dort & Jones 1970). This event has been referred to as the Holocene Climatic Optimum (HCO), Mid-Holocene Warm Period, Hypsithermal, or Altithermal but all agree that it was the most recent warming analogue to modern climate change (Dort & Jones 1970). The HCO affected different areas to varying degrees but is the most applicable precedent for developing predictive climate models to anticipate the results of modern climate change (Swanston et al. 2018). Some of the predictive models that were developed for the Great Plains region were founded on relatively recent periods of drought that mirrored Pleistocene and Holocene ecosystem migrations (Swanston et al. 2018).

Paleoecology: Prairie Peninsula Prehistory

Transeau (1935) and Weaver (1968) were instrumental in understanding the dynamics that resulted in current prairie species distribution. The Prairie Peninsula is an area of grassland that protrudes east in areas many have hypothesized should be forested due to geomorphological and climatic conditions of the region (Transeau 1935; Wells 1965). Scholars on the subject of this divergent vegetation patterning attribute the presence to long term Native American influences on the land (Anderson 2006). The belief was that fire and poor shallow soil conditions are what contributed to the retreat of woody vegetation and grassland occupation. The areas affected by this transition were believed to be more geomorphologically favorable for woodland ecosystems (Anderson 2006). However, Transeau (1935) argued that such influences coincided with unusually dry climatic conditions in the 1930's. The extended drought mirrored HOC conditions that led to the development of the Prairie Peninsula 6,000-10,000 years ago (Transeau 1935). The woody vegetational responses represented a high mortality rate in upland trees while grasslands persisted (Transeau 1935). The greater drought tolerance was attributed to deeper soil moisture depths and the ability of grasses to utilize their deep and extensive rooting system to access moist soil. Alternatively, water absorption in trees occurs at shallower soil depths than grasses making them less tolerant to similar droughts (Albertson & Weaver 1945). Weaver (1968) noticed that not only did grasslands fare better, but certain grassland species also experienced greater species proliferation than others due to growing season water availability. C4 grasses like *Andropogon gerardii* (Big Bluestem), *Schizachyrium scoparium* (Little Bluestem), *Panicum virgatum* (Switchgrass), *Sorghastrum nutans* (Indiangrass), and *Bouteloua curtipendula* (Sideoats Grama) of which the tallgrass prairie is most readily composed, are found in greater abundance in eastern portions of the prairie peninsula. Yet, cool season C3 grasses, like *Pascopyrum smithii* (Western Wheatgrass), did significantly better due to greater available soil moisture during their growing season in early spring. This is compared to warm season C4 grasses that have a later growing season and therefore respond to reduced soil moisture through a reduction in vegetative productivity. The loss of vegetation has broad ramifications for all the wildlife that depends upon their presence and role in ecosystem development (Anderson 2006).

Modern Ecology: Historic to Post Industrial

Extinction & Extirpation: Story of the Great Plains Biodiversity

Grasslands once comprised 42% of the plant cover on earth's surface and roughly 1/7th of it was found in the North American Great Plains totaling roughly 750 millions acres of short, mixed, and tallgrass prairies (Anderson 2006). However, only 4% of the 170 millions acres of tallgrass prairie once covering North America have persisted today. With the massive loss in grassland habitat, and historically poor and non-existent conservation practices of the 19th century, much of the wildlife and biodiversity has been lost with it (Flores 2016). Flores (2016) talks of the American Serengeti and references historical records of the 1800's that describe the romanticized experiences of European expeditions west. Historical accounts from James Audubon, Brigadier General Zebulon Pike, among numerous other notable figures throughout the 19th century, describe the immense biodiversity that this area once accommodated (Flores 2016). As Flores (2016) notes, when the once biodiverse Great Plains region of the United States was first wandered by Europeans, it was taken for granted, culled of life, and then despised for it being so. The region was even bypassed for federal protection despite it being the muse that inspired George Catlin to fight for the program's establishment in 1832 (Flores 2016). The *Cervis canadensis* (Elk), *Canis lupus nubilus* (Great Plains wolves) and *Ursus arctos horribilis* (grizzly bears), *Bison bison bison* (Plains Bison), and many other species no longer thrive in this region because of human activity. However, the current mass extinction caused by human activity has and is projected to result in even greater loss of life in the future of the Great Plains region and beyond.

Sprawl & Ecosystem Degradation

The Anthropocene Epoch is upon us and while there are critics that assert the self-important declaration of a new era is a mischaracterization of our role in the world, the impacts humanity has had on the biosphere are unequivocal. Industrialization and post-industrial society altered and disrupted complex environmental relationships between life and geomorphological processes that ecosystem foundations were built upon. Dismantling natural riparian flow regimes to accommodate development in less than suitable areas is one such example. Rapid urbanization and sprawling developments have also fragmented essential wildlife corridors for habitats. The disconnection limits wildlife dispersal and gene flow that can ultimately lead to extirpation and extinction (Forman & Godron 1981). During this period of post-industrialism, mass polluting also contributed to the degraded health of the environment. Rivers and riparian forest of the Great Plains were tamed through deforestation, agriculture, channelization and resource mining (Sedell et al 1990). Massive tracts of tall, mixed, and shortgrass prairies were further reduced by industrial uses and developmental sprawl leaving a dysfunctional mosaic of poor planning practices and land ethics (Forman 1995; Forman 2008). Developmental sprawl and poor land-use stewardship have already threatened region-wide biodiversity, yet climate change has the potential to exacerbate ecosystem impacts to even greater extents (Forman & Godron 1981; Forman 1995; Forman 2008).

Future Ecology

It has been said, "history doesn't repeat itself, but it often rhymes." The relationship between past thermal maxima and modern climate change may be analogous but urbanization presents a new twist. Predictions of specific Great Plains ecosystem migration are predicated largely on foundational understandings of Transeu and Weaver's Prairie Peninsula theory and predictive climate-change data. Through this paleoecological lens and available fossil records, scholarship has identified that, much like the hypsithermal and alithermal periods 11,000-6,000 years ago, temperatures are increasing, drought is worsening, and ecological systems will be in a state of flux (Anderson 2006; Anderson 2016; Grose 2017; IPCC 2018). Species and ecosystem migrations are on the rise again; however, urbanization and a degraded ecosystem will limit this already vulnerable process.

Range Shifts

Empirical evidence for contemporary range shifts in response to climate change has now been documented for over 1000 species of mammals, reptiles, amphibians, and birds (Anderson et al. 2016). Anderson et al. (2016) suggests focusing attention on the four most common and mappable patterns of species' responses to climate change to anticipate areas of likely and potential refuge of which two are applicable to the Great Plains region. Anderson et al. (2016) suggests identifying "downslopes" toward moist riparian areas and "local microclimates" as they offer greater opportunities for flora and fauna to persist. Yet despite habitat ranges shifting, many species cannot adapt or migrate quickly enough to outpace climate change.

Climate Refugia

Refugia can be defined as habitats or environmental factors that reduce impacts of disturbance on an organism or group of organisms. Refugia largely depend on morphology, life history, and behavioral attributes of species (Sedell et al. 1990). Sedell et al. (1990) suggests there are two types of basic refugia. One depending on spatial conditions, and the other on the age/size of a specific population(s). Spatial refugia are sites offering habitat haven that protect species from detriments and climatic forces, such as heat, water availability, or avoidance from predation that would impact population sizes. Age/size refugia are more ephemeral and tenably bound. Age/size refugia function through a prey population's ability to physically fend off predation and varies among species. What might be age/size refugia for bison from the great plains wolf would vary greatly from a black-footed ferret and black-tailed prairie dog. Yet by and large, refugia are places that actively resist attack from outside forces or can dynamically adapt through internal and external processes. Climate refugium specifically, must be a physical spatial refuge that provides for a broad spectrum of microclimates for a breadth of high taxonomic species diversity. While Sedell (1991) references two types of refugia, further scholarship has determined greater distinctions that have caused confusion across the available literature (Ashcroft 2010). Despite the nuances in refugia distinctions, the advancement in refugia scholarship has resulted in new progressive concepts that are yielding promising climate solutions, which will be addressed in following sections.

Classic Refugia Research

Literature on refugia in the 21st century builds upon foundational definitions in phylogeography (a field of study that analyzes historical processes that led to geospatial distributions of geneological lineages) that refer to the phenomenon of refugia through past, present, and future climate changes (Avise et al. 1987; Sedell et al. 1990; Noss 2001; Petit et al. 2003; Bennett & Provan 2008; Ashcroft 2010; Grose 2017). Refugia literature has been developed and adapted from early references to Quaternary glacial (cooling) and interglacial (heating) climatic periods. Refugia in its earliest sense, was referenced as hypothesized regions of biotic refuge from climatic extremes (Avise et al. 1987). Sedell et al. (1990) opine the term's applicability in stream restoration for the various microclimates and zones created by morphological processes of fluvial systems. After decades of development and modifications to refugia concepts, Ashcroft (2010) urges crafting careful definitions when referencing certain types of refugia to accurately describe the context of the refugia. Some of the descriptors that have been used in refugia literature include those previously mentioned as they relate to greater historical climatic trends as well as a nested subset of increasingly specific categories. Refugia from the interglacial period, which we live in today, can be further categorized through in situ (in original place) and ex situ (off-site) refugia. This distinction refers to climate induced range-shifting marking places of origin and destination. This is an important to specify due to dispersal capabilities or incapabilities of individuals and designing for specific conservation needs. Yet even these distinctions are rather nebulous at larger scales. That is why clarification in scale is presented through micro/macro distinction to provide clarity by introducing a spatial numeric value (sqft/acres). Grose et al. (2017) describes microrefugia as localized microclimates within a larger, less-habitable matrix. Accordingly, at large scales, macrorefugia has been used, yet classically, the term refugia has been referenced synonymously. It is also important to clarify that refugia do not just occur naturally, but can be constructed as well.

Refugia as Constructed Ecologies

Types of Constructed Ecologies

Grose (2017) discusses various types of constructed ecologies under three overarching categories. The first of which are sites of environmental history. These are intrinsically native ecosystems that are constructed, for example, by expanding a preserved natural place like the Tallgrass Prairie National Preserve by burning and seeding using a mix of species found in that preserve. The second are sites that have been designed or engineered for a particular environmental intervention. For instance, creating a floodplain wetland for stormwater management. The third, are those ecologies that have occurred inadvertently. For example, when the bush honeysuckle was introduced for its aesthetic qualities, the resulting widespread understory invasion that occurred was an inadvertent ecological construction.

Constructing refugia can and should be viewed in similar terms. Sites of environmental history, or prehistory in this case, present target sites and geomorphological qualities for creating stable climatic refugia. Based on those areas of prehistoric refugia, supplemental design strategies that increase species adaptability and connectivity can potentially result in unforeseen species associations or inadvertent fluctuations in species proportions. Grose et al. (2017) suggests this is not necessarily good or bad, just a trend of “shifting continuities” that have and will continue to persist as long as the earth can support life.

Designed Refugium: Novel Ecosystems Construction & Assistance Strategies

Projective construction of novel ecosystems around predicative climate models to aid in migration and or refugia is contested among conservation ecologists (Grose et al. 2017). Presence of natural microrefugia can aid in temporary species persistence yet leveraging these areas through construction of a broadly suitable refugia can either promote or hinder greater species persistence in the long run (Grose et al. 2017). Contention lies in the potential for assisted migration and relocation to unnaturally displace native organisms that can ultimately do more harm than good (Grose 2017).

Assisted Colonization

Plants migrate naturally through generational dispersal. There are two types of assisted relocation in aiding plant migration to shift to new ranges in response to climate change (Midgley et al. 2007; Hunter 2011). The first is actual physical placement of plants in a new area and should largely be conducted by or aided by conservationists (Hunter 2011). The second, and most applicable to landscape designers and land planners, is the enhancement of landscape connectivity (Hunter 2011). Design solutions that focus on relocation and improve connectivity are important because by 2050, plant extinctions (not including extirpations) will rise by 15-37 percent (Hunter 2011). Just like terrestrial wildlife, migration occurs at different rates for different plant species as well. Hunter (2011) created an assisted plant migration playbook that ranks specific plant species by resiliency in order to create corridors for optimum climate change resilience. The ranking system helps determine an assisted plant migration plant list for designers to use in climate corridor design (Hunter 2011).

Riparian Climate Corridors

Riparian corridors are stream systems that serve as interfaces between terrestrial and aquatic ecosystems that provide highly productive energy and biomass exchanges among plant and animal species (Anderson et al. 2016). As Forman and Godron (1995) suggest, riparian corridors function well as migration pathways but Hilty et al. (2006) assert that they are also particularly well suited for migration through highly modified landscapes (Anderson et al. 2016). Riparian corridors are effective microclimate refugia as they promote biodiversity through connectivity (Sedell et al 1990; Olsen et al. 2007; Seavy et al. 2009; Anderson 2016). Riparian corridors along ecotones and climate gradients are especially effective in promoting refugia and migration at larger scales because they offer microclimates and contiguous vegetated corridor edges (Seavy et al. 2009; Krosby et al. 2014). The connectivity of major rivers and streams offer characteristics that are expected to enhance a refuge's ability to facilitate large scale climate-driven range shifts and provide insular microclimatic and macrorefugia. These riparian corridors offer the greatest climate resilience and landscape permeability for species movement. Riparian corridors provide refuge from warming that spans major temperature gradients, offer layers of vegetative cover, have low solar insulation, have wide forested buffers, and are devoid of or have very limited human modification, which all ultimately offer the greatest climate resilience and landscape permeability (Sedell et al 1990; Olsen et al. 2007; Seavy et al. 2009; Anderson 2016; Grose 2017). However, it is essential to note that while these conditions offer the greatest climate resilience for species, they're also the most threatened by protracted drought conditions. Therefore, greater amelioration to prolong their efficacy as climate corridors is equally important (Krosby et al. 2018).

Refugia Development Strategies

Grose (2017) suggests that creation of projective novel ecosystems as destinations for ecosystem migration isn't a suitable strategy in promoting resilience because it is impossible to know how species, particularly invasives, will respond. However, assisted migration through barrier mitigation and landscape permeability enhancement offers greater adaptability, especially for plant migrations. Enhancing topographic variation through landform manipulation is another assistance strategy that can help facilitate natural migrations and refuge. Grose refers to this landform-based microclimate creation as "Topographical buffering", which can improve an area's in-situ microrefugia potential. These constructed microclimates, also referred to as "Climate Spaces," can be used to help mitigate heat and drought impacts for organisms incapable of migrating fast enough to survive climate change (Grose 2017). Grose (2017) discusses these migration and refuge assistance strategies through a strategic phasing approach that's referred to as Short-Heading and Long-Tailing. Short-Head references a highly intensive and catalytic first phase of a design solution that creates a foundation for continued development down the line. Long-Tailing refers to a longterm phasing plan that seeks to monitor, improve, and build upon the effects of the initial Short-Head intervention through stepwise additions over time. This ecological assistance strategy mirrors urban planning methodology where similar approaches are taken when creating new policies and new community developments.

Conclusions

Understanding how climate change will affect ecosystem migration and refugia, shared interests with human needs suggest promoting multi-dimensional climate resilient solutions. Certain ecosystems and their regional contexts will have specific needs and vulnerabilities that will require a level of design and analysis appropriate for addressing them. No single design solution across the environmental spectrum will be able accomplish this. Different species in different environments may be more or less capable of adjusting or migrating in the face of climate change. It is important to understand broad climate trends, regional effects of those trends, and local areas and corridors of opportunity to better address ways to protect species believed to be the most vulnerable and ecologically valuable to any given region. By doing this, enhancement of naturally dynamic native species associations, and the environmental systems they are a part of can begin to occur and ultimately provide tremendous benefits for prolonging biodiversity well into an uncertain climate future.

Methods:

Methodology:

Research

Development of Refugia Metrics

Precedent Study Selection, Analysis, & Synthesis

Site Selection and Analysis

Design Application

Design Guideline Development

Methods

After examining existing climate change and refugia literature, common threads became evident in what could define the framework for creating a broad climate refugia analysis model. Specific data helped reveal how the detrimental climatic forces of the future could be mitigated through enhancing physical features capable of creating a more habitable oasis. Through literature review, scanning of publicly available map datasets, and the completion of a pilot study design, a foundation for refugia selection criteria was formed. With the aid of a precedent study analysis and synthesis to gauge success of the identified selection criteria, adjustments to these metrics were conducted to improve efficacy. These adjustments helped inform site selection and criteria for design development, which led to a series of refugia design guidelines and typical design solutions for Eastern Kansas that could be applied to the Great Plains Ecoregion.

Pilot Study

The pilot study was conducted in Eastern Kansas. The selection of this region was based on the presence of the Kansas River, which allowed for opportunities to utilize prime habitat connectivity and large-scale water availability across the rivers and streams themselves but also the reservoirs that feed them. Hydrologic features are especially important in the Great Plains region because connectivity and refugia potential in the ecoregion is widely accepted as being one of the poorest across the country (McGuire et al. 2016 & Flores 2016). After regional site selection, the pilot study design process was partitioned into a set of smaller urban and rural site scales, which highlighted the need to reform traditional refugia development models. Such models, which will be touched on more in the following chapters, look simply at temperature, topography, and precipitation yet other factors play a role in refugia suitability for different species and ecosystems (Michalak et al. 2020). The need for supplementary data become especially apparent when zooming in and looking at site-specific conditions. The lack of pertinent information at smaller scales across studies and literature had shown the need for a greater set of refugia criteria in order to help identify refugia across multiple scales and ecoregions. This refugia criteria became instrumental in conducting precedent studies that helped inform universal design guidelines and their typical design application in an ecoregion believed to be incapable of climate refugia. For more information on the pilot study, see Appendix B.

Climate Refugia Development Layers

Climatic trends are identified and analyzed showing areas of greatest climatic volatility to compare with refugia identification datasets. Individual metrics of each dataset were decided based on source data formatting and individualized layer subset weighting. Data was scaled from -4 -0- +4 based on significance, whether positive or negative, to refugia development, which was presented in the literature review. Rationale for specific datasets and their significance are outlined as follows and illustrated in Tables 3.1 and 3.2.

Climatic Trends

Several datasets were observed and utilized to understand and reveal significant climatic changes and nuanced climate patterns in precipitation and temperature gradients across historical records and future predictions throughout the United States. Seasonal extremes were referenced to observe the extent of potential range shifts. However, these temperature and precipitation minimum and maximum data sets were not used in the official analysis process because of the availability of more concise absolute change and percent change data that were more effective in representing areas of least and greatest volatility. For visual representation of climate reference datasets, see Appendix C.

Refugia Datasets

Refugia metrics used in the following precedent, regional design, and design analysis revolve around 3 main datasets; abiotic framework, biodiversity and connectivity, and human disturbance. Each of these 3 main datasets have 3 subsets chosen to best analyze refugia from an ecosystem neutral standpoint in order to reduce bias found in research on refugia determination. Standard approaches tend to place higher value in mountainous areas above all else based on tendencies for species seeking altitudinal refugia to abate climate extremes. Such trends therefore diminish the ability of flatter regions to adapt because similar migrations are not possible. The following datasets have been compiled to aid in eliminating regional bias in refugia identification strategies.

<u>Abiotic Framework</u>
This dataset refers to the ability of a site to mitigate climate extremes. Soil bedrock depth is used to broadly identify soil depth for the purpose of highlighting potential areas that could have high water storage capacity. Northern aspect is used to identify areas that offer greater protection from solar radiation and therefore heat stress. Streams and flowlines are also used to highlight migration corridors and potential refugia sites.

<u>Biodiversity & Connectivity</u>
Biodiversity and connectivity datasets were used to identify the availability of diverse habitat for a breadth of species. High-taxanomic wildlife species distributions are used to find where the most biodiversity is and highlights areas in need of the most protection. Habitat communities show where unique ecosystems are located based on plant communities and abiotic conditions. Public and privately protected lands offer insight into areas that currently have the potential to aid in refugia creation.

<u>Human Disturbance</u>
Development and human activity detract from the refugia potential of a region. Cultivated & disturbed lands show areas that have poor ecological value. Urban development and roadways fragment habitats and wildlife corridors, which are a major detriment to protecting ecosystem health as well as a potential refugia construction.

Climatic Trends

		DATA LAYER	SIGNIFICANCE	WEIGHTED METRICS	SOURCE
TEMPERATURE	Historic	Winter Minimum	Used to identify a region's hardiness zone and the various types of vegetative communities that can live in any given region	<- 10˚C – -3˚C -3˚C - 4.5˚C 5˚C - 13˚C 13˚C - >16.0˚C	USFS Geospatial Data Discovery
TEMPERATURE	Historic	Summer Maximum	Helps create a foundation for comparing future extremes and shifts in temperatures	< 5˚C - 11˚C 11˚C - 18˚C 18˚C - 25˚C 25˚C - 30˚C	USFS Geospatial Data Discovery
TEMPERATURE	Future	Winter Minimum	Elevation and seasonal refugia will shift ranges of biota to the north	<- 10˚C – -3˚C -3˚C - 4.5˚C 5˚C - 13˚C 13˚C - >18.0˚C	USFS Geospatial Data Discovery
TEMPERATURE	Future	Summer Maximum	Heat stress and drought will displace biota in southern climates	< 5˚C - 11˚C 11˚C - 18˚C 18˚C - 25˚C 25˚C - 30˚C	USFS Geospatial Data Discovery
TEMPERATURE		Absolute Change	Summation of the projected changes indicates areas expected to see the greatest absolute change in temperature gradients	1 – < 3˚C - 3.7˚C 2 – 3.7˚C - 4.5˚C 3 – 4.5˚C - 5.3˚C 4 – 5.3˚C - >6.0˚C	USFS Geospatial Data Discovery
PRECIPITATION	Historic	Winter	Very important for C3 cool season grasses needing groundwater in Spring growing season	< 25 - 200 mm 200 - 600 mm 600 - 1000 mm 1000 - >3000 mm	USFS Geospatial Data Discovery
PRECIPITATION	Historic	Summer	Very important for C4 warm season grasses that actively grow in the summer months.	< 25 - 125 mm 125 - 300 mm 300 - 550 mm 500 - >3000 mm	USFS Geospatial Data Discovery
PRECIPITATION	Future	Winter	More rainfall events are expected to occur during the winter	< 25 - 200 mm 200 - 600 mm 600 - 1000 mm 1000 - >3000 mm	USFS Geospatial Data Discovery
PRECIPITATION	Future	Summer	Extended dry periods will exacerbate increased summer temps causing range shifting of many species	< 25 - 200 mm 200 - 600 mm 600 - 1000 mm 1000 - >3000 mm	USFS Geospatial Data Discovery
PRECIPITATION		Percent Change	The Great Plains is likely to see similar trends as what was observed in the prairie peninsula	1 – <-16 – -2% 2 – -2 - 14% 3 – 4.5˚C - 5.3˚C 4 – 5.3˚C - >6.0˚C	USFS Geospatial Data Discovery

Table 3.1 - Climatic Trends (Ryan 2021)

Refugia Datasets

	DATA LAYER	SIGNIFICANCE	WEIGHTED METRICS	SOURCE
ABIOTIC FRAMEWORK	Soil Bedrock Depth	Helps determine potential areas of greater soil availability for water retention	1 – 0 - 100 cm 2 – 100 - 200 cm 3 – 200 - 300 cm 4 – > 300 cm	NRCS
ABIOTIC FRAMEWORK	Topographical Aspect	Northern aspects offer greater protection from solar radiation and heat stress	1 – 67.5 - 292.5˚ 2 – 292.5 - 337˚ 3 – 22 – 67.5˚ 4 – 0 - 22˚; 337 - 360˚	USGS
ABIOTIC FRAMEWORK	Streams & Flowlines Euclidean Distance to Habitat	Waterways are largely undeveloped and act as contiguous pathways for wildlife connectivity essential for habitat	1 – < 2,000 ft. 2 – 2,000 – 1,000 ft. 3 – 1,000 - 500 ft. 4 - > 500 ft.	ESRI
BIODIVERSITY & CONNECTIVITY	High-taxa Wildlife Biodiversity species distribution	Amphibian, Bird, Mammal, Reptile taxonomic groups help indicate areas of greatest biodiversity and therefore importance	1 – 0 - 70 Species 2 – 70 - 140 Species 3 – 140 - 210 Species 4 – 210 - 270 Species	USGS GAP Analysis
BIODIVERSITY & CONNECTIVITY	Habitat Communities	Inventory of various land-use and ecosystem types across the Continental US indicate areas of greatest success for refugia development	1 – Urban Development 2 – Agriculture 3 – Public Open Space & Woodland 4 – Natural Habitat	GAP LANDFIRE National Terrestrial Ecosys-tems
BIODIVERSITY & CONNECTIVITY	Public & Private Protected Lands	National, State, FWS, and Native Lands offer areas of minimal human impact and native ecosystems for building refugia from or in conjunction with	1 – < 100 sq mi 2 – 100 – 250 sq mi 3 – 250 - 500 sq mi 4 – > 500 sq mi	PAD-US, NPS, FWS,
HUMAN DISTURBANCE	Cultivated & Disturbed Land	Agricultural and similarly disturbed lands represent both opportunities and limitations for connectivity and habitat development	-1 – Harvested Forest -2 – Non- Irrigated Agriculture -3 – Irrigated Agriculture -4 – Quarries & Mines	GAP LANDFIRE National Terrestrial Ecosys-tems
HUMAN DISTURBANCE	Urban Development	Urban and suburban areas detract from habitat and contribute to pollution affecting quality of adjacent areas.	-1 – Open space -2 – Low Intensity -3 – Medium Intensity -4 –High Intensity	GAP LANDFIRE National Terrestrial Ecosys-tems
HUMAN DISTURBANCE	Vehicular Barriers	Highways and vehicular infrastructure fragment habitat and create potentially deadly conflicts	-1– > 2,000 ft. -2 – 2,000 – 1,000 ft. -3 – 1,000 - 500 ft. -4 - < 500 ft.	USDOT

Table 3.2 - Refugia Metrics (Ryan 2021)

Precedent Studies

Upon review of the pilot study, and the identification of climate refugia datasets, analysis of existing precedents was done to determine the efficacy of the climate refugia datasets. To perform this analysis, a multi-criteria decision analysis model was created in ArcGIS using the model builder function. Upon precedent study selection, map data was collected to compare climate refugia identification processes. After projecting, transforming, and reclassifying the data to match the necessary dataset requirements for analysis, the raster calculator function was used to process the multiple criteria. The resulting raster layer allowed for a qualitative comparison between the precedents and the results of this studies climate refugia identification methods.

Precedent Study Selection Criteria

Criteria for case study selection focused on climate refugia site and migration corridor selections. The following precedents in Figures 3.1-3.3 look at different methods, metrics used to determine climate refugia, and focused on a variety of scales and regions. Merit of cases were acknowledged by acceptance through peer review.

<u>Refugia Identification Selection Criteria</u>

- The studies must look at high-taxanomic biodiversity in both flora & fauna
- Studies must promote connectivity as well as habitat refugia.
- Studies must account for projected climate-change impacts

Precedents

State

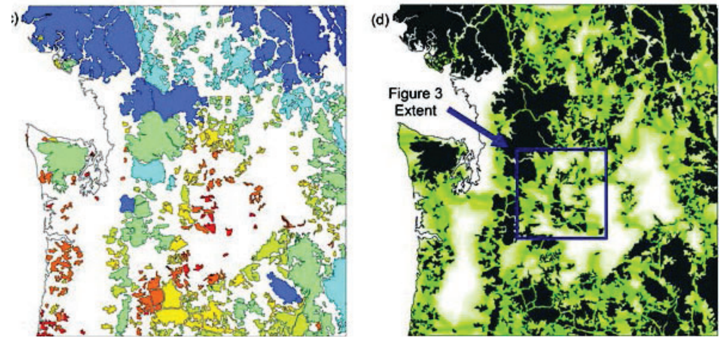


Figure 3.1 - Illustrating range of precedent study from Nunez et al. (2013)

National

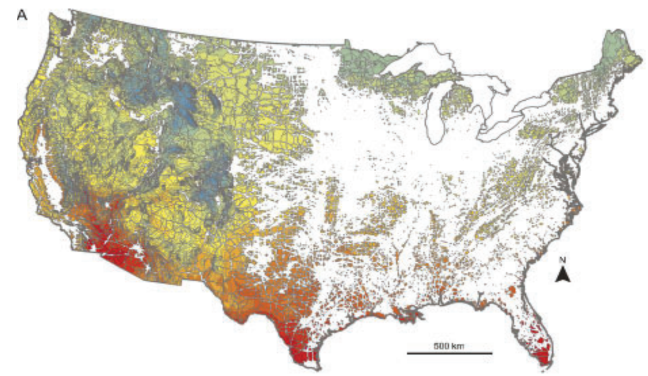


Figure 3.2 - Illustrating range of precedent study from McGuire et al. (2016)

Ecoregional

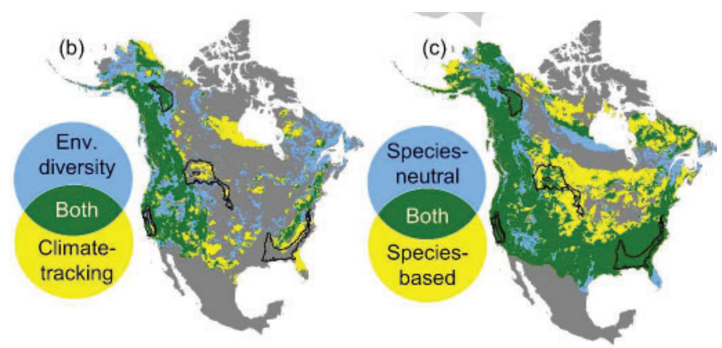


Figure 3.3 - Illustrating range of precedent study from Michalak et al. (2020)

Data Collection

Datasets were collected from a variety of online databases. ArcGIS Online was initially utilized to find availability of the requisite data. Once the ArcGIS Online data was determined to be effective, direct downloads of individual raster, shapefile, metadata, and other associated files were compiled from their original source locations for full editability in ArcGIS.

Projection

After the collection of data from their original sources, the associated layers were projected onto the requisite coordinate planes for the specific sites and scales that are necessitated across precedent and design scales. For analyzing the precedent studies that identified the contiguous US and expansive ecoregion of the Northern Prairies, the utilization of the USA Contiguous Albers Equal Area Conic projection was used. Corresponding State Plane Coordinate System Projections (NAD83) were used for analysis of Nunez et al. (2013) in Washington states as well as the Eastern Kansas design application discussed in later chapters.

Transformation & Rasterization

After Projection of the collected source data, transformation using the ArcGIS spatial analyst and conversion tools were done to create the needed datasets used to identify Refugia. This includes creating aspect maps from DEM elevation files, Euclidean distances from highways and rivers, merging of National, State, FWS, and Native Land shapefiles, raster calculations of climatic trends and species distributions. Once files were created and placed, polyline and polygon shapefiles were converted into raster files for reclassification and a weighed sum overlay.

Reclassification & Weighted Sum Overlay

The reclassification of data was conducted to process the data into a Multi-Criteria Decision Analysis (MCDA). With the Reclass tool in ArcGIS, the datasets were given a weighted value ranging from -4 - 0 - +4 from lowest to greatest Refugia suitability where negative values are detrimental to refugia, positive values beneficial, and zero being neutral. The weighted sum overlay tool was then used to compile the overlapping datasets to create a raster file showing areas of greatest suitability and vulnerability to refugia development.

Interpretation of Results

Once the MCDA had been completed, visual and qualitative interpretation of the results allowed for greater understanding of the correlations that were generated. Depending on the availability and variability of different datasets and their precision at various scales, further analysis could be needed to determine the viability of site selection and its extents with the MCDA.

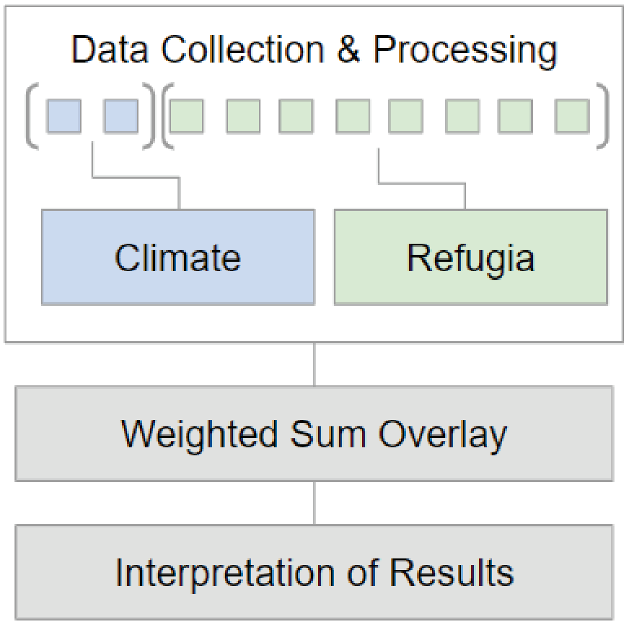


Figure 3.4 - Visualization of methods for Climate Refugia map development

Precedent Studies

Precedent Studies:

State – Washington

Connectivity Planning to Address Climate Change (Nunez et al. 2013)

National – Continental United States

Achieving Climate Connectivity in a Fragmented Landscape (McGuire et al. 2016)

Ecoregional – Northern Prairie

Combining physical and species-based approaches improves refugia identification (Michalak et al. 2020)

Synthesis –

Takeaways across precedents & efficacy evaluation of proposed climate refugia MCDA identification model.

Background information and imagery will be introduced for each precedent to provide a brief overview of the studies being analyzed. Following an introduction of each precedent, the climate refugia MCDA mentioned in the methodology section of this report will be conducted at a scale that corresponds with each precedent in order to gauge efficacy of the climate refugia and corridor model. For more details on each map dataset used in the MCDA, reference Appendix C.

“Connectivity Planning to Address Climate Change”

Background Information

Location	Washington
Scale	State
Date	Research Published in 2013
Authors	Tristan A. Nuñez, Joshua J. Lawler, Brad H. Mcrae, D. John Pierce, Meade B. Krosby, Darren M. Kavanagh, Peter H. Singleton, Joshua J. Tewksbury
Research Aims	“Traditional connectivity models are used to identify areas that facilitate species movements at one point in time between their current habitats and within their current distributions” (Nuñez et al. 2013). This study focused instead on connectivity that enables species to move among suitable areas and to newly suitable areas over time as climate changes (Nuñez et al. 2013).

Metrics	- Mean Annual Temperature
	  - Mean annual temp from 1971 to 2000
	- Landscape Integrity
	  - Metric of naturalness that incorporates data on urban areas, distance to roads, agriculture, and other land uses (Nuñez et al. 2013).
	- Corridors along temp and integrity
	  - Differences in temperature within high landscape-integrity patches
	  - Network of corridors modeled between the patches that contained unidirectional changes in temperature and high landscape integrity (Nuñez et al. 2013).
	- Metrics can be seen in Figure 4.1.

Table 4.1 - Precedent Study Background information (Nuñez et al. 2013)

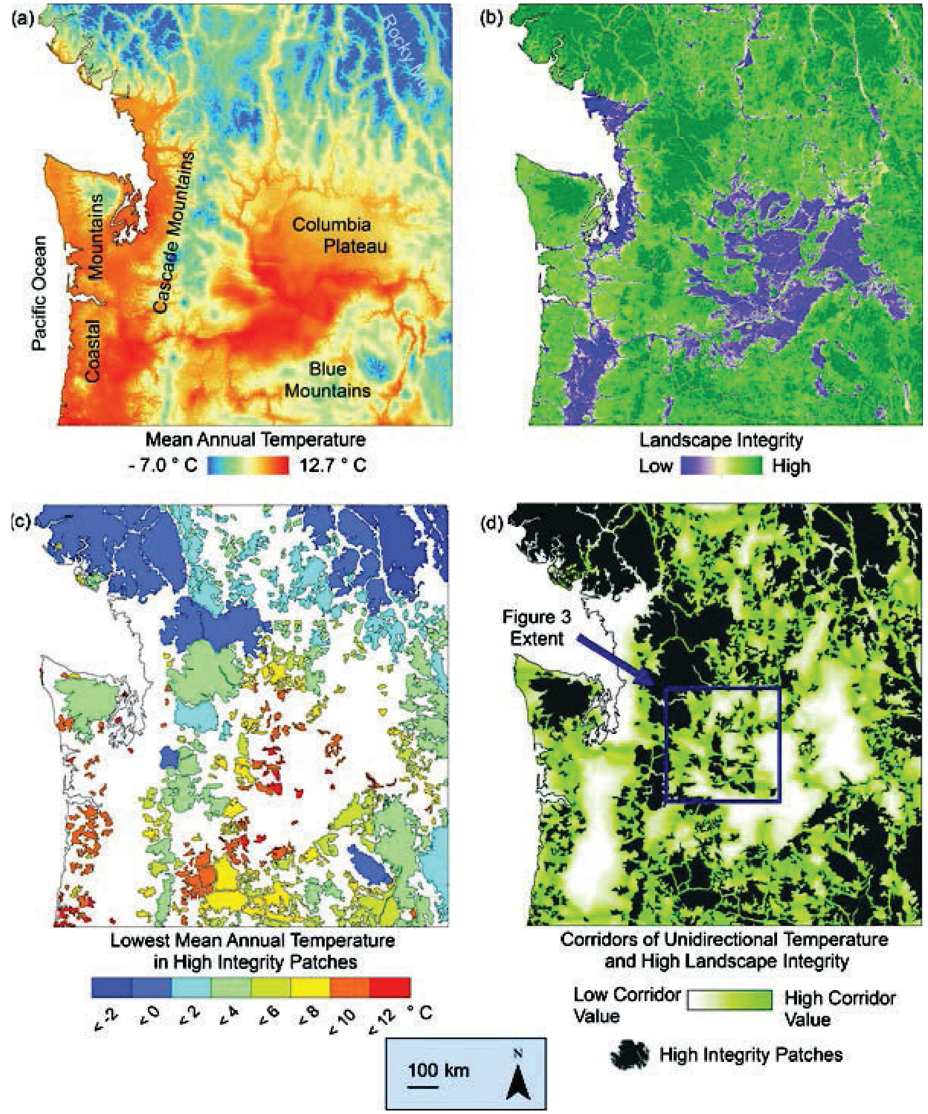


Figure 4.1 - Precedent Study imagery showing evolution of climate connectivity mapping (Nuñez et al. 2013)

As the earliest precedent in this set of studies, it has influenced later works on climate corridor and refugia identification. To gauge the efficacy of the proposed MCDA climate refugia modeling in this report, the work of Nuñes et al (2013) and later precedents are used as references for qualitative visual comparison. The following maps in Figures 4.1.1 and 4.1.2 are curated by Ryan (2021) and analyzed to develop a new climate refugia identification model. For more information on MCDA datasets reference Appendix C.

Climate Refugia Datasets & MCDA Synthesis

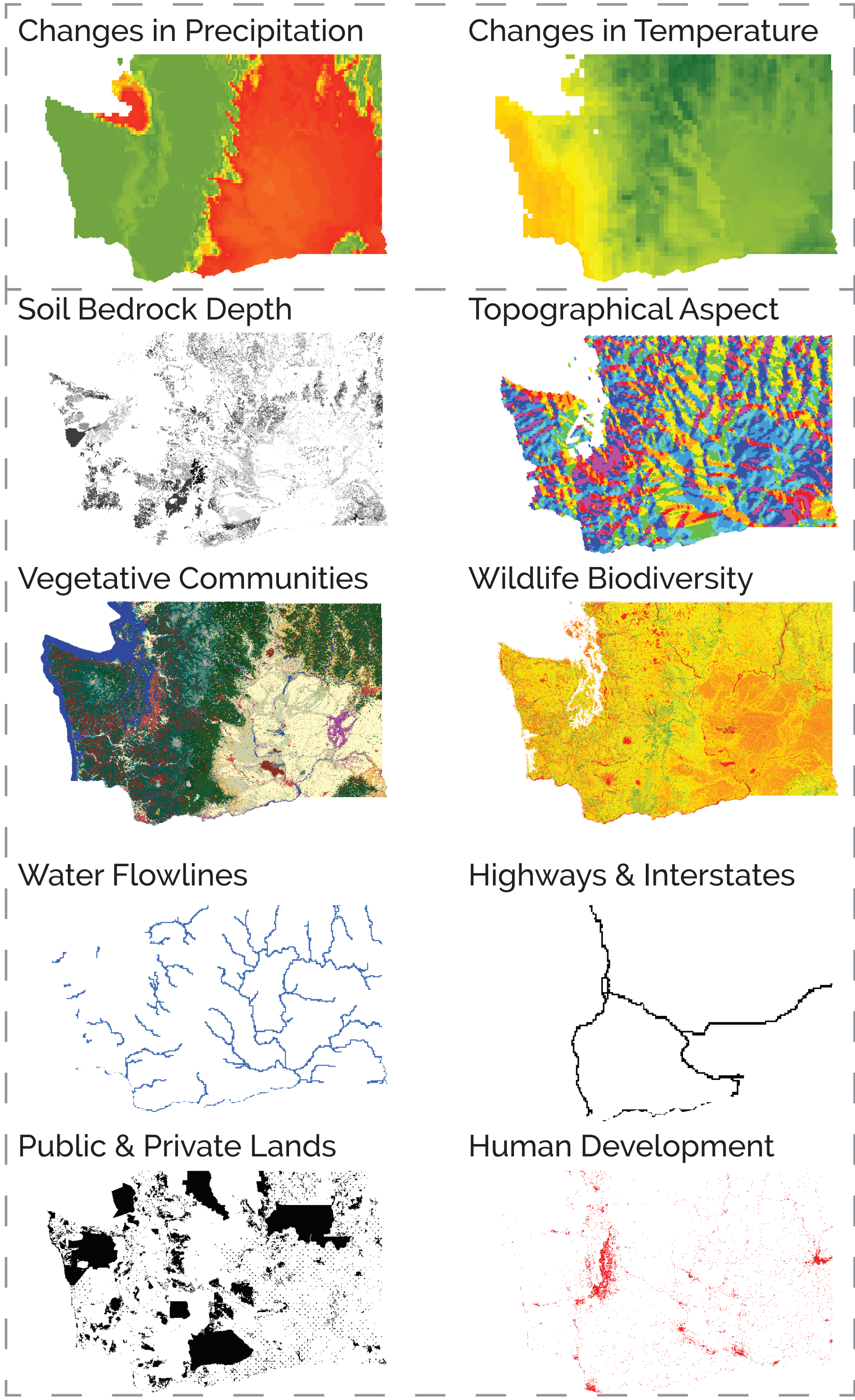


Figure 4.1.1 - Climatic Trends & Refugia Datasets (Ryan et al. 2021)

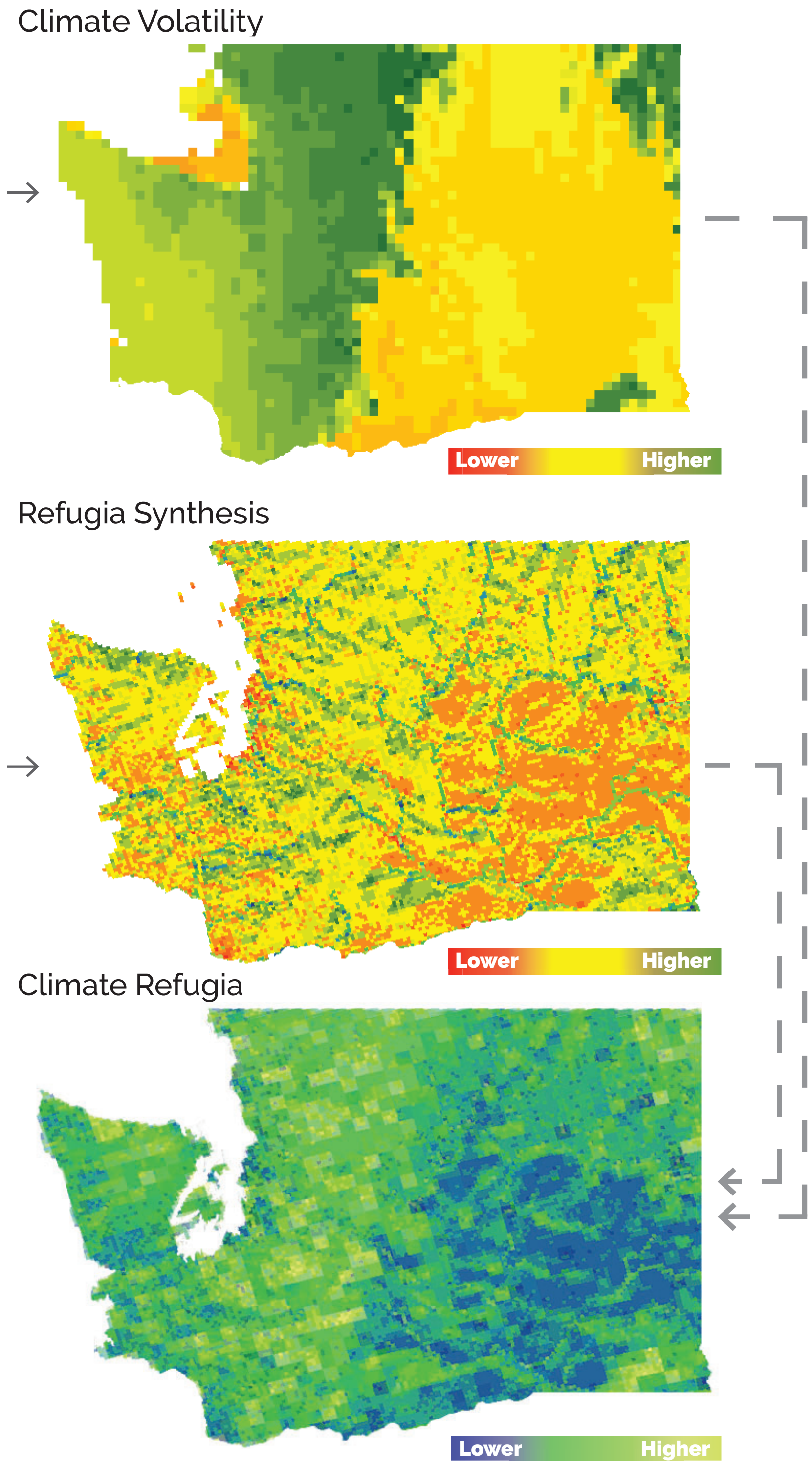


Figure 4.1.2 - Climatic Refugia MCDA (Ryan et al. 2021)

Corridors of Unidirectional Temperatures and High Landscape Integrity

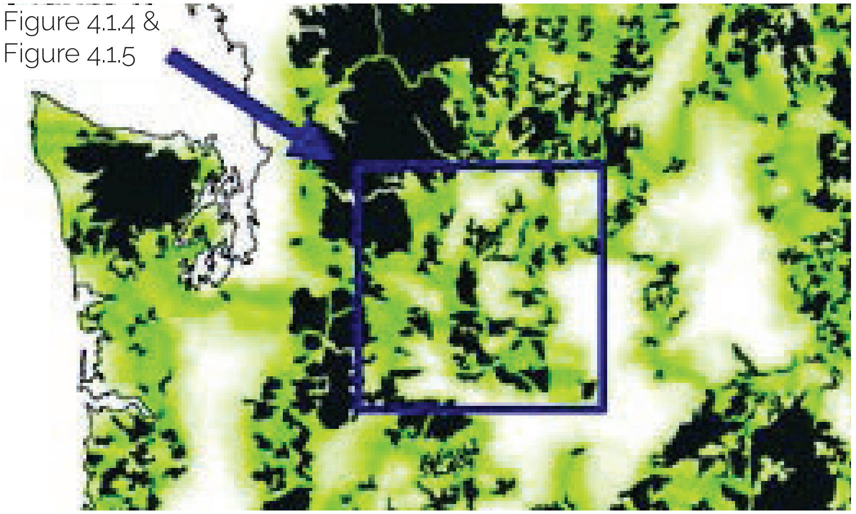


Figure 4.1 Corridor of Unidirectional Temperature and High Landscape Integrity(Nuñez et al. 2013)

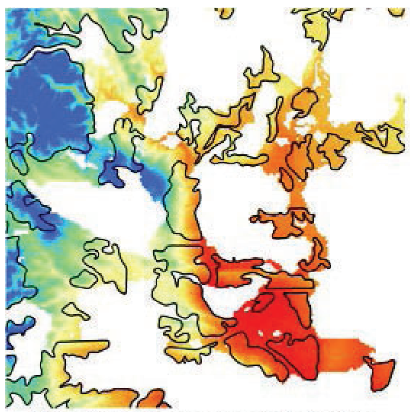


Figure 4.1.3 - Mean annual temp. within patches and corridors mapped using temperature gradients and landscape integrity

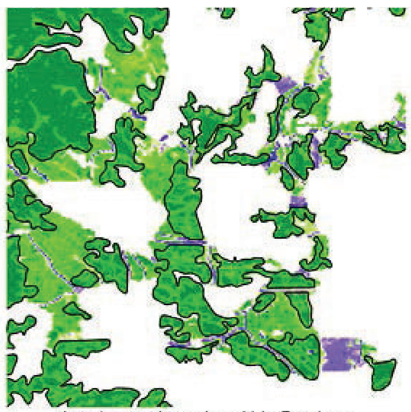


Figure 4.1.4 - Landscape integrity within patches and corridors mapped using temperature gradients and landscape integrity

Results

In the discussion section, Nuñez et al. (2013) admits that their approach is merely a starting point in identifying key corridors for species movement in a changing climate. Nuñez et al. (2013) asserts that riparian corridors are key to movement and are great identifiers in locating corridors along climate gradients. Nuñez et al (2013) are the first to note that species-specific models and datasets tailored to designated regions is the next step in determining climate corridors and refugia.

Climate Refugia

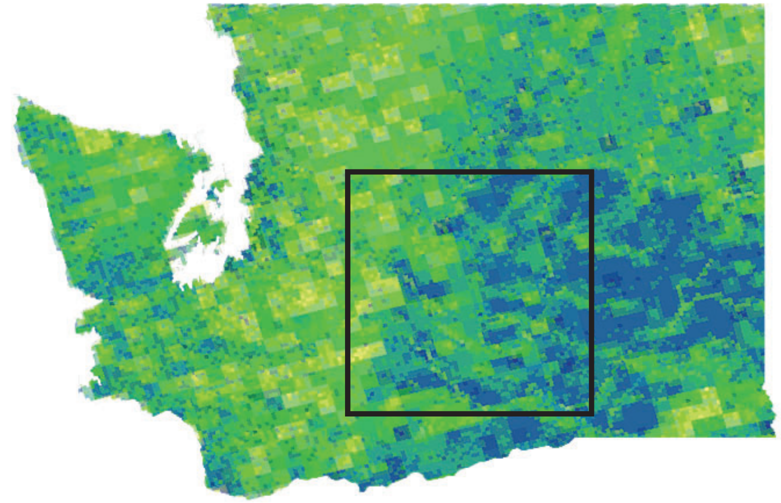


Figure 4.1.2 - Climatic Refugia MCDA (Ryan et al. 2021)

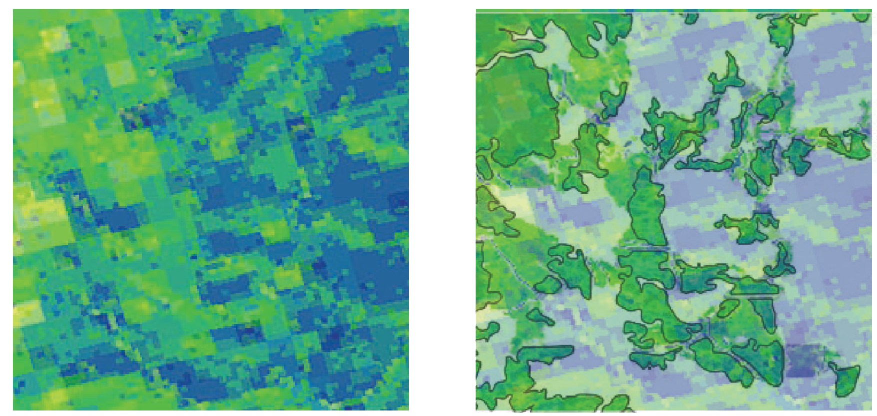


Figure 4.1.5 - Climatic Refugia MCDA with the work of Nuñez et al. (2013) overlapped to show visual correlations between methods.

Through qualitative visual analysis, the corridors and patches represented by (Nuñez et al. 2013) correlate fairly well with the patches and corridors outlined by the climate refugia MCDA developed for this report (Ryan et al. 2021). However, the discrepancy between map resolutions of the work produced by Nuñez et al. (2013) and Ryan et al. (2021) prevents the ability to analyze or gather further understanding of patterns between models.

“Achieving Climate Connectivity in a Fragmented Landscape”

Background Information

Location Contiguous United States of America (lower 48 states)

Scale National

Date Research Published in 2016

Researchers Jenny L. McGuire, Joshua J. Lawler, Brad H. McRae, Tristan A. Nuñez, and David M. Theobald

Research Aims “The contiguous United States contains a disconnected patchwork of natural lands. This fragmentation by human activities limits species’ ability to track suitable climates as they rapidly shift ranges. However, most models that project species movement needs have not examined where fragmentation will limit those movements”. (McGuire et al. 2016)

Metrics

- Margin of Climate Connectivity Success or Failure
  - Current temp origin patch minus future temp destination patch
- Mean Annual Temperature
- Projected Temp. Change (1950-2000 & 2050-2099)
- Potential for Temp. Change
  - Difference in future temp-based around connectivity of adjacent patch temps. (hotter or cooler)

Table 4.2 - Precedent Study Background information (McGuire et al. 2016)

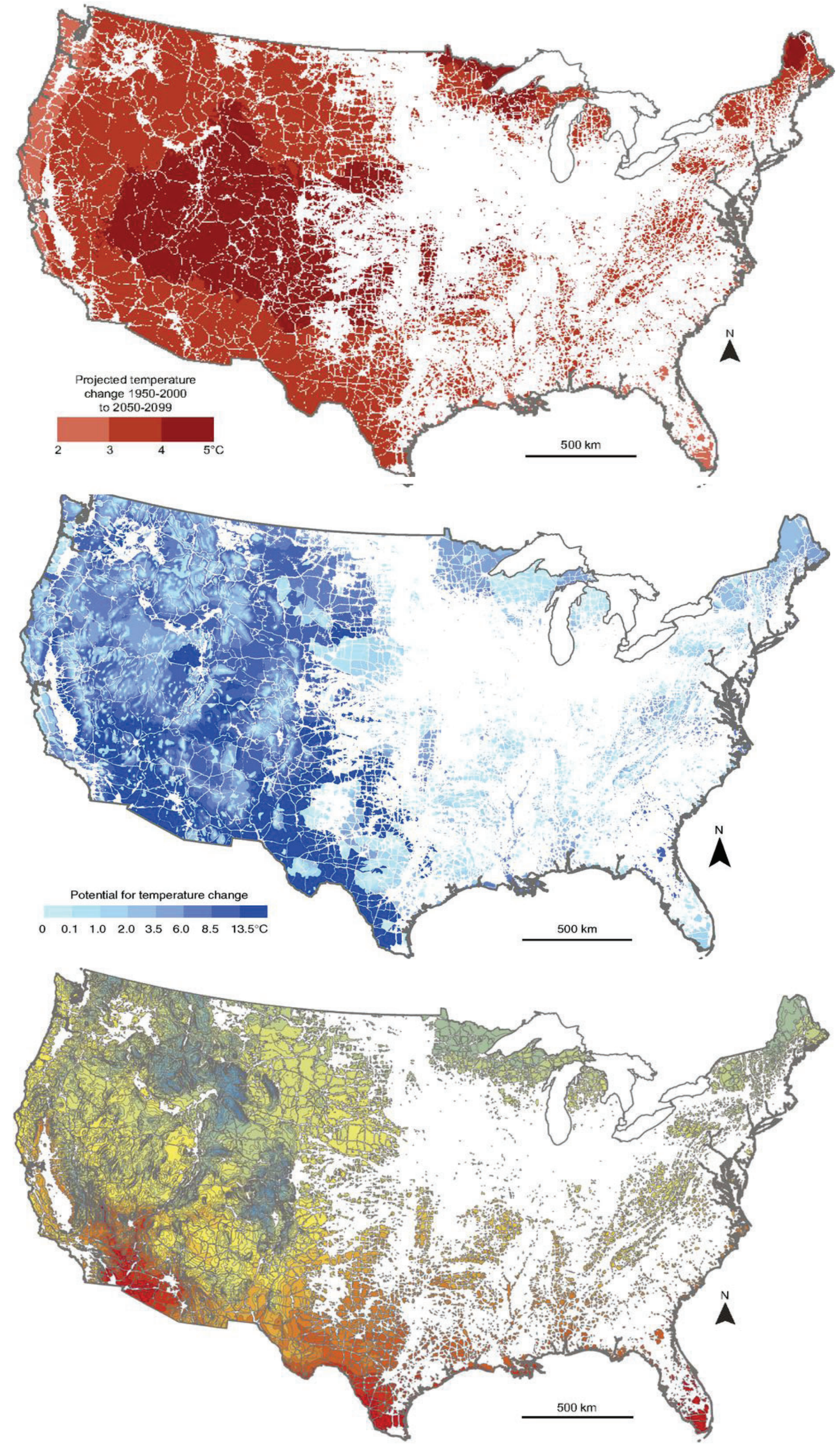


Figure 4.2 - Summation of mean annual temperature changes across high-integrity habitat patches (McGuire et al. 2016)

Climate Refugia Datasets & MCDA Synthesis

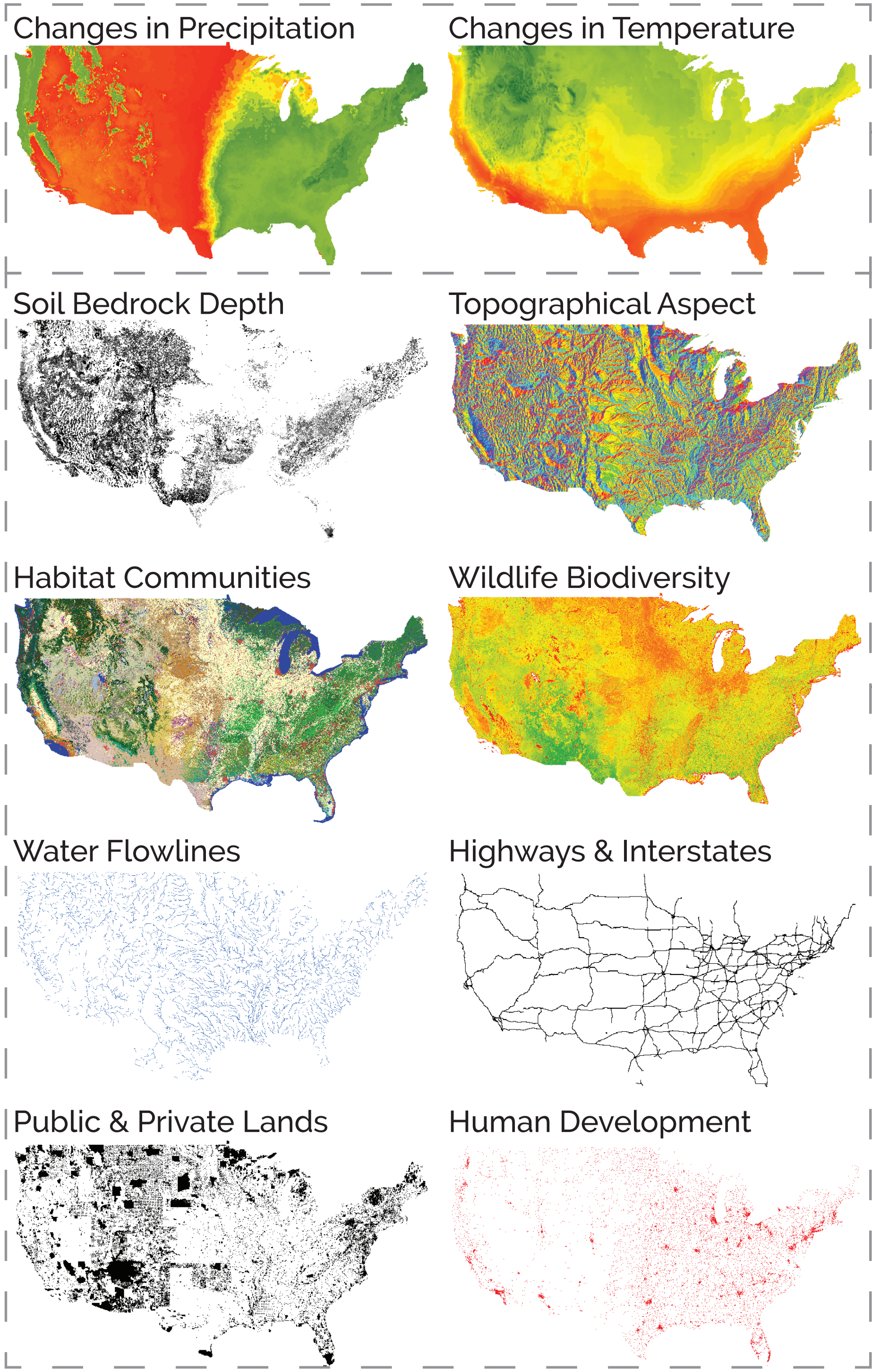


Figure 4.2.1 - Climatic Trends & Refugia Datasets (Ryan et al. 2021)

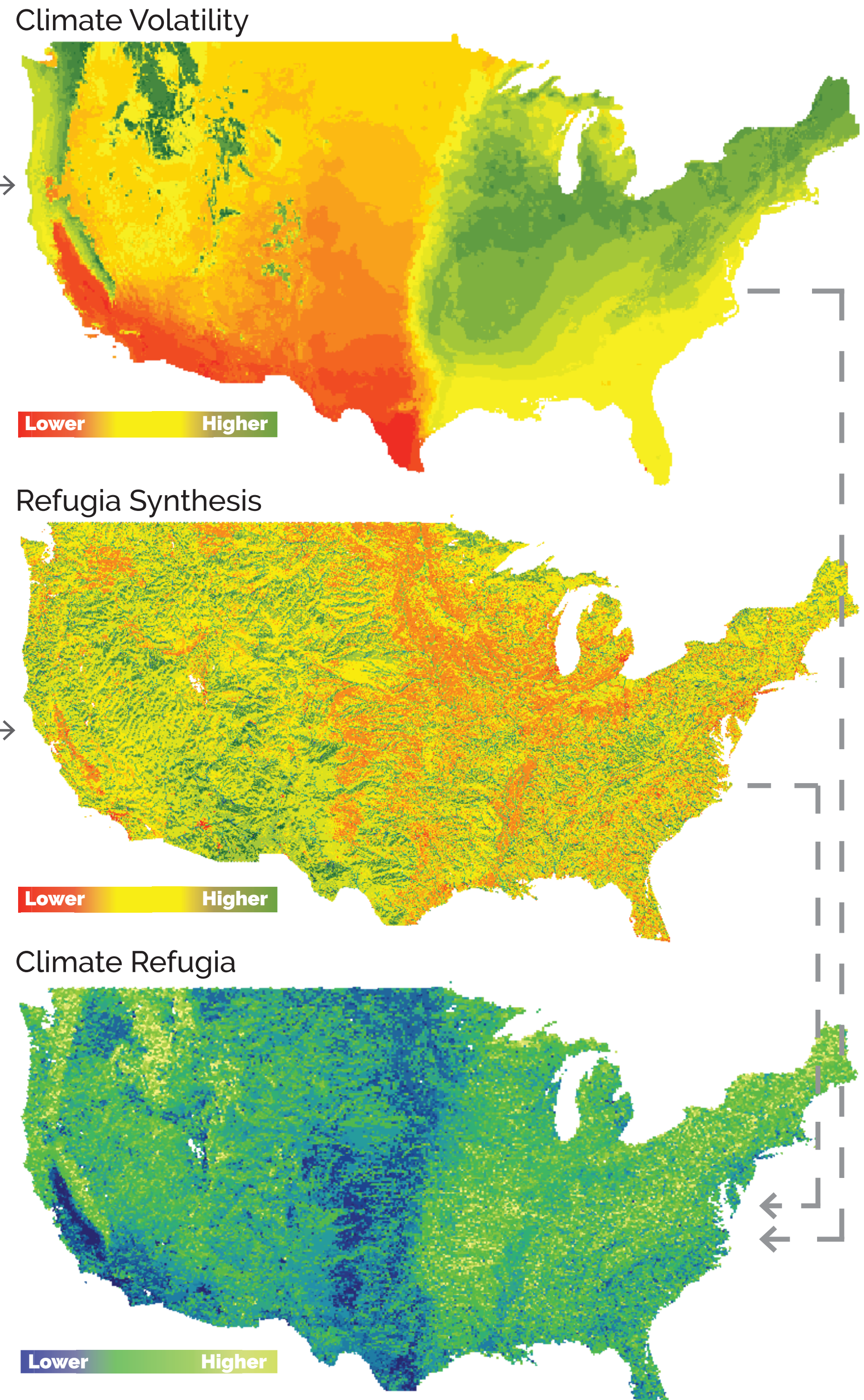


Figure 4.2.2 - Climatic Refugia MCDA (Ryan et al. 2021)

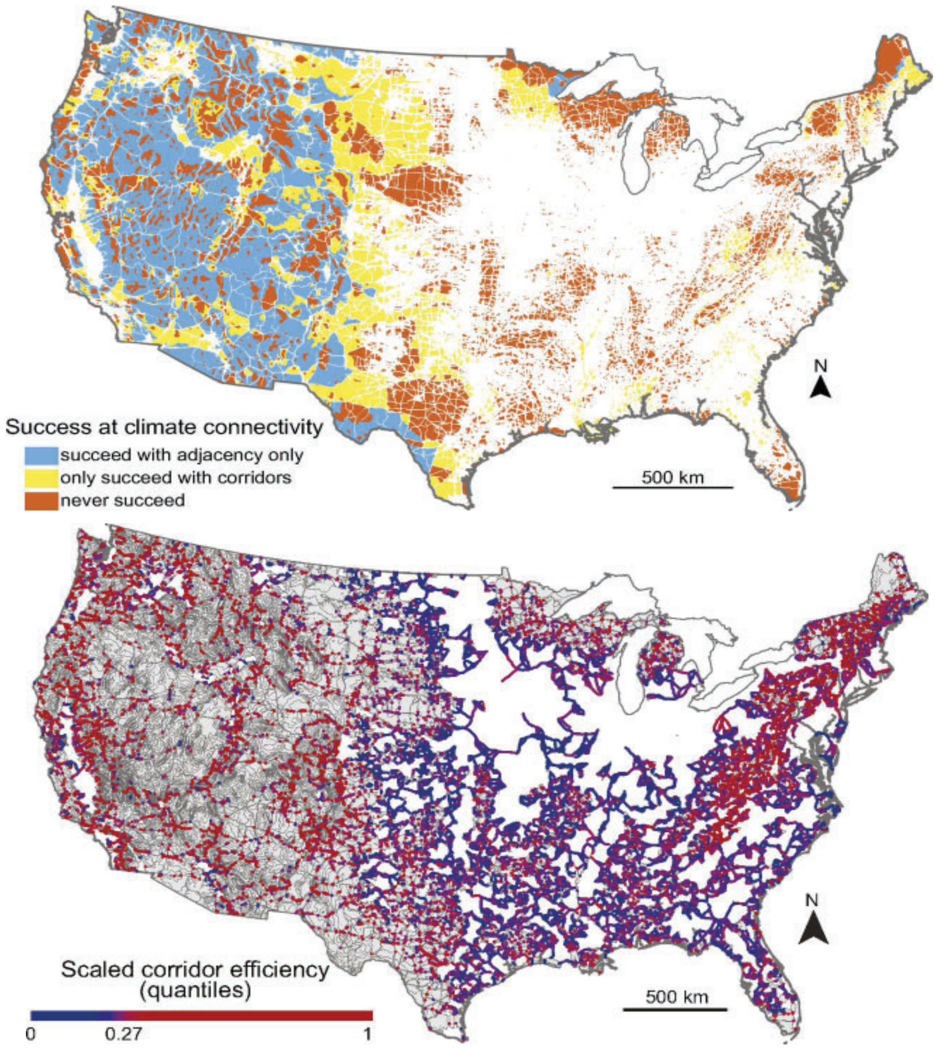


Figure 4.2.3 - Climate Connectivity Success and Corridor Efficiency (MCGuire et al. 2016)

Results

Based on purely qualitative visual comparison, climate corridor efficiency seems to align across studies. to some degree The distinction between areas capable of succeeding in climate connectivity/ecosystem migration due to climate change are depicted with hard visual edges. However, climate predictions are purely projections and subject to change, which leaves concerns with such graphic and verbal rigidity in saying a certain habitat is never going to succeed in climate connectivity. Regardless, the overall results and visual comparisons between studies yielded

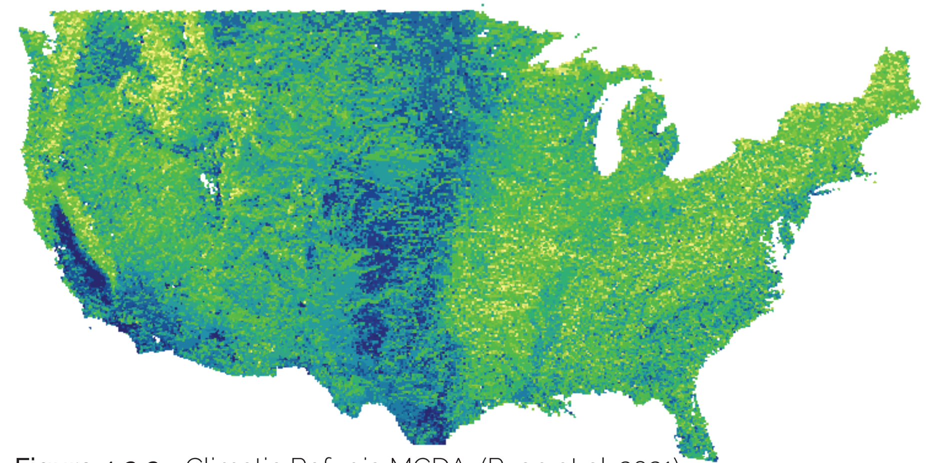


Figure 4.2.2 - Climatic Refugia MCDA (Ryan et al. 2021)

interesting correlations. In comparing the dark orange "never succeed" and white data vacancies in the Success at Climate Connectivity map by McGuire et al. (2016) and the areas in dark blue that were created by this study's climate refugia synthesis map, certain geographic landmarks and their suitability seem to align with one another. For example, the Central Valley and Sonoran Desert in California, Columbia Plateau in Washington, and overall Great Plains region all seem to be areas that will struggle to adapt and migrate in the face of a changing climate. Yet, as was mentioned previously, I am hesitant to use such exacting language to suggest the Great Plains region is incapable of succeeding in climate connectivity.

Another significant observation to note, is the potential for success of the Eastern United States in my MCDA. The amount of bright yellow indicated in this study"s climate refugia synthesis map places high value in the forests adjacent the Missouri/Mississippi riparian corridors. While the areas directly adjacent to the rivers are prime agricultural land, research suggests their restoration could create immense opportunities for climate connectivity and refugia development.

“Combining physical and species-based approaches improves refugia identification”

Background Information

Location	Northern Prairie (Montana, North & South Dakota, & Nebraska)
Scale	North America - Ecoregional Focus
Date	Research Published in 2020
Authors	Julia L Michalak, Diana Stralberg, Jennifer M. Cartwright, & Joshua J. Lawler
Research Aims	Determining continental approaches to refugia identification through species-neutral and species-based methodologies. By asking the question “refugia for what?” and incorporating species-specific information into refugia planning, it may help better understand and manage refugia selection, especially in areas lacking topographic complexity (Michalak et al. 2020).

Metrics	- Environmental Diversity
	  - Land Facet Diversity
	  - Current Climate Diversity
	  - Ecotypic Diversity
	- Climate Exposure
	  - Climate Dissimilarity
	- Climate Tracking
	  - Backward Velocity Index
	  - Analog Base Macrorefugia: Forest Songbird Macrorefugia
	  - Grassland Songbird Macrorefugia
	  - Open Woodland Songbird
	  - Scrub Songbird Macrorefugia
	  - Tree Macrorefugia

Table 4.3 - Precedent Study Background information (Michalak et al. 2020)

Michalak et al. (2020) utilize species-specific and species-neutral approaches to understand differences in the refugia capacity of various ecoregions. Specifically, ecoregions that are normally overlooked through the previous precedents climate connectivity models. That is why the Northern Prairie ecoregion portion of this precedent will be the sole focus in the following qualitative visual comparison. However, due to limitations of data availability, the Canadian portion of the Northern Prairie is excluded in MCDA climate identification, The extent of the Northern Prairie band US portion being analyzed, can be seen in Figures 4.3 and 4.3.1.

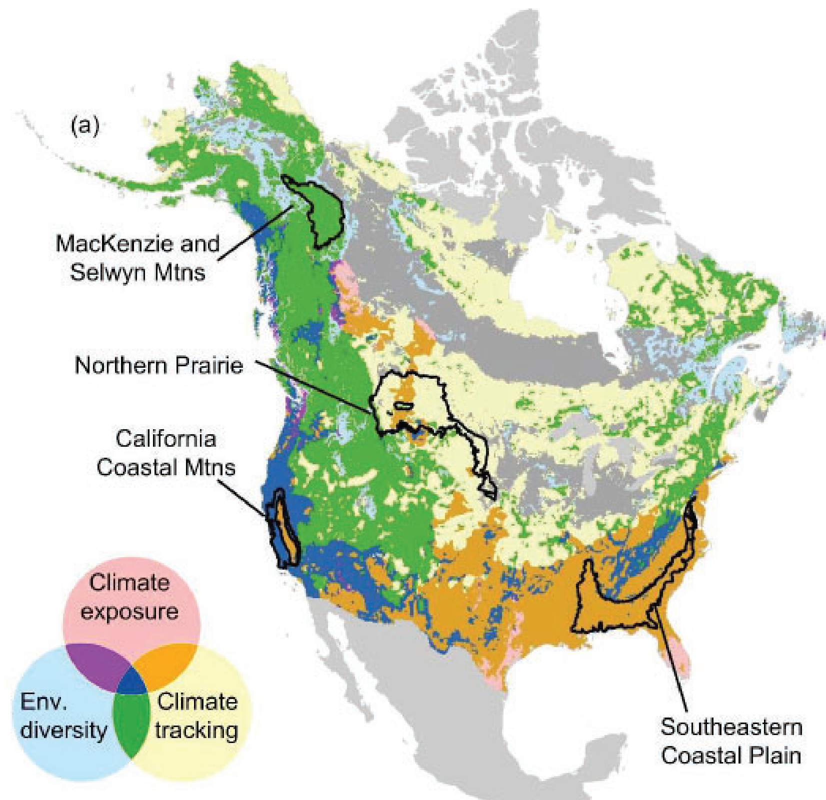


Figure 4.3 - Harnessing species-neutral and species-specific datasets to identify ecoregional refugia (Michalak et al. 2020)

- Large-tract species-neutral habitat

Northern Prairie Extents

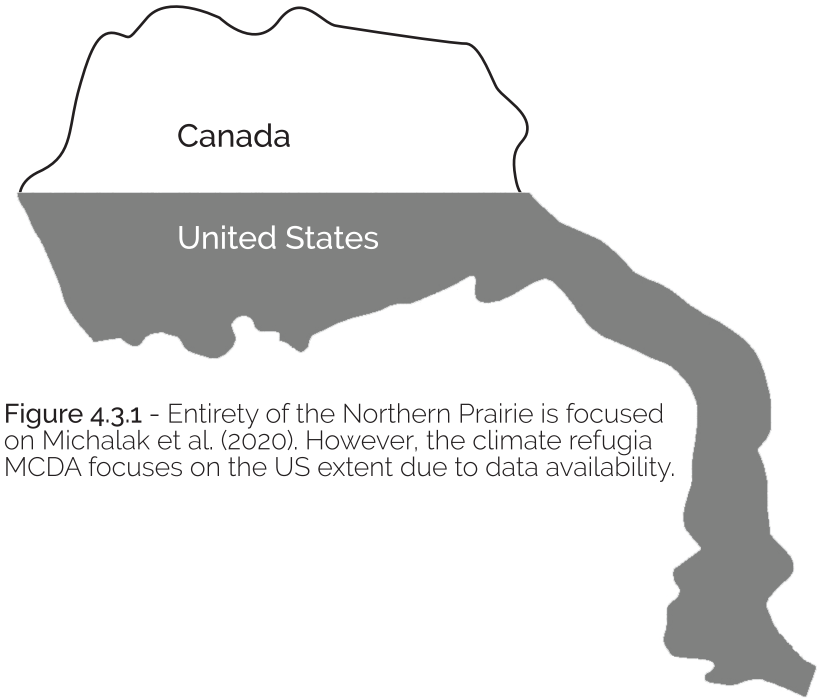
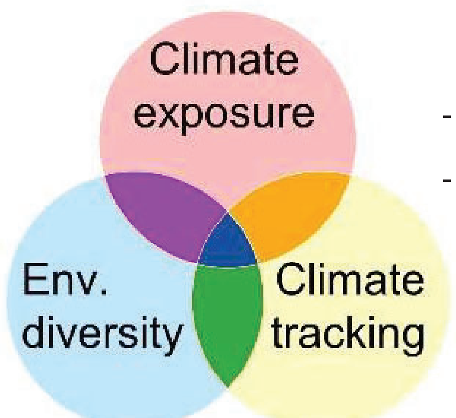


Figure 4.3.1 - Entirety of the Northern Prairie is focused on Michalak et al. (2020). However, the climate refugia MCDA focuses on the US extent due to data availability.

Michalak et al. (2020) compiles climate and macrorefugia datasets that focus specifically on bird species and climate change data, which can be seen in Figure 4.3.2. The categories they were compiled into and their relationships to one another can be seen in Table 4.3 and Figures 4.3.2. & 4.3.3

Northern Prairie Extents



- Environmental Diversity
  - Land Facet Diversity
  - Current Climate Diversity
  - Ecotypic Diversity
- Climate Exposure
  - Climate Dissimilarity
- Climate Tracking
  - Backward Velocity Index
  - Analog Base Macrorefugia:
  - Forest Songbird Macrorefugia
  - Grassland Songbird Macrorefugia
  - Open Woodland Songbird
  - Scrub Songbird Macrorefugia
  - Tree Macrorefugia

Figure 4.3.2 - Species-specific & Climate datasets (Michalak et al. 2020)

Refugia Identification Datasets

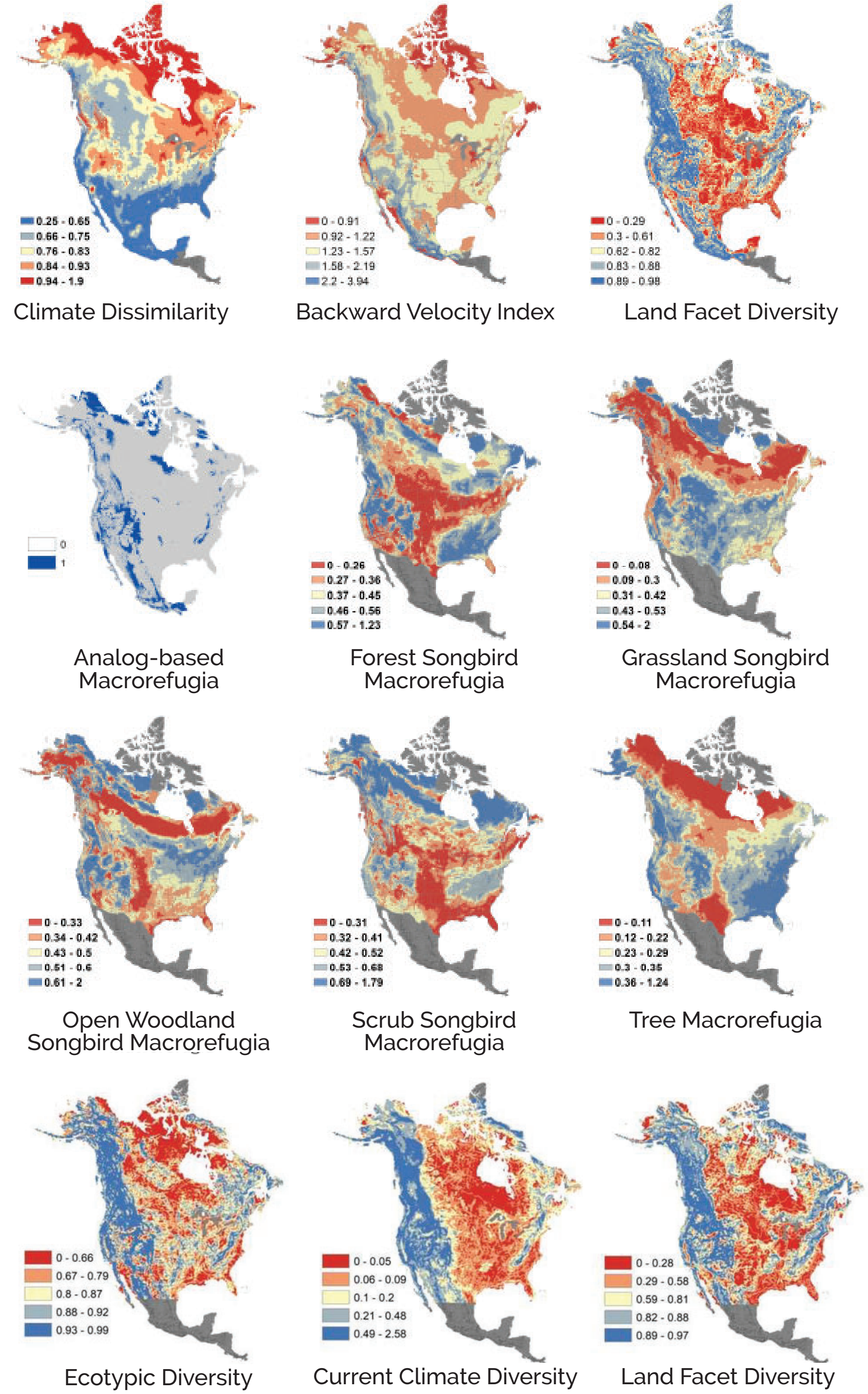


Figure 4.3.3 - Climatic and macrorefugia datasets across North America (Michalak et al. 2020)

Climate Refugia Metrics

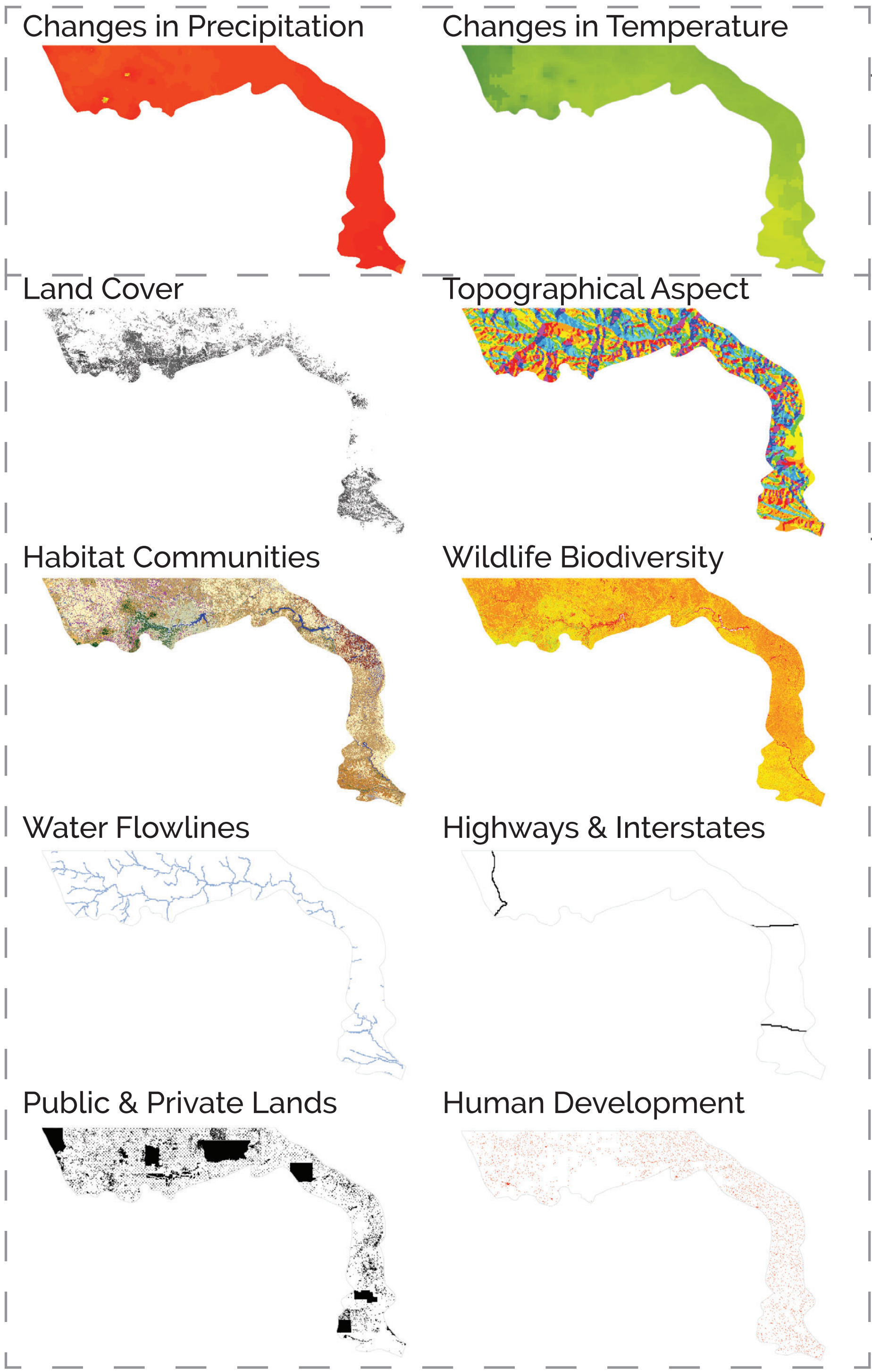


Figure 4.3.4 - Datasets for the US extent of the Northern Prairies (Ryan et al. 2021)

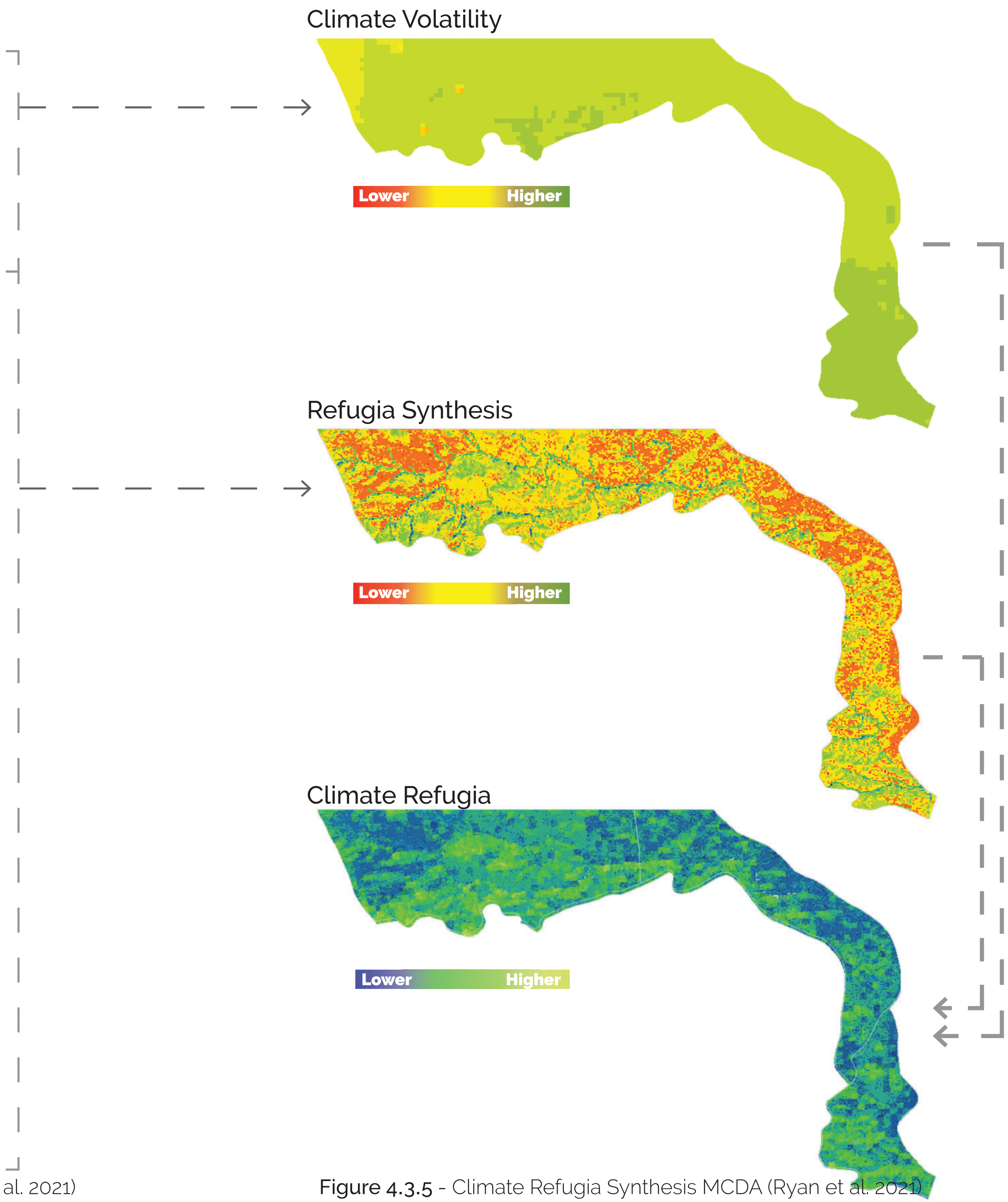


Figure 4.3.5 - Climate Refugia Synthesis MCDA (Ryan et al. 2021)

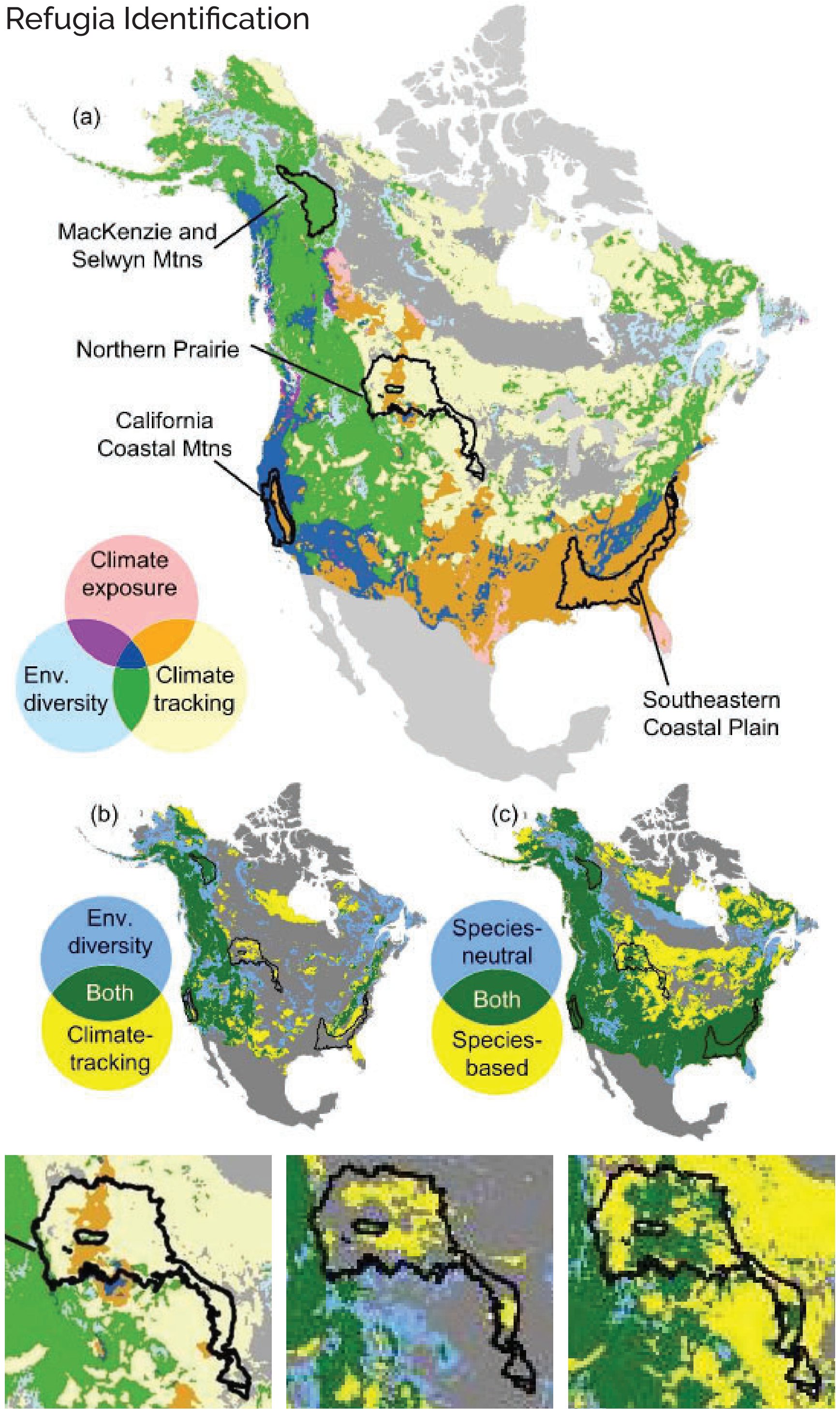


Figure 4.3.6 - Climate Exposure, Climate Tracking, and Environmental Diversity refugia analysis (Michalak et al. 2020)

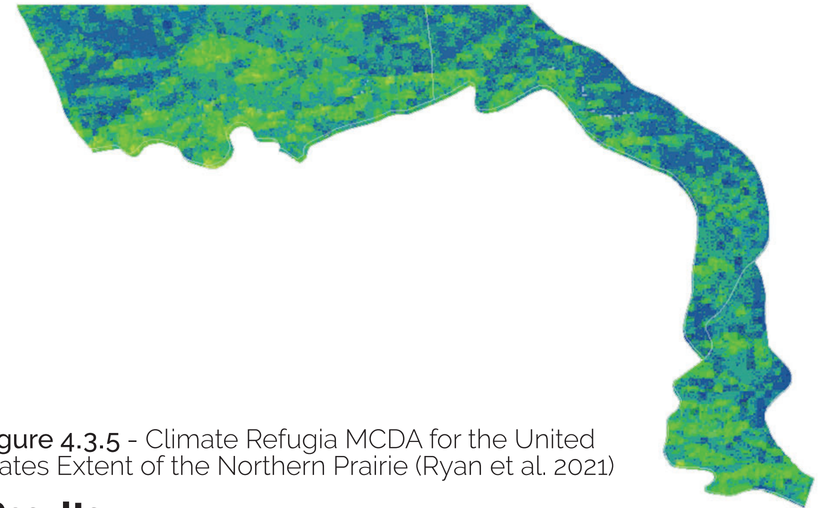


Figure 4.3.5 - Climate Refugia MCDA for the United States Extent of the Northern Prairie (Ryan et al. 2021)

Results

Many refugia-identification approaches and datasets vary widely among studies but the emphasis of the work by Michalak et al. (2020) highlights the importance of species-based approaches. Michalak et al. (2020) asserts that the Northern prairie ecosystem, while lacking in the topographic complexity that would normally disqualify the region as a refugia candidate, has refugia potential for certain species native to the ecoregion. While the climatic exposure in Figure. 4.3.6 is high in the Northern Prairie, riparian corridors and other hydrologic features offer respite through surface water availability, increased soil moisture, and vegetative cover. However, as Michalak et al. (2020) notes, agriculture is often found along these fertile riparian areas, reducing opportunities for refugia, which is largely responsible for the dark blue representation in Figure 4.3.5. This dilemma presents a unique opportunity for rethinking agricultural practices and locations if any meaningful climate refugia is to be developed or existing conditions to be enhanced. Regardless of the issues presented by these findings, a species-based or perhaps an ecosystem/ecoregional-based approach to refugia development seems especially important for the Midwest.

Precedent Synthesis

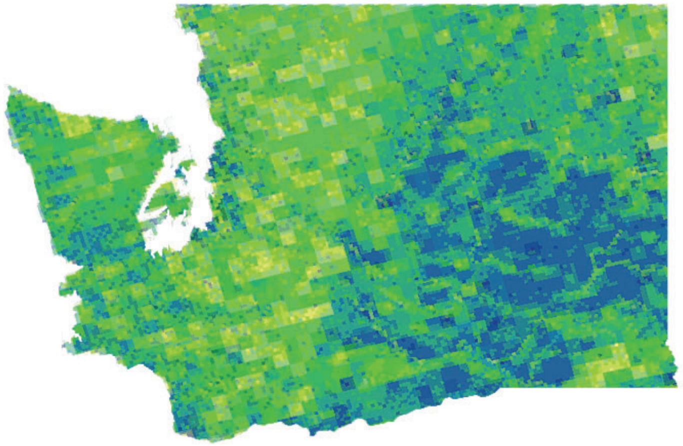


Figure 4.1.2 - Climatic Refugia MCDA (Ryan et al. 2021)

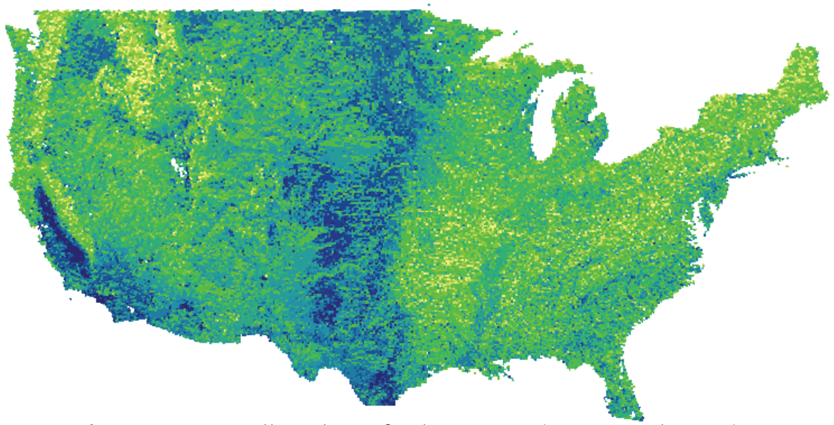


Figure 4.2.2 - Climatic Refugia MCDA (Ryan et al. 2021)

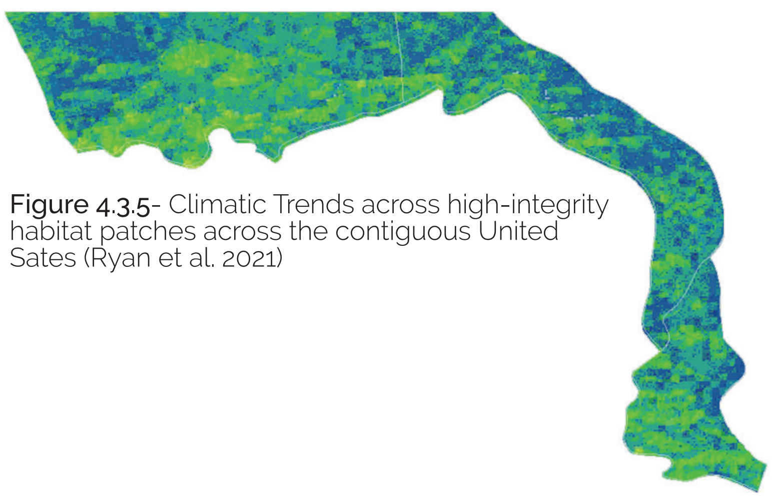


Figure 4.3.5- Climatic Trends across high-integrity habitat patches across the contiguous United Sates (Ryan et al. 2021)

Based on qualitative visual analysis of the precedent studies and their visual comparison with the MCDA generated Climate Refugia Map, it appears that the metrics chosen for identifying climate refugia in this project and report are effective. These datasets have helped determine potential sites and corridor suitability across multiple scales and ecosystems. Some of the most enlightening results of this analysis process came from the realization that agriculture is currently one of the greatest setbacks to climate refugia for the Great Plains region. Since rivers and streams are essential for migration and refugia development, agriculture leaning on these hydrologic features are detracting from refugia development. While agriculture may be detrimental to refugia, reexamining the issue as a potential opportunity, not only in refugia development, but also developing agricultural practices, could lead to innovation. Exploring this concept further can hopefully yield greater insights into ways of reconnecting climate corridors believed to be incapable of succeeding in a changing climate. Based on this, further development of more regionally rooted metrics focused on Great Plains ecosystems and agriculture can perhaps help to find other insights and potentially mitigate competing needs between agricultural production and Midwest refugia development.

Design Application

Design Application:

Multi-Criteria Decision Analysis

Kansas Climate Refugia
Northeastern Kansas Refugia
Wyandotte County Refugia
Qualitative Analysis of MCDA Results

Designs for Northeastern Kansas

Goals & Objectives

Regional Refugia: Northeastern Kansas
Urban Refugium: Wyandotte County

Refugia Design

Topographic Manipulation
Ecosystem Creation
Barrier Mitigation
Design Visualization

Urban Refugium Design

MetroGreen & Wildlife Corridors
Missouri Riparian Refugium & Corridor Bridge

Designing Climate Refugia

Upon synthesis of the precedent studies, a significant trend became apparent. Considerations on refugia identification and corridor establishment require cooperation across scales and political boundaries. Wildlife and ecosystems do not see the same national or state boundaries humanity does so any solution for the Great Plains must require legislation and oversight at the federal level, planning across ecoregions, strategic implementation state-wide, and local design and construction. Planning, designing, and monitoring across a range of scales and ecosystems allows for the ability to protect vulnerable systems and species from extinction or extirpation in the coming decades. Through precedent analysis, National, ecoregional, and state refugia suitability leans heavily on projected climate map data. The predictions can be immensely effective at larger scales for master planning purposes but real change requires more tactile data that is collected and verified on-site in order to maximize design efficacy.

Great Plains Region & Kansas

The Kansas River and other major riparian corridors in the region have the potential to play a major role in climate connectivity as greater Midwestern ecosystems are projected to migrate with little evidence of being able to succeed. This is partly due to the relationships that the United states and the Midwest have on riparian floodplain agricultural products. The competing land-use needs between agriculture and ecosystem migration and refugia are common along major rivers. By looking specifically at floodplain agricultural plots (those areas that are currently flood prone and expected to worsen as rainfall events increase in intensity and diminish in frequency) more target regions can be found to supplement the existing riparian climate corridors that fill in missing gaps, and act as refugium stepping stones in a greater Midwest climate refugia system.

National, State, Fish and Wildlife Services managed, and Native lands can work together in conserving land for public and private conservation to varying degrees. Particularly in Eastern Kansas, finding ways to engage those willing to aid and conserve in ecological revitalization, can create a more effective refugia system to increase chances of success.

By harnessing the constructed habitats around the existing man-made reservoirs and system of creeks and streams, a datum or spine can be created to function as a major thoroughfare for wildlife to migrate along Native and conservation lands that are most capable of maintaining species-neutral and species-specific climate refugium sites.

Assessing Kansas Climate Refugia

Kansas climate refugia

Great Plains

Migration & Refugia

Multi-Criteria Decision Analysis

Kansas Climate Refugia
MCDA of Northeastern Kansas Refugia
MCDA of Wyandotte County Refugia
Synthesis of Qualitative Results

Kansas Climate Refugia

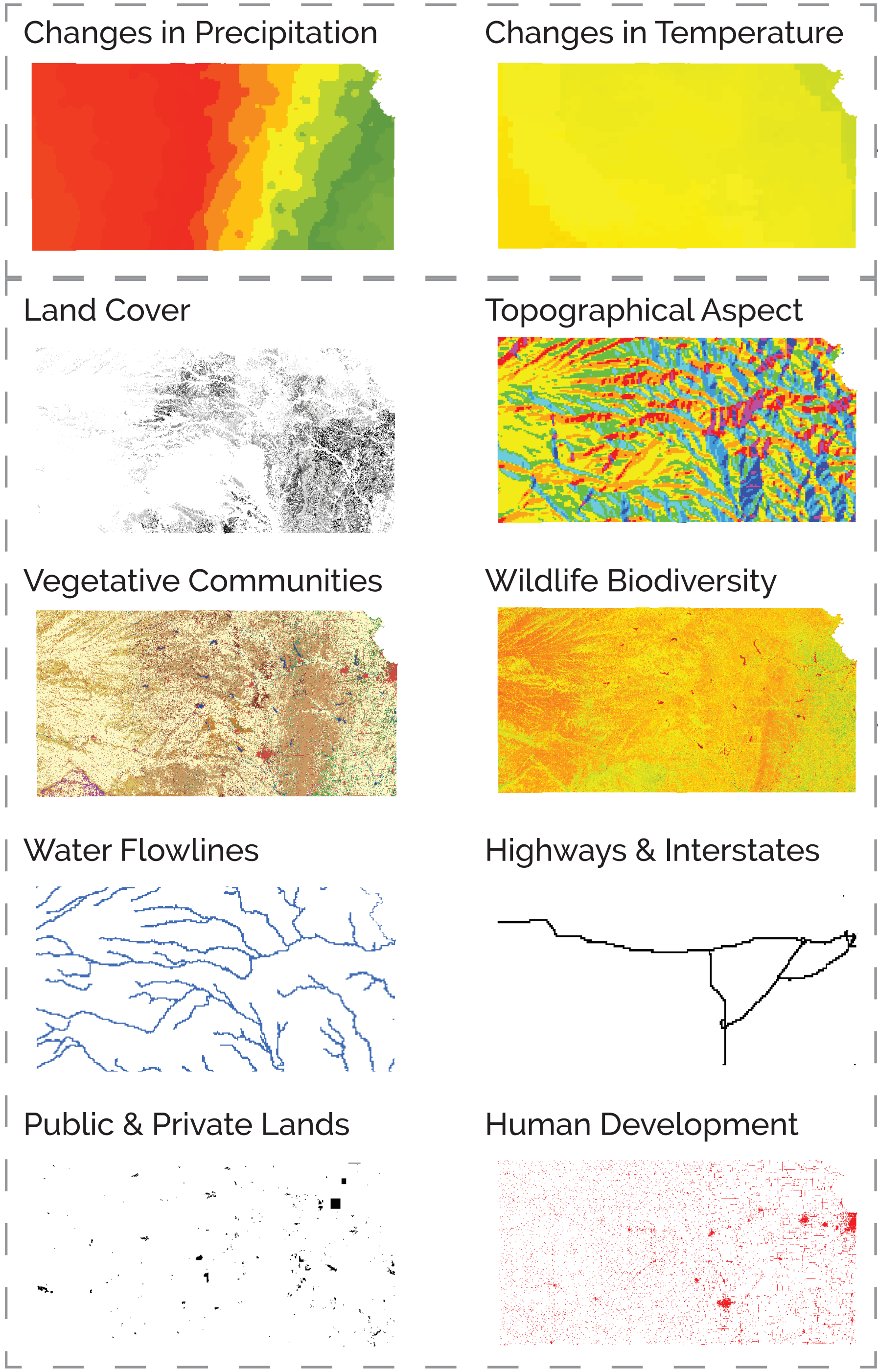


Figure 5.1 - Individual Kansas MCDA map dataset keys in Appendix D (Ryan et al. 2021)

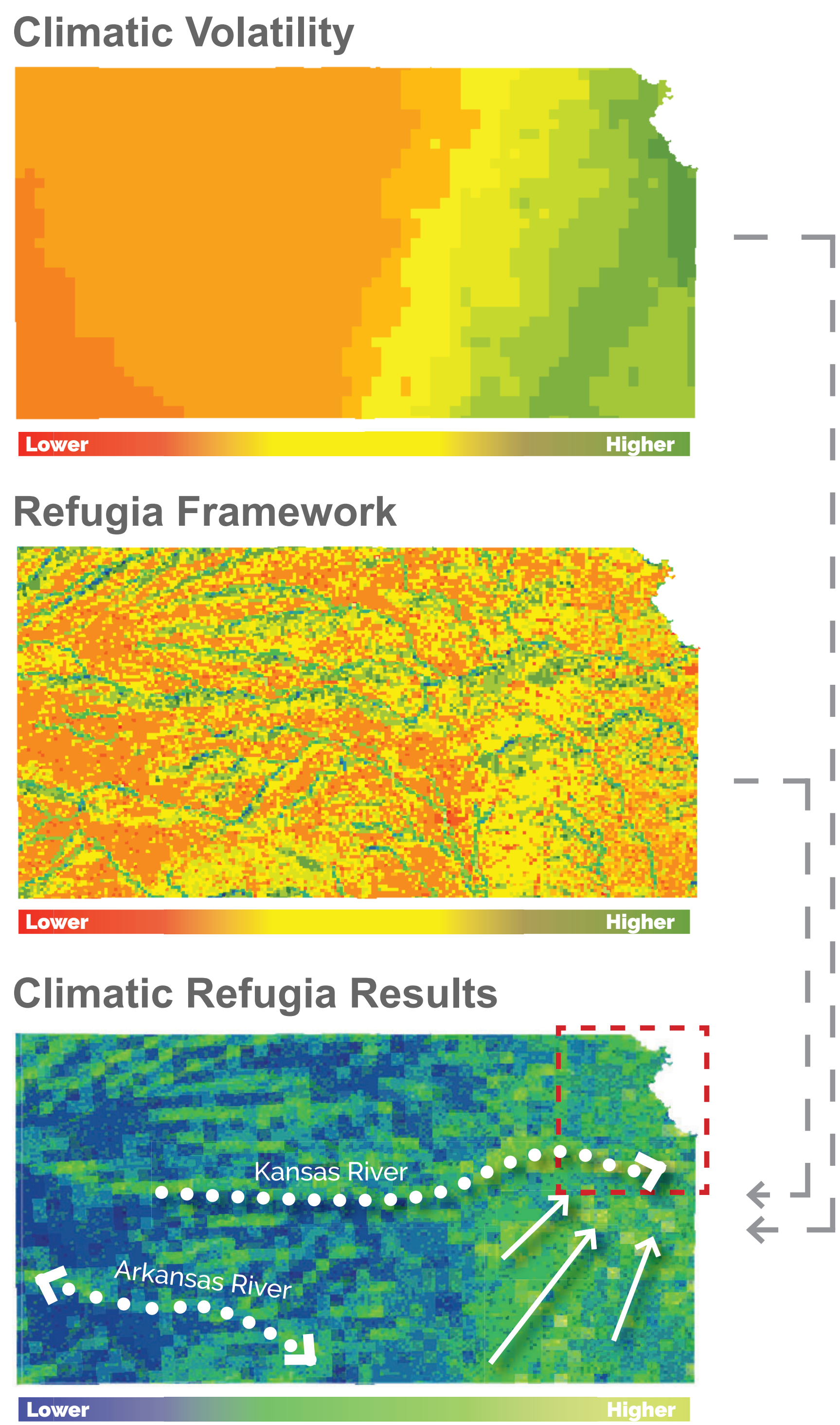
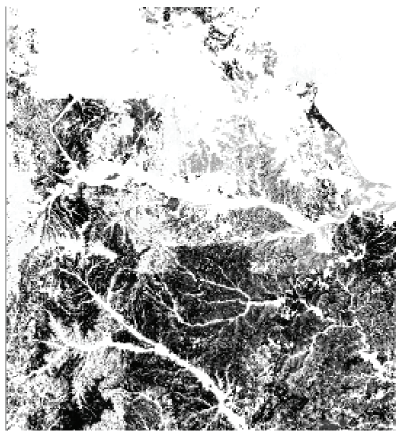


Figure 5.2 - Kansas Climate Refugia results & qualitative analysis (Ryan et al. 2021)

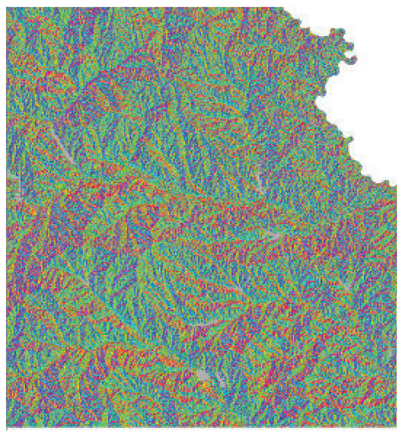
Northeast Kansas Refugia

By excluding climatic volatility conditions from the weighted sum overlay, cell sizes (resolution) of the MCDA raster is far greater and can allow for finer analysis to understand site specific conditions and areas of opportunity for enhancing with design. Based on visual analysis of Kansas Climate Refugia in Figure 5.5, range shifting is expected to flow east on the Kansas River and through Northeastern Kansas, this focus area was developed. Inclusion of region and scale-specific datasets like Agricultural Lands and vegetative communities, has helped understand refugia capabilities.

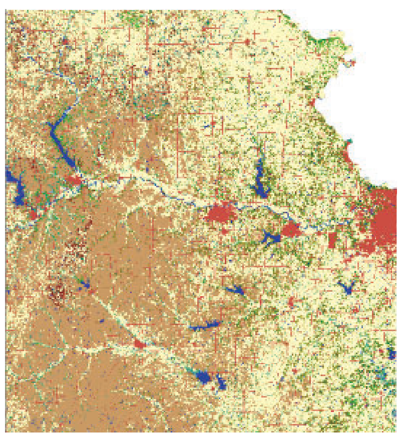
Soil Depth To Bedrock



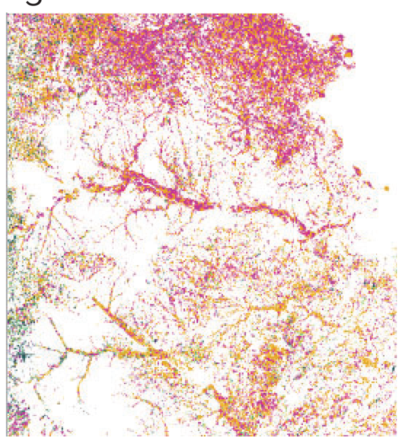
Topographical Aspect



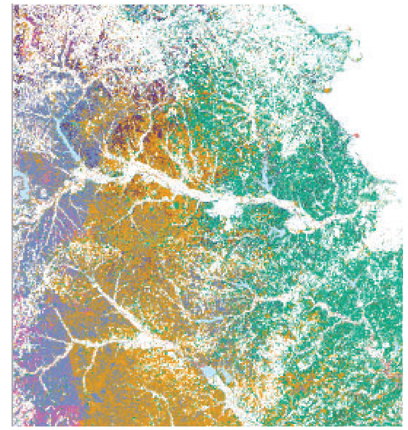
Land Cover



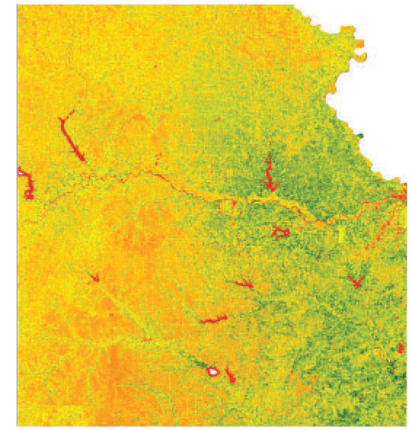
Agricultural Lands



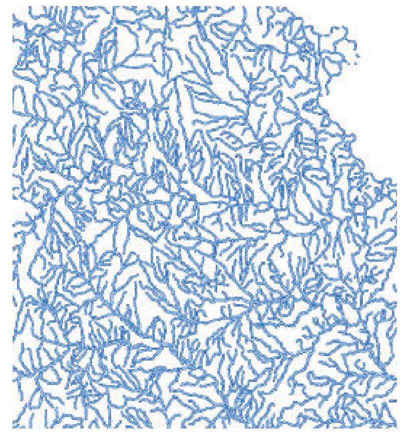
Vegetative Communities



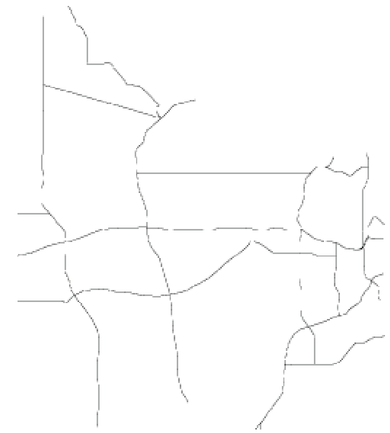
Wildlife Biodiversity



Water Flowlines



Highways & Interstates



Public & Private Lands

Human Development

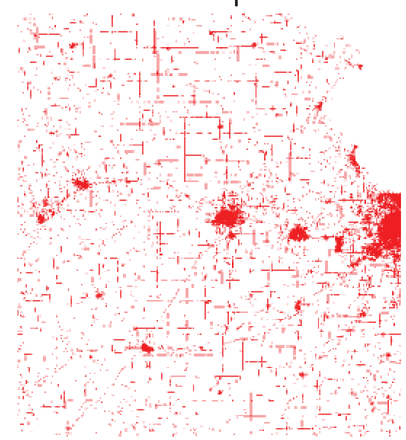


Figure 5.3 - Individual Northeastern Kansas MCDA map dataset keys in Appendix D (Ryan et al. 2021)

MCDA of Northeastern Kansas Refugia

Northeastern Kansas Refugia

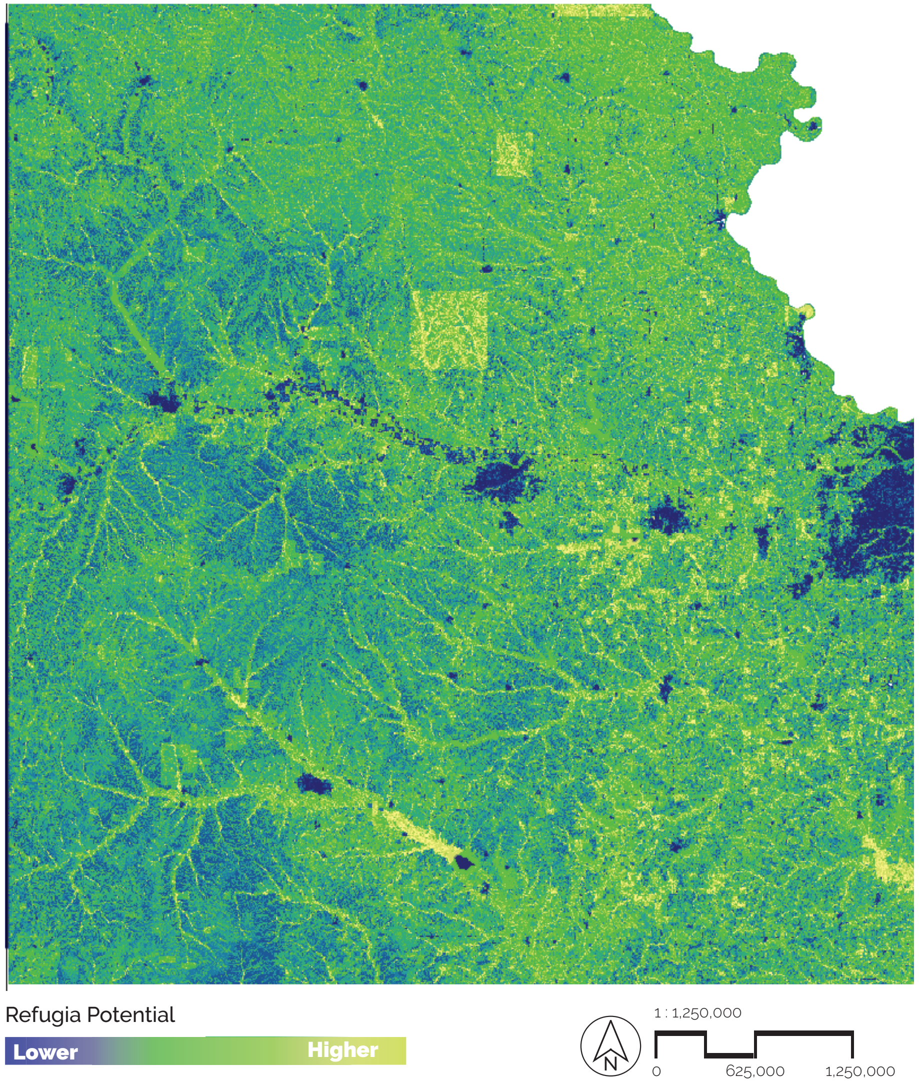


Figure 5.4 - Northeastern Kansas Refugia MCDA results (Ryan et al.2021)

Riparian corridors have historically been essential for community developed and why most of the communities in this part of the state follow the extent of the Kansas River. Figure 5.5. shows the route of the Kansas River and because of development along the river and agriculture datasets

Qualitative Analysis of MCDA Results

Northeastern Kansas Refugia

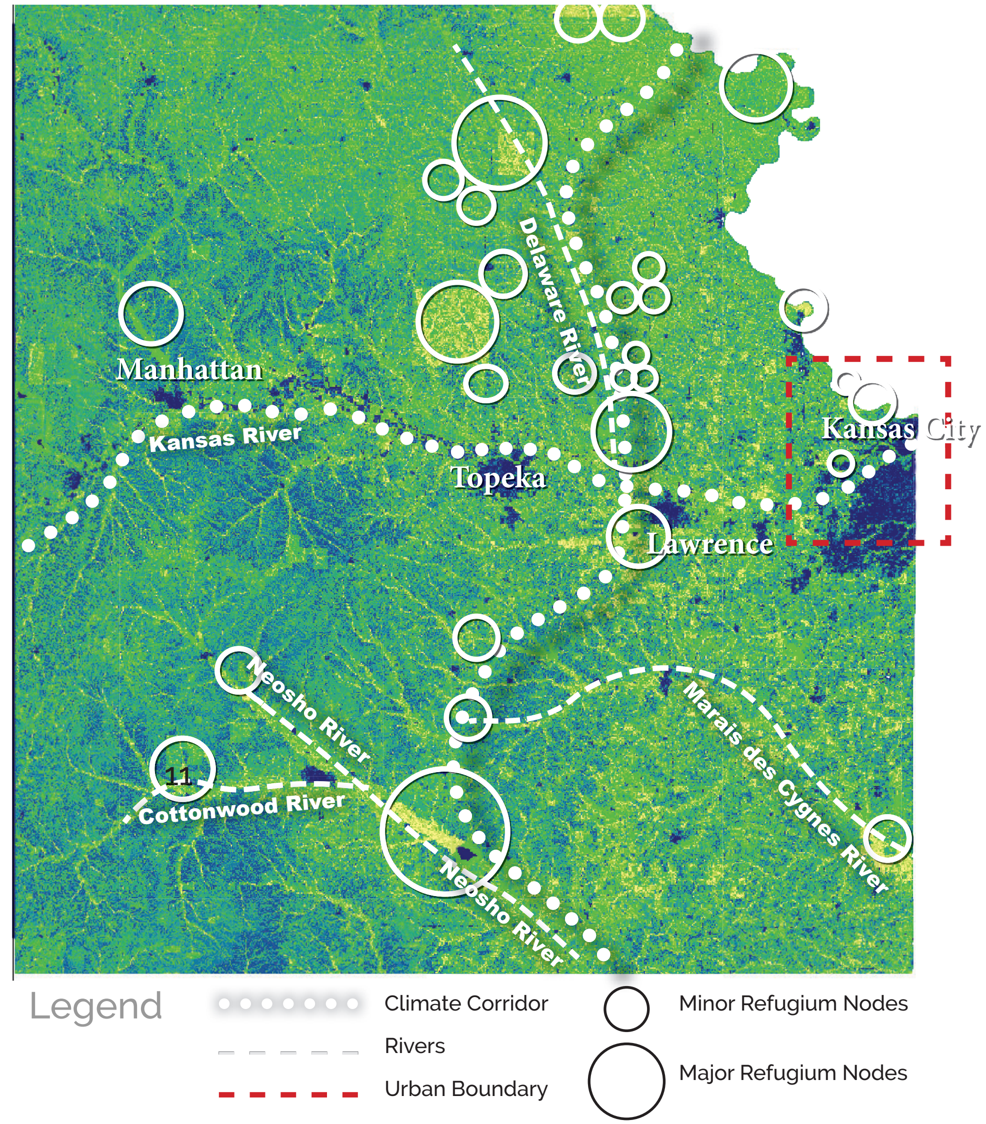
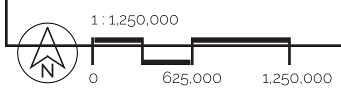


Figure 5.5 - Northeastern Kansas Refugia MCDA results & qualitative analysis (Ryan et al. 2021)

in the MCDA, the river isn't shown as a key component for migration or refugia. However, that is only showing existing conditions and not the inherent potential for the future. The same can be said about the confluence of the Kansas and Missouri Rivers in Kansas City.

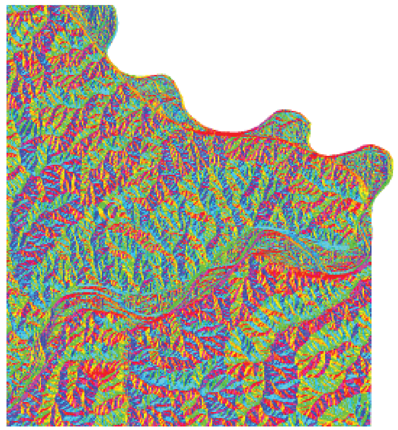
Wyandotte County Refugia

Since riparian corridors are essential to ecosystem migration and climate refugia for the Great Plains, finding ways to migrate and coexist alongside urban conditions can help mitigate the dilemma of the Kansas City metropolitan region orienting itself around this river confluence.

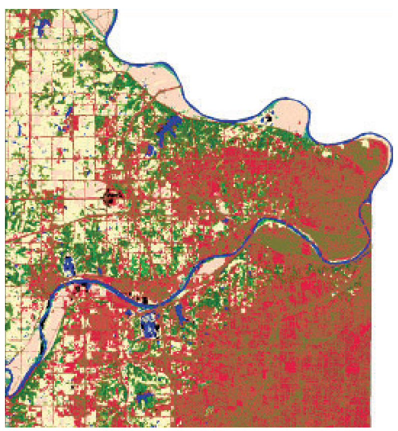


Soil Depth To Bedrock

Topographical Aspect

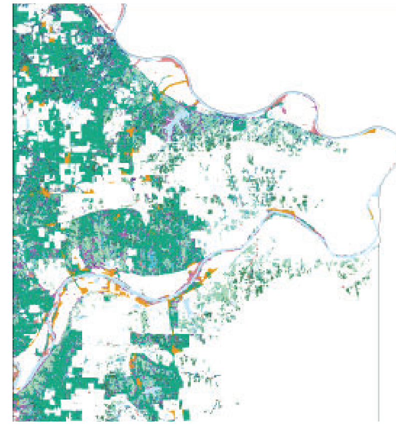


Land Cover

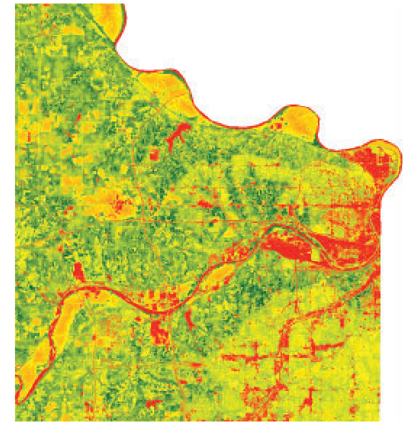


Agricultural Lands

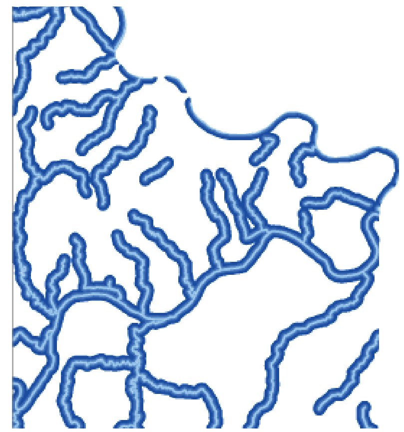
Vegetative Communities



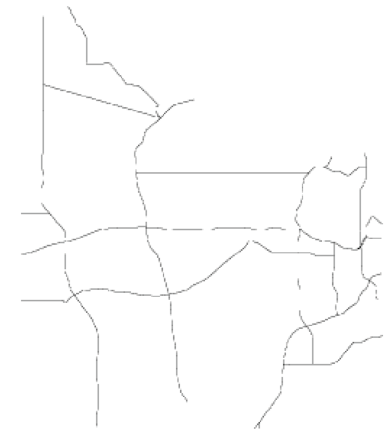
Wildlife Biodiversity



Water Flowlines



Highways & Interstates



Public & Private Lands

Human Development

Figure 5.6 - Individual Wyandotte County MCDA map dataset keys in Appendix D (Ryan et al. 2021)

MCDA of Northeastern Kansas Refugia

Wyandotte County Refugia

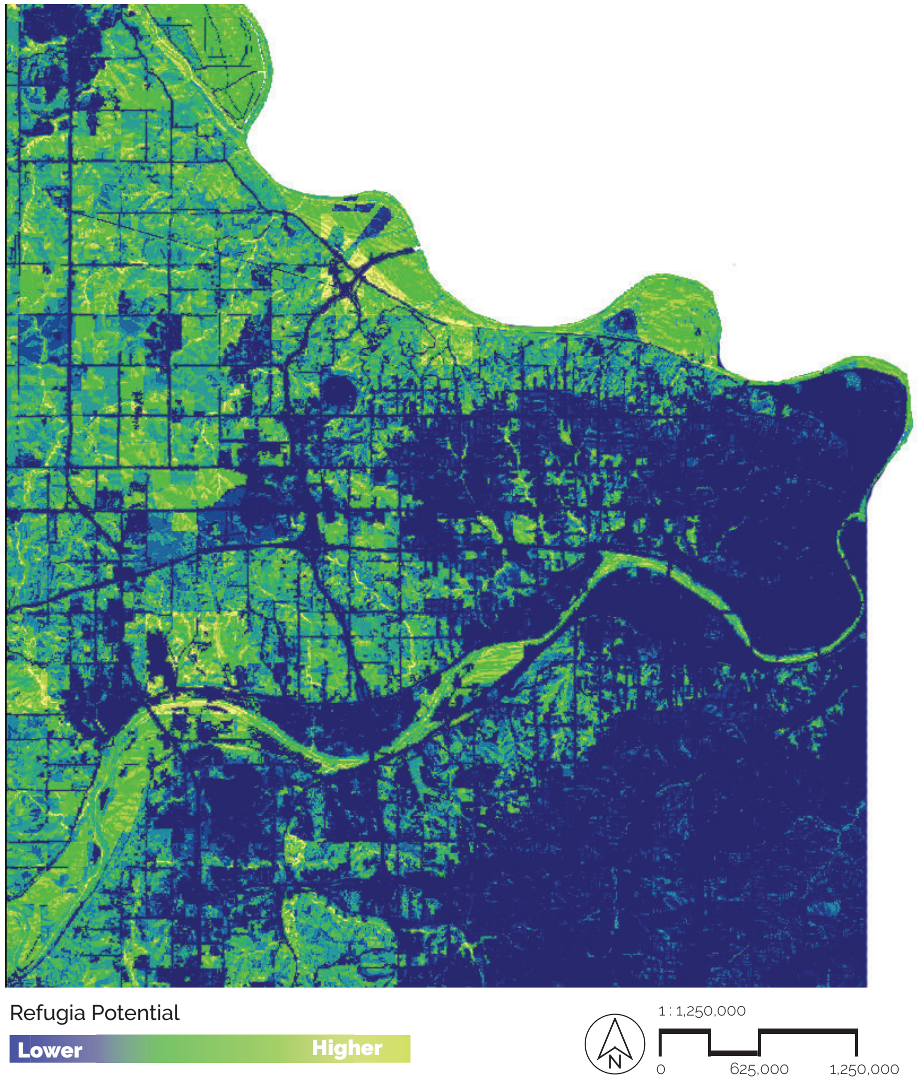


Figure 5.7 - Wyandotte County Refugia MCDA results (Ryan et al.2021)

The development-constricted riparian corridor in this section of the Kansas River is a haven among the high-density urban development. Areas denoted with having higher refugia potential are along creeks and rivers. Man-made lakes and

Qualitative Analysis of MCDA Results

Wyandotte County Refugia

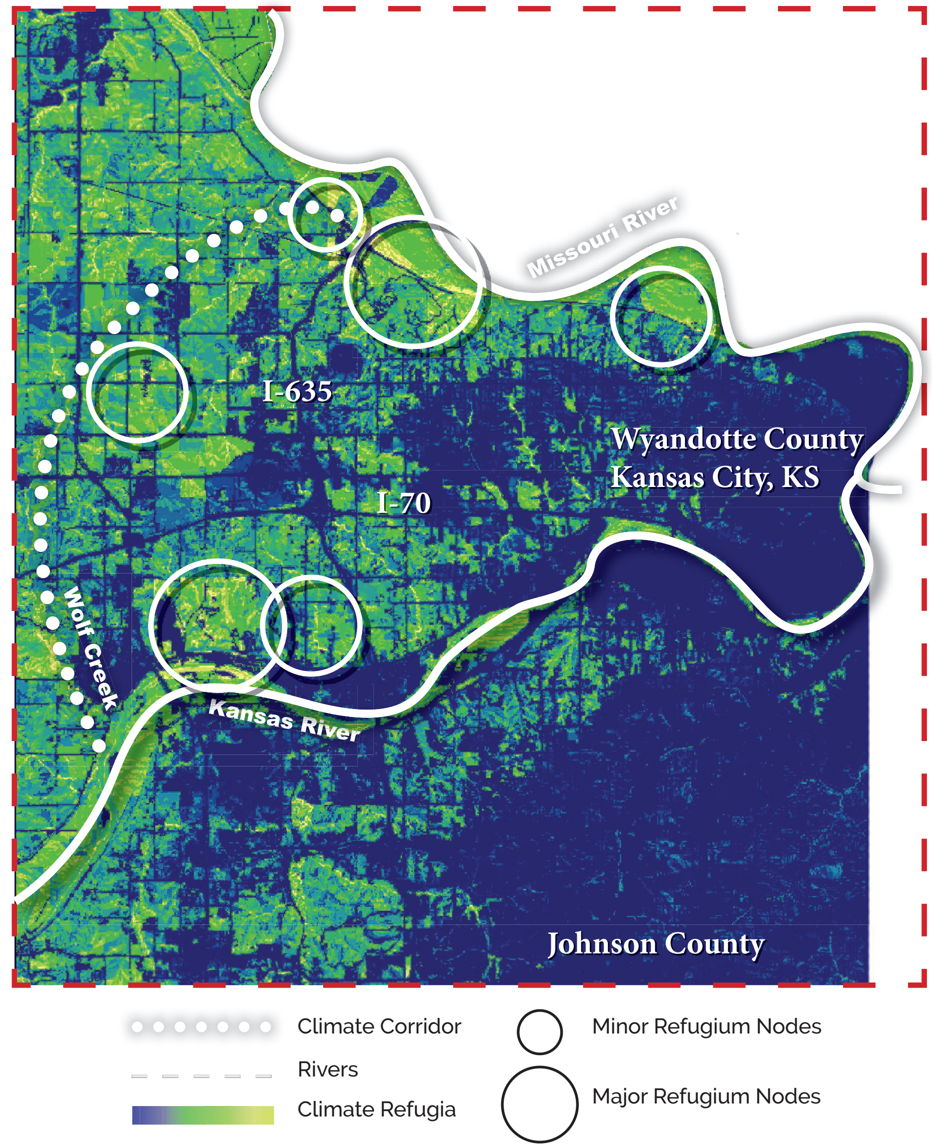


Figure 5.8 - Wyandotte County Refugia MCDA results & qualitative analysis (Ryan et al. 2021)

reservoirs are also represented as having higher refugia potential. These water bodies areas are also major refuges for people seeking immersion in nature and show great potential for climate refugia for people, wildlife, and fauna.

Synthesis of Qualitative Analysis

Northeastern Kansas Refugia

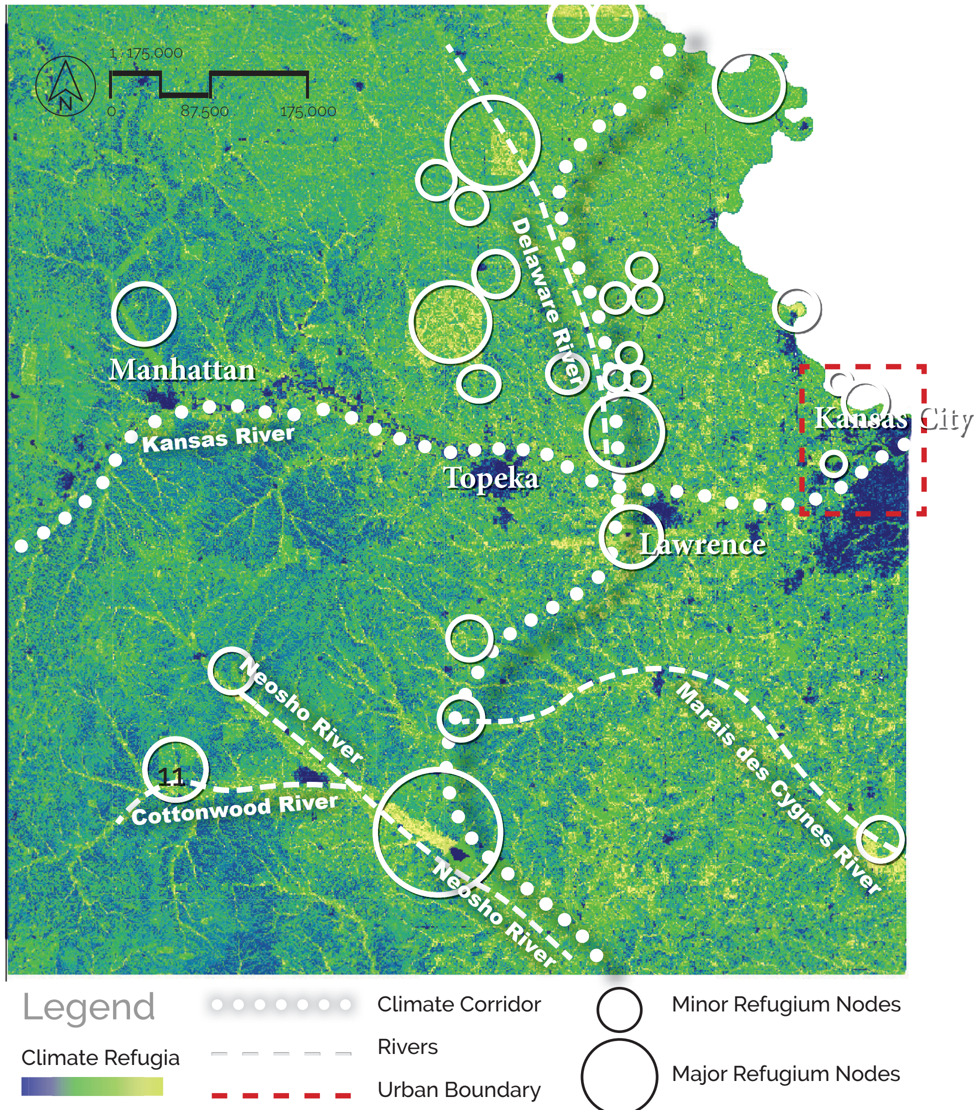


Figure 5.5 - Northeastern Kansas Refugia MCDA results & qualitative analysis (Ryan et al. 2021)

The Kansas River corridor climate refugia potential is indistinguishable from it's surroundings because detrimental land-uses currently occupy the areas surrounding it. High density development and agriculture flank many rivers and detract from existing climate refugia capabilities. The areas of high climate refugia potential (yellow) are protected

Wyandotte County Refugia

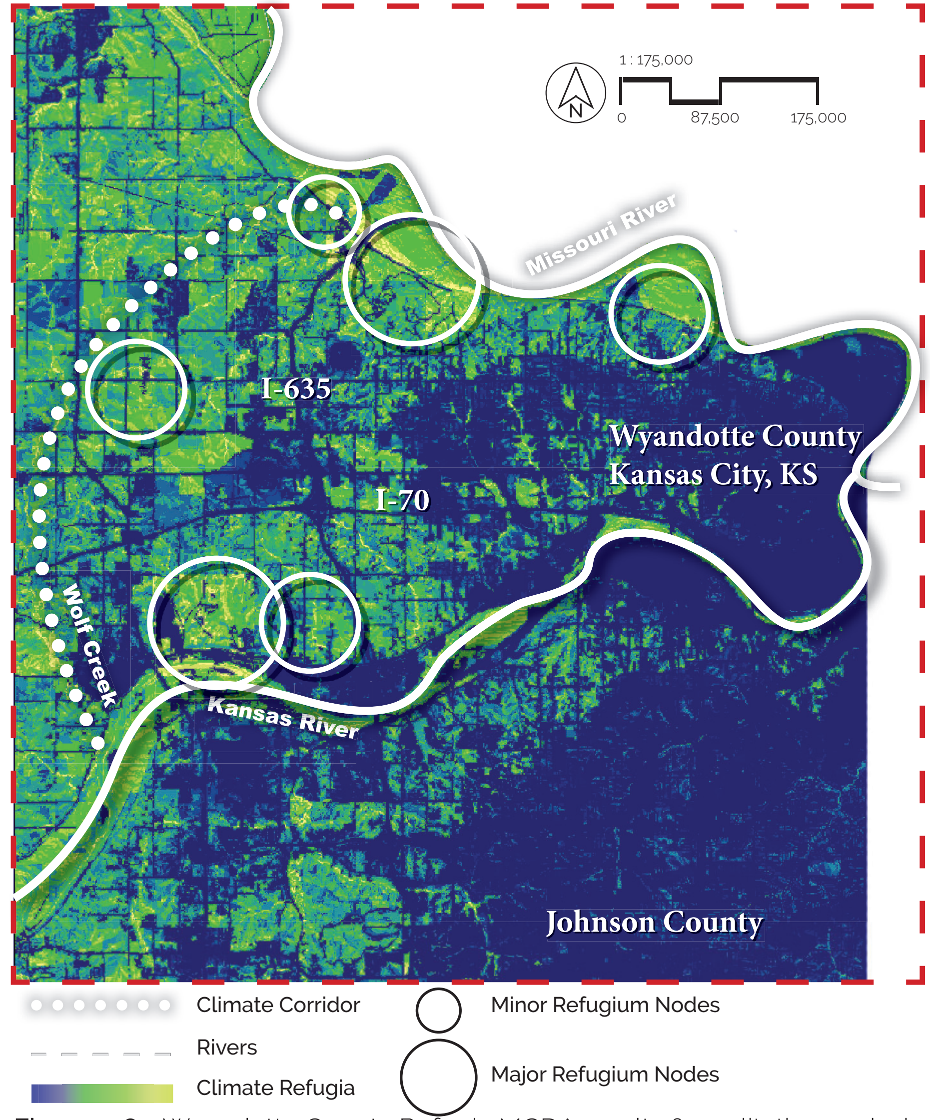


Figure 5.8 - Wyandotte County Refugia MCDA results & qualitative analysis (Ryan et al. 2021)

lands with high levels of habitability and water availability. Across the two scales, similarities in areas of with numerous refugium nodes also have multiple creeks and rivers that feed into larger reservoirs. These key reservoirs and rivers create a climate refugia necklace capable of increasing climate connectivity in the Northeastern Kansas region.

Great Plains

Migration & Refugia

Designs for Northeastern Kansas

Goals & Objectives
Regional Refugia: Northeastern Kansas
Urban Refugium: Wyandotte County

Refugia Design
Topographic Manipulation
Ecosystem Creation
Barrier Mitigation
Design Visualization

Urban Refugium Design
MetroGreen & Wildlife Corridors
Missouri Riparian Refugium & Corridor Bridge

Great Plains Ecosystem Migration & Climate Refugia Goals & Objectives

Northeastern Kansas Climate Refugia System

Concept Statement

Establishing regional approaches in creating a climate refugia offer a starting point for design and implementation for site-specific climate refugia enhancement. A climate refugia and climate corridor plan for Northeastern Kansas enhances adaptable regional ecosystems in the face of impending climate predictions that indicate low probability of success in adapting to a changing climate.

Goals & Objectives

1. Resolve Land-use Conflicts
    a. Improve Conservation Reserve and Wetland Reserve Program enrollment with increased incentives in MCDA identified target areas
    b. Expand Native American Reservation lands for refugium creation
    c. Protect existing habitats while increasing refugia potential in target areas.
2. Construct Climate Refugia & Corridors
    a. Manipulate existing topography to match regional landforms for microclimate creation
    b. Design for potential species associations for climate change resilient ecosystems
    c. Assist colonization of migration-inhibited plant communities
3. Mitigate Barriers to Terrestrial Wildlife Migration
    a. Increase driver awareness at vehicular and climate corridor intersections
    b. Connect climate corridors using culvert crossings under high-traffic state highways and roads
    c. Aid wildlife crossing by bridging across I-70

Urban Climate Refugium Nodes & Corridors

Concept Statement

Urban conditions are often considered to be detrimental to successful habitat creation due to problems with connectivity, pollution, and human disturbance. However, these challenges also present unique opportunities to re-imagine what climate change influenced refugia creation can look like and how people can begin to interact with it. By celebrating climate refugia in the public realm, greater awareness of Great Plains species extinction and extirpation can be promoted.

Goals & Objectives

1. Connect People and Wildlife
    a. Enhance MetroGreen park connections
    b. Supplement creeks and riparian corridors with climate refugia construction strategies.
    c. Route MetroGreen extensions along climate refugium nodes and corridor edges to minimize human disturbance and improve nature access
2. Establish a multi-functional Climate Refugium
    a. Entice & educate Wyandotte County Lake site users with sculptural appeal of Refugium Bridge
    b. Provide a gradient of ecosystems by leveraging bridge structures and existing site conditions.
    c. Promote plant and terrestrial wildlife migration and refugium.

Great Plains

Migration & Refugia

Climate Refugia System for Northeastern Kansas

Concept Statement

Establishing regional approaches in creating a climate refugia offers a starting point for design and implementation for site-specific climate refugia enhancement. A climate refugia and climate corridor plan for Northeastern Kansas enhances adaptable regional ecosystems in the face of impending climate predictions that indicate low probability of success in adapting to a changing climate.

Northeastern Kansas Climate Refugia

Refugium Clusters & Corridors

Legend

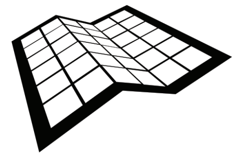
1. Tuttle Reservoir
2. Prairie Band Potawatomi Reservation
3. Kickapoo Reservation
4. Sac & Fox Reservation
5. Iowa Reservation
6. Topeka, Kansas
7. Clinton Lake
8. Pomona Lake
9. Council Grove Lake
10. Melvern Lake
11. Tallgrass Prairie National Preserve
12. Flint Hills National WIldlife Refuge, John Redmond & Wolf Creek Reservoirs
13. Marais des Cygnes National Wildlife Refuge

Figure 5.9 - Northeastern Kansas Refugia site and feature identification (Ryan et al. 2021)

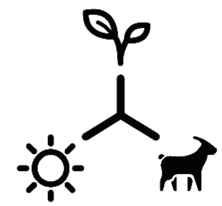
Conceptual Development Layers

Climate Refugia & Corridor Enhancement

Topographic Manipulations



Ecosystem Species Associations



Assisted Colonization Plant Palette

Land-use Conflict Resolution

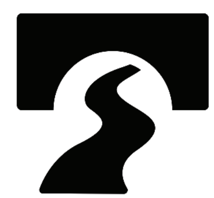
Agricultural Land Transition

Native American Reservation Expansion

Terrestrial Migration Barrier Mitigation

Crossing Awareness

Road Culvert



Corridor Bridge

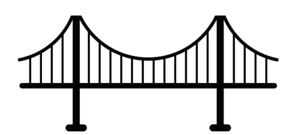
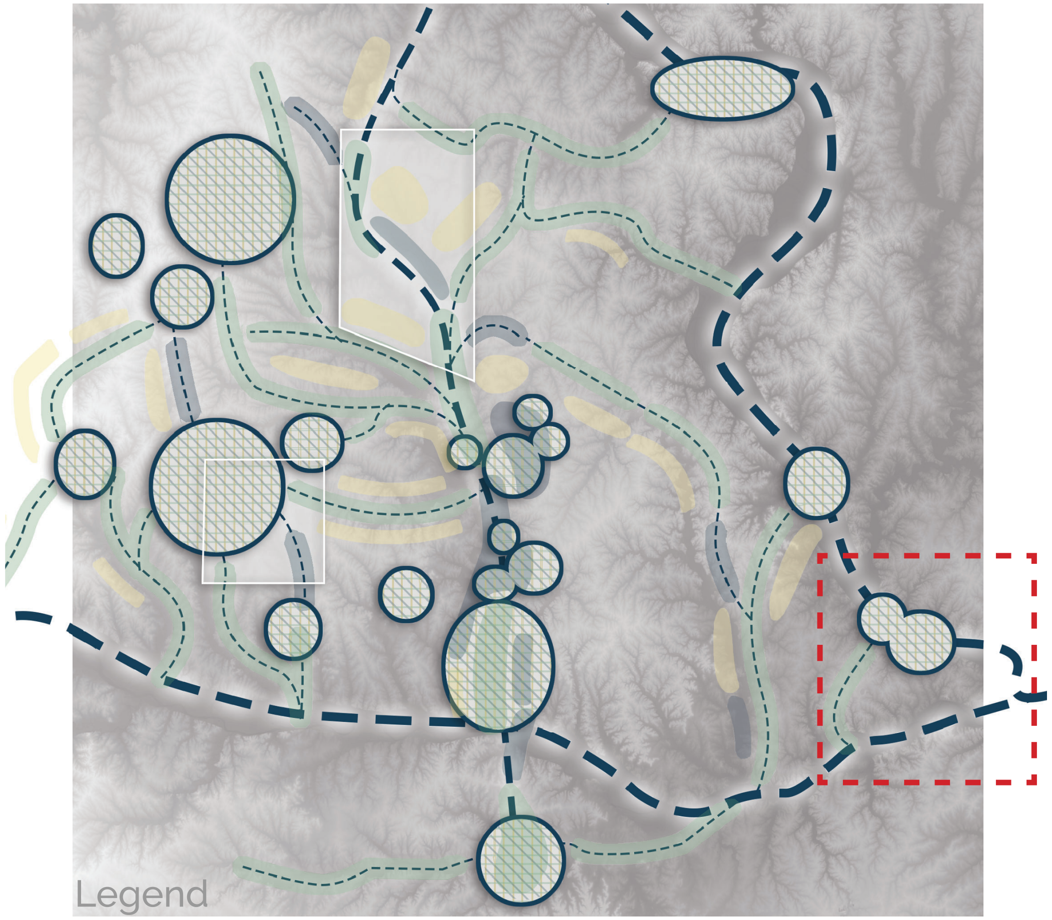


Figure 5.10 - Noun Project iconography to illustrate design decisions (Ryan et al 2021)

Northeastern Kansas Climate Refugia

Ecosystem Refugia Development Focus Area



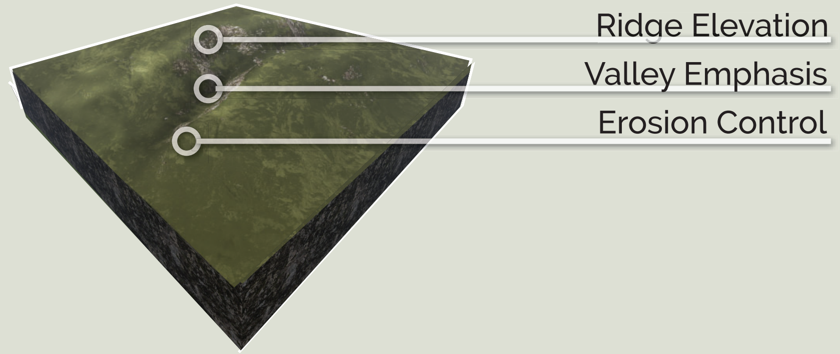
Legend

Floodplain Forest	Ecoregion-Spanning Rivers
Wet Meadow	Delaware River
Short/Tallgrass Prairie	Creeks & Wildlife Corridors

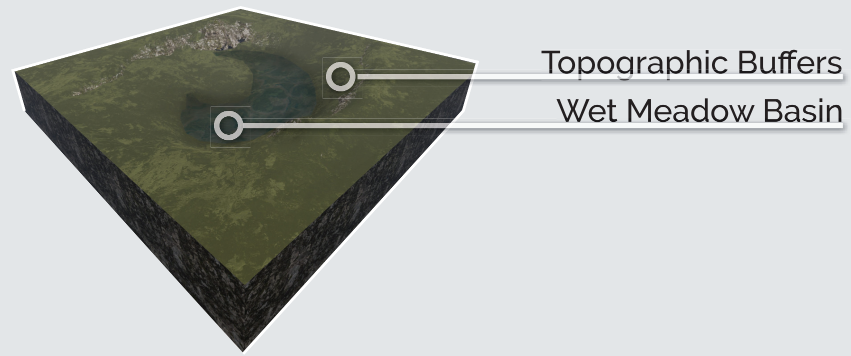
By abstracting regional landforms found in climate adaptable ecosystems, their introduction may provide microclimates that are more capable of sustaining longer term climate refugia. While this strategy may be the first step for improving strategies outlined in following sections of this report, exaggerated earthwork manipulation may not be the most financially feasible and only applicable in certain areas.

Topographical Manipulations

River Terrace



Oxbow Lake



Cuesta

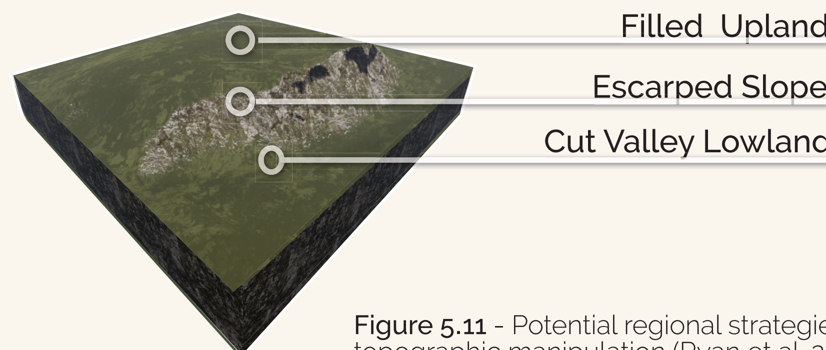


Figure 5.11 - Potential regional strategies for topographic manipulation (Ryan et al. 2021)

Northeastern Kansas Climate Refugia

Ecosystem Species Associations

Southeastern Great Plains Floodplain Forest

Wildlife

- Wood Duck
- Whooping crane
- Bald Eagle
- Ornate Box Turtle
- Eastern Tiger Salamander

Vegetation

- Silver Maple
- Sycamore
- Cottonwood
- Black Willow
- Hackberry

Great Plains Wet Meadow, Prairie and Marsh

Wildlife

- American Bittern
- Yellow Rail
- Meadow Jumping Mouse
- Plains Leopard Frog
- Prairie Massagua

Vegetation

- Arrowheads
- Buttonbush
- Swamp Milkweed
- Prairie Cordgrass
- Blue Flag

Western Short and Central Tallgrass Prairie

Wildlife

- Horned lark
- Western Meadowlark
- Black-Footed Ferret
- Black-tailed prairie dog
- Bullsnake

Vegetation

- Western Wheatgrass
- Blue Grama
- Side-Oats Grama
- Little Bluestem
- Big Bluestem

Assisted Colonization Plant Palettes

Southeastern Great Plains Floodplain Forest

The Gallery Forest utilizes a riparian corridor vegetation plant lists leaning heavily on large shade trees like Cottonwoods for solar radiation protection and moisture retention.

Great Plains Wet Meadow, Prairie and Marsh

A mix of tallgrass bottomland prairie vegetation and riparian woodlands, this microcosm of habitat opportunities can become an incredibly biodiverse refugia

Western Short and Central Tallgrass Prairie

This catena of mixed grasslands offers short and tallgrass refuge through assisted migration of vegetation defined by upland and lowland cuesta construction

Figure 5.12 - Ecosystem focused plant palette visualizations (Ryan et al 2021)

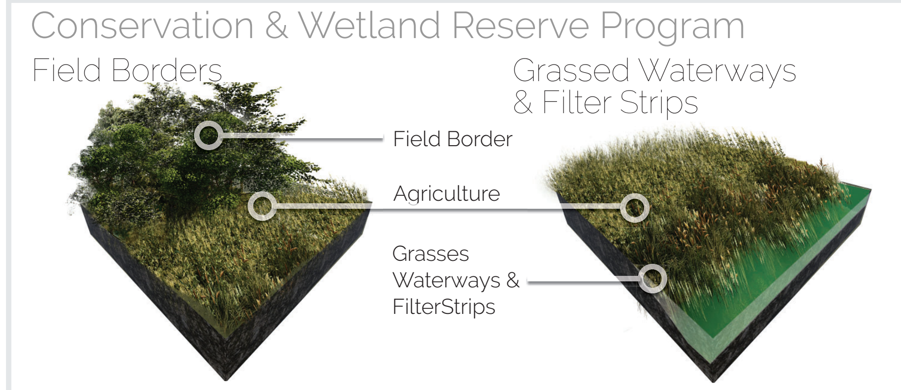
Northeastern Kansas Climate Refugia

Agriculture, Protected Lands, & Refugia

Constructing a complex refugia system requires more land than is presently available along essential riparian corridors. Between existing agriculture in these fertile areas and protected lands, finding solutions that appease agricultural land owners, Native American communities, and vulnerable wildlife presents dilemmas and opportunities for coexistence.

Land-use Conflict Resolution Strategies

Agricultural Transition



Native American Reservation Expansion

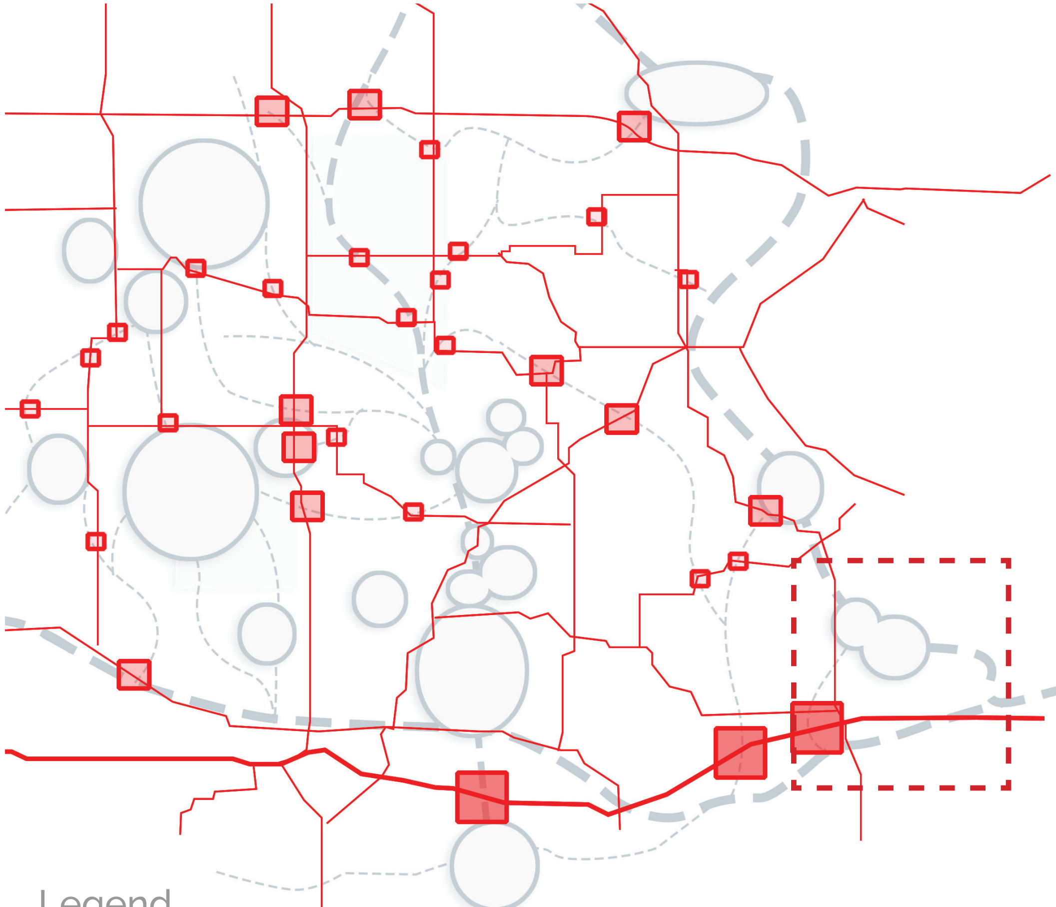
Increasing subsidies for CRP or WRP enrollment of non-irrigated and flood-vulnerable agricultural land, creates opportunities for climate refugia and corridor development. By fostering CRP/WRP enrollment and application of agriculture best management practices along key or vulnerable refugia/corridor edges, agriculture can begin to work alongside and in conjunction with climate resilient design strategies. Incentivizing environmental stewardship can help celebrate and foster growth of vulnerable agricultural and Native American communities at greatest risk of disenfranchisement through refugia implementation..

Non-Irrigated Agriculture Along Refugia & Corridors

Figure 5.13 - Refugia land-use conflict mitigation strategies (Ryan et al 2021)

Northeastern Kansas Climate Refugia

Vehicular Barriers to Refugium Connectivity



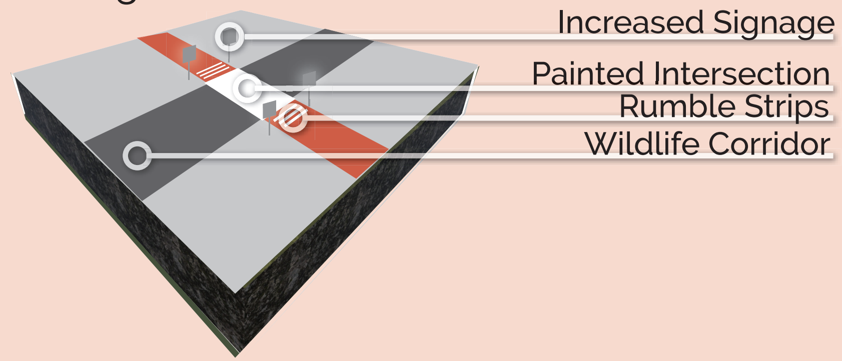
Legend

- Corridor Bridges
- Road Culverts
- Crossing Awareness
- Interstate 70
- State Highways

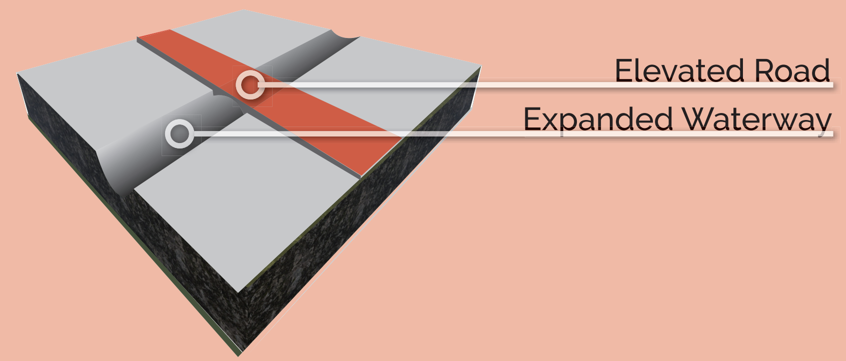
Streets, highways, and Interstates create major and potentially fatal conflicts between wildlife and drivers. To facilitate and promote migration in the face of major vehicular barriers, applying mitigation strategies will help increase the success of a Midwest climate refugia system and the climate corridors such a system depends on.

Terrestrial Migration Barrier Mitigation

Crossing Awareness



Road Culvert



Corridor Bridge

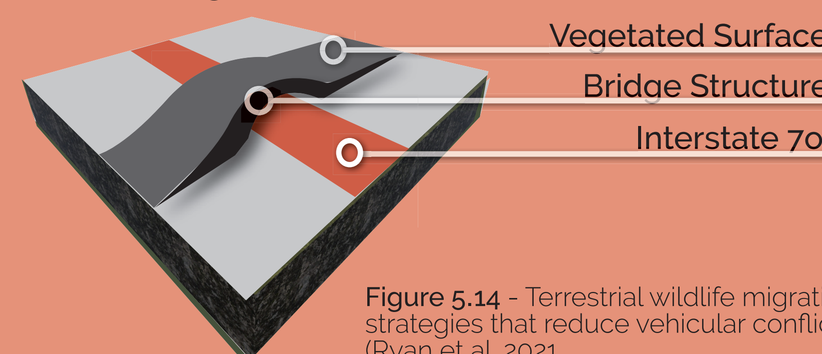
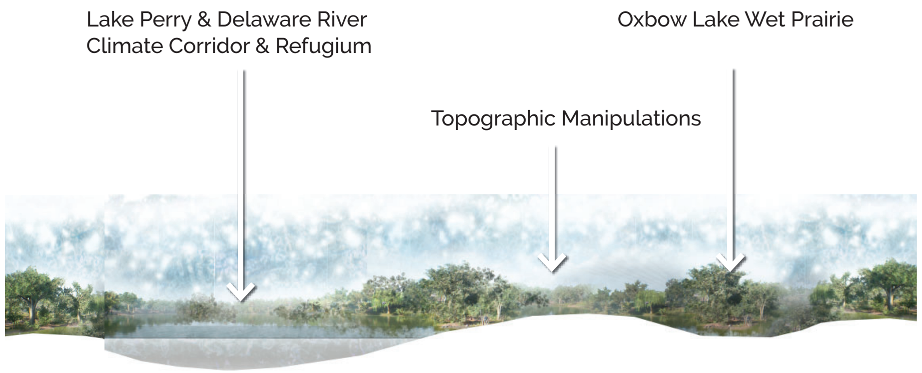


Figure 5.14 - Terrestrial wildlife migration strategies that reduce vehicular conflict (Ryan et al. 2021

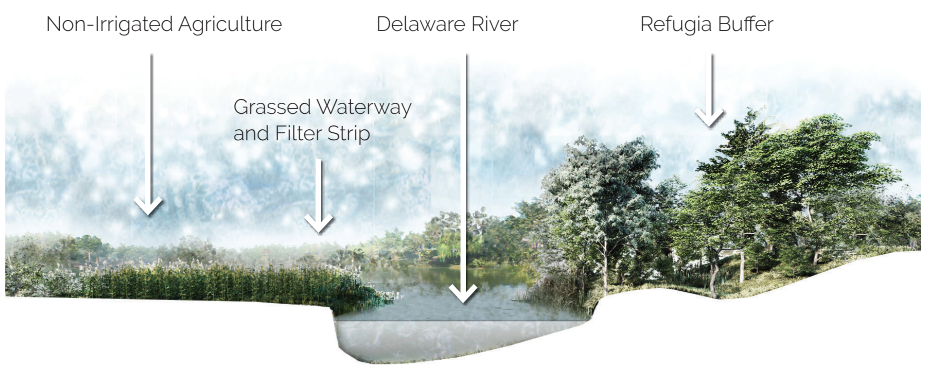
Northeastern Kansas Climate Refugia

Climate Refugia & Corridor Enhancement

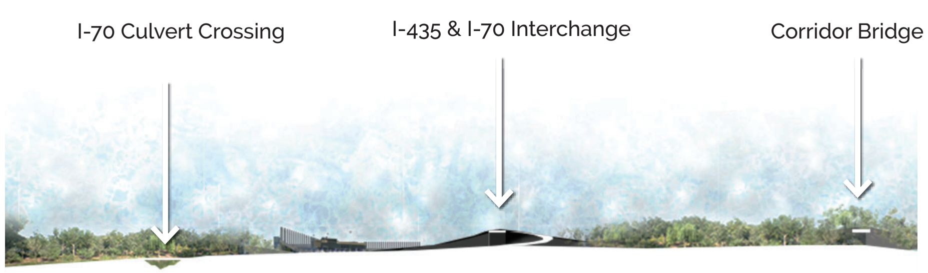
Refugium Node: Lake Perry & Delaware River Corridor



Agriculture Revitalization: Native American Reservations



Migration Barrier Mitigation: I-70 Vehicular Corridor



CRP & WRP Implementation

Corridor Bridge

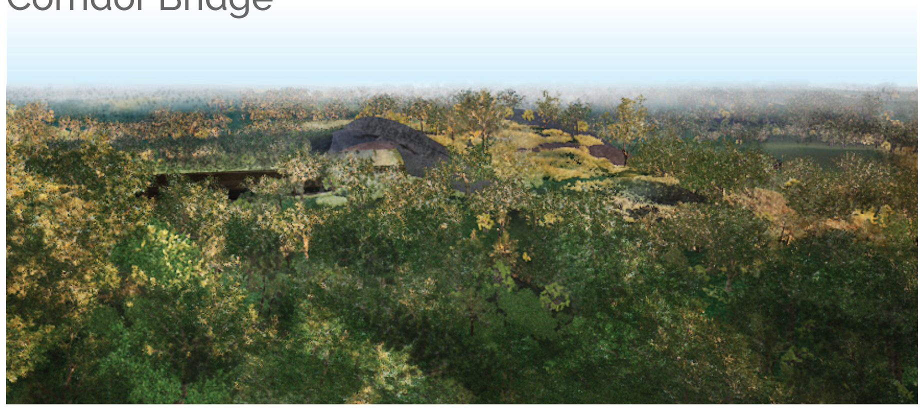


Figure 5.15 - Visuals of climate refugia design strategies (Ryan et al 2021)

Great Plains

Migration & Refugia

Urban Climate Refugium
Nodes & Corridors

Concept Statement

Urban conditions are often considered to be detrimental to successful habitat creation due to problems with connectivity, pollution, and human disturbance. However, these challenges also present unique opportunities to re-imagine what climate change influenced refugia creation can look like and how people can begin to interact with it. By celebrating climate refugia in the public realm, greater awareness of Great Plains species extinction and extirpation can be promoted.

Urban Refugium Nodes & Corridors

Site Plan

Legend

1. Wyandotte County Lake
2. Quindaro Bluffs
3. Lake of the Forest

Habitats

Metrogreen

Kansas & Missouri River

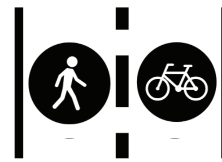
Climate Corridors

Refugium Node

Concepts

MetroGreen & Wildlife Corridors

Bike & Pedestrian Rights-of-way



Multi-Used Paved

Low-Impact with Limited Development

Missouri Riparian Refugium & Corridor Bridge

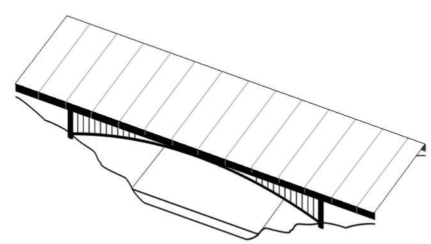
Facilitating Ecosystem Migration

Plant Migrations
Wind Dispersal

Wildlife Migrations
Fragment Connections

Refugia Fabrication

Overpass Zones



Underpass Zones

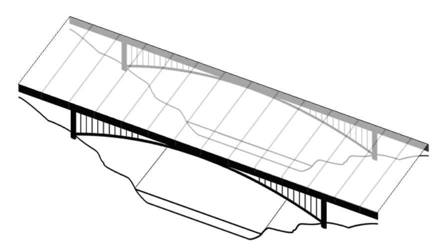
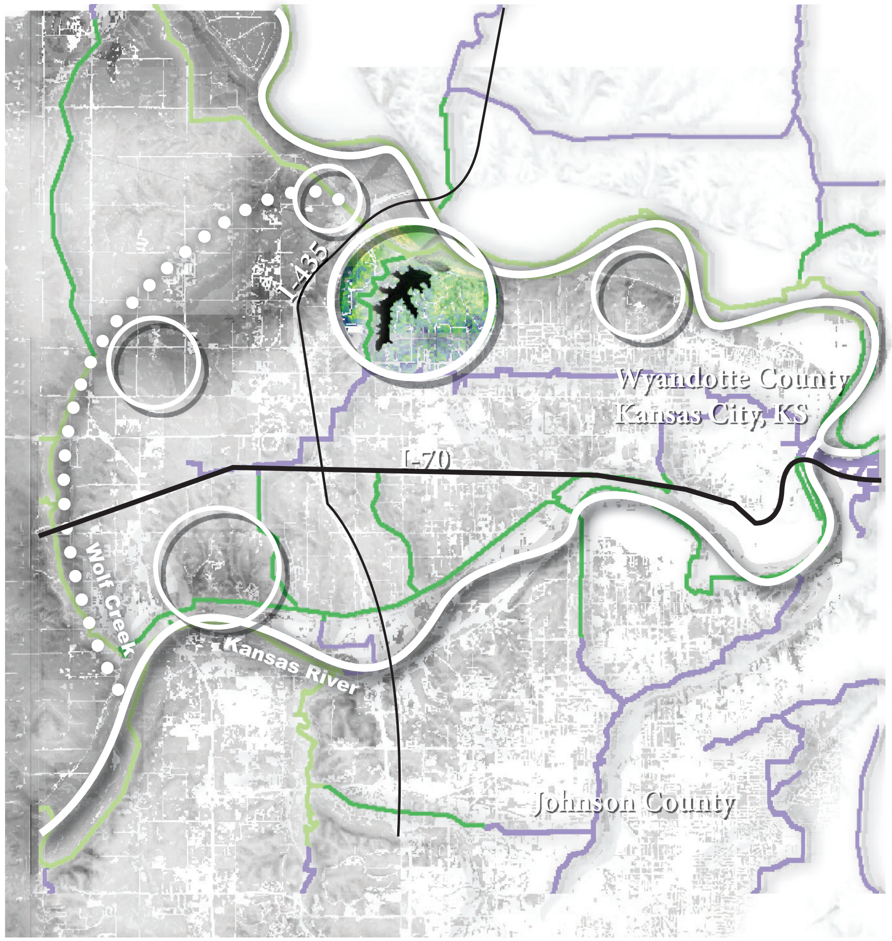


Figure 5.16 - Noun Project iconography to illustrate urban refugium design decisions (Ryan et al 2021)

Urban Climate Refugium Corridors

MetroGreen & Wildlife Corridors



Legend

Multi-use Trail

Unpaved Trail

Low-Impact Trail

The Metrogreen system is an existing multi-use greenway that connects parks, open spaces, and natural areas across the Kansas City metropolitan region. The proposed and already connected trails within Wyandotte county follow similar areas identified as climate corridors. While being wary of human disturbance, bringing people back to nature can help bring light to the Great Plains climate dilemma.

MetroGreen Corridor Types

County-Wide - Multi-use paved trail development

Wyandotte County Lake - Unpaved trail development

Wolf Creek - Natural low-impact trail

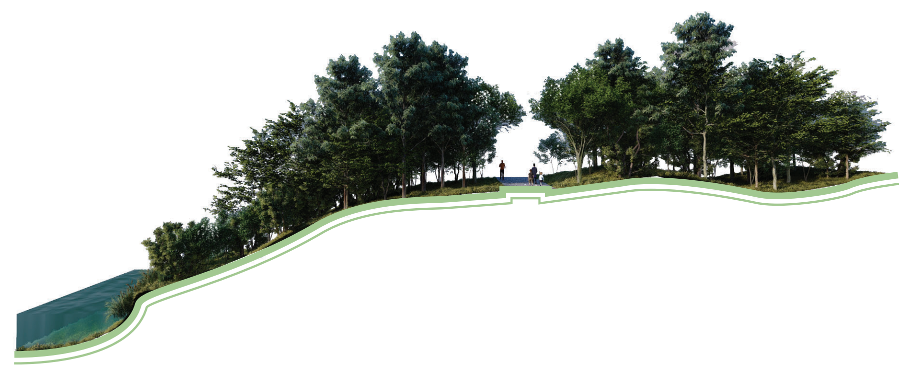


Figure 5.17 - Mid-American Regional Council's Metrogreen trail strategies reinterpreted in climate refugia contexts (Ryan et al. 2021)

Urban Climate Refugium Node

Climate Refugium & Corridor Bridge

Site Plan

Legend

1. Wyandotte County Lake
2. Climate Refugium & Corridor Bridge

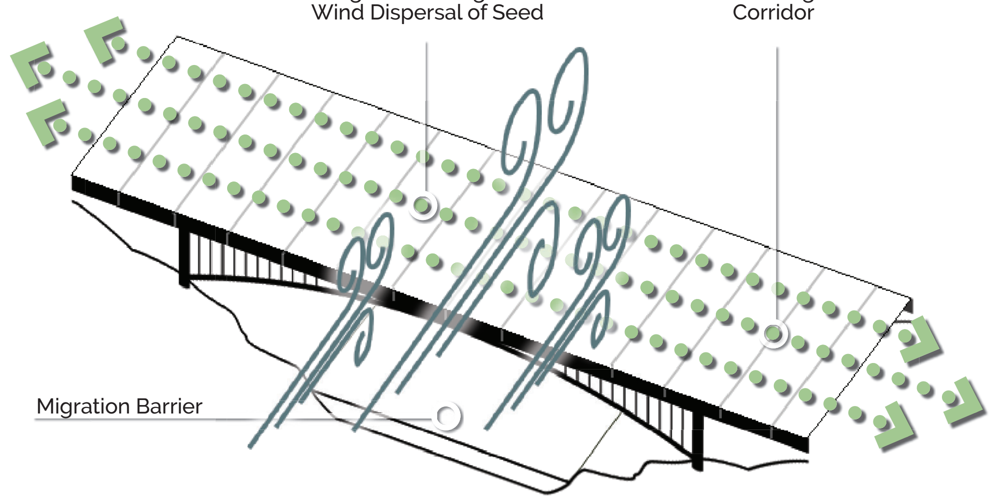
Climate Refugium act as oases for organisms unable to migrate or adapt to climate change. To date, no attempts have been made to construct an entirely man-made refugium structure that is capable of providing refuge as well as connectivity for migration. Leveraging common wildlife corridor bridge strategies, this design utilizes the space atop and below a standard wildlife corridor bridge for aid in generational prairie grass plant migrations through wind dispersal and creation of various habitats and microclimates across the layers of the bridge/shelter design.

Concepts

Climate Refugia & Corridor Bridge Design

Overpass Zones

Short & Tallgrass Prairies



Underpass Zones

Floodplain Forest & Wet Prairies

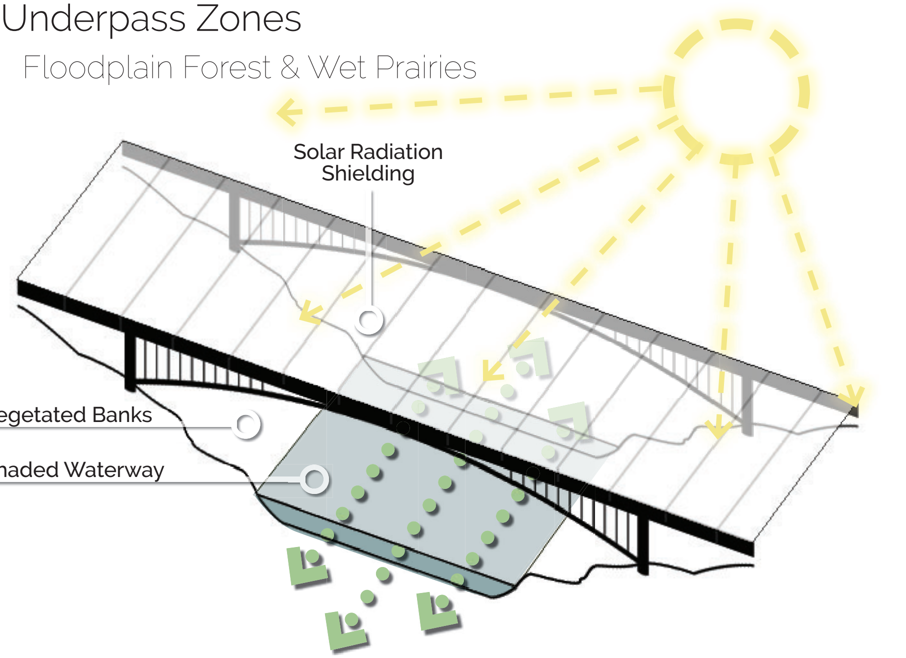


Figure 5.18 - Climate Refugium & Corridor Bridge Design (Ryan et al 2021)

Urban Climate Refugium Node

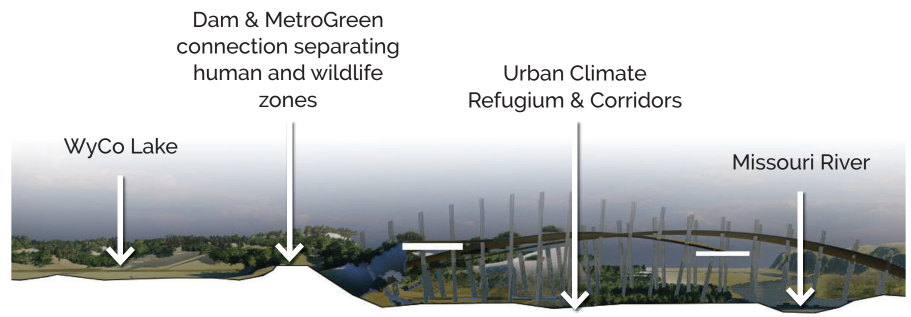
Climate Refugium & Corridor Bridge

Wyandotte County Human/Wildlife Relationships

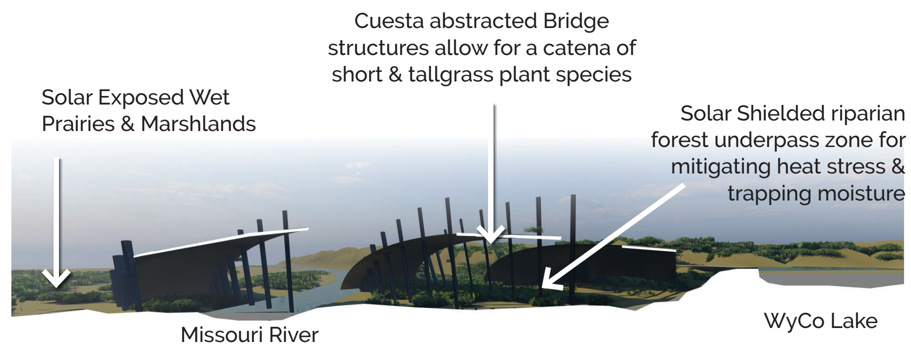
Climate Refugium & Corridor Bridge

Climate Connectivity`

Wyandotte County Human/Wildlife Relationships



Refugium Bridge Ecosystems



Vegetation Dispersal & Terrestrial Migration

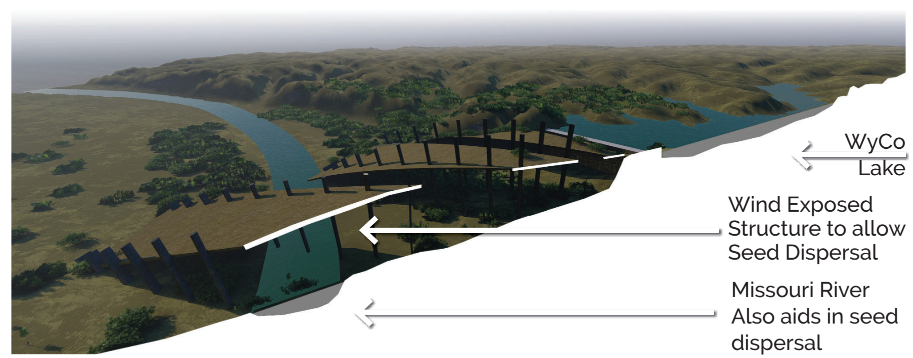


Figure 5.19 - Visuals of urban refugium design strategies (Ryan et al 2021)

Conclusions

Results & Conclusions:

Design Analysis

Before

Great Plains Level I Ecoregion

State of Kansas

After

Great Plains Level I Ecoregion

State of Kansas

Design Guidelines

Planning & Community Outreach

Team Assembly
Regional & Site Assessment
Community Stakeholder Meeting

Design Implementation

Rural-Scale Design Strategies

Site-Scale Design Strategies

Phasing & Monitoring

Short-Head Phase Construction
Monitoring & Maintenance
Long-Tail Phase Construction
Monitoring & Maintenance

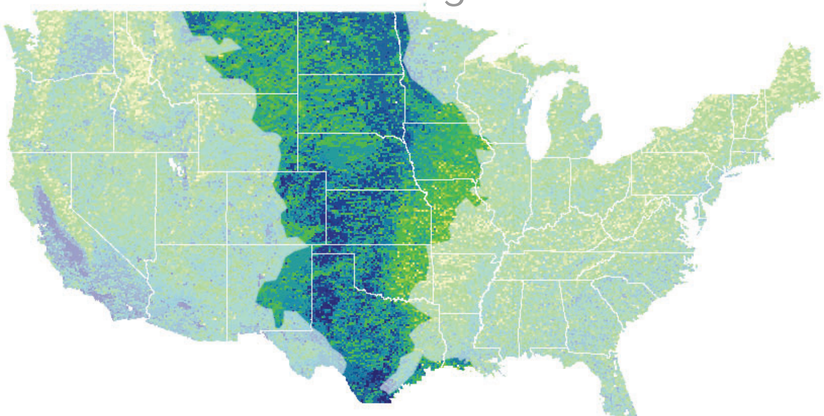
Results

Design Analysis Process

The design analysis was conducted by editing the refugia datasets that were used in the Multi-Criteria Decision Analysis in order to reflect the Northeast Kansas Climate Refugia design proposal. The editing of datasets was done by creating shapefiles reflecting the changes, rasterizing said shapefiles, and then combining the original dataset with the design additions to create a post-design map. After all datasets had been recreated to reflect the design, the MCDA was reprocessed and the Climate Refugia Design Analysis Map was created as can be seen in Figures 6.1, 6.2 and 6.3.

Design Analysis - Before

Great Plains Level 1 Ecoregion



State of Kansas

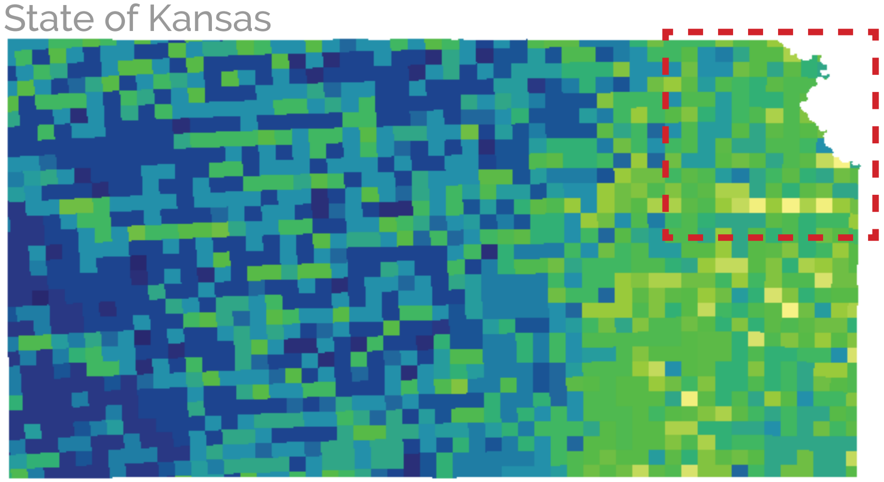
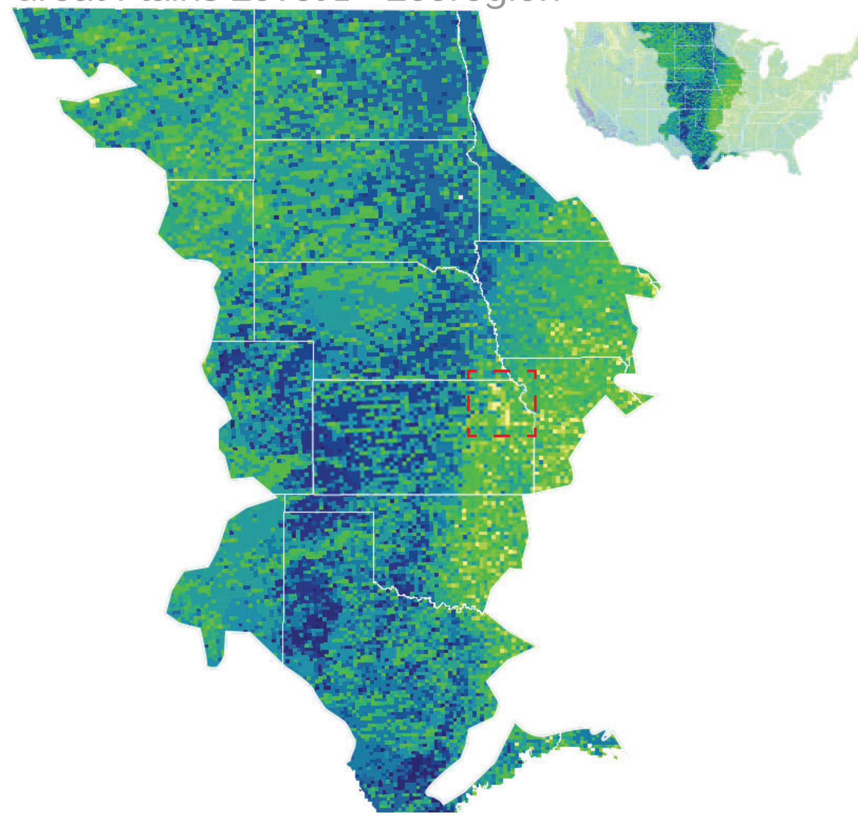


Figure 6 - Climate Refugia before design implementation

Design Analysis - After

Great Plains Level 1 - Ecoregion



State of Kansas

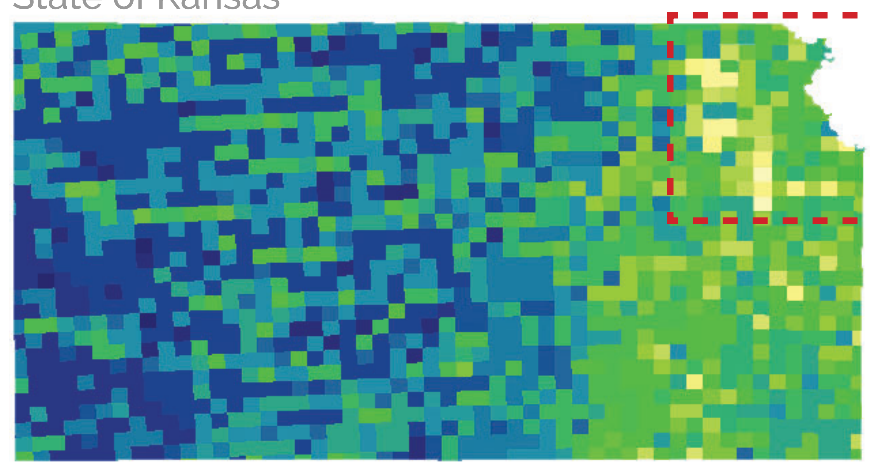


Figure 6.1 - Climate Refugia after design implementation

Results

Design Analysis Conclusions -

Great Plains Analysis with Satellite Imagery Context

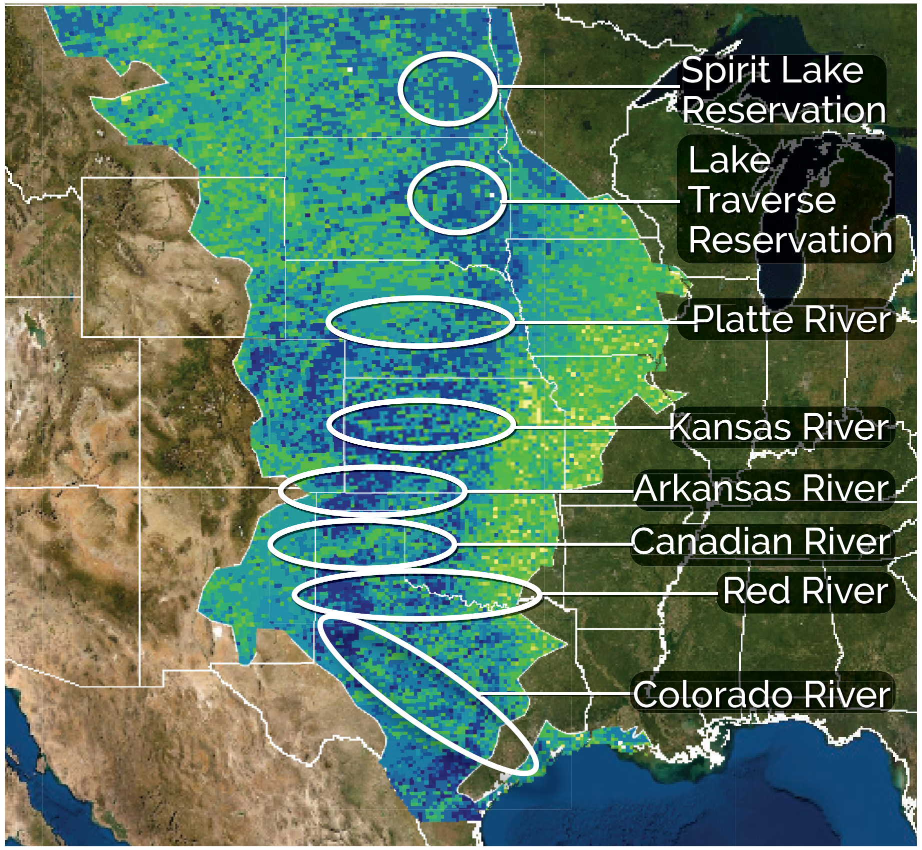


Figure 6.2 - Corridors and areas of opportunity for Level 1 ecoregion-wide Great Plains climate refugia and corridor system.

As significant improvements have been identified in climate refugia and climate connectivity for Northeastern Kansas, little improvement can be seen across the rest of the region. The need for wide-spread application of similar design strategies that were applied in the design application portion of this work is apparent and the application of which, could yield a far greater result for the broader region. North of the Platte River, prairie potholes as well as natural and man-made reservoirs become more prevalent within the Great Plains region. which alters the impact of the rivers and flowlines datasets that were crucial for identifying refugia within lower portion of the ecoregion. Nevertheless, a series of design strategies and datasets that are oriented around specific ecoregions are essential in defining and creating region specific climate refugia and corridor design interventions.

Application of Results

Understanding the impacts of the design and climate refugia MCDA provide best practices that can be used to guide landscape designers and planners as they seek to improve climate change resilience.

Design Guidelines

Planning & Community Outreach

- Establish Qualified Team
  - Landscape Architect/Environmental Planner
  - Transportation Planner
  - Landscape Ecologist
  - Biologists
  - Environmental Engineer
  - Environmental Construction Manager
  - Geologist & Soil Scientist
  - Legal Team

- Perform Multi-Criteria Decision Analysis Using...
  - Climatic Trends
    - Absolute Change in Temperature
    - Percent Change in Precipitation
  - Abioitic Framework
    - Soil Bedrock Depth
    - Topographical Aspect
    - Stream Flowline proximity to Habitat
  - Biodiversity & Connectivity
    - High Taxonomic Biodiversity Species Distribution
    - Vegetative Habitat Structures
    - Public & Privately Protected Lands
  - Human Disturbance
    - Cultivated & Disturbed Lands
    - Urban Development
    - Vehicular Barriers

- Host Community Stakeholder Meeting on Local Impact
  - Introduce Project, Assessments, & Preliminary Goals
  - Address Community Concerns from...
    - Agricultural Landowners
    - Community Leaders
    - Local Residents

Design Implementation

- Propose Regional & Site-Scale Design Strategies
  - Expanding Secured Lands
  - Increasing Carbon Storage
  - Identifying Shared Priorities with Land Owners
  - Protecting Water Supply
  - Siting Energy Infrastructure
  - Managing Forest & Grasslands
  - Influence Future Development
  - Identify Regionally Vulnerable Species
  - Topographical Manipulations (if applicable)
  - Species Neutral & Species focused Interventions
  - Mitigating Road Crossing

Phasing & Monitoring

- Introduce a Short-Head phase
  - Major Refugia Node Focus
  - Construction of Migration Barrier Mitigation Strategies
  - Major Earthwork Alterations
  - Assistant Plant Colonization Plantings
- Monitor
  - 6-month Plant Establishment Monitoring
  - Assess Species-Associations and Wildlife
- Apply Long-Tailing management
  - Minor Refugia Node focus
  - Improvement to climate corridor
- Monitor long-term
  - Continued monitoring in 5, 10, 25, 50, 100 year Intervals
  - Perpetual adjustments and Improvements

Conclusion

While analytical models of climate connectivity and refugia suggest the Great Plains ecosystems have little chance at persisting in an inhospitable climate future, steps can be made to increase the potential for saving vulnerable Midwest biota. While the design analysis shows visible improvements to climate refugia at the scale of this study, a design that spans entire riparian corridors is essential in making any meaningful change.

Contributions of the Study

The promising results of this study shows the value in the metrics used to identify climate refugia and it's potential for advancing environmental land planning. By developing a landscape analysis and design playbook, identifying and enhancing areas capable or best positioned to act as refugia for vulnerable ecosystems, reduces the necessary groundwork for landscape architects and other land planners when advancing projects ranging from urban development or habitat restoration.

Future Areas of Research

Development of a comprehensive plan for the Great Plains will be imperative in protecting the remaining biodiversity of the ecoregion. Based on precedent research and analysis conducted in this work, the Great Plains region is one of the most vulnerable ecoregions in North America. Climate change and human disturbances will continue to threaten the range shifting of flora and fauna thus increasing the need for the development of a comprehensive ecoregion wide refugia plan that follows similar steps identifying and designing refugia in order to aid in the perseverance of the regions unique ecosystems.

Limitations of Study

The creation, variety, and scope of the datasets that were used to create the MCDA have a level of uncertainty in their accuracy and dependability. The lack of on-site verification and the projective nature of climatic predictions, requires a level of assumption that needs further assessment before results of this work can truly be verified.

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List of Figures & Tables

Appendix A

Glossary

Key Terms

1. **Analog-based Macrorefugia:** Contiguous & large-patch interior habitat.
2. **Backward Velocity Index:** Areas of end of century climatic suitability to the nearest area of current climatic suitability (Stralberg et al. 2018)
3. **Catena:** A connected series or chain of soils from hilltop to valley floor
4. **Long-Tailing**: Series of small-scale interconnected design interventions phased over time that work off of Short-head catalyst.
5. **Novel Ecosystems:** "A new species combination that arises spontaneously and irreversibly in response to anthropogenic land-use changes, species introductions, and climate change without correspondence to any historic ecosystems."
1. **Refugia:** Areas in which a population of organisms can survive through a period of unfavorable conditions.
    a. events.
    b. **Ex Situ** - off-site refugia away from native range.
    a. **Glacial** - area of refugia from climatic cooling
    b. **In Situ** - On-site refugia near native habitat.
    c. **Interglacial** - area of refugia from climatic warming events.
    d. **Macro** - Large expanse of refugia.
    e. **Micro** - Small microclimates with refugia capabilities.
2. **Refugium:** Single patches of habitat of that are pieces

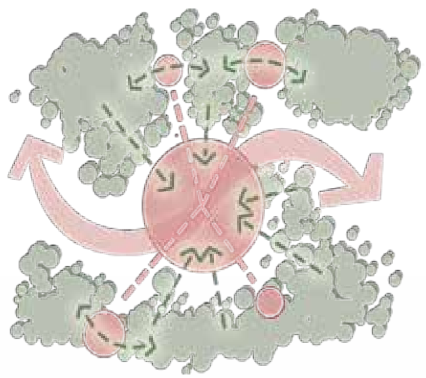
Appendix B

Pilot Study
Presentation Boards

PROSPECT REFUGIA:

Concept

Climate change will cause range shifts for flora and fauna alike. The increased temperatures, invariability of weather events, drought, loss of habitat are all things that will force organisms from their current homes. The shifting of habitat ranges will occur at different speeds and distances depending on the need of the species. However, riparian conditions are well positioned to be excellent corridors to help facilitate these staggered migrations of ecosystems en route to refugia.



Goals & Objectives

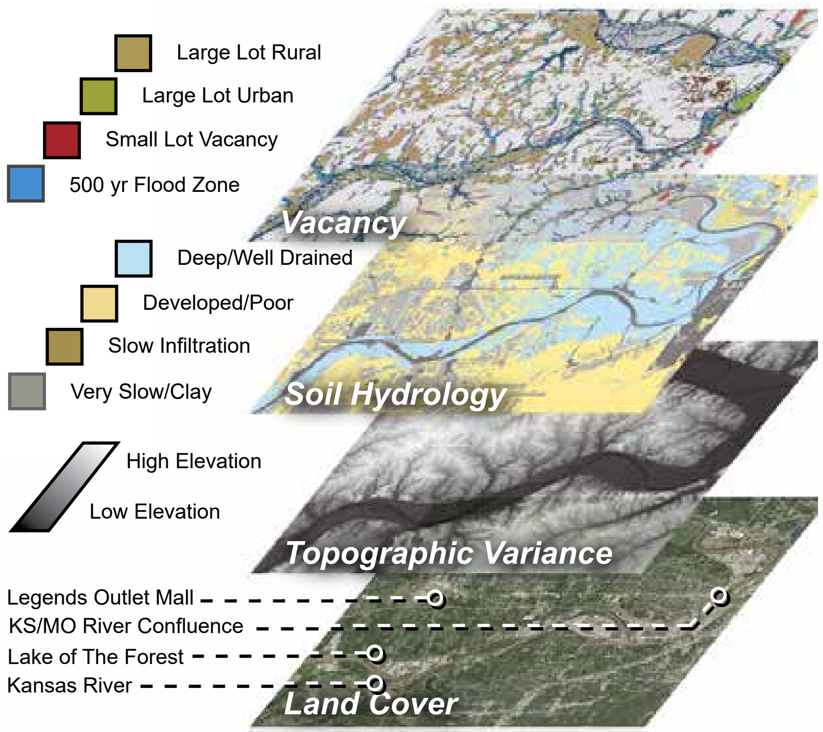
Coordination between land use, transportation, & Open space planning.
- Improve accessibility and safety in public transportation and wildlife migration infrastructure
- Adaptive reuse of UG vacancy lots to address public and environmental needs
- Reclaim brownfield, underutilized, or other land-uses in areas that are either highly vulnerable or suitable for migration and or refugium

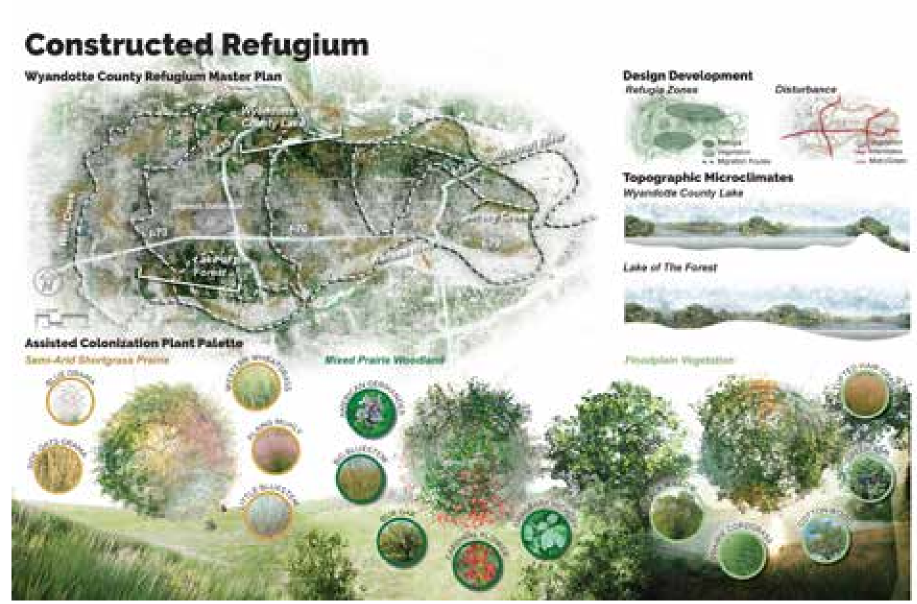
Good Governance & Integrated Policy Coordination
- Adapt and reuse UG vacancy
- Enhance scope and incentives of Wetland Reserve Easements
- Improve and expand Conservation Reserve Program

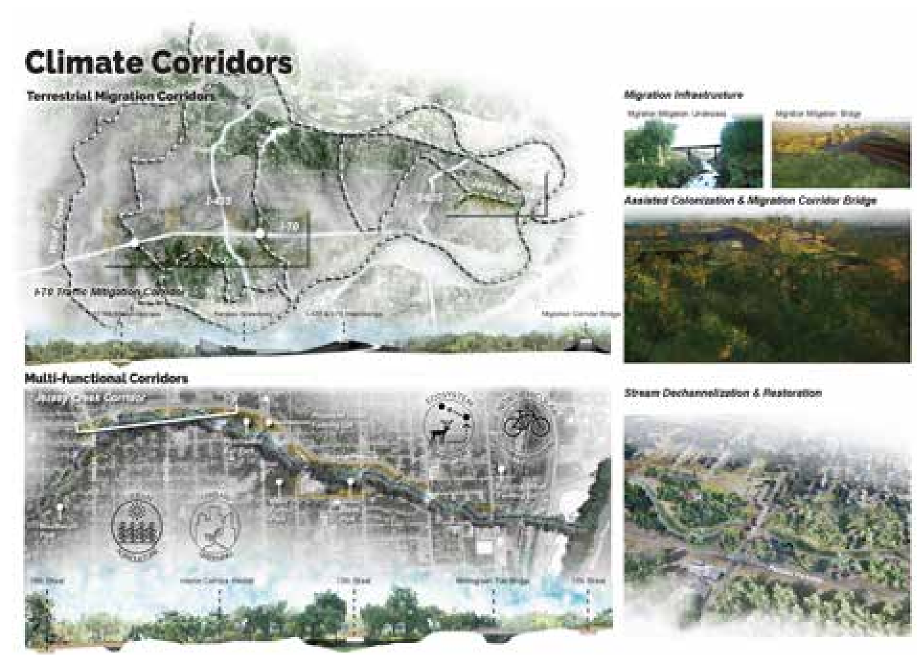
Urban Containment by Conservation & Densification
- Establish MetroGreen (belt) & migratory Climate Corridors
- Mitigate barriers between land-use, transportation, and migratory climate corridors
- Establish climate change resilient ecosystem refugium sites

Development of a compact garden city with attractive inner city areas
- Infuse natural amenity to areas of blight
- Increase availability and connectivity of open space and outdoor recreation

Development Layers







Spread of Pilot Project Boards

Appendix C

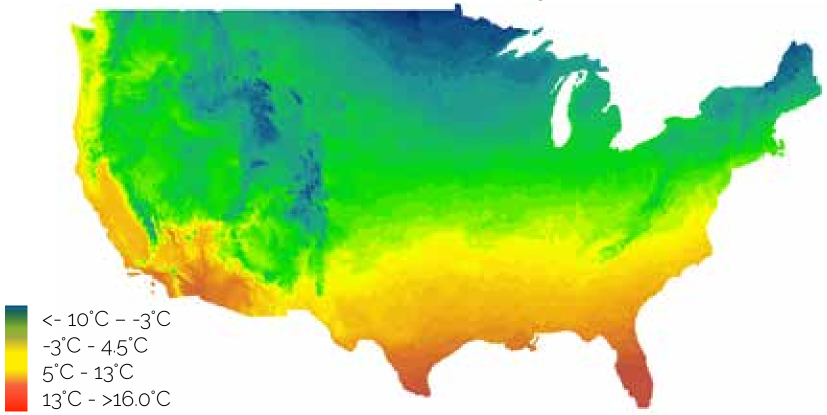
Precedent Study
MCDA Map Data

United States Climate Datasets

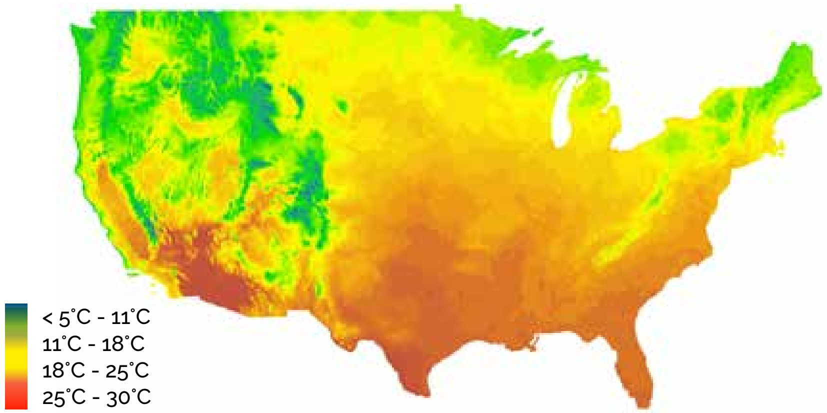
Temperature References

U.S. Forestry Service (USFS) National Forest Climate Change Maps, 2020,
https://data.fs.usda.gov/geodata/rastergateway/OSC/climate.php

Historical Winter Minimum Temperature

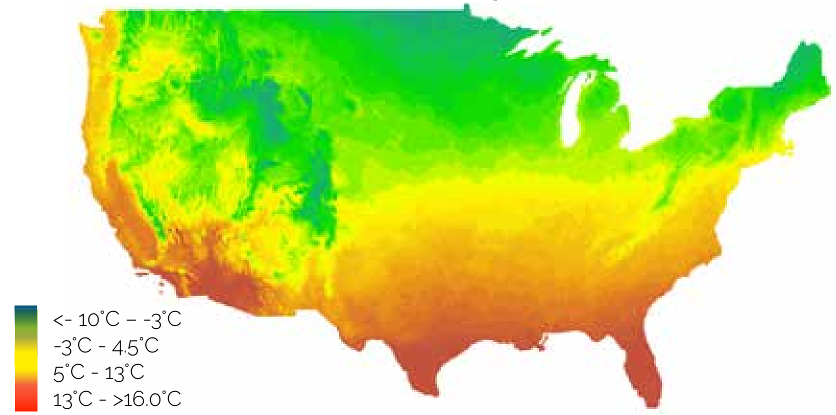


Historical Summer Maximum Temperature

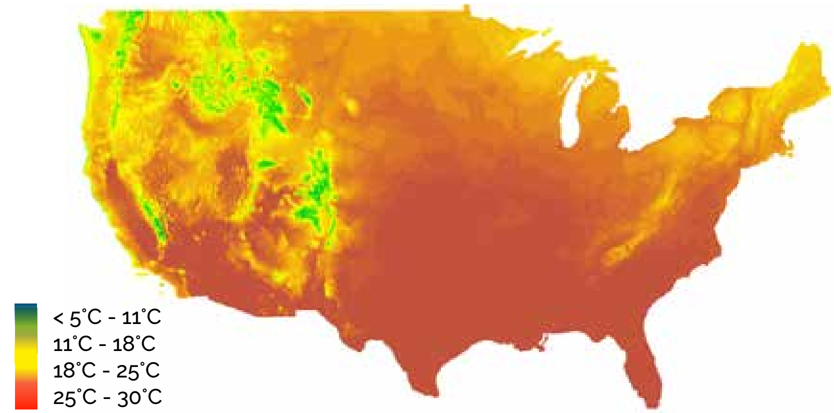


Historical Absolute Change in Seasonal Temperature

Future Winter Minimum Temperature



Future Summer Maximum Temperature

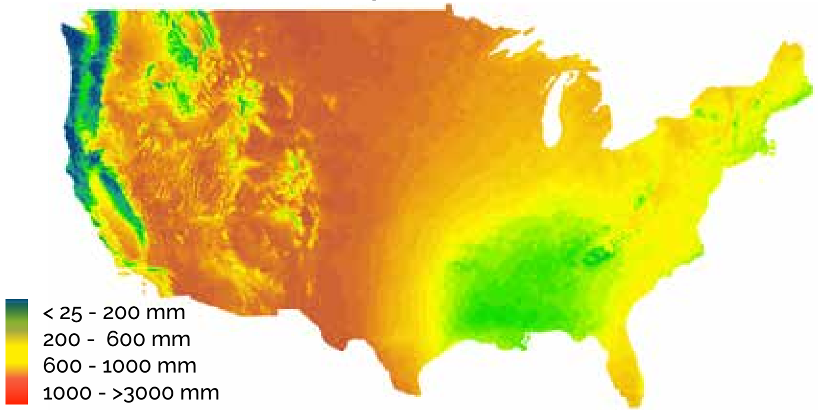


Future Absolute Change in Seasonal Temperature

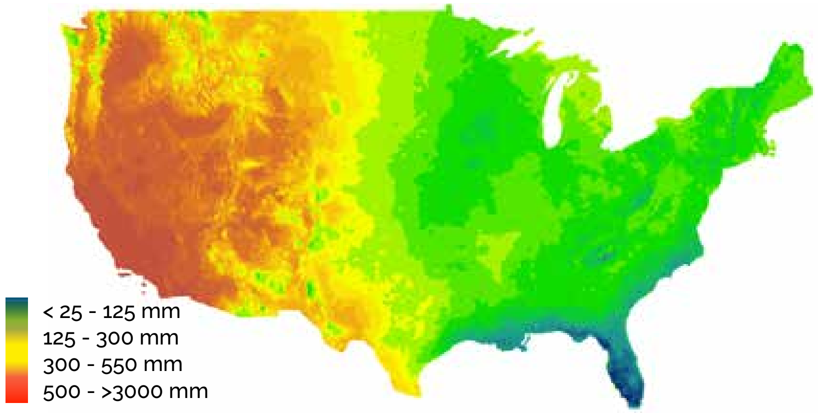
United States Climate Datasets
Precipitation References

U.S. Forestry Service (USFS) National Forest Climate Change Maps, 2020, https://data.fs.usda.gov/geodata/rastergateway/OSC/climate.php

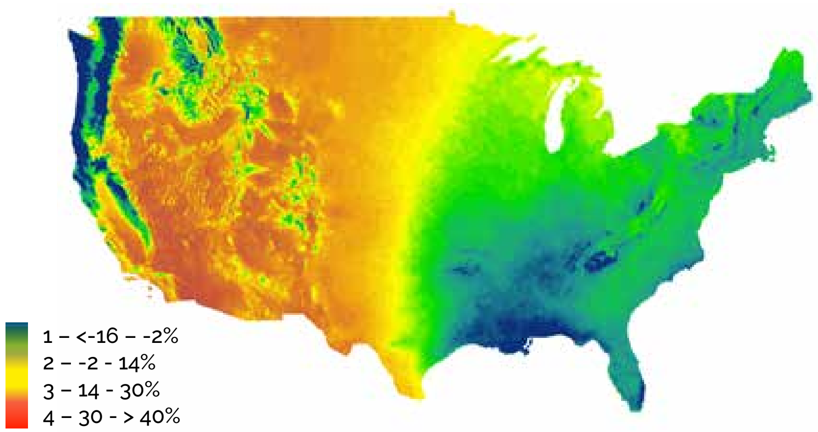
Historical Winter Precipitation



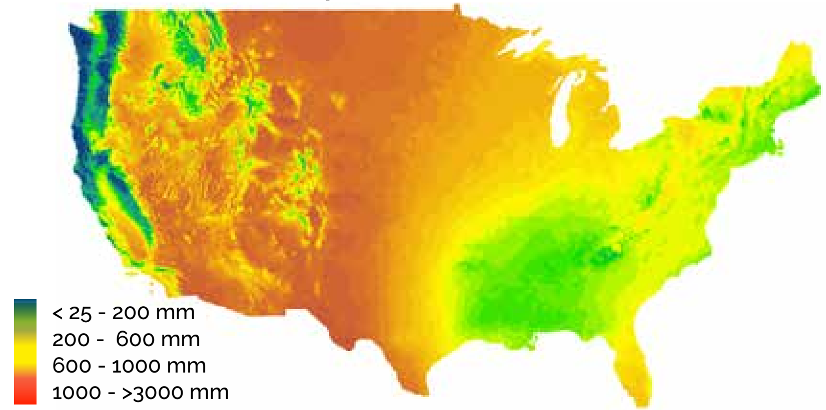
Historical Summer Precipitation



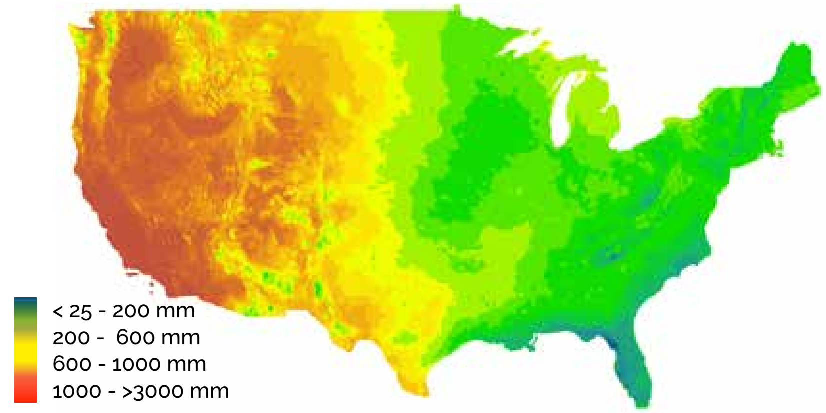
Historical Percent Change in Seasonal Precipitation



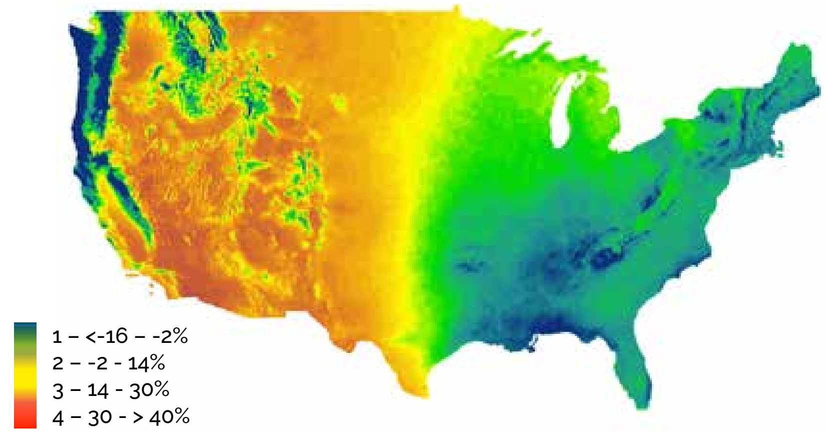
Future Winter Precipitation



Future Summer Precipitation

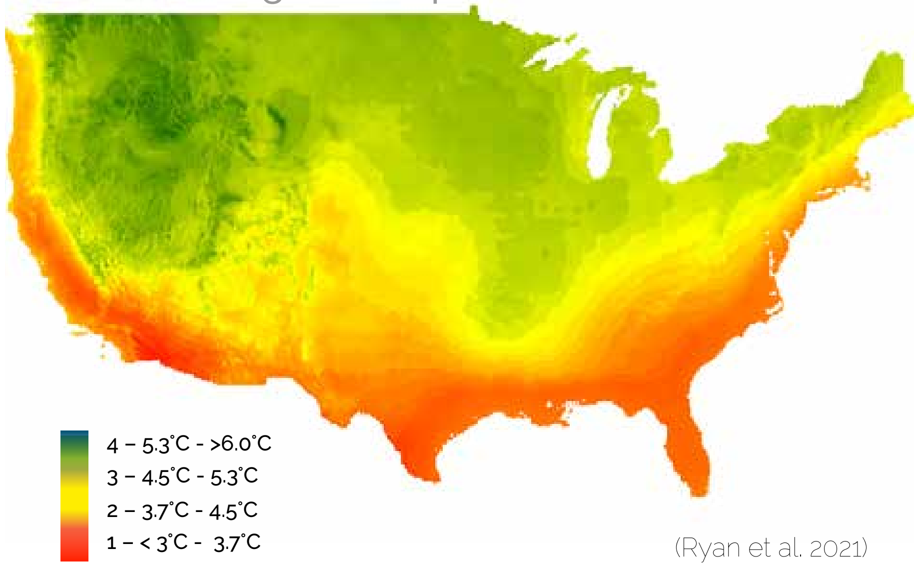


Future Percent Change in Seasonal Precipitation



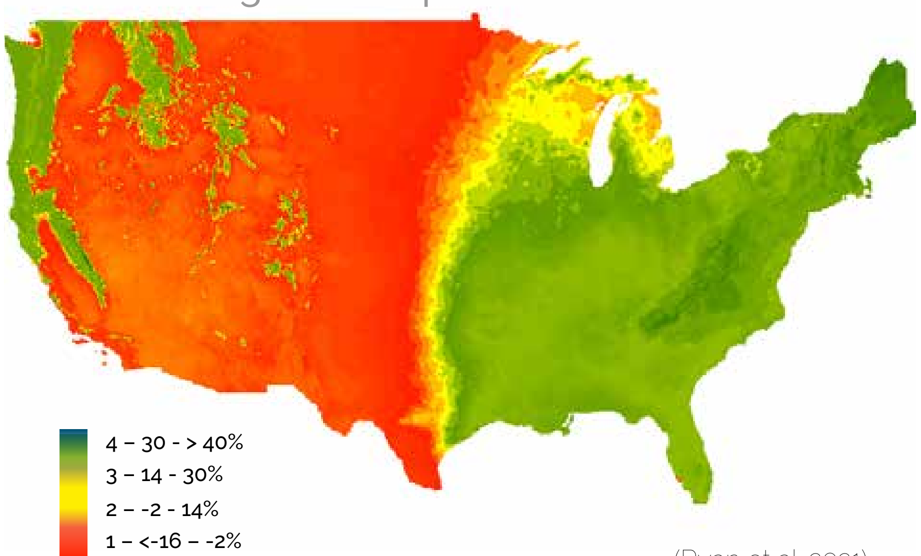
United States Climate Datasets
MCDA Weighted Maps

Absolute Change in Temperature



(Ryan et al. 2021)

Percent Change in Precipitation



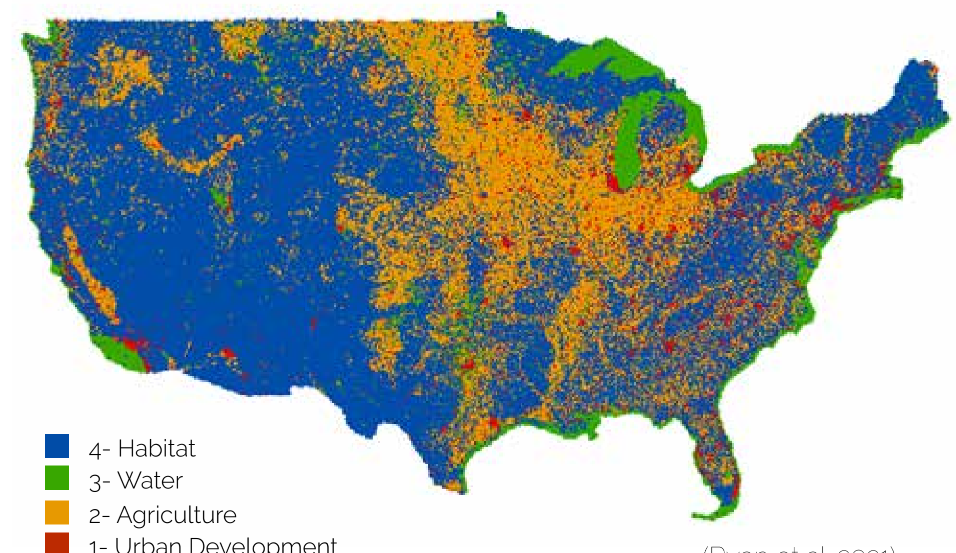
(Ryan et al. 2021)

Refugia Datasets
MCDA Weighted Maps

Land Cover

U.S. Geological Survey (USGS) Gap Analysis Project (GAP), 2016, GAP/LANDFIRE National Terrestrial Ecosystems 2011: U.S. Geological Survey data release, https://doi.org/10.5066/F7ZS2TM0.

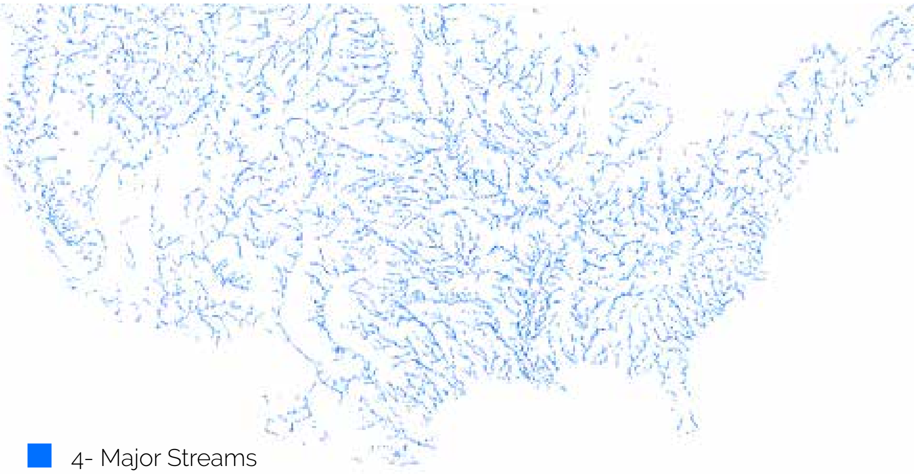
Reclassified Land Cover



(Ryan et al. 2021)

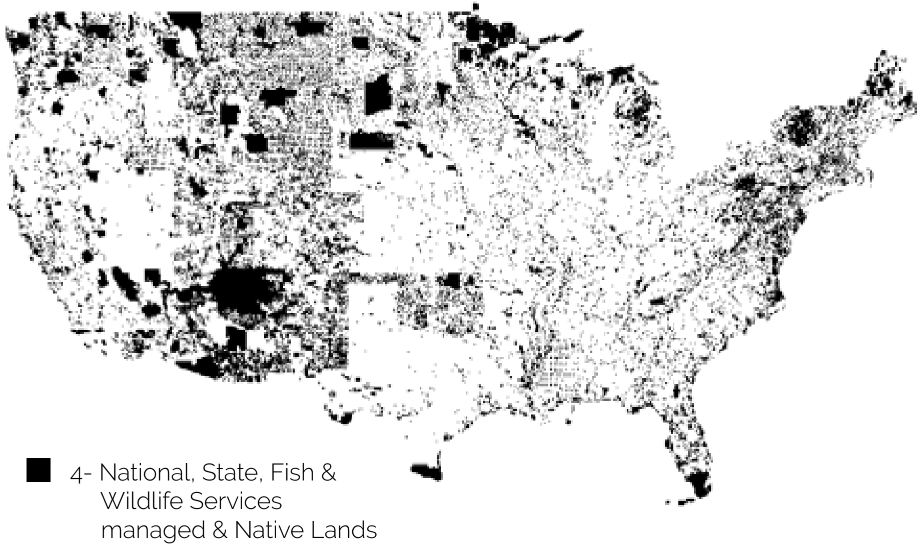
United States Refugia Datasets
MCDA Weighted Maps

Water Flowlines



U.S. Geological Survey (USGS); National Hydrography Dataset (NHD) National Hydrography Datasets Plus Version 2.1 - Flowlines. 2016: U.S. Geological Survey data release, https://nhdplus.com/NHDPlus/#NHDPlusV2%20User%20Guide

Public & Private Lands

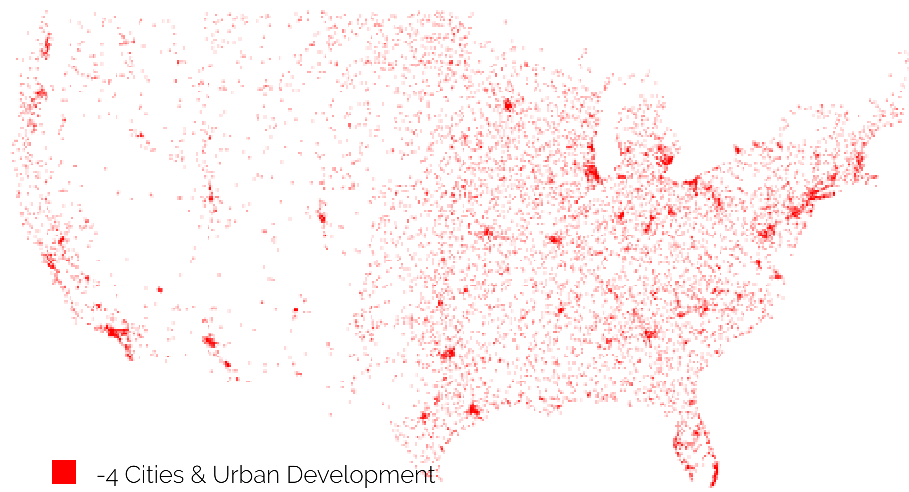


U.S. Geological Survey (USGS); Protected Areas. Gap Analysis Project (GAP), 2016, https://www.usgs.gov/core-science-systems/science-analytics-and-synthesis/gap/science/protected-areas

Major Highways & Interstates

Federal Highway Administration (FHA) National Highway Planning Network.. 2019. https://learn-students.maps.arcgis.com/home/item.html?id=51275617f1274103b81d99cd0ad94a40

Human Development



U.S. Geological Survey (USGS) Gap Analysis Project (GAP), 2016, GAP/LANDFIRE National Terrestrial Ecosystems 2011: U.S. Geological Survey data release, https://doi.org/10.5066/F7ZS2TM0.

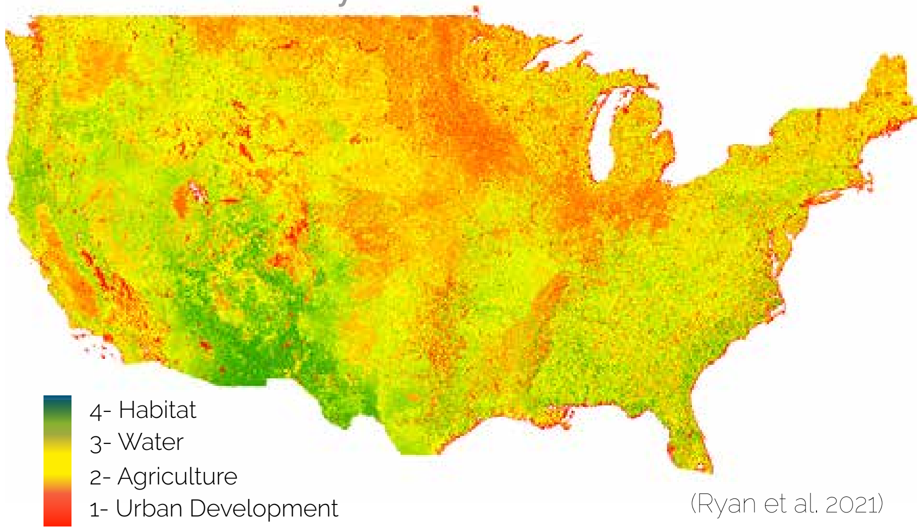
United States Refugia Datasets

MCDA Weighted Maps

Soil Bedrock Depth

Soil Survey Staff. Gridded National Soil Survey Geographic (gNATSGO) Database for the Conterminous United States. United States Department of Agriculture, Natural Resources Conservation Service. Available online at https://nrcs.app.box.com/v/soils. December 1, 2020 (FY2020 official release).

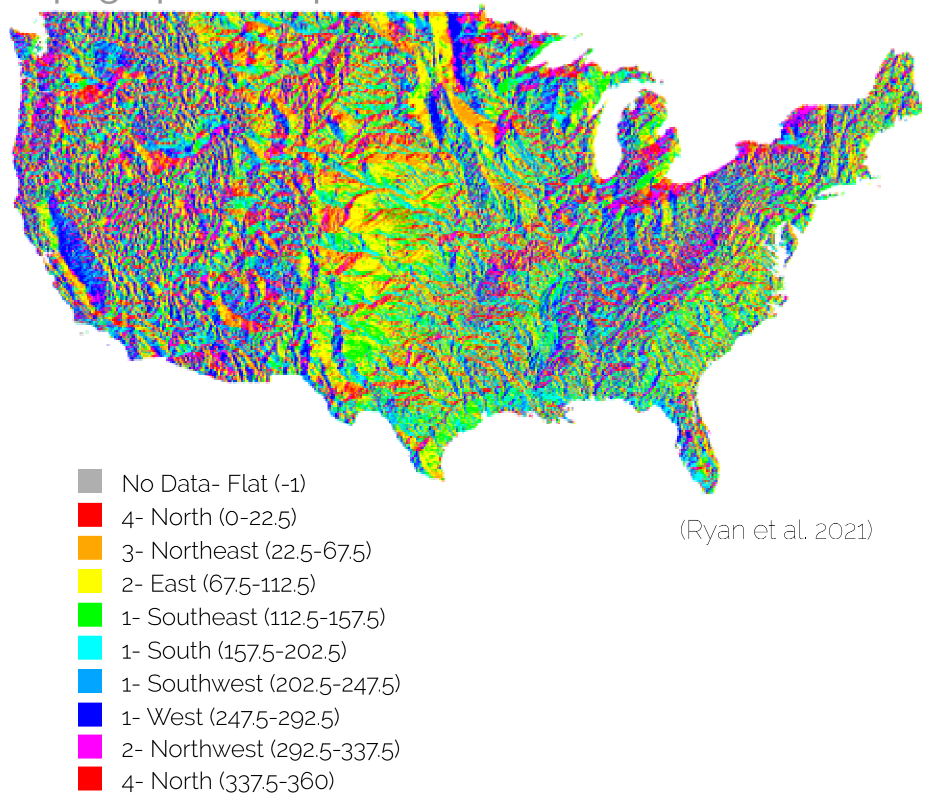
Wildlife Biodiversity



(Ryan et al. 2021)

U.S. Geological Survey - Gap Analysis Project, 201810, U.S. Geological Survey - Gap Analysis Project Amphibian Species Habitat Richness: U.S. Geological Survey, https://doi.org/10.3133/sir20195034, https://doi.org/10.5066/P9YW3ZQ2.

Topographical Aspect



(Ryan et al. 2021)

U.S. Geological Survey (USGS)- 2021. The National Map (TNM) Download. Elevation Products. https://viewer.nationalmap.gov/basic/

Appendix D

Kansas MCDA
Map Data

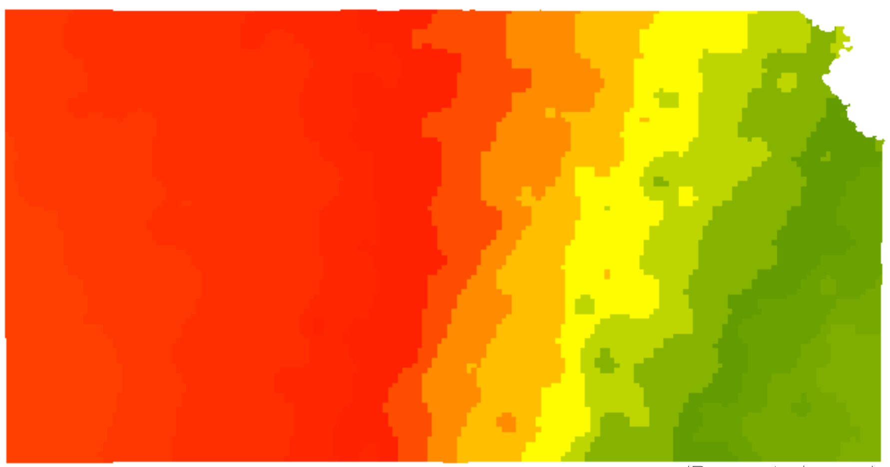
Kansas Climate Datasets
MCDA Weighted Maps

Absolute Change in Temperature

(Ryan et al. 2021)

4 – 5.3˚C - >6.0˚C
3 – 4.5˚C - 5.3˚C
2 – 3.7˚C - 4.5˚C
1 – < 3˚C - 3.7˚C

Percent Change in Precipitation

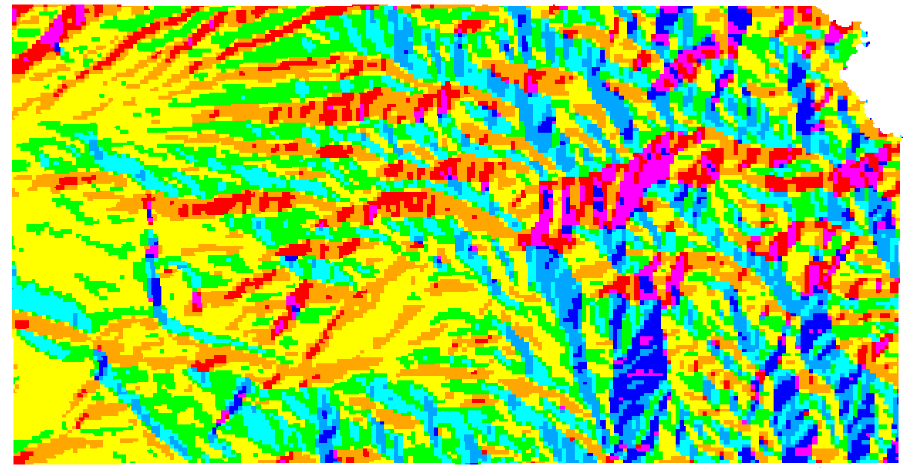


(Ryan et al. 2021)

4 – 30 - > 40%
3 – 14 - 30%
2 – -2 - 14%
1 – <-16 – -2%

Kansas Refugia Datasets
MCDA Weighted Maps

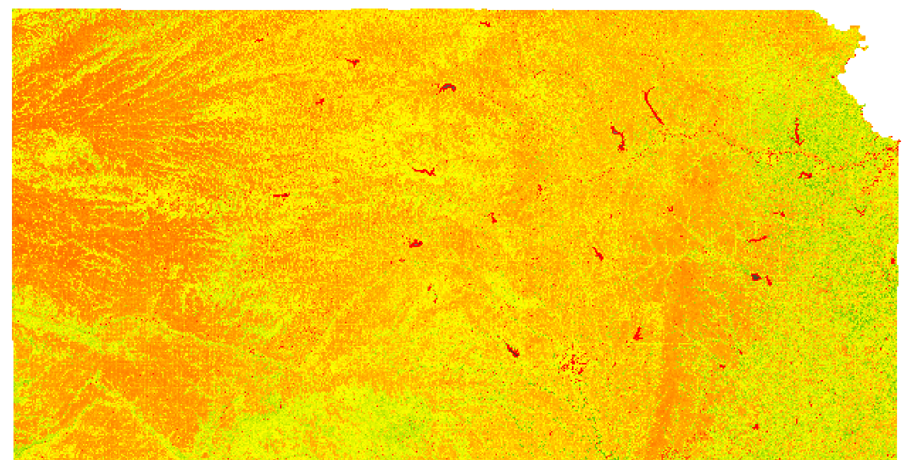
Topographical Aspect



(Ryan et al. 2021)

No Data- Flat (-1)
4- North (0-22.5)
3- Northeast (22.5-67.5)
2- East (67.5-112.5)
1- Southeast (112.5-157.5)
1- South (157.5-202.5)
1- Southwest (202.5-247.5)
1- West (247.5-292.5)
2- Northwest (292.5-337.5)
4- North (337.5-360)

Wildlife Biodiversity



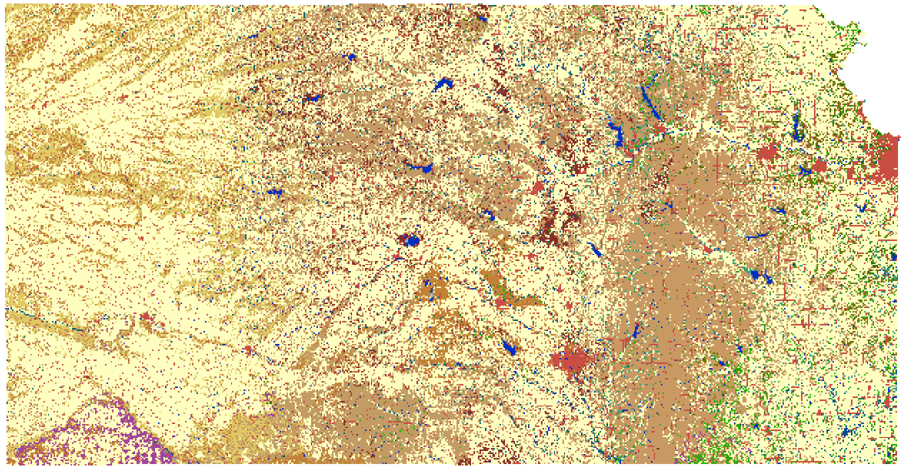
(Ryan et al. 2021)

4- Habitat
3- Water
2- Agriculture
1- Urban Development

Kansas Refugia Datasets

MCDA Weighted Maps

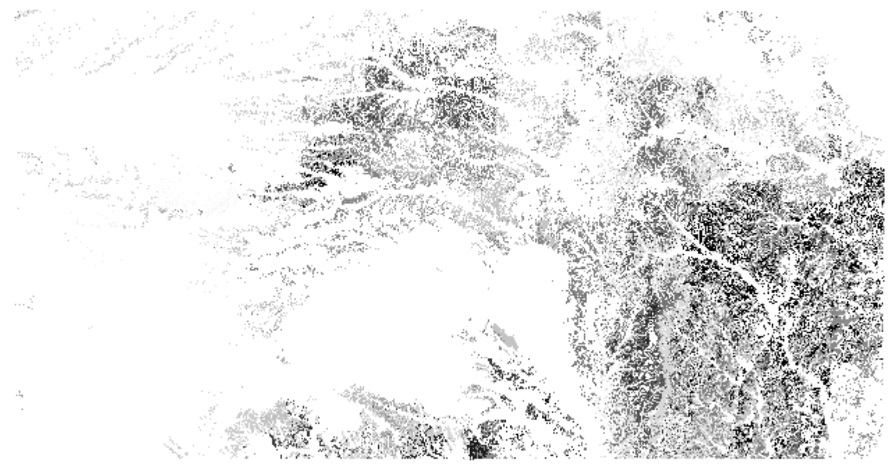
Land Cover



USGS et al. 2016)

- 65 - Crosstimbers Oak Forest and Woodland
- 73 - North-Central Interior Dry Oak Forest and Woodland
- 74 - North-Central Interior Dry-Mesic Oak Forest and Woodland
- 83 - Ozark-Ouachita Dry-Mesic Oak Forest
- 90 - Managed Tree Plantation
- 91 - Ruderal forest
- 118 - Western Great Plains Dry Bur Oak Forest and Woodland
- 119 - Western Great Plains Wooded Drawn and Ravine
- 124 - North-Central Interior Maple-Basswood Forest
- 125 - Ozark-Ouachita Mesic Hardwood Forest
- 193 - Western Great Plains Floodplain Systems
- 197 - Central Interior and Appalachian Floodplain Systems
- 204 - North-Central Interior and Appalachian Rich Swamp
- 224 - Southeastern Great Plains Floodplain Forest
- 324 - Central Mixedgrass Prairie
- 328 - Western Great Plains Sand Prairie
- 333 - Central Tallgrass Prairie
- 335 - North-Central Interior Sand and Gravel Tallgrass Prairie
- 336 - North-Central Oak Barrens
- 338 - Southeastern Great Plains Tallgrass Prairie
- 346 - Central Interior Highlands Calcareous Glade and Barrens
- 422 - Eastern Great Plains Wet Meadow, Prairie and Marsh
- 555 - Orchards Vineyards and Other High Structure Agriculture
- 556 - Cultivated Cropland
- 557 - Pasture/Hay
- 579 - Water
- 580 - Quarries, Mines, Gravel Pits and Oil Wells
- 581 - Developed, Open Space
- 582 - Developed, Low Intensity
- 583 - Developed, Medium Intensity
- 584 - Developed, High Intensity

Soil Bedrock Depth

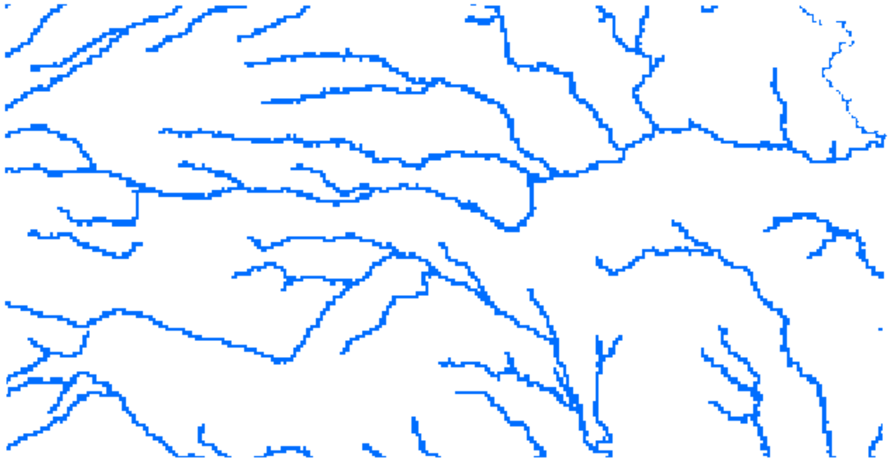


- 4- > 300 cm
- 3- 200-300 cm
- 2- 100-200 cm
- 1- < 100 cm

SSS et al. 2020)

Kansas Refugia Datasets
MCDA Weighted Maps

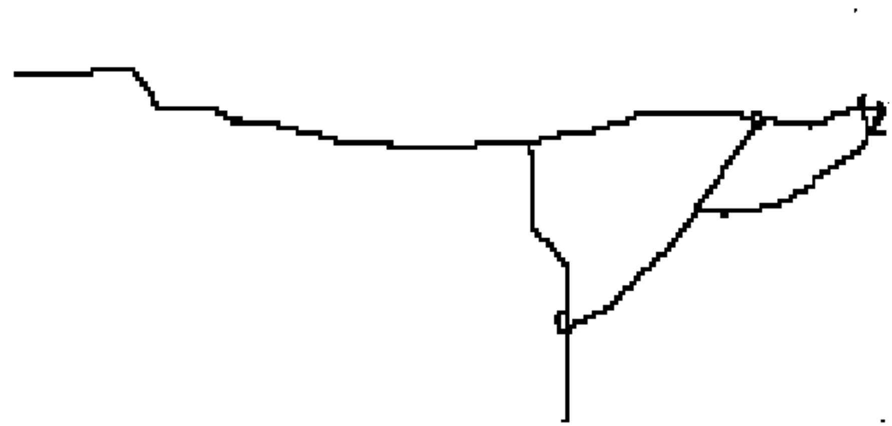
Water Flowlines



4- Major Streams

USGS & NHD 2016)

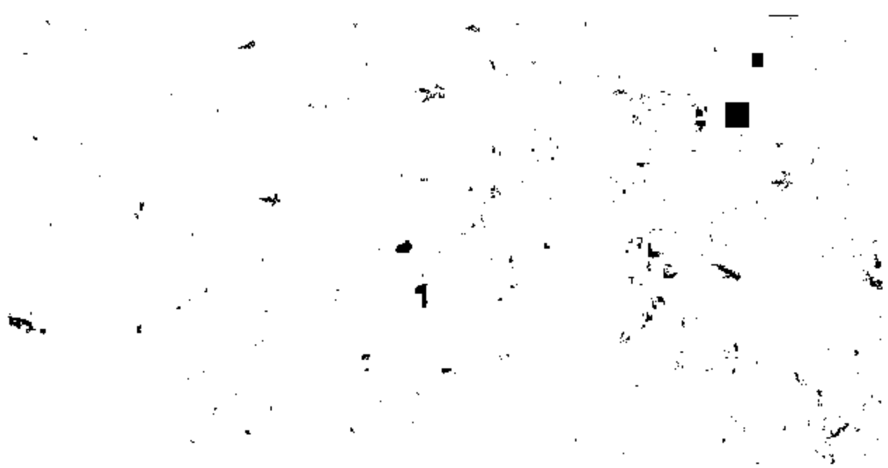
Major Highways & Interstates



-4 Interstates

(FHA 2019)

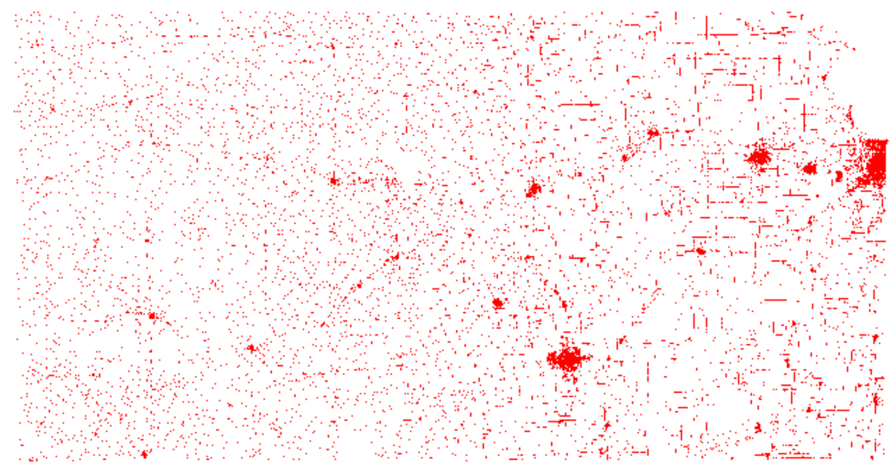
Public & Private Lands



4- National, State, Fish & Wildlife Services managed & Native Lands

(USGS & PAD. 2021)

Human Development



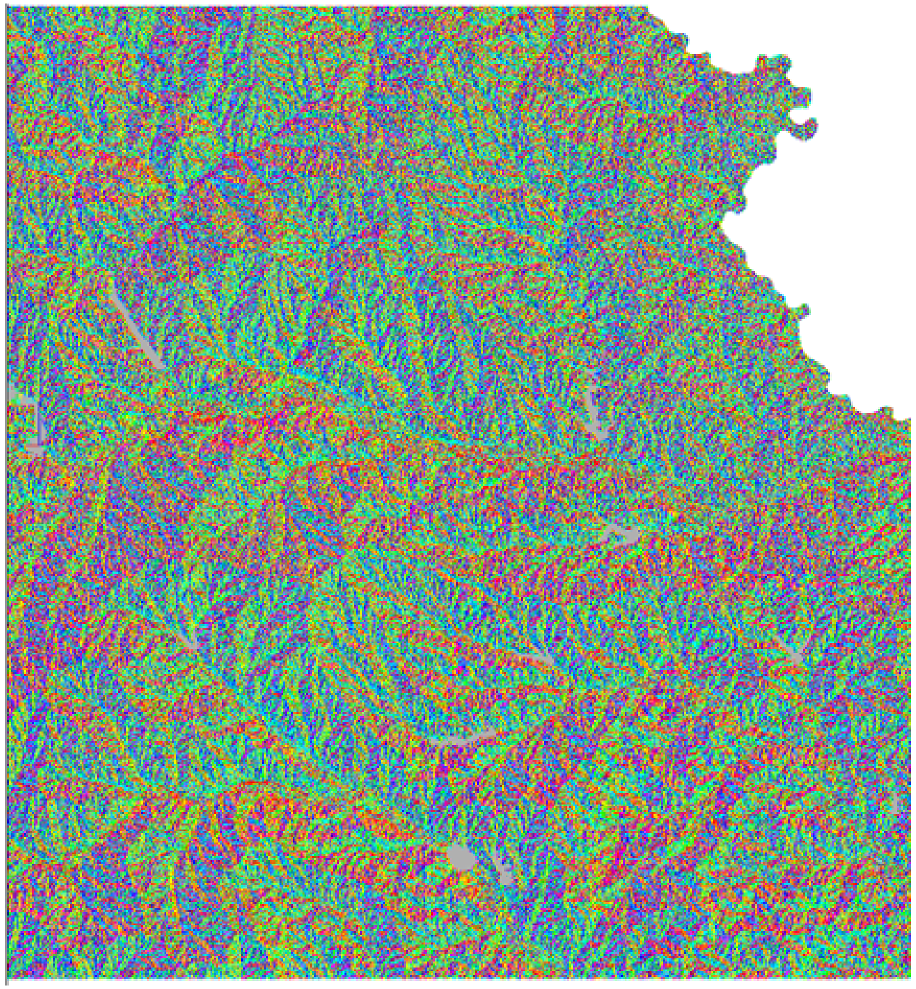
-4 Cities & Urban Development

USGS et al. 2016)

Northeast Kansas Refugia Datasets

MCDA Weighted Maps

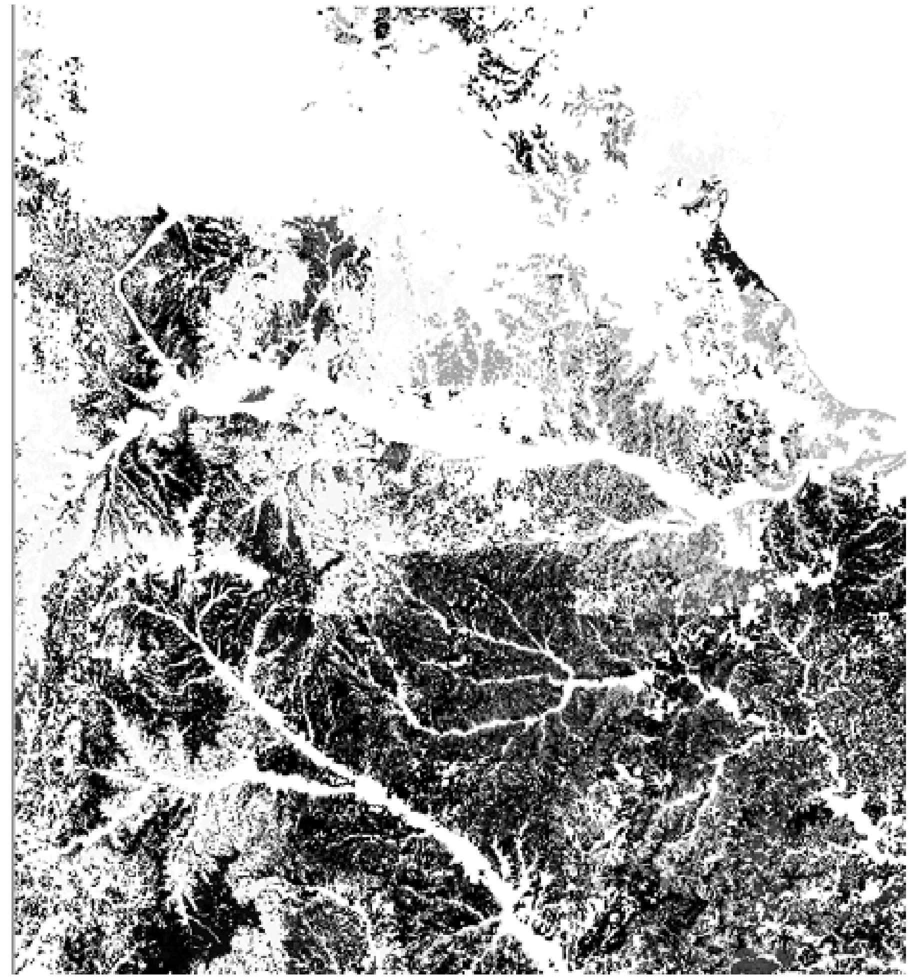
Topographical Aspect



(Ryan et al. 2021)

- No Data- Flat (-1)
- 4- North (0-22.5)
- 3- Northeast (22.5-67.5)
- 2- East (67.5-112.5)
- 1- Southeast (112.5-157.5)
- 1- South (157.5-202.5)
- 1- Southwest (202.5-247.5)
- 1- West (247.5-292.5)
- 2- Northwest (292.5-337.5)
- 4- North (337.5-360)

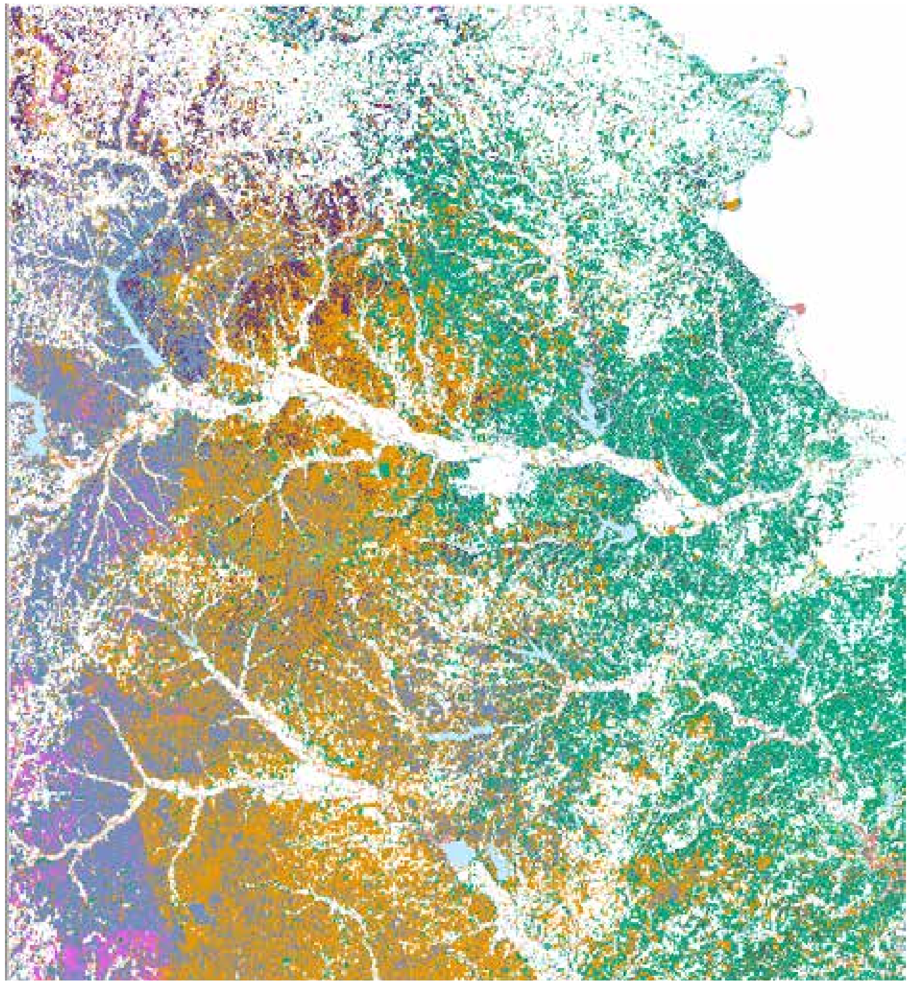
Soil Depth to Bedrock



SSS et al. 2020)

- 4- > 300 cm
- 3- 200-300 cm
- 2- 100-200 cm
- 1- < 100 cm

Northeast Kansas Refugia Datasets
MCDA Weighted Maps
Vegetative Communities



USGS et al. 2016)

- 65 - Crosstimbers Oak Forest and Woodland
- 73 - North-Central Interior Dry Oak Forest and Woodland
- 74 - North-Central Interior Dry-Mesic Oak Forest and Woodland
- 83 - Ozark-Ouachita Dry-Mesic Oak Forest
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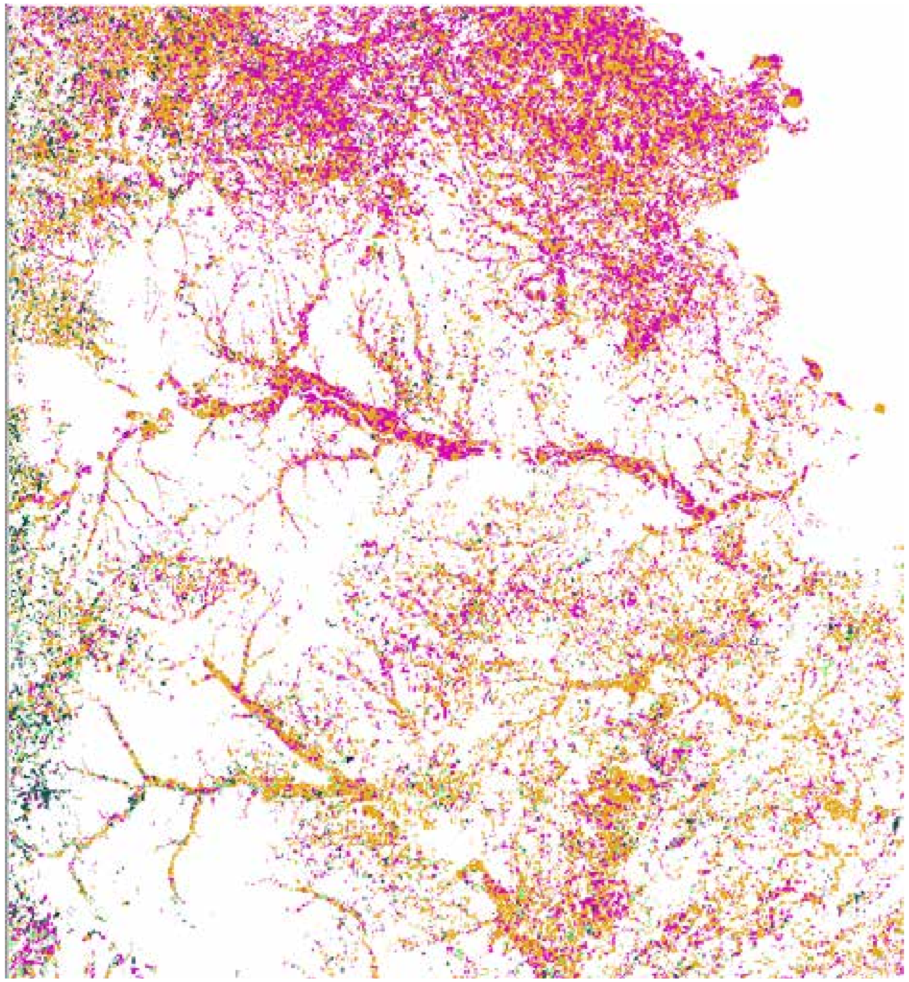
- 125 - Ozark-Ouachita Mesic Hardwood Forest
- 193 - Western Great Plains Floodplain Systems
- 197 - Central Interior and Appalachian Floodplain Systems
- 204 - North-Central Interior and Appalachian Rich Swamp
- 224 - Southeastern Great Plains Floodplain Forest
- 324 - Central Mixedgrass Prairie
- 328 - Western Great Plains Sand Prairie
- 333 - Central Tallgrass Prairie
- 335 - North-Central Interior Sand and Gravel Tallgrass Prairie
- 336 - North-Central Oak Barrens
- 338 - Southeastern Great Plains Tallgrass Prairie
- 346 - Central Interior Highlands Calcareous Glade and Barrens
- 422 - Eastern Great Plains Wet Meadow, Prairie and Marsh
- 555 - Orchards Vineyards and Other High Structure Agriculture

Northeast Kansas Refugia Datasets
MCDA Weighted Maps

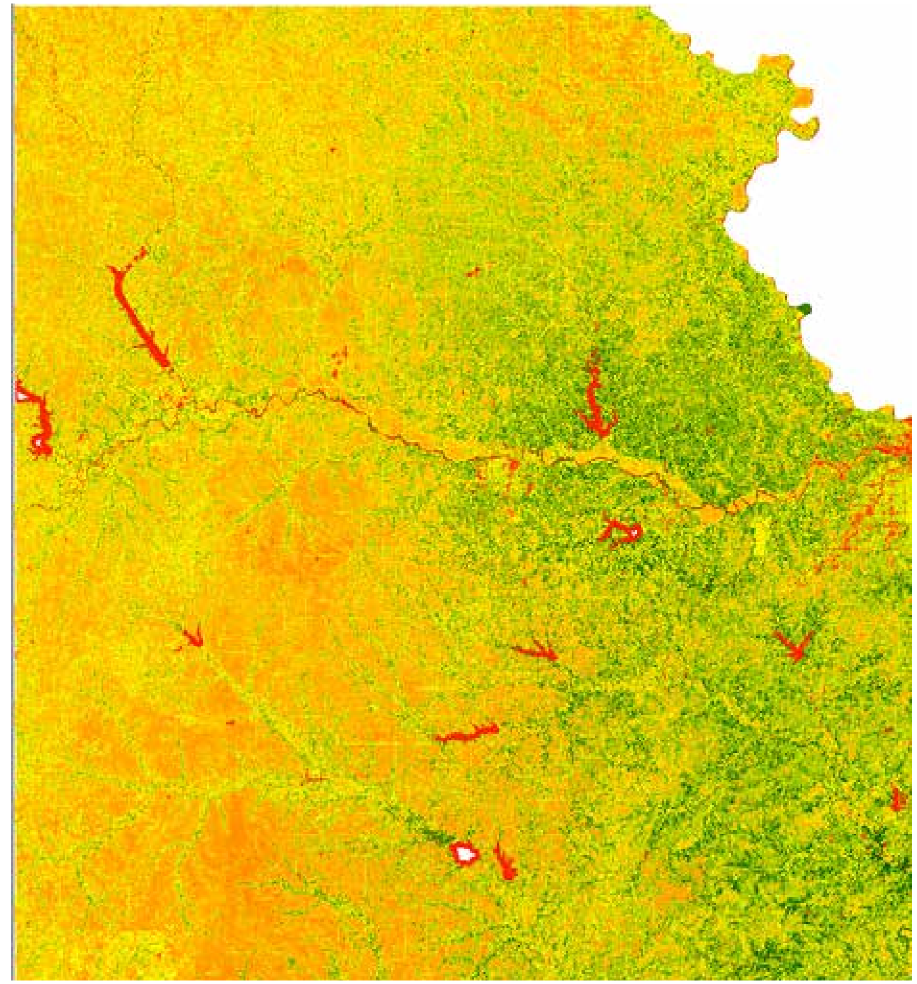
Agricultural Land



USGS et al. 2016)

- Non-Irrigated Corn
- Irrigated Corn
- Non-Irrigated Soybean
- Irrigated Soybean
- Non-Irrigated Sorghum
- Irrigated Sorghum
- Non-Irrigated Winter Wheat
- Irrigated Winter Wheat
- Non-Irrigated Alfalfa
- Irrigated Alfalfa
- Fallow
- Double-Crop
- Conservation Reserve Program

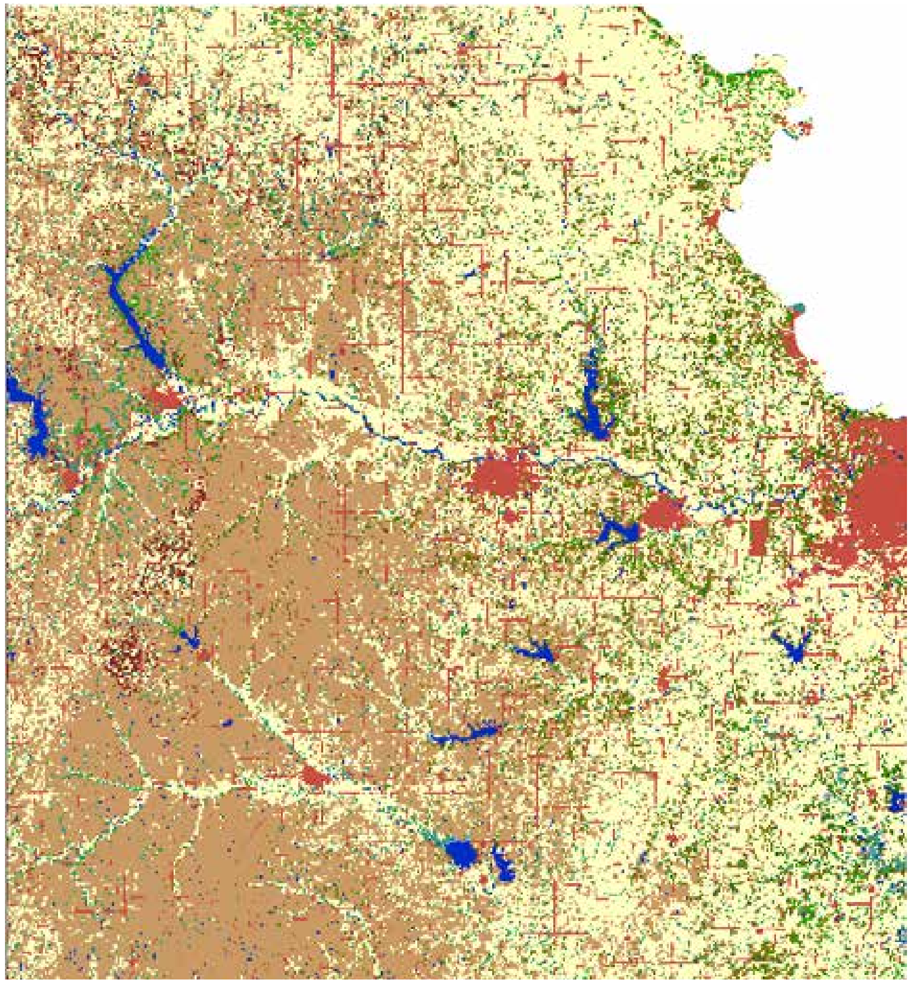
Soil Depth to Bedrock



(Ryan et al. 2021)

4- Habitat
3- Water
2- Agriculture
1- Urban Development

Refugia Datasets
MCDA Weighted Maps
Topographical Aspect



USGS et al. 2016)

- 65 - Crosstimbers Oak Forest and Woodland
- 73 - North-Central Interior Dry Oak Forest and Woodland
- 74 - North-Central Interior Dry-Mesic Oak Forest and Woodland
- 83 - Ozark-Ouachita Dry-Mesic Oak Forest
- 90 - Managed Tree Plantation
- 91 - Ruderal forest
- 118 - Western Great Plains Dry Bur Oak Forest and Woodland
- 119 - Western Great Plains Wooded Drawn and Ravine
- 124 - North-Central Interior Maple-Basswood Forest
- 125 - Ozark-Ouachita Mesic Hardwood Forest
- 193 - Western Great Plains Floodplain Systems
- 197 - Central Interior and Appalachian Floodplain Systems
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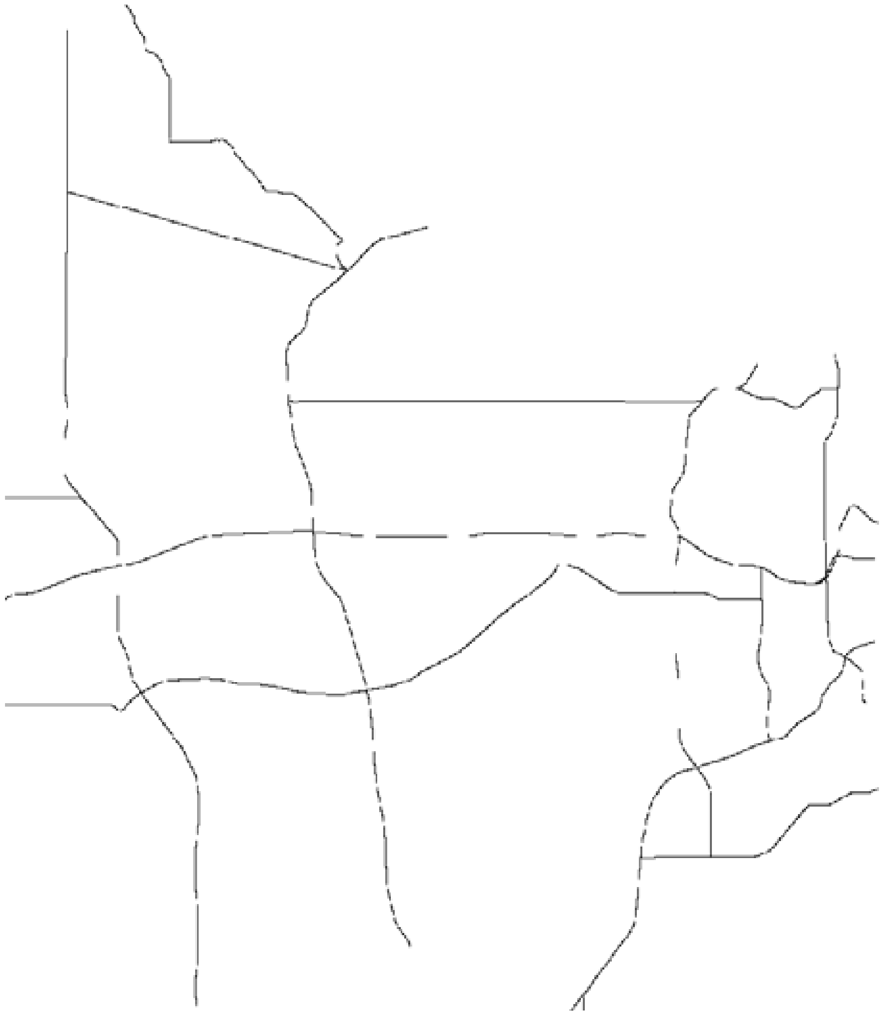
- 338 - Southeastern Great Plains Tallgrass Prairie
- 346 - Central Interior Highlands Calcareous Glade and Barrens
- 422 - Eastern Great Plains Wet Meadow, Prairie and Marsh
- 555 - Orchards Vineyards and Other High Structure Agriculture
- 556 - Cultivated Cropland
- 557 - Pasture/Hay
- 579 - Water
- 580 - Quarries, Mines, Gravel Pits and Oil Wells
- 581 - Developed, Open Space
- 582 - Developed, Low Intensity
- 583 - Developed, Medium Intensity
- 584 - Developed, High Intensity

Refugia Datasets

MCDA Weighted Maps

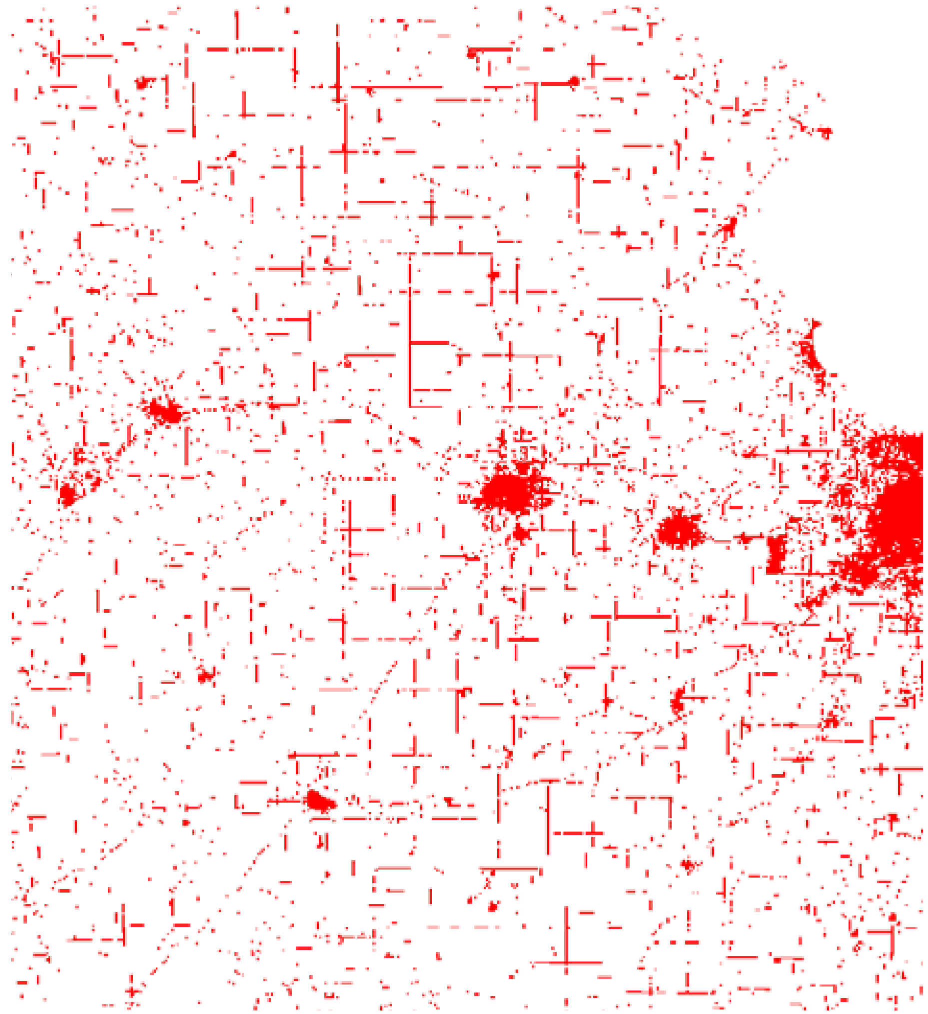
Highways & Interstates



-4 Interstates

(FHA 2019)

Human Development

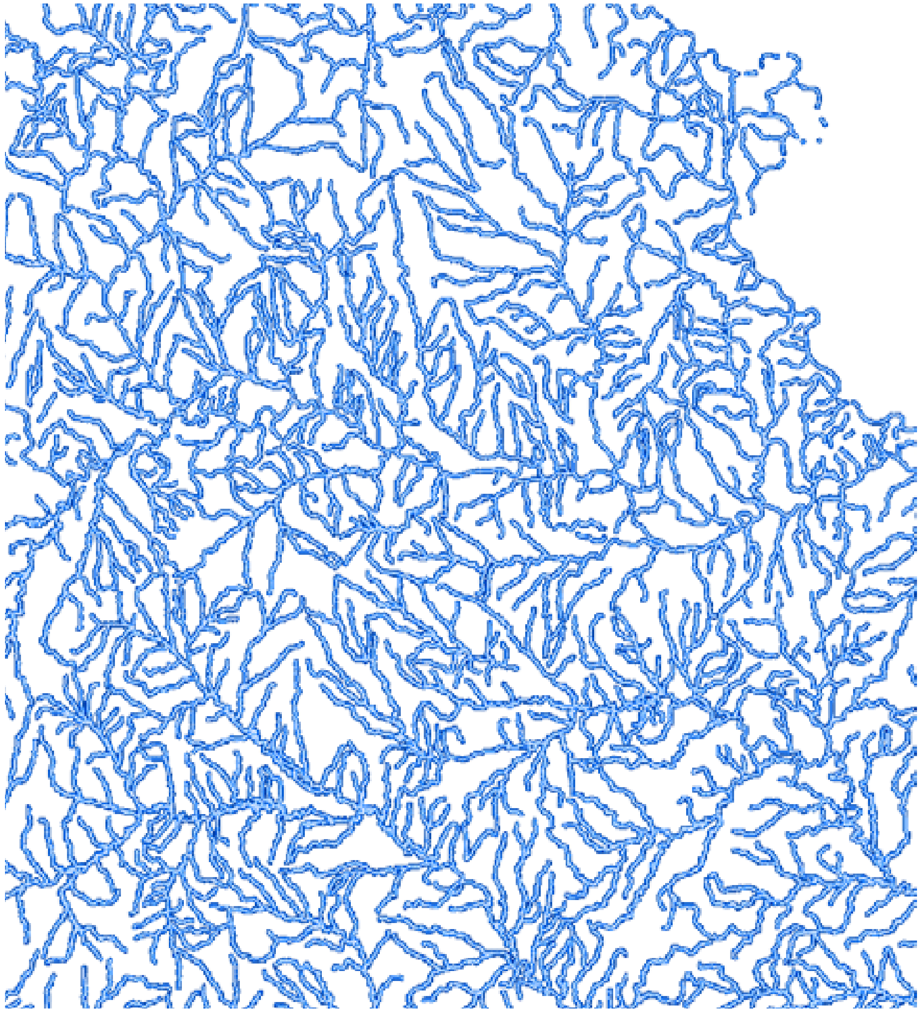


-4 Cities & Urban Development

USGS et al. 2016)

Refugia Datasets
MCDA Weighted Maps

Topographical Aspect



4- Major Streams

USGS & NHD 2016)

Soil Depth to Bedrock

4- National, State, Fish & Wildlife Services managed & Native Lands

(USGS & PAD. 2021)