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A GIS Look at Woody Plant Encroachment (WPE): Mapping Grassland Degradation Through Habitat Succession

Brandon M. Wolf

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The grasslands of North America remain at a fraction of their historic range. Estimates of acreage remaining vary between 4% and 13%. Affectionately known as the Great Plains, these grasslands have been converted for agriculture, rangeland, infrastructure, and civilization itself. Woody Plant Encroachment (WPE) on the grasslands is a silent, often overlooked, serious threat. The use of a simple GIS can estimate current acreage of a grassland, its adjacent woodland corridor, riparian buffers, and predict future acreage based on trends and hypothetical management scenarios, or lack thereof. The American prairie, though a remnant of its former self, is still home to a wide variety flora and fauna. Some of these species are endemic to the region while others are seasonally reliant upon the dwindling habitat. In addition to grasslands being ecologically significant, grasslands offer unseen benefits to society as well. A few of these benefits are carbon sequestration, water filtration, livestock grazing, and erosion control. These grassland benefits are current topics of discussion on their own. One of the more well-known benefits, erosion control, was historically highlighted with the events of the 1920's Dust Bowl.

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Notable Terms, Abbreviations and Acronyms:

WPE– woody plant encroachment

GIS – geographic information system

DBH – diameter at breast height

Grassland – an ecosystem comprised of grasses and forbs, largely void of woody shrubs or trees

Xerification – the drying of an area overtime; grasses being replaced by shrubs and bare soil

Habitat Succession – a landscape naturally transitioning from one habitat to another

Invasive species – a terrestrial or aquatic species, often non-native flora, or fauna, known to displace native and desirable species from the landscape.

Monoculture – often associated with agriculture**,** a landscape composed of a single species

Forb – herbaceous non woody plant

Introduction

Historically, the prairies of the United States stretched from the front range of the Rocky Mountains east to central Ohio, from Texas spreading north into Canada. There were also isolated prairie pockets in the northeast. The grasslands of the United States, covering 40% of the country, were once the most widespread ecosystem on the North American landscape. There are numerous factors responsible for the current state of the American prairie. The factor which this project investigates, woody plant encroachment (WPE), is a silent, methodical, destroyer of grasslands. If left unmanaged, a species such as the Eastern Redcedar, *Juniperus virginiana*, will degrade a grassland in a few short years. WPE is the result of a natural cycle called habitat succession. Habitat succession is a process driven by the reproductive strategies and growing habits of plant species. The beginning stage of habitat succession is a grassland. A grassland is an ecosystem comprised of grasses and forbs and is largely void of woody shrubs or trees. Prior to European settlement the grasslands of the United States were grazed by mass herds of ungulates, and wildfire would regularly sweep the plains. Grazing would keep the vegetation under control between fires, and fire would regularly force the landscape back to the first stage of habitat succession, a grassland. Without fire and grazing, woody plant species take hold and transform the landscape. Once WPE begins, the species first seen on a grassland are those species with advantageous reproductive strategies, are adaptable and/or tolerant to adverse growing conditions. These species produce large amounts of seeds, grow quickly, and adapt to a wide variety of environmental conditions, creating the next stage of habitat succession, a shrubland. A shrubland, composed of remnants of a grassland, is a mix of woody shrubs and small trees such as the Eastern Redcedar. This intermediate stage of habitat succession has its place in the cycle, but it negates any benefits, societal or ecological, of the prior stage. The final stage, a woodland, is composed of more selective species. Species which produce fewer seeds, grow slower, and require more specific environmental conditions. Woodlands have their own series of succession, starting with intermediate and culminating in old growth. Habitat succession is far more complex, but for the purpose of this project, we will be focusing solely on the transition between the first two stages of succession. All stages of succession offer habitat and are a necessary part of the cycle of the landscape. However, it is the grasslands that are most vulnerable under modern land use and land use practices. The more "advanced" stages become in succession, the more difficult they are to transform or revert to a former state of the habitat cycle. Once an old growth forest or a prairie are lost, they are essentially gone forever. Leaving its residents and beneficiaries to adapt or expire.

Background

The western extent of the prairie, often receiving the least amount of precipitation, is comprised of short, drought resistant species. This semiarid region is known as the shortgrass prairie. On the eastern extent, often receiving the largest amount precipitation, species experience more favorable growing conditions, and grow quite vigorously. This region is known as the tallgrass prairie. The region between, receives an intermediate amount of precipitation, and is called the mixed grass prairie. The mixed grass prairie is comprised of a combination of the species found in the other two regions. Annually, under historic natural conditions, the eastern fringe of the prairie wavered between young forested shrubland and grassland. This fluctuation was dependent upon varying amounts of precipitations, and the reach of the season's prairie fires. Wildfires occurred naturally from lightning strikes, or anthropogenically by the Native Americans. Native Americans knew of the benefit of fire on their landscape and would initiate the natural cycle of the prairie.

When fire and grazing are absent from the grassland landscape, woody plants species begin their encroachment. A botanical competition ensues as a tussle for nutrients and photosynthetic resources is encapsulated as WPE. There are many species involved in the transition of a grassland to a proper woodland. In the early stages of succession however, there are far fewer woody species involved. Regionally, culprit species will vary as well. Siberian Elm, *Ulmus pumila*, and Red Mulberry, *Morus rubra*, can be seen exhibiting WPE in the lower Great Plain States. These species have become invasive across their range as well. Invasive species are often nonnative and will dominate the landscape, eventually forming monocultures. Some invasive species are more aggressive than others. Black locust (*Robinia pseudoacacia*), also called false acacia or yellow locust, is one of the most difficult invasive trees to eradicate (Stannard, 2020). The Black locust thrives in dry, poor soil conditions. *Populus deltoides*, the eastern cottonwood, will contribute to WPE when conditions dampen. *Juniperus, virginiana* the Eastern Redcedar, can be found growing in variety of conditions across the eastern half of the North America, Oregon, Wyoming, and Colorado. Due to this adaptability to various growing conditions, the Eastern Redcedar is a major contributor to WPE. The Eastern Redcedar, as its Latin name suggests, is in fact a species of Juniper and not a true cedar.

Often, modern thought is to suppress wildfires. In many peripheral areas of civilization, this is a tricky balance. There is the obvious need to protect citizens of these lands from fire, but there is also the ongoing need for the grassland landscape to be kept as such by combating WPE with fire. These junctions are often former rangeland that have been fragmented and sectioned off for residential dwellings or hobby ranches. Typically, these areas are not managed well and species like the Easter Redcedar can carry out their life cycle uninterruptedly. These trees are often planted along driveways or as wind breaks. When properly stewarded these interfaces can be a rewarding place to reside, however when the land is left to run rampant, issues arise. Adjacent lands, which may be managed for rangeland and/or native grassland habitat, will in time, become tainted by the poorly managed plots. Prescribed burning, replicating historic wildfires, is the most efficient tool at mitigating WPE and invasive species advance.

Problem Statement

It is known that habitat loss, through degradation, fragmentation, and conversion are problematic across all ecosystems of the world. The impacts of habitat alteration range in severity. There is a plethora of factors which contribute to habitat alterations worldwide. Some conversions of habitat can now be considered historic, while others are ongoing. The settlement of New York City, New York, for example. New York City was once a thriving coastal wetland, home to the now extinct winter range of the Labrador Duck, where the Hudson River meets the Atlantic Ocean. It has been altered to suite one of the most iconic cities in the world. The ongoing alteration, conversion, and division of the natural landscape is most severely felt in regions where the most damage has already been done. Coastal and inland wetlands, mangroves, and the grasslands of the world are the most imperil ecosystems. Both wetlands and mangroves, while under threat, are not yet as high risk as the prairie. GIS and remote sensing are playing key roles in monitoring the health of these ecosystems and driving the restoration/conservation efforts of them. There is one key difference with the prairie and the other challenged ecosystems. A common saying, “out of sight, out of mind,” is true regarding the presence, or lack thereof, a prairie. Simply, society cannot exist “on a prairie”. A grassland needs to be a vast expanse of minimally, negatively, influenced land. And for this, the presence of homesteads or civilization hinder the ecosystem. The main reason for this is the need for fire. Fire keeps WPE controlled. The prairie needs to burn. As society moves into the grasslands, fire is stifled, and WPE is let to commence. The effect is not seen immediately. There is a lag between sapling germination and maturation. Once woody species become mature, they begin to spread their offspring, compounding the effect of WPE. We are learning how WPE plays its role in habitat degradation. But, at what point is habitat lost? How much habitat transformation is too much? How long will it take such a unique ecosystem to be transformed into another? Given the current state of the study area, Sand Hills State Park, seen in Figure 2, if current management practices ended, how long until the woody species snuff out the grasslands rendering the habitat unsuitable for any species reliant upon it?


Photo 2 - Remnants of a grassland enveloped by woody vegetation.

Research Objectives

Photo 1- WPE can be seen as grassy terrain transitions to wooded.

The main objective of this research project is to identify WPE point source locations and to develop a timeline for habitat transition of the grasslands of Sand Hills State Park in Hutchinson, KS. Scenarios, as seen at Sand Hills, give a good understanding of how quickly WPE can shift the terrain. Due to the composition of the state park, there is the possibility for woody species interacting with grassland species, and the size of the park allows for these interactions to be frequent. Adjacent properties, to both the north and south, are residential and do not permit the use of fire due to the risk of incidental spread. Habitat management practices are therefore limited to mechanical and/or chemical control. Chemical control is not necessary, due to the lack of overly aggressive/invasive species. Ailanthus, or the Tree of God, is an invasive tree found nearby and should be monitored closely to prevent an outbreak which would necessitate the need for chemical control. Black locust is also found in the park and could pose a threat necessitating chemical control if management practices ended. Under current park conditions, mechanical control, in the form of haying, is the best option. Grazing could be an additional method for WPE control but is not currently exercised by the state of Kansas. Due to the nature of a state park, as a commodity to the public, free range livestock would pose a safety concern, as well as a liability for adjacent property owners.

Certain species, such as the prairie grouse of North America, tolerate little to no WPE. Others, like the Northern Bobwhite, require escape cover on the landscape which involves minimal WPE. Escape cover, for quail, is woody vegetation, shorter than 15', sparsely scattered on a plot in the event an escape from predator or weather is needed. Botanically, reactions to WPE are similar to those of the avian preference. Some species take very little to be displaced, while others adapt. Eventually, however, WPE will force the flora and fauna of a grassland out, to be replaced by new species. The question being, where is the next prairie for displaced species to relocate? Plants and ground dwelling species cannot simply move to the next grassland. These species then become extirpated from the landscape; hope being that there is enough habitat elsewhere to sustain populations and avoid extinction.

It is known that certain species of woody plants readily encroach on grasslands without factors inhibiting their advance. The Eastern Redcedar has been determined as the most likely, within the study area, to be responsible for WPE. Other species previously discussed contribute to WPE, but none appear to have the impact as much as the cedar does in south central Kansas. For this, only data pertaining to Eastern Redcedar were collected.

A grassland can be restored at any point of WPE, although it is more cost effective to conserve rather than restore. If a grassland is ranked as a high concern, heavily wooded, it will take more time and resources to restore the grassland. Grasslands, due to natural habitat succession, require efforts of conservation or maintenance to ensure adequate botanical composition for proper ecological and societal benefits.

Literature Review

Besides from the complete conversion of the landscape for human needs, woody plant encroachment is the biggest threat to this unique ecosystem. Grassland vegetation is patterned largely by climate, and locally by disturbance and land use practices (e.g., fire, herbivory, agriculture), and area geomorphology (Madden, M. Elizabeth, 1996). Historically the grasslands of the world were kept as such by natural forces, but the modern landscape is composed of different elements, and the natural maintenance of the landscape has been lost. Land has been converted for agricultural purposes, native species have been removed, people are scattered about the former prairie, and wildfires are controlled or kept to a minimum.

The encroachment of woody vegetation on the grasslands appears to be accelerating, and some say that the higher concentrations of atmospheric CO_2 may play into the advantage of woody vegetation. Atmospheric CO_2 concentrations have increased over the time period that WPE has occurred, from ~290 ppm at the beginning of the twentieth century to ~380 at the end (Briske, D. David, 2017).

Moreover, climate warming and intensifying droughts in the growing season have the potential to increase the competitive advantage of juniper over other species and may reinforce juniper dominance even during times of high drought-induced tree mortality (Twidwell *et al*. 2013). This transformation of the landscape both directly and indirectly is displacing species which rely on the ecosystem, and it is also influencing society's climate and water availability. The presence of grasslands on the landscape is valuable beyond ecology. Society also benefits from grasslands in terms of water availability, water filtration, erosion control, and atmospheric CO_2 sequestration. Unlike forests, grasslands sequester most of their carbon underground, while forests store it mostly in woody biomass and leaves (Kerlin, 2018). When a forest fire occurs, the carbon once stored in biomass, is released back into the atmosphere. On the contrary, when a prairie fire occurs, the stored carbon is largely left underground. Woody plant encroachment (WPE) into grasslands is a global phenomenon that is associated with land degradation via xerification, which replaces grasses with shrubs and bare soil patches (Schreiner-McGraw, P. Adam, et.al., 2020). Xerifcation is the process of a region drying up overtime. After a rainfall, prairie plants absorb their required moisture, filter the water, and allow the water to return to the water table relatively quickly. However, woody plants are larger and require more moisture to survive. Thus, limiting the overall amount of water which returns to the water table. Additionally, woody plants have roots which extend deeper into the soil than that of the grasses and forbs. Typically, trees have a network of fibrous lateral roots, as well as a long vertical taproot. This extension of roots allows woody plants to uptake more moisture from the water table. Over time this has the potential to influence the available freshwater for civilization not only during drought, but on a regular year-round basis. This limitation could then strain uses of ground water for things like irrigation for crops. In the Great Plains of the central United States, water resources for human and aquatic life rely primarily on surface runoff and local recharge from rangelands that are under rapid transformation to woodland by the encroachment of Eastern redcedar (redcedar; Juniperus virginiana) trees (Zou, B. Chris, et. al., 2018).

Cumulative effects of overgrazing, suppression of fire, and conversion of prairie to cropland have severely reduced and fragmented grassland habitats throughout the Great Plains

(Madden, M. Elizabeth, 1996). Several in peril, nonmigratory, avian species claim residency to the Great Plains. The Greater, Lesser, and Attwater's Prairie Chicken are all dependent on the grassland habitat found on the Great Plains. The cause for their threat is due to habitat loss through degradation, fragmentation, or conversion. The Attwater's Prairie Chicken is classified as endangered, while the other two birds are classified as vulnerable. Another subspecies, formerly found on the East Coast, the Heath Hen has gone extinct due by the same forces acting on the remaining populations. Just as the prairie grouse rely on this habitat, other species migrate to these grasslands and seasonally rely on the Great Plains. Discussing a study area on the North Dakota prairie, Madden (1996) states, "Common migratory songbirds breeding on upland areas include eastern kingbird, house wren, Sprague's pipit, common yellowthroat, a variety of grassland, sparrows (grasshopper, Baird's, Le Conte's, vesper, savannah, song, clay-colored), bobolink, western meadowlark, Brewer's blackbird, brown-headed cowbird, and American goldfinch." Some of the species that inhabit the grasslands of the Great Plains are adaptive and can live in a variety of habitats. However, others such as the Bobolink, Scissor-tailed Flycatchers, and Dickcissel, migrate solely to the grasslands of North America. Consequently, such specific species are of concern as habitat continues to be altered and lost. The presence of a tall structure on the landscape, such as a tree, degrades habitat by offering a perch for a predatory raptor. Once the diversity of flora decreases due to WPE, fauna follows. Some species, like the Northern Bobwhite, prefer intermediate habitat found on the edges of grasslands. However, the quail will move out once the habitat becomes more forested than not.

As previously discussed, there are several species that exhibit characteristics that lead to WPE. These characteristics include adaptability and varying levels of invasiveness. One of the most widely distributed conifers, the Eastern Redcedar (Figure 1) is found across much of the United States. The Eastern Redcedar has a durable wood which is naturally insect and weather resistant. This wood was valuable in the settlement of the West, where it was fashioned into canoes, cordage, fence posts, timber, baskets, and other useful tools. It still is and valuable in modern construction and wood working. The Eastern Redcedar, though technically a Juniper, is still used as wind breaks and shelter bets. The utility of the Eastern Redcedar has catalyzed its spread across its range. Like other advantageous species, if left unmanaged it will spread and transform its surroundings to better suit their needs. Though a native tree, it is considered invasive due to its ability to transform the landscape. Over time these trees will form a monoculture. Monoculture is a term most often associated with agriculture and is paired with a lack of biodiversity. A monoculture is a landscape composed of a single species. The more a landscape is of a monoculture the less biologically diverse it becomes, both flora and fauna alike. The transition from grassland to shrubland or to woodland decrease species diversity (Ratajczak et. al., 2012). In the case of the Eastern redcedar this decrease in diversity is driven by the nature of the species. As the Eastern Redcedar grows it forms a dense canopy which shades out any underlying species. Percent groundcover and type of ground cover can then be compared to the density of the redcedars (Brooks et.al., 2010).

There is a negatively correlated relationship between grassland species and redcedars. The higher quantity of cedars yields a denser canopy, and a denser a canopy dictates the suppression of desired species. The Eastern Redcedar also requires more nutrients than grasses and forbs. The intruder hinders the photosynthesis of desirables and removes much needed nutrients from the soil. The Eastern Redcedar also presents a danger to cattle in the form of toxicity if ingested. Ranchers habitually burn their ranges to mitigate WPE and the possibility of toxic exposure to their heard. Burning has proven to be an efficient way to manage a

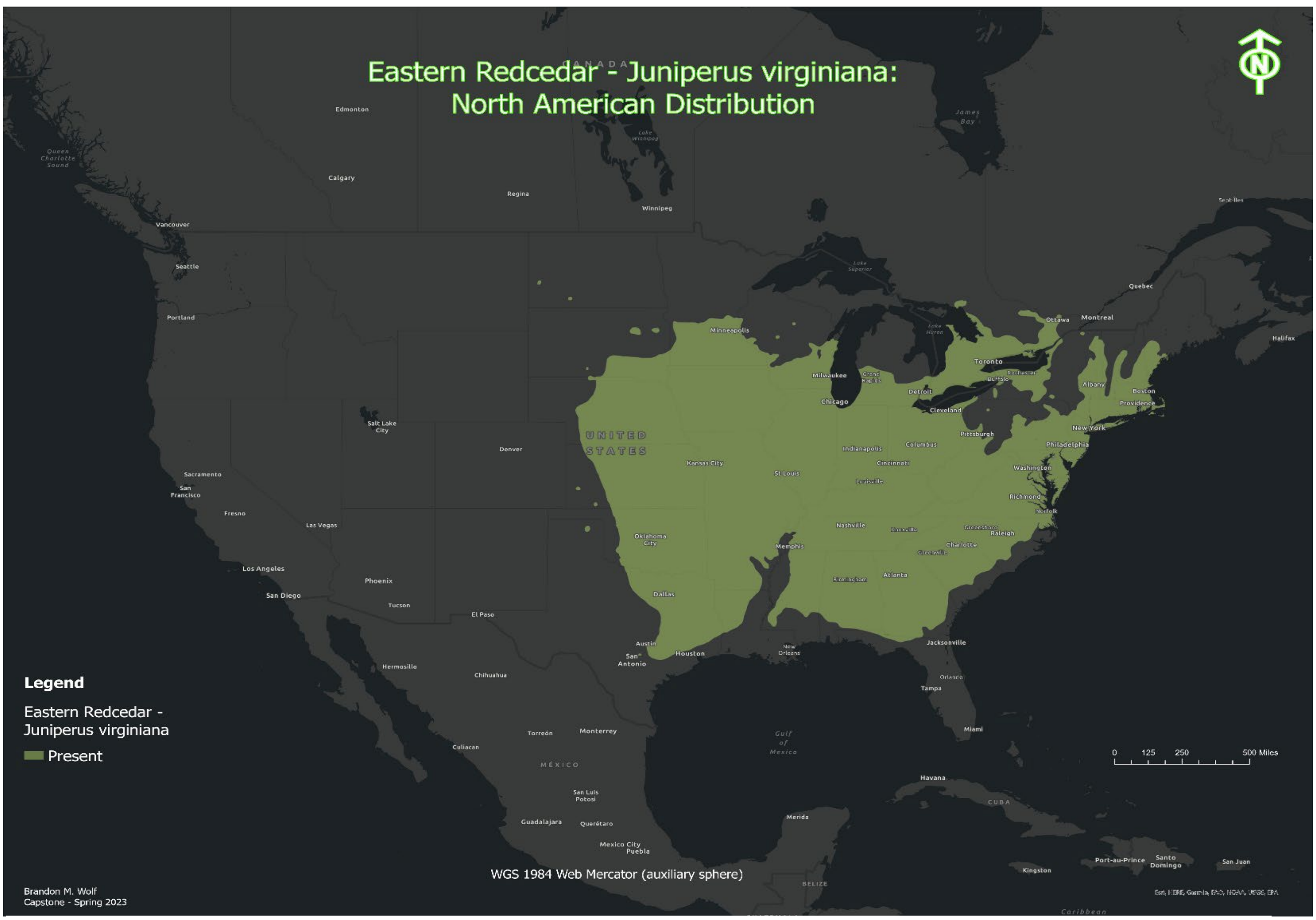
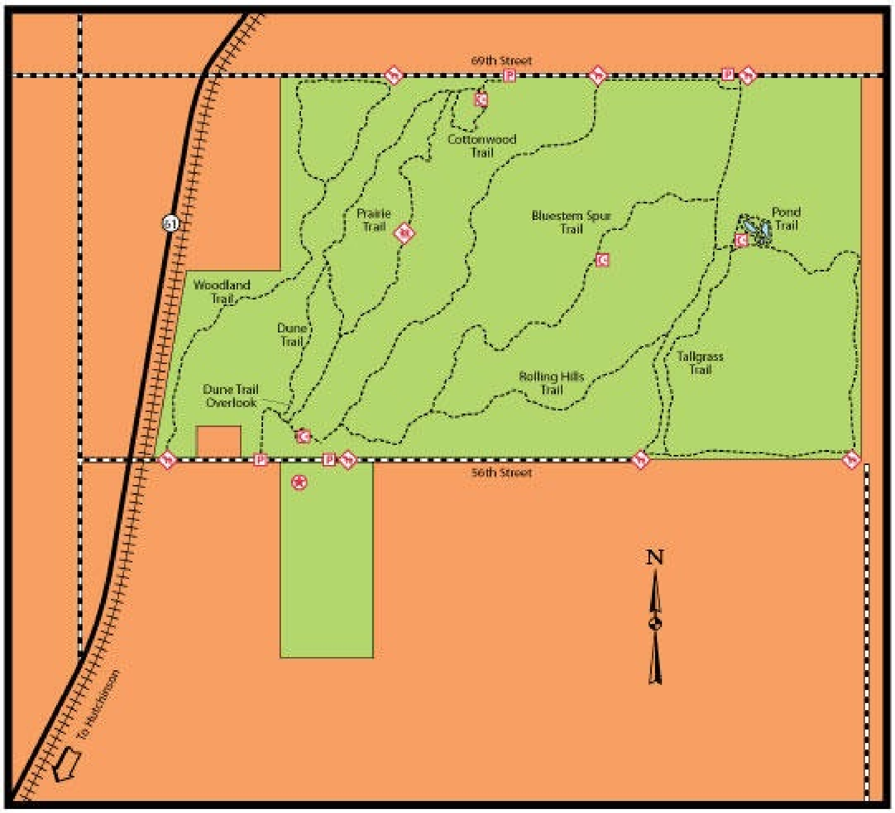


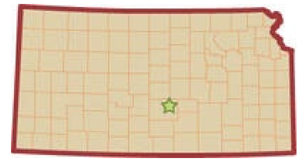
Figure 1: Native range of Eastern Redcedar- Juniperus virginiana

threatened area or an area that has already been affected by invasion (Brooks, Jared, et. al., 2010).

Depending on the extent of WPE and the scenario in which it is found, there are a variety of techniques to be used to combat WPE. When possible it is best to replicate natural forces and to introduce fire to the landscape. When this not possible, the next best practice is the physical removal of wood plant species. This can be done by haying, grazing, or termination of individual organisms by use of tools. Individual targeted organism practices include mechanical or chemical treatments of individual trees. The larger the landscape, the more practical the use of fire is, and as the treatment area narrows, the more practical it is to treat single trees with herbicide or tools. This practice of resetting the clock of habitat succession with fire makes ready nutrients for vigorous cyclical growth. The differentiation in reaction to fire, between herbaceous plants and deciduous/coniferous species is that grasses and forbs do not perish. Herbaceous species defoliate but their roots remain unharmed. Woody plants on the contrary will perish when 50% or more of the bark circumference is damaged, crown scorch of 50% or more, and/or structural roots are damaged by heat. After a burn the chemical components of a woody plant’s tissues like Nitrogen, Phosphorus, and Potassium, are returned to the soil as ash and aid in the strengthened, fertilized, growth of perennial prairie species.

Geographic Study Area – *Sandhills State Park, Hutchinson, KS*





State of Kansas

Figure 2: Sand Hills State Park. Map courtesy of Kansas Department of Wildlife and Parks

Sand Hills State Park is a 1,123-acre park located in Reno County, northeast of the town of Hutchinson, in south central Kansas. Due to the size of the state park, only the northeast quarter of the park's habitat was sampled. Roughly two-thirds of the northeast quarter was deemed suitable to be sampled. The quarter was further subdivided by a creek bed (visible in Figures 3, 4 and 5). This creek bed separated a large area, 101.5 acres, to the east which is classified as a woodland corridor and a 2.5-acre pond. The woodland and wetland corridors to the east of the creek bed were omitted from habitat sampling due to non-target species, and a lack of grasslands. The 208.5 acres to the west of the creek bed was sampled for mature cedars.

Sand Hills is comprised of grasslands, wetlands, shrublands, and woodlands. The diverse habitats found within this park make it a good candidate to study habitat succession, in particular the phenomena of WPE. There is a succession of habitat that occurs without management, and this park was examined to corelate a timeline associated with the transition from grasslands to a woody plant dominated habitat, a shrubland. Currently haying is the only management technique employed in the park, which in turn brings profit from the sale of bales of hay. Upon reaching out to the park managers it was determined that they are currently not concerned with WPE as their management techniques are successful at maintaining the park for the intended recreational and habitat purposes.

Methodology

The goal of this capstone project was to develop a timeline associated with WPE on the grasslands of Sandhills, and to create a sense of urgency in terms of conservation and/or restoration of their grasslands. The objective was to locate and record geospatial data relating to individual mature Eastern Redcedars, as their presence is correlated with an accelerated rate of WPE.

Prior to setting foot in the park for ground truthing and habitat sampling, satellite images of the park were analyzed. Google Earth images showed evidence of woodland and wetland corridors as well as grasslands. This gave insight for what to expect when collecting data, as well as illustrated a broad overview based on the assumption that tree cover is that of Eastern Redcedar. Initial thoughts were to utilize Landsat images of the region and use these to decipher variations in vegetation. For their study of WPE in Australia, Lunt, et al. (2010) “analyzed Landsat images from 14 time periods between 1972 and 2005 to document changes in the extent of national forest cover.” The Normalized Difference Vegetation Index (NDVI) provides information on the greenness of vegetation and thereby allows the observation of the status of land, especially when analyzing this index over time with time-series trend analysis (Nkonya et al., 2011). By viewing a series of satellite images of the Sandhills, over a period of years, it was hoped to determine via seasonal foliage variations the precise location of cedars as they remain foliated during winter months. However, due to the limited extent of the park this was deemed not feasible with existing, large, aerial images. By utilizing UAV technology, one could capture imagery specific to this parks extent and analyze data accordingly should the need arise. Lunt, et al. (2010) state their beginning steps began when “data were first converted from raster to vector format and clipped to the Victorian state boundary.” GIS will play a crucial role in understanding the current and future states of the landscape of Sandhills State Park. Phasha, et al. (2010) states that “GIS overlay analysis using the non-encroached category enabled the quantification and mapping of change in the preferable open grass rangeland typifying savannas.” When working with GIS for the analysis of this state park, functions relating to proximity were focal. The location of data points in relation to each other, as well as the adjacent grassland.

Photo 3 - Eastern Redcedar measuring just under 2”.

According to Lawson (2023), sexual maturity of an Eastern Redcedar is reached approximately by 10 years. At their study site in the Tennessee Valley, Lawson and his team found that mature trees, 86% of the time, measured greater than 4” DBH (diameter at breast height). Once mature a cedar will produce fleshy seed-bearing fruit yearly, with a bumper crop every 2-3 years. These cones are distributed the ingestion and excretion of wildlife. Lawson (2023) also states that 1st year seedlings often develop long fibrous root systems, often at the expense of top growth. A seedling may look inconsequential on the landscape, but it is already competing with grasses and forbs for moisture and nutrients. Although individuals do not start to reproduce until 10 years, they are impacting the ecosystem from germination. However, mature trees are far more influential in WPE, and for this they were decided to be the focal point of data collection.

Trees measuring greater than 4” were documented via Esri’s ArcGIS Quick Capture, version 1.16.294. The geospatial data was then uploaded to ArcGIS Online. The assumed presence of cedars, from the evaluation of aerial imagery, was confirmed and disproven when Sand Hills State Park was visited and data was collected. In ArcGIS Online, a pond, creek bed, and trails were digitized to accurately represent the layout of the study area. As previously stated, the significance of the creek and pond is that they represent geographic barriers which separate the grassland, woodland, and wetland corridors. The trails were digitized to document possible seed distributing traffic, and to layout points of entry for WPE mitigation efforts. With the study area further refined a layer was created for export and the geospatial data, points representing target tree species, polygons (pond and study area boundary), and lines (trails and creek bed) were exported to ArcGIS Pro. In ArcGIS Pro, the geospatial data was analyzed using

Kernel Density to display the nature of the data and their proximity to one another. The proximity of mature trees to one another is significant. The higher concentration of mature trees means a higher concentration of seeds for distribution. Which then leads to more possibility of WPE. Using the Kernel Density tool, dense clusters are represented by varying intensities of color culminating in a deep red as the highest value, densest, was recorded. Kernel Density identifies less dense areas and symbolizes them accordingly on the color intensity scale. Yellow symbolizes the least dense data. Outliers, single trees with distant neighbors, are noted as a soft yellow and are deemed statistically less significant still, but not insignificant. By using this tool, we have laid out a clear conservation strategy based on priority ranking. Given time, all target species recorded should find resolution by termination to mitigate WPE on the grasslands of Sand Hills. Recommended termination for Eastern Redcedar, under park conditions, is mechanical.

Results

The primary objective of this research project was to use GIS to identify point source area(s) of WPE within the study area of Sand Hills State Park, identify future WPE concerns, and correlate a timeline with habitat degradation. Data points were comprised of 192 records representing mature cedars capable of carrying out WPE. To understand how these data points translate into the concept of WPE, and to develop a management plan to combat it, various geospatial analysis tools were used to create several visual aids. All data points represent individual mature trees capable of contributing to WPE. The closer these trees are to one another; the more seeds are available for distribution. Therefore, the higher density of trees yields higher seeds produced, which in turn accelerates WPE. There is a positively correlating relationship (negatively in terms of their impact on the grassland) between the proximity of trees to one another and the potential for WPE. It is not only important to understand where the trees are on the landscape, but how close they are to one another.

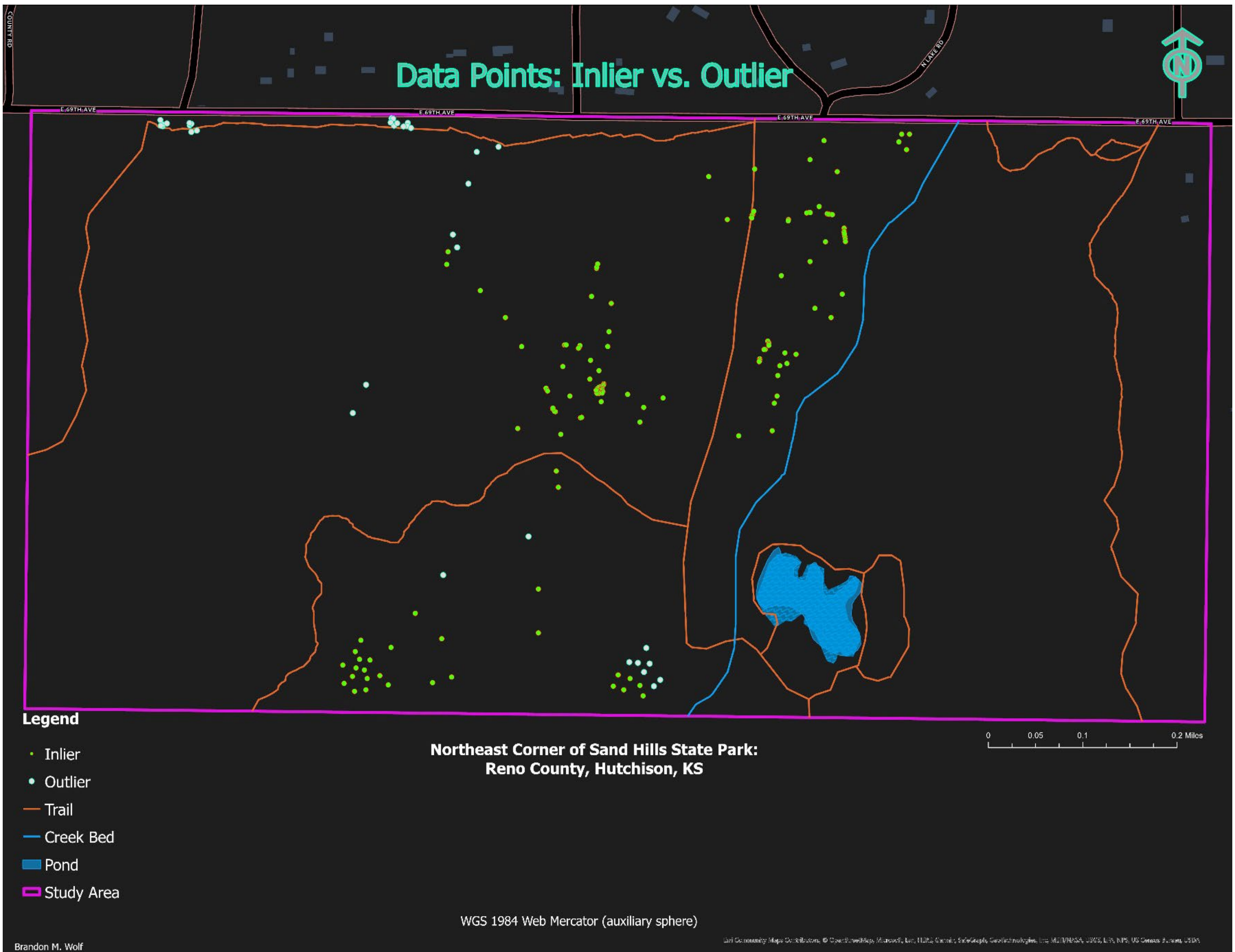


Figure 3: Statistical outliers and inliers of recorded data.

By using the spatial outlier detection tool in ArcGIS Pro, the 192 data points were separated into two categories. The software examines each data point's proximal relationship to its neighbors and determines relevancy to the data set as a whole. As seen in Figure 3, data are either spatially relevant, an inlying data point, or they are an outlier, spatially non-relevant data points. A data point which is categorized as non-relevant indicates that its relevancy, to conservation priority, is low when compared to the inlying data points which are proximal to

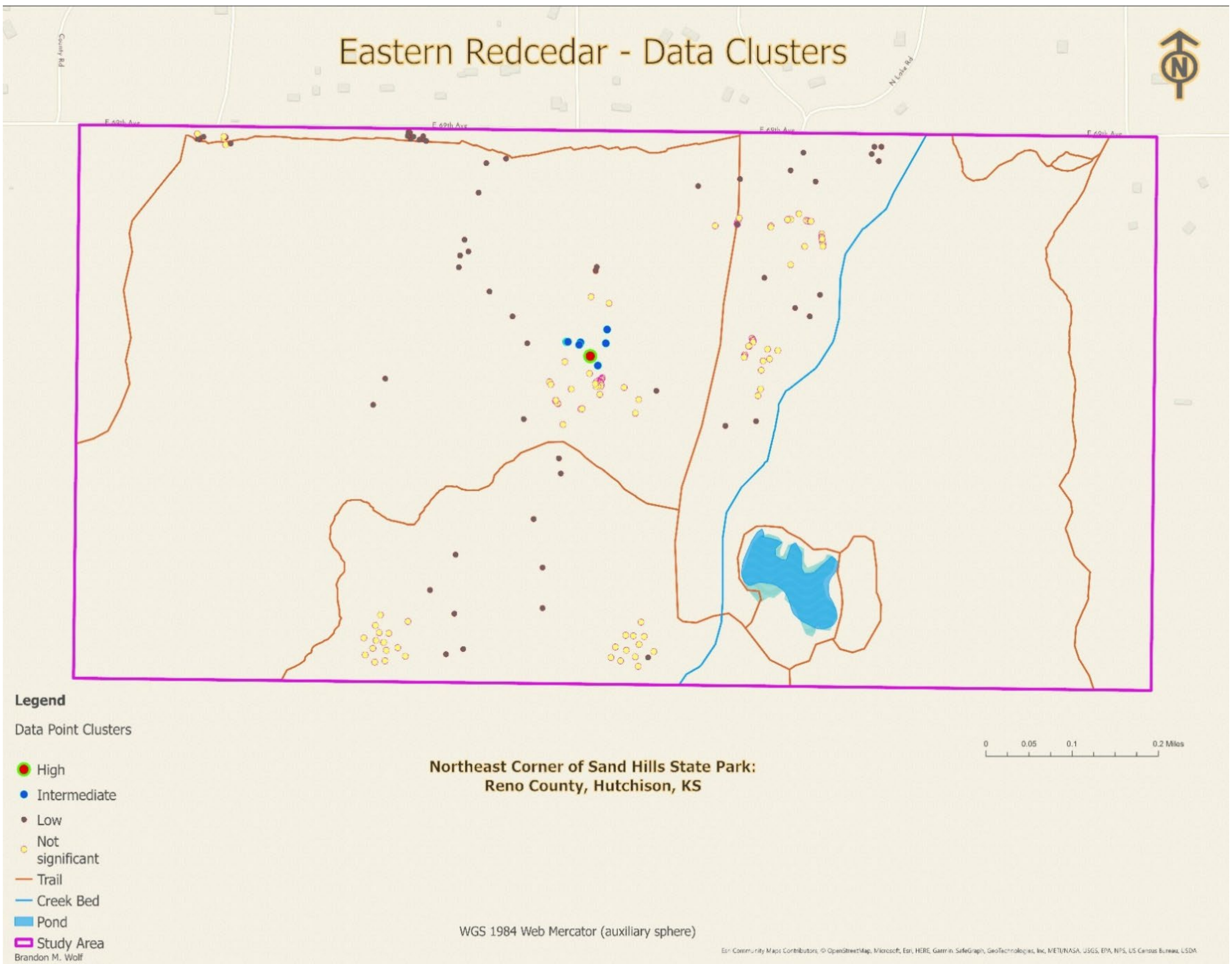


Figure 4: Data Clusters indicating areas of high density of data.

other inlying data points. These inliers indicate probable WPE and should be ranked as priority for conservation efforts. Additional analysis (Figure 4) will further rank these data points for conservation priority. A low priority data point is not omitted from the results since it is not considered unimportant. Rather they are less important for WPE mitigation efforts, at the present state. Near the center of Figure 3, a highly clustered area of inliers, a red outlined green dot, can be seen. This area appears to be the epicenter of WPE in the northeast quarter of the park.

The two clusters of outliers, cyan outlined large white dots, in the northwest area of the study area are classified as such due to the lack of proximal neighbors. For this, the data are considered outliers. However, they are clustered significantly, and this leads to elevated risks of WPE. Due to possible discrepancies of data and/or its interpretation, it is advisable to use several methods to classify and analyze data. By referencing Figure 5, we can see that the outliers in the northwest exhibit a density value of around 2 at the center of the cluster. An outlier with a density value less than one would be deemed as not immediate concern. Therefore, relying on only one method to analyze data may lead to inaccurate WPE representation, and consequently skew mitigation efforts. Another output of the spatial relationship between data points is seen in Figure 4. Discrepancies are seen between Figures 3 and 4 when analyzing outliers (Figure 3) and data deemed “not significant” in Figure 4. Terminology would have these two synonymous, but as previously discussed an outlier in Figure 3 is less significant in terms of WPE mitigation not insignificant. Discrepancies aside, it is clear where data was recorded at its highest density. In Figure 3, this is apparent quantitatively as individual data points can be seen forming clusters. In Figure 4 this is apparent qualitatively with symbology representing high and intermediate clusters of data.

Figure 5 gives the most accurate and expected analysis of the collected data in terms of their proximity to one another and their potential for WPE. A point source of Eastern Redcedar production is seen in all figures. This will be the point of WPE reversal initiation. The highest

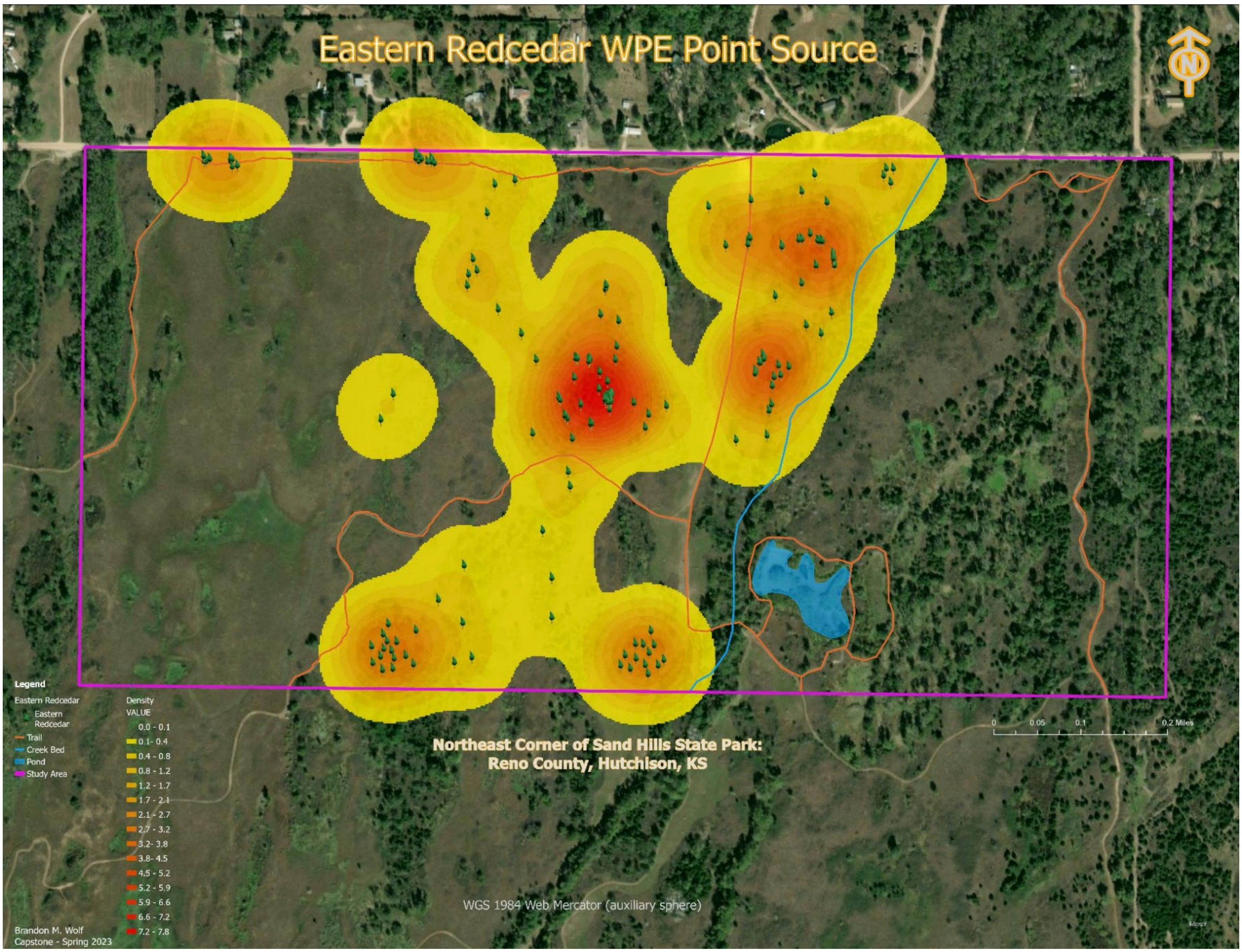


Figure 5: Kernel Density tool clearly illustrates the relationship between data, and a point source for Eastern Redcedar WPE

density value of 7.8 is recorded with the deepest red. To the northeast of the epicenter is also highly dense and reporting density values between 4 and 5. To the left of the WPE point source is a representation of how two data points interact. A single cedar represents a minimal level of WPE with a density value of .1 and it covers an area of about 5 acres. When a second data point is entered nearby, the acreage of WPE impact is minimally affected, but the overlapping area between the two data points jumps to a level of .4 density value. The more data input in the same space compounds the density values exponentially, and the potential for WPE. An important characteristic of data delivered from the Kernel Density tool is the buffered footprint displayed by each unique data point. In areas near the border of the study area you can see how WPE can spread according to the concentration of trees. Along the north and south boundaries a few clusters of data can be seen, but they are not all reporting equal density values. They are relatively equal distances from the boundaries, but the clusters which are most dense appear to have the ability to encourage WPE to bleed to adjacent properties.

By cross referencing Google Earth imagery and utilizing the Ruler tool, set for measuring the area of a given circle, it was established that a single data point creates a 5-acre footprint from which WPE can leach. It is important to note that the presence of an additional tree nearby increases the rate of WPE, but not necessarily the physical reach (distance) of WPE. Since we know the reach of WPE yields approximately a 5-acre footprint, and it will fluctuate little, it can be assumed that all clusters of data, concentrated or not, will amount to roughly 85 acres that are susceptible to accelerated WPE due to the presence of mature Eastern Redcedar in the northeast quarter of Sand Hills State Park.

The process which allowed for the analysis of Eastern Redcedars data follows the flowchart seen in Figure 6. The amount of data analyzed guaranteed an ample amount of varying geospatial data points, but due to variances in proximity detection several tools were used within ArcGIS Pro.

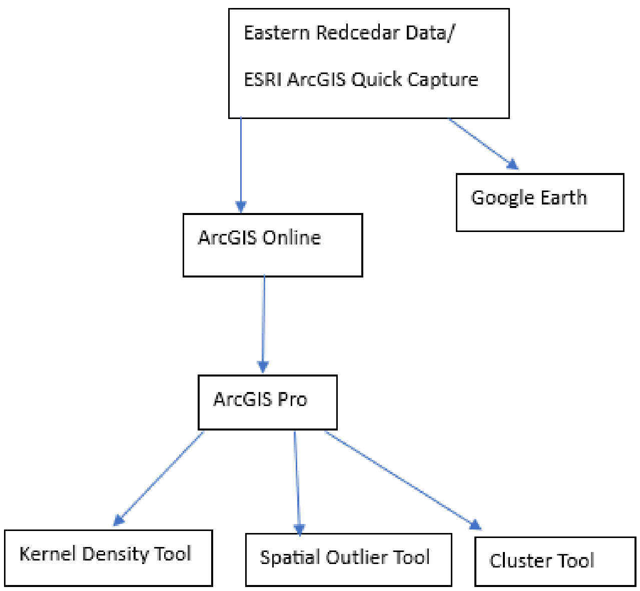


Figure 6 – Simple flowchart to illustrate how data was processed for analysis.

CONCLUSION

The outcomes of this research project have delivered very important take aways for Sand Hills State Park in Hutchinson, KS. The most important take away is the point source for WPE, delivered in Figure 5. By glancing at the map from the Kernel Density analysis (Figure 5) it can be seen where seed production and distribution of Eastern Redcedar is the highest. This point source is further made evident in Figure 4. All maps display a trail system which can be used to access desired points for WPE mitigation efforts.

All data points represent mature cedars exhibiting varying levels of WPE potential. All cedars should be removed to safeguard grassland health. To ensure areas of highest concern are controlled, the Kernel Density analysis should be used as a guide to address the epicenter for WPE by Eastern Redcedar. Once the point source is eliminated, other less dense areas should be focused on until all mature cedars are eradicated from the study area. By removing about 20 trees a day, all 192 recorded trees can be felled in under 10 days. This equates to a feasible 2.5 trees an hour in an 8-hour workday. Cedars under 4” were omitted from data collection as they were not contributing to WPE at the time of data collection. Saplings will mature to produce fruit and disperse the next WPE driving generation of trees. Consequently, saplings under 4” DBH should be terminated once the high and low priority areas are extinguished. Removal of saplings is far less intensive than mature trees. A high quantity of saplings can be removed easily and quickly by mechanical measures, but due to the scope of this project a timeline for their removal was not investigated. A rough estimation suggests an additional 3 days for sapling removal. Full cedar removal in the northeast corner of Sand Hills State Park can be accomplished in just under 2 weeks.

Concluding, the current management plan, to maintain the grasslands via haying, will continue to effectively combat WPE. In the event haying of Sand Hills State Park should end, the grasslands have the potential to be fully degraded due to WPE, from Eastern Redcedar, in 5 years. Without removing the mature Eastern Redcedars highlighted with this GIS analysis, once mechanical maintenance ends the seedlings are free to grow and outcompete grass and forbs.

According to the Kansas Forest Service (2022), it [Eastern Redcedar] grows from 1 to 1 ½ feet per year. At 5 years old, the saplings are not yet producing fruit, but they are at least 5' tall and are out competing grass and forbs, degrading habitat for WPE intolerant wildlife. If mature cedars are removed, and if the haying fails to persist, the risk of WPE is theoretically nonexistent due to a lack of offspring producing trees on the property. However, in practice future WPE is reliant upon adjacent properties and their management, or lack thereof Eastern Redcedar.

WPE, via habitat succession, is an ongoing natural cycle. Many woody species are responsible for this succession, but some more apparently than others. The Eastern Redcedar has significantly skewed this balance due to their invasive nature. It is important for Sand Hills to remove the existing WPE catalyzing cedars, and to continue to maintain and monitor their grasslands. Though Sand Hills is relatively small, the same analysis techniques and knowledge are applicable on a larger scale. With proper management, formerly fragmented and degraded grasslands can be restored and reinvigorate ecological and societal benefits for the modern world.

FURTHER RESEARCH

Time constraints and personnel limited the scope of work for this research project. Of the 1,123 acres of state park, only 310 acres were sampled for habitat analysis. In the northeastern quarter of Sand Hill's State Park Eastern Redcedar is the primary species degrading the grasslands. In the southwest quarter of the park Black Locust is heavily present.

Black locust has the potential to be equally as invasive, especially if haying fails to remain the predominant means of WPE mitigation. As conditions remain dry in south central Kansas, WPE could accelerate in the future, be led by another species, and/or require additional management strategies. The strategy carried out to monitor the state of the grasslands in the northeastern quarter of the park could be altered to include additional species. Supplemental research is needed to further understand and protect the grasslands of Sand Hills State Park if the park is to remain relevant and beneficial to both ecology and society.

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