# COMPARATIVE STUDY OF THE SPATIAL ORGANIZATION AND ZOOGEOMORPHIC EFFECTS OF BLACK-TAILED PRAIRIE DOGS

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COMPARATIVE STUDY OF THE SPATIAL ORGANIZATION AND

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PRAIRIE DOGS

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## DEDICATION

I would like to dedicate this thesis to those individuals whom strive to do what they love.

It is possible…it can be painful at times…but it is worth it.

## ACKNOWLEDGEMENTS

I would like to thank everyone for the support that they have provided throughout my graduate career. Many of these individuals pushed me to become the person that I have always wanted to be. Graduate school is a journey of self-discovery that is irreplaceable. Lessons in life, love, and research were experienced in response to adversity as well as encouragement. Most of all, I would like to thank my husband, Jamie, for his undying devotion to my sanity. He helped me to escape pure chaos through laughter and little moments that others would see as trivial.

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**ABSTRACT**

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Site specific burrow densities of black-tailed prairie dog towns were estimated via point counting on aerial imagery for the following three sites managed by the National Park Service (NPS): Devil's Tower National Monument (DTNM), Theodore Roosevelt National Park (TRNP), and Wind Cave National Park (WCNP). These average burrow densities were 14, 7, and 5 burrows per 30 $m^2$ respectively. The burrow densities in conjunction with burrow dimensions from Sheets et al. 1971 were used to quantify the volume of sediment excavated by black-tailed prairie dogs. Observations reveal that WCNP contained the largest, most stable towns. Consequently, WCNP had the largest volume of excavated sediment, which was 163,379.68 $m^3$. TRNP contained the greatest number of towns and an average burrow density greater than WCNP. Town size and

percentage within TRNP resulted in excavated sediment estimates approximately half the volume of the WCNP estimates.  Estimates of excavated sediment within DTNM were limited by park size and town percentage.  Slight variations in habitat characteristics, epizootic disease history, and management objectives within WCNP provided the most favorable conditions for prairie dog town persistence.

As compared to excavated sediment estimates by Butler 2006, the estimates of this study are up to five times larger.  Excavated sediment estimates are influenced by burrow density.  Discrepancies in burrow density may be potentially caused by differences in town area calculations, changes in town growth and population stability, and/or an overestimate of burrow density because of the methodology or data used in this study.  Based on the historic records of town area in Wind Cave National Park, it was found that town area calculations of this study were concurrent with town growth projections of Dalsted et al. 1981.  For this reason, town area calculations are believed to be sound.  Discrepancies in burrow density are likely attributed to mistaken counts of inactive prairie dog burrows, natural increases in burrow density via town growth and stability associated with improved management techniques, and/or the use of aerial imagery and observation extents which were poorly suited for differentiation between burrows and bare ground.

Although there are discrepancies in burrow density estimates and consequently sediment estimates, the implementation of different techniques and lessons learned from this project can only move the field of zoogeomorphology forward.  Temporal information regarding burrow longevity and excavation rates can be used with estimates of excavated sediment to quantify the zoogeomorphic effects of black-tailed prairie dogs in past and present environments.  Management of keystone species within the Great Plains will be more comprehensive as we better define the role of black-tailed prairie dogs in grassland habitat.

*prairie dog, remote sensing, and zoogeomorphology*

## CHAPTER I

## INTRODUCTION

Zoogeomorphology is defined as "the study of the geomorphic effects of animals (Butler 1992)." As fossorial mammals, black-tailed prairie dogs exert a zoogeomorphic effect on grassland habitat. Burrowing activities of prairie dogs serve to move, mix, and sort sediment. Burrow systems within prairie dog towns influence surface and subsurface drainage, microclimate, and sediment load. Butler addressed the indirect impacts of prairie dogs on basin hydrology and sediment load using a modified table from Hall and Lamont (2003). He explained that burrowing activity leads to hollows underground which can decrease slope stability, increase water infiltration, change pedogenesis, and alter the outflow chemistry of water within drainage basins and lake catchments. Butler associated the direct removal of sediment by prairie dogs with vegetation disruption, downslope sediment transport and dispersal, and mass movements (Hall and Lamont 2003; Butler 2006). Qualitative measures have been addressed and provide valuable insight into the potential effects and mechanisms that cause the zoogeomorphic effects of prairie dogs. However, without quantitative measures, the magnitude of such effects is unknown.

In his book, *Zoogeomorphology: Animals as Geomorphic Agents*, Butler affirmed the importance of quantifying the zoogeomorphic effects of prairie dogs in terms of bulk density of soil, surface runoff, erosion, and infiltration capacity (1995). Butler also compared the burrowing efficiency and geographic range of prairie dogs to the North American beaver and called for quantitative research into the topic (1995). Using sediment estimations and burrow densities from Whicker and Detling, Butler estimated that anywhere from 5,000 to 67,500 kg of soil was mixed per 10,000m$^2$ by prairie dogs prior to European contact (Whicker and Detling 1988; Butler 2006). In the context of the dramatically reduced range of the prairie dog, Butler stated that "an enormous zoogeomorphic influence on the hydrology of the Great Plains region was removed by the efforts to eradicate prairie dogs (2006)." Prairie-dog-induced zoogeomorphic effects should be quantified at a macroscale to determine the impact of prairie dogs in past and present environments. Considering that prairie dog towns once spanned over 1 million km$^2$ of land within the Great Plains and keeping in mind that a single prairie dog town can contain millions of individuals, the potential zoogeomorphic effects of prairie dogs is apparent (Davis 1974 in Wuerthner 1997; Sidle et al. 2001).

This study will contribute site-specific estimates of excavated sediment by black-tailed prairie dogs across three study sites within the geographic range of the species and identify possible causes for differences in the estimates. These estimates will be compared to the sediment extrapolation by Butler mentioned previously. In addition to calculating burrow density, the study will recognize sites with physical properties that make it more vulnerable to the zoogeomorphic effects of prairie dogs. This information may encourage further research into the management of prairie dog populations and provide insight into potential landscape changes. The findings of this study may also reveal geomorphological and biological data which validate past research on the habitat preferences of prairie dogs. Variability in habitat and management style of the three study sites will also be explored.

In order to comprehensively manage prairie dog populations, it is imperative to understand the spatial organization and influence of the species. As public perception changes and grasslands within the Great Plains continue to be altered by agricultural land conversion and urban influences, it is paramount to explore the impact of black-tailed prairie dogs. Black-tailed prairie dogs are keystone species to the grassland habitat in which they reside. The vitality of the grasslands is influenced by the stability of black-tailed prairie dog populations. Through selective foraging prairie dogs alter the diversity, height, extent, and nutritional value of grasses (Hansen and Gold 1977; Coppock et al. 1983; Agnew et al. 1986; Whicker and Detling 1988; Fahenstock and Detling 2002). Other herbivores such as elk, pronghorn, and bison benefit from the grassland alterations initiated by prairie dogs (Hoogland 2006). The shift from a rodent ideology to keystone status has changed and will continue to change public perception of the species. Quantitative research into the zoogeomorphic effects of black-tailed prairie dogs on grassland habitat will serve to further describe the role of the species and ultimately provide information relevant to grassland management.

**CHAPTER II**

LITERATURE REVIEW

## 2.1 Natural History of Prairie Dogs:

### *2.1.1 Scientific Nomenclature and Geographic Range:*

Prairie dogs belong to the ground squirrel family, Sciuridae, and are comprised of five species which are separated by geographic range. The five species of prairie dog include: black-tailed (*Cynomys ludovicianus*), Mexican (*C. mexicanus*), Gunnison's (*C. gunnisoni*), white-tailed (*C. luecurus*), and Utah (*C. parvidens*) (Hoogland 1996). In the past black-tailed prairie dogs and Mexican prairie dogs were grouped into the subgenera *Cynomys* because they live at elevations ranging from 1,300 to 2,000 masl, share similar alarm calls, and do not hibernate in the winter months (Hollister 1916, Clark et al. 1971, and Pizzimenti 1975 in Hoogland 1996).

Black-tailed prairie dogs ingest short perennial grasses and are usually found on short and mid-grass plains (Koford 1958; Wuerthner 1997). Prior to European settlement, black-tailed prairie dog towns spanned over 1 million $km^2$ of land within the Great Plains (Sidle et al. 2001). Historical records of Meriwether Lewis describe prairie dog populations as infinite (Davis 1974 in Wuerthner 1997). Prairie dogs, *Cynomys ludovicianus*, were found continuously from Alberta, Canada, to Northern Mexico (Koford 1958; Wuerthner 1997). The largest colony was recorded by the U.S. Biological Survey in the Texas Panhandle; the colony was approximately 40,234 $km^2$ and contained over 400 million prairie dogs (Davis 1974 in Wuerthner 1997). The geographic range of black-tailed prairie dogs has been fragmented, and the population has decreased 98 to 99 percent as a result of agricultural and urban conversion of grasslands, sylvatic plague outbreaks, and eradication efforts (Miller et al. 1994; NPS 2008b).

### *2.1.2 Group Organization and Dynamics:*

One of the most notable behaviors of black-tailed prairie dogs is that they live in towns or colonies. The burrowing rodents are diurnal and forage from dawn until dusk. As compared to other prairie dog species, black-tailed prairie dogs live in larger, more densely populated colonies (Hoogland 1996). Although they do not hibernate, black-tailed prairie dogs experience facultative torpor as a result of environmental changes such as rapid temperature decreases (Lehmer et al. 2001). Prairie dog colonies are subdivided into family groups called coteries. Coteries are territorial harem-polygynous units that can contain up to 40 members and can cover approximately 3,300 $m^2$. Coteries typically contain one male, two or three adult females, and several pups. To avoid extreme inbreeding with their offspring, males leave their natal coterie before breeding and leave their breeding coterie before the offspring reach sexual maturation. Females reside in the same coterie for their entire lives (Hoogland 1995). Coloniality has advantages and disadvantages. By living in large groups prairie dogs can more easily avoid predation and rely on coterie members for grooming and burrow maintenance.

*2.1.3 Keystone Species:*

Prairie dogs influence the height, cover, diversity, and nitrogen content of vegetation within their towns (Hansen and Gold 1977; Coppock et al. 1983; Agnew et al. 1986; Whicker and Detling 1988; Fahenstock and Detling 2002). Selective foraging creates heterogeneous vegetation patches, which contain a greater diversity of annual and perennial plants (Koford 1958; Bonham and Lerwick 1976; Whicker and Detling 1988). In an effort to improve visibility of predators, prairie dogs clip vegetation. Clipping decreases canopy height and increases the dominance of dwarf morph vegetation (Coppock et al. 1983). Repeated defoliation of plants, excrement deposits, and changes in microclimate via denudation have been cited as explanations for the increased nitrogen content of plants within prairie dog towns (Whicker and Detling 1988). Fahnestock and Detling found that net nitrogen mineralization was four times larger on colonies, and aboveground biomass was twice as large outside of the colonies (2002).

Upon removing prairie dogs from grassland habitat, annual forb and leaf litter increases, and the composition of perennial grasses changes (Ryerson and Parmenter 2001). Although prairie dogs consume many grassland plants, other large grassland herbivores such as elk, pronghorn, and bison benefit from the prairie-dog-induced alteration of the grassland plant species (Hoogland 2006).

## 2.2 Burrow Dimensions, Description, and Organization:

Prairie dogs dig burrows for shelter against predators and weather. Entrance burrows are 10 to 13 cm in diameter and narrow with increasing depth. The length of the entrance burrow ranges from two to five meters. Once the entrance burrow branches, the diameter expands to 20 to 25 cm and may extend for five to 33 m in length (Sheets et al. 1971). Three types of entrance burrows have been described in the literature. The first type includes burrows that lack an entrance mound. This type of burrow is found at the periphery of the town and is used for predator evasion and respite from the heat of the day (Hoogland 1995; King 1955 in Hoogland 1996). Dome craters are the second type of entrance burrow. These burrows are capped with 0.2 to 0.3 meters of dirt that can reach a diameter of three meters. The third type of burrow is known as a rim crater; rim craters can reach 1 meter in height and 1.5 meters in diameter. After heavy rains, prairie dogs have been observed reconstructing craters by digging, pushing, scraping, and piling soil with their noses and legs (King 1955 and 1984 in Hoogland 1996).

Of the five species of prairie dogs, rim craters are unique to black-tailed and Mexican prairie dogs (Hoogland 1995; King 1955, Ceballos and Wilson 1985, and Trevino-Villarreal 1990 found in Hoogland 1996). The dirt mounds associated with dome and rim craters protect against flooding, improve burrow ventilation, and provide an elevated platform from which predators can be found (Vogel et al. 1973 in Hoogland 1996). The microclimate of the burrows maintains a relatively constant temperature and is damp (Koford 1958). The burrows lead to chambers that may serve the following purposes: nursing chambers, food caches, communal sleeping chambers, escape chambers, and excrement chambers (Koford 1958; Sheets et al. 1971; Hoogland 1996). Nursing chambers, which are elliptical in shape, are 30 to 46 cm wide and 25 cm deep; the chambers are often lined with dry grass and have as many as six entrances (Sheets et al. 1971).

Previous research suggests that burrow density ranges from 10 to 250 burrows per 10,000 $m^2$ (Campbell and Clark 1981; Hoogland 1981; Martin and Schroeder 1978 and Martin and Schroeder 1980 in Hoogland 1996). Whicker and Detling listed densities from 50 to 300 burrows per 10,000 $m^2$ (1988). Observations by Sheets et al. revealed that burrow patterns are not uniformly distributed across towns (1971). The population density varies from 10 to 35 individuals per 10,000 $m^2$ (Hoogland 1981). Burrow density and number do not predict colony size or colony density of black-tailed prairie dogs (Hoogland 1995). Prairie dogs plug their burrows to protect against predators, protect their young, defend coterie territory, and avoid unfavorable objects such as black-footed ferret scat (Sheets et al. 1971; King 1955, Henderson et al. 1969, Clark et al. 1984, and Halpin 1983 in Hoogland 1996). Coterie burrow entrances do not connect and coterie territories are approximately 3,333 $m^2$ on average (Hoogland 1995).

In terms of quantitative zoogeomorphic data, Koford estimated the amount of sediment that prairie dogs excavated using the burrow dimensions listed in articles by Merriam, Osgood, and Wilcomb (Koford 1958; Merriam 1902, Osgood no date, and Wilcomb 1954 in Koford 1958). He calculated that a town with 25 burrows would move approximately 3,629 kg of soil or 145 kg of soil per burrow (Koford 1958). However, Whicker and Detling estimated that 200 to 225 kg of soil is mixed per burrow; they referenced burrow dimensions from Sheets et al. and found that the majority of the excavated soil is used to create soil mounds at burrow entrances (Sheets et al. 1971; Whicker and Detling 1988). Koford also attempted to estimate the volume of water retained in the burrows after a flooding event (1958). In 1938, Cole was one of the first individuals to count prairie dog burrows using aerial photography. He counted approximately 36 burrows in the Norbeck Dam prairie dog town in Wind Cave National Park (Koford 1958).

## 2.3 Using Aerial Photography and Digital Data for Prairie Dog Research:

Field work is a viable methodology for mapping and describing towns, but it is time-intensive and confined to small geographic areas. As aerial photographs and digital data improve in resolution and prevalence, techniques to predict the geographic extent and habitat preferences of animals also improve. These techniques allow researchers to better analyze spatial aspects of prairie dog towns at a macroscale, which makes data processing more time efficient.

Using aerial photography and digital data, researchers have developed new methodologies to delineate and monitor prairie dog towns. For example, Luse and Wilds (1992) used satellite imagery at a scale of 1:24,000 to map prairie dog towns for the purpose of determining how the towns affect animal stocking rates. In 1998, Severson and Plumb discounted aerial videography as a viable method for estimating prairie dog populations. Infrared photography was rejected as a method to count burrows because of its poor resolution. Because of the quality of videography and photography, Severson and Plumb favored visual counts and mark-recapture techniques for population estimation (1998). Mann et al. used land cover, soil, geology, and slope information to predict the location of rare calcareous ecosystems (1999).

Sidle et al. provided the first quantitative assessment of the extent of black-tailed prairie dogs across the Great Plains using an aerial transect method (2001). After flying several transects by aircraft, they determined that active prairie dog colonies covered

2,377.8 $km^2$ ±186.4 $km^2$ and that inactive colonies covered 560.4 ±89.2 $km^2$ (2001). This groundbreaking research made viewing prairie dog towns from a macroscale more manageable. White et al. (2005) used the methodology of Sidle et al. (2001) to map colonies in Colorado by county. In 2002, research by Sidle et al. found that Ikonos satellite imagery with a resolution of 1 m was just as adequate in monitoring prairie dog town growth as large scale aerial photography. Odell et al. (2008) conducted aerial transect surveys in conjunction with ground truthing methods to predict the length of prairie dog colonies. They found that the aerial transect method predicted the length of colonies with 96 percent accuracy, but overestimated the proportion of active colonies.

Anderson et al. (2004) applied land use maps and information about black-tailed prairie dogs to predict the risk that certain military activities would pose to the species. Assal and Lockwood tested three remote sensing techniques at a macroscale to determine the best technique for prairie dog town detection (2007). The three methods tested included raw satellite imagery, enhanced satellite imagery, and aerial reconnaissance. The methods yielded accuracies of 64.4, 69.2, and 39.9 percent, respectively. It was concluded that enhanced satellite imagery was the best method to remotely sense prairie dog towns at a macroscale, because it was accurate, cost-effective, repeatable, and objective. Layers used to enhance the imagery included information about slope, soil type, land cover, and the Normalized Difference Vegetation Index. The analysis of habitat characteristics found that the most suitable habitat for prairie dogs was located in areas with 0 to 4.5 percent slope, land use classifications of mixed-grass/dry-land crop, with deep, well-drained clay loams, sand loams, and loams (Assal and Lockwood 2007).

Research on burrow longevity is pertinent to the detection and interpretation of burrows in aerial imagery. According to research by Cid et al. in Wind Cave National Park, the colonization of habitat by prairie dogs and bison can be reversed in two years after the exclusion of the species (1991). However, Cid et al. mentioned that the rate of grassland recovery is dependent on the following variables: initial plant composition, intensity of grazing, grassland type, and weather (1991). During research on burrowing owl nests, Green and Anthony discovered that soil texture significantly influences burrow longevity in the Columbia Basin of Oregon. Burrows excavated in more sandy soils fill more rapidly than those in loamy soils. With a sample size of 85 burrowing owl nests, 46 percent of burrows in sandy soils were filled with sediment by the next nesting season. With a sample size of 13 burrowing owl nests, zero percent of burrows excavated in silty-loam soils were silted in by the next nesting season (Green and Anthony 1989). According to Koford, prairie dogs prefer to dig in loamy soils (1958); so by their very nature, the majority of prairie dog burrows are relatively resistant to filling over the course of one year. In 1982, Butts and Lewis noted that the majority of burrows were unidentifiable within three years after prairie dog disappearance in Oklahoma. Within three years, the burrows were filled with soil, debris, and grasses (Butts and Lewis 1982).

In terms of town persistence, research by Lomolino et al. discovered that in all cases across a 30 year span, larger towns have the highest persistence (2003). Prior to a plague outbreak in the 1990s, town persistence in Oklahoma favored large towns with adjacent towns near by. However from 1989 to 1997, large isolated towns had greater persistence. Protection from the plague was listed a potential explanation for shifts in persistence from adjacent towns to isolated towns (Lomolino et al. 2003).

# CHAPTER III

## METHODOLOGY

### 3.1 Site Selection:

The study sites selected include: Devil's Tower National Monument (Wyoming), Theodore Roosevelt National Park (North Dakota), and Wind Cave National Park (South Dakota) (Figure 1). Study sites were selected based on prairie dog presence and park status. Only sites managed by the National Park Service (NPS) were considered. Prairie dog towns on private land may have been exposed to poisoning, hunting, and/or other eradication efforts. National preserves, national forests, and state lands allow prairie dog hunting (National Atlas of the United States 2008). Sites managed by the National Park Service seek to preserve the natural habitat of prairie dogs. Within these parks, the spatial patterns of prairie dog towns are as protected from human influence as possible. By including these sites in the study, it can be reasonably assumed that the spatial patterns created are free from human interference.

Although the sites are managed by the same federal agency, they vary in geographic location, town growth, exposure to epizootic diseases, and management objectives. Devil's Tower National Monument (DTNM) is located in Crook County, Wyoming and is approximately 140 km northwest of Wind Cave National Park (WCNP). Both DTNM and WCNP occur in the central portion of the black-tailed prairie dog's geographic range. The towns at Theodore Roosevelt National Park (TRNP) occur near the northernmost portion of the geographic range of black-tailed prairie dogs. TRNP is located 360 km north of WCNP and is comprised of two distinct park units. The North Unit is located in McKenzie County, North Dakota, and the South Unit is located along Interstate 94 in Billings County, North Dakota; the Little Missouri River bisects both units of the park. The prairie dog town in Devil's Tower National Monument (DTNM) is relatively static in town growth; along the southwest portion of the town the National Park Service installed a containment fence. Wind Cave National Park has a long history of prairie dog research and is surrounded by natural areas (Koford 1958; NPS 2008a). From 1982 to 1999, WCNP has had nine to 10 very large, stable towns that have only changed moderately in size (Figure 2; NPS 2009a). According to Hoogland, several prairie dog towns have maintained their size and shape for fourteen years (1995). WCNP, is the only site of the three that did not experience the severity of the sylvatic plague. Wind Cave National Park is located outside of the modern range of the plague and avoided population declines associated with plague outbreaks (Cully and Williams 2001).

Management objectives regarding black-tailed prairie dogs vary across the three sites. In Devil's Tower National Monument, prairie dog towns are managed to the extent that they provide incentives for visitation. The general management plan of DTNM, which was drafted in late 2001, lists a preferred alternative which addressed widening pull offs near prairie dog towns and included the prairie dog town trail as part of the pedestrian zone for better viewing (USDI, NPS 2001). In TRNP, current management practices tend to favor endangered species as well as the elk population. Prairie dogs are managed to the extent that they use and improve habitat in the park. Very little mention of prairie dog specific management decisions can be found within the 1986 general management plan (USDI, NPS 1986). Of the three study sites, Wind Cave National Park has the most comprehensive management plan for black-tailed prairie dogs. In 1982, the prairie dog management plan was drafted; it dedicated approximately three square kilometers to prairie dog towns within the park (USDI, NPS 2006). With expanding towns, the National Park Service finalized a prairie dog management plan in 2006 that would dedicate four to 12 $km^2$ of land to prairie dog conservation within WCNP. The focus of this conservation was to provide viable populations of black-tailed prairie dogs to sustain the reintroduction of the endangered black-footed ferret population (NPS 2008a). Additionally, the plan designated two management zones to guide staff activities regarding prairie dogs. Prairie dogs that burrowed into the "no prairie dog zone" were to be removed and prairie dogs within the "active management zone" were allowed to stay but are kept from surrounding private land (USDI, NPS 2006).

## 3.2 Pilot Study:

In the fall of 2008 a pilot study of Wind Cave National Park was conducted to assess the feasibility of the study in terms of data, time, and resources. The pilot study provided invaluable information used to alter the methodology of this research project. The pilot study revealed no significant difference between randomly sampling five percent and 30 percent of a medium sized town in Wind Cave National Park. Because the t-score associated with the 5 percent sample was close to the critical value, a sampling size of 10 percent of each town was considered adequate for burrow density estimations. The pilot study failed to demonstrate correlations between burrow density and distance from town centroids. It was decided that local variations in burrow density were better represented using N-S and E-W transects across each town. The pilot study confirmed the feasibility of delineating black-tailed prairie dog towns using high resolution aerial photography. It was also discovered that within Wind Cave National Park, black-tailed prairie dogs prefer locations with relatively low slopes which are near water. Land-use data was omitted because it lacked detail to describe differences in prairie-dog habitat preferences.

Because soil series data failed to display clear spatial patterns, it was decided that soils patterns would be observed at the soil order level. It is possible that burrowing activity and subsequent town establishment of black-tailed prairie dogs is not at the soil series level of resolution. For this reason, the soil series layer was reclassified at a coarser soil resolution of soil order to look for spatial patterns. Within Wind Cave National Park, the Paunsaugunt-Gurney Complex was the most frequent soil series found in nine out of the fifteen sampled towns. This soil series contains moderately deep, well drained soils, which form from the residual weathering of sedimentary rocks on the open prairie within mountainous environments (USDA, NRCS 2008c).

### 3.3 Digital Data Description:

In February of 2009 aerial imagery, digital elevation models (DEM), and soil data were retrieved from the USDA's Geospatial Gateway for the following locations: Crook County, Wyoming, Custer County, South Dakota, and select portions of North Dakota. The data used in this project is the highest resolution imagery available to the public. By analyzing public data at a macroscale, the monetary and temporal costs associated with conservation efforts can be decreased. Aerial imagery received from the gateway was acquired by the USDA's Farm Service Agency (FSA) as part of the National Agriculture Imagery Program (NAIP). Aerial imagery from Devil's Tower National Monument was a three-band RGB ortho image file compressed as a Mr. Sid file at a ratio of 15:1. The image was an interim year image with combined images from July 2006 and February 2007. The resolution of the image was 1 m (USDA, FSA 2008d). Aerial imagery from Theodore Roosevelt National Park was an ortho rectified image from film. The scale of the original photo was 1:40, 000 meters and was taken between 5 July, 2006 and 18 July, 2006. Resolution was 2 m ground sample distance on film. The image was compressed at a ratio of 15:1 as a Mr. Sid file (USDA, FSA 2008a and 2008b). The image and compression type were chosen because they provided the most contrast between prairie dog burrows and surrounding grassland. Aerial imagery from Wind Cave National Park was a three-band ortho image file compressed as a Mr. Sid file at a ratio of 15:1. The image date was 26 August, 2008 and the resolution was 1 m rectified to within +/- 6 meters to true ground (USDA, FSA 2008c).

Soil data for all three sites were retrieved from the USDA's Soil Survey Geographic database (USDA, NRCS 2008a, 2008b, and 2008c). Information from the database was prepared via on-screen digitization from remotely sensed and other information. Tabular data were joined according to the data model from the USDA. Digital elevation models (DEM) were originated by the National Cartography and Geospatial Center as seamless mosaics of the best of all available elevation data. All DEMs were 10 m or better resolution (USDA, NRCS, NCGC 2008a, 2008b, 2008c, and 2008d). Stream networks containing second order streams and above were generated using the DEMs and tools within ArcHydro®. Park boundaries, the containment fence at

DTNM, and maps of past prairie dog towns from WCNP were provided by the National Park Service Data Store (NPS 2009a, 2009b, and 2009c).

## 3.4 Describing Prairie Dog Town Size, Distribution, and Other Characteristics:

Using high resolution aerial photography from the USDA and park boundaries from the NPS Data Store, prairie dog towns were delineated using on-screen digitization (Figure 3A). Prairie dog towns were delineated at a fixed extent of 1:1,800 meters for towns within Devil's Tower National Monument and Wind Cave National Park. This extent was favorable for the resolution of prairie dog burrows within these sites and resulted in a minimum mapping unit of 1.7 mm using the maximum dome crater diameter of three meters (King 1955 in Hoogland 1996). The fluvial deposits, which are also known as the badlands, of Theodore Roosevelt National Park made it difficult to differentiate burrows at this extent. For this reason a favorable extent of 1: 2,500 meters was used to delineate prairie dog towns; a minimum mapping unit of 1.2 mm was calculated for this site using the maximum dome crater diameter of three meters (King 1955 in Hoogland 1996). In general, prairie dog towns were digitized so as to contain all burrows but not to exceed any visible clip zones. Clip zones are areas in which prairie dogs clip the vegetation so as to not obstruct the view of predators. These zones are visible in aerial photography, as discovered in a pilot study of Wind Cave National Park. Towns that did not exhibit a clip zone were digitized using the location of the outermost burrows. Towns near the park boundary were selectively digitized; towns were excluded if fifty percent or more of the town area resided outside of the park boundary.

Using DEM data, mean elevation, mean slope, and dominant (resultant) aspect were calculated for each study site using the Spatial Analyst tool within ArcGIS®. After town delineation was completed, town area was calculated for all prairie dog towns. Tabular data associated with the soil data were joined to the spatial data using SSURGO data models from the USDA (USDA, NRCS no date 1 and no date 2). Soil order frequency within the towns was explored. In order to see patterns in soil distribution across the towns, data which was classified to the soil order level was observed. Additionally, information from the soil data was used to describe taxonomic particle size, vegetation, dominant drainage class, and wettest drainage class for the parks. Taxonomic particle size was used during data analysis because it describes particle size and composition of the soils. Frequencies of the aforementioned nominal data were then explored using SPSS 17.0. Using the distance tool within ArcMap®, the distance from the prairie dog towns to the nearest streams was calculated and classified into fifty meter increments. All data obtained was combined to describe the habitat characteristics of each site.

## 3.5 Burrow Density and Spatial Analysis of the Towns:

Burrow densities were determined for all prairie dog towns using a point counting method (Figure 3A). A vector sampling grid was generated for each site using Hawth's tools in ArcMap® (Beyer 2004). The sampling grid was comprised of 30 by 30 meter grid cells. Originally grid cells were set to 30 meters in accordance with the resolution of the coarsest data. After 30 meter resolution land use data was excluded from the research project during the pilot study, it was determined that the cell size should remain 30 meters for efficiency in point counting burrows. After generating the grid, it was further refined by excluding all grid cells that intersected the town boundaries (Figure 3B). By clipping the grid by the town boundaries, edge effects may be minimized and burrow density can be more accurately represented.

Hawth's tools were also used to randomly select 10 percent of the cells within each town (Figure 3C). The sampling proportion of 10 percent was selected because, after performing a t-test on data from the pilot study, it was found that there was no significant difference between sampling five percent and 30 percent of the town. The t-score after counting five percent of the cells was close to the critical value, and therefore a sampling size of 10 percent was selected. Record by record, the number of burrows within each selected cell was counted at the same fixed extent of town delineation (Figure 3D and 3E). After generating centroids for each sampled cell within the grid, burrow densities were assigned to the centroids (Figure 3F).

Burrow density was explored along N-S and E-W transects for each town using the Trend Analysis tool within ArcGIS® Geostatistical Analyst. In addition, burrow density was tested for correlations with habitat characteristics using SPSS. Interpolated surfaces were created for each town using the inverse distance weighted (IDW) tool. The IDW tool interpolates unsampled points within the prairie-dog town by weighting the burrow densities of sampled points in accordance with distance. This tool operates using Tobler's Law. The values of burrow density located closest to the unsampled point were given the most influence during interpolation. During interpolation, the p value which resulted in the smoothest boundaries was selected for each town.

## 3.6 Zoogeomorphic Effects:

The minimum burrow diameter and depth determined by other research (Sheets et al. 1971, Hoogland 2006), in conjunction with the burrow density estimated by this study, were used to estimate the volume of sediment removed to create each town (Figure 4). Average burrow density was used to estimate the total volume of excavated sediment removed to create all of the towns within each site. If a town was too small to sample, then the average burrow density of all sampled points within a park was used to estimate excavated sediment. The equations used in the zoogeomorphic analysis include the following:

**Number of Burrows per Town:**

Average Burrow Density per Town X Town Area

**Volume of a Burrow/Cylinder:**

(V) = (V=πr2h) Where r is the average radius of the burrow and h is the depth.

**Sediment Excavated per Town:**

Number of Burrows per Town X Avg. Volume of a Burrow

**Total Volume of Sediment Excavated by Prairie Dogs to Construct the Towns at Each Site:**

∑ of Sediment Excavated per Town

Burrow density and habitat characteristics of each site were used to identify locations that may be potentially more vulnerable to the zoogeomorphic effects of black-tailed prairie dogs. Areas with high burrow densities, relatively high slopes, at short distances from streams, and with new undeveloped soils such as Entisols and Inceptisols were deemed as vulnerable to the zoogeomorphic effects of black-tailed prairie dogs because of their increased erosion potential. The Raster Calculator from ArcGIS®

Spatial Analyst was used to select vulnerable areas that met the following criteria: ten or more burrows per 30 $m^2$, slopes of 15 degrees or more, and stream distances equal to 100 meters or less. Entisol and Inceptisol data, which are underdeveloped soils with poor structure, were overlaid on the output data from the Raster Calculator to describe areas of vulnerability to erosion (Christopherson 2006; USDA, NRCS 2010).

Excavated sediment estimations from this study will be compared with estimations from Butler (2006) using dimensions from Whicker and Detling (1988). In order to complete this comparison, the minimum volume value used in sediment estimates will need to be converted from volume to mass. The soil bulk density must be known to complete this conversion. Because Whicker and Detling did not include this value in their calculations, a bulk density for loamy soils of 1.34 g/cm3 will be used in accordance with prairie dog soil preferences (Koford 1958; Pedosphere.com 2009). Additionally, burrow density will also be compared.

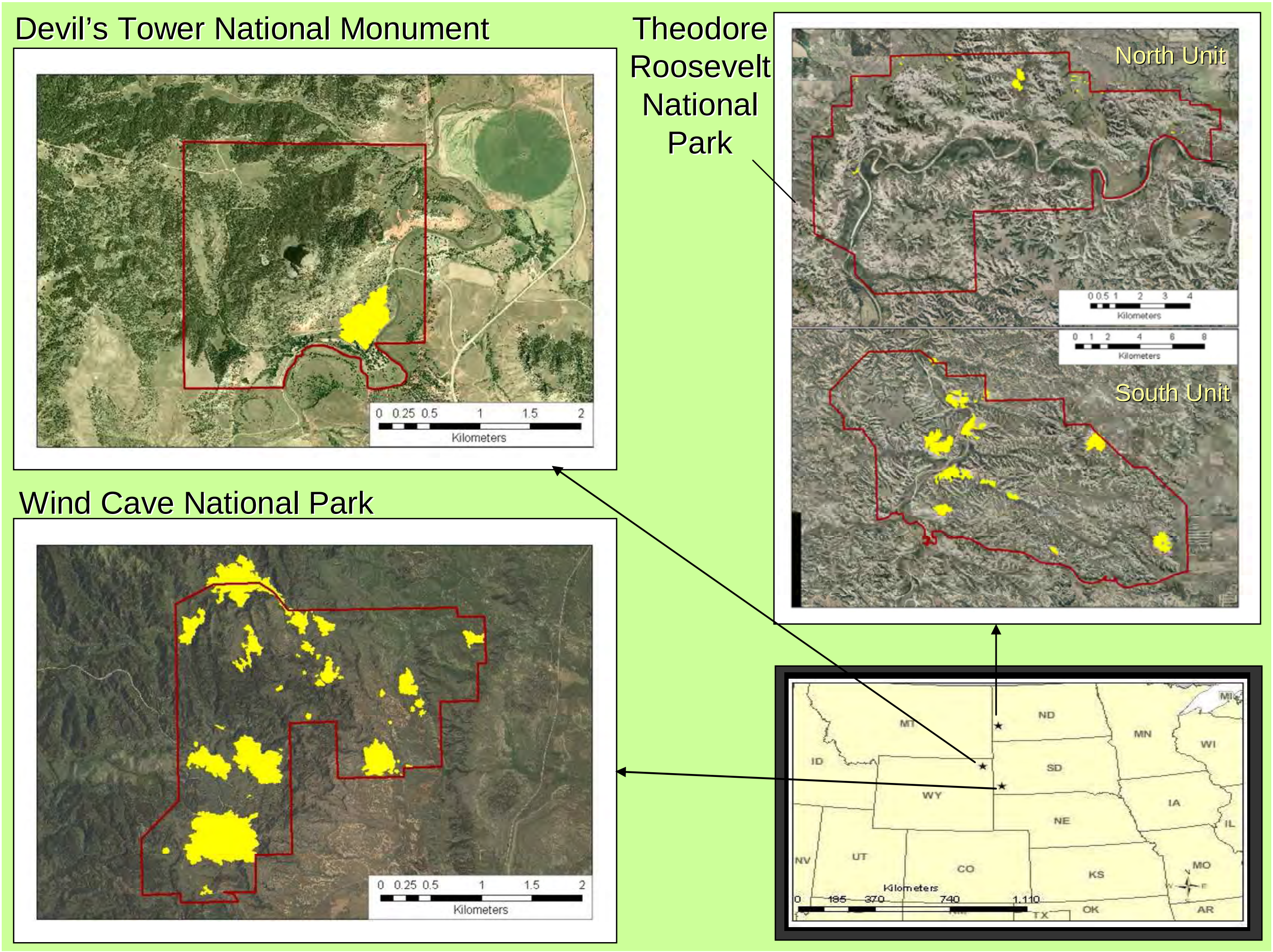

Figure 1: Site Map.


Figure 2: Wind Cave National Park: NPS Images of Town Changes from 1982 to 1999. a. 1982 b. 1990 c. 1994 d. 1999 (National Park Service 2009c).

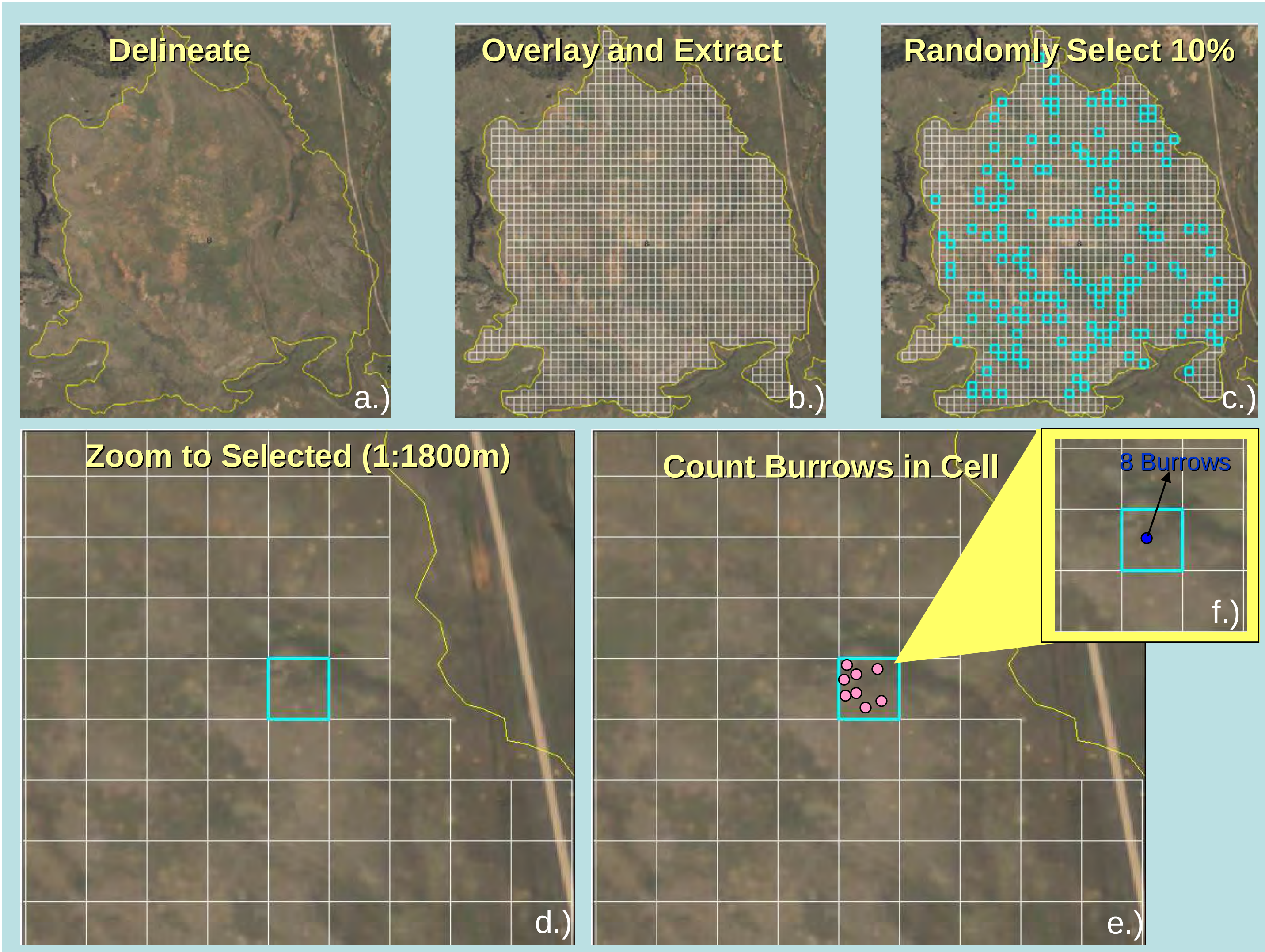


Figure 3: Delineating Towns and Determining Burrow Density for Each Town.

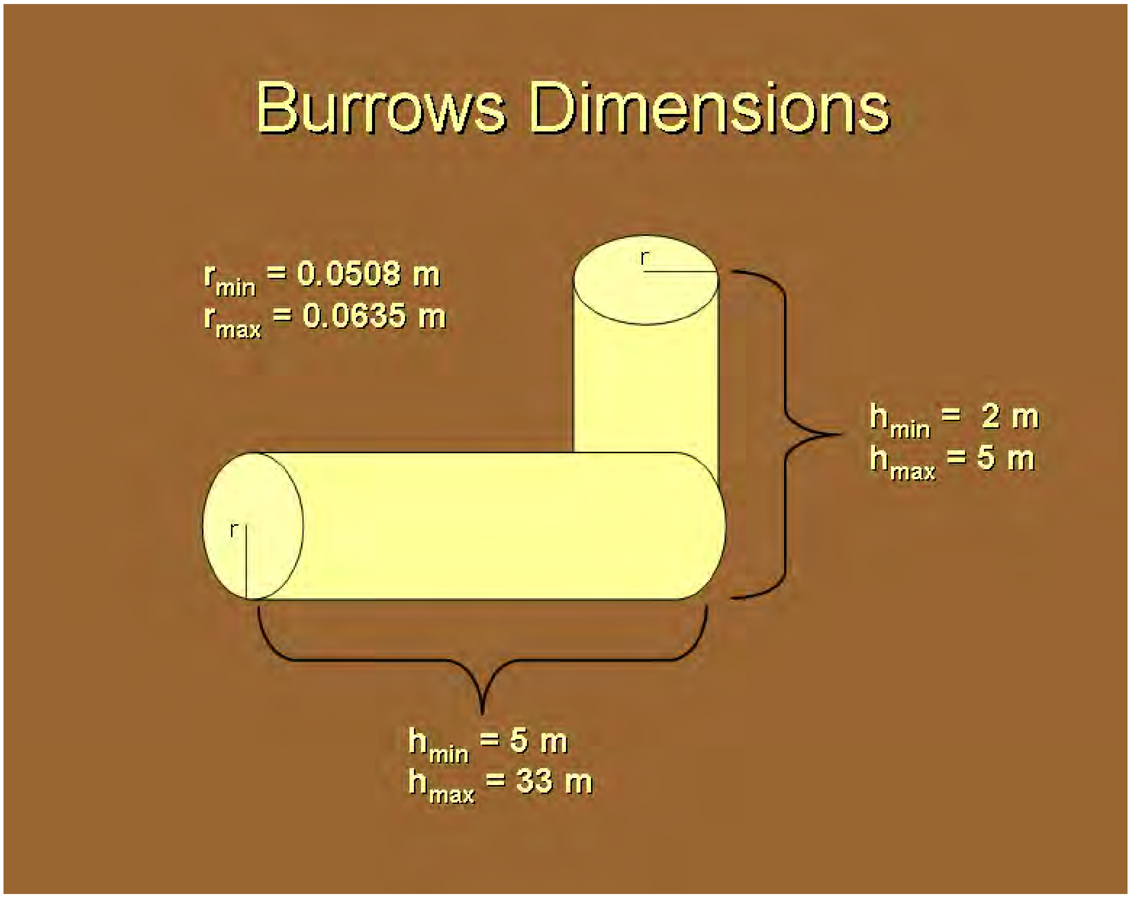


Figure 4: Burrow Dimensions. Measurements derived from Hoogland 2006 and Sheets et al. 1971.

# CHAPTER IV

## RESULTS

### 4.1 Excavated Sediment:

Devil's Tower National Monument spans 5,433,415.2 $m^2$ of land. Within DTNM, one prairie dog town was delineated. The town is 168,796.9$m^2$ in size and occupies 3.1 percent of the entire park (Figure 5A and Table 1). A minimum volume of 4,598.1 $m^3$ of sediment was excavated during the creation of this town. The maximum volume of excavated sediment was 39,002 $m^3$. Burrow densities within the town range from 9 burrows to 18 burrows per 30 $m^2$. The average burrow density of the town is 14 burrows per 30 $m^2$ (Table 1 and Table 2).

Theodore Roosevelt National Park covers an area of 284,701,149.6 $m^2$. A total of 55 towns were delineated in the park; thirty-three of the towns were too small for sampling burrow density (Figure 6A and Figure 7A). Of the total park area, prairie dog towns represent 2.2 percent. Town size ranges from 399.4 $m^2$ to 1,434,528.6 $m^2$ and the average town size is 115,275.9 $m^2$ (Table 3). Burrow densities within the park range from zero to 20 burrows per 30 $m^2$ and on average contain seven burrows per 30 $m^2$. The minimum amount of sediment excavated during town creation was 88,751.5 $m^3$. The maximum volume of excavated sediment was 752,803.1 $m^3$ (Table 4).

Wind Cave National Park is 113,773,026.5 $m^2$ in size. A total of 39 towns were delineated within WCNP. Eleven of these towns were too small to sample burrow density (Figure 8A). Prairie dog towns comprise 13.7 percent of the total park area at Wind Cave. The average town size is 448,794.3 $m^2$, and town size ranges from 1,243.3 $m^2$ to 5,308,346.2 $m^2$ (Table 5). The average burrow density was five burrows per 30 $m^2$ and the range was from zero to eighteen burrows per 30 $m^2$. Minimum excavated sediment estimates reveal 163,379.7$m^3$ of sediment. The maximum value for WCNP was 1,385,809.8 $m^3$ (Table 6).

As part of this study it was determined that per burrow, a minimum of 76.0 kg of sediment is removed during burrow excavation using minimum burrow dimensions and soil density equal to 1.34 g/$cm^3$. This number is considerably lower than the 200-225 kg of mixed sediment calculated by Whicker and Detling (1988). Unfortunately, no mention of soil density was listed in Whicker and Detling's calculation (1988). Using burrow densities of 25-300 burrows per hectare and a mixed sediment value equal to 225 kg, Butler estimated 5,625 to 67,500 kg of soil was mixed per 10,000 $m^2$ (2006). Average burrow densities in DTNM, TRNP, and WCNP are 4,667, 2,333, and 1,667 burrows per 10,000 $m^2$, respectively. These densities vary considerably from past research. Using burrow densities from each park, estimated excavated sediment per 10,000 $m^2$ were 354,667 kg/10,000 $m^2$ in DTNM, 177,333 kg/10,000 $m^2$ in TRNP, and 126,667 kg/10,000 $m^2$ in WCNP. Minimum values of kg/10,000 $m^2$ in DTNM were five times larger than the maximum estimation by Butler (2006). Minimum estimates in TRNP were three times larger than Butler's maximum estimate (2006). Within WCNP, excavated sediment estimates per hectare were two times larger than maximum estimates of Butler (2006).

## 4.2 Habitat Characteristics by Park:

### *4.2.1 Elevation, Slope, Aspect ,and Distance to Streams:*

Devil's Tower National Monument has a mean elevation 1,240 masl and ranges from 1,168 to 1,560 masl; Upper elevations are concentrated at Devil's Tower. Highlands are to the northwest and lowlands are to the southeast (Figure 5B). The resultant aspect within the park is 150 degrees which faces to the southeast. In terms of slope of the surface, DTNM ranges from zero to 73.7 degrees and has an average slope of 11.3 degrees. Slopes greater than 30 degrees are observed from the park's center to the northwest. The southeastern portion of the park, which is home to the solitary prairie dog town, is dominated by slopes less than 3.5 degrees and contains a floodplain (Figure 5C). This stream delineates the irregular park boundary to the southeast, and tributaries of the stream cross the northeastern portion of the prairie dog town. Stream orders ranging from second degree streams to sixth degree streams can be found in and around Devil's Tower National Monument. A large portion of land northwest of Devil's Tower trends in a NE-SW direction and faces W-NW. Areas within the floodplain are facing E-SE (Figure 5D). Within the park, distances from streams range from zero to 676.8 meters, but the average distance is 218.8 meters. Streams within the park line the perimeter of the park (Figure 5E).

Elevations surrounding Theodore Roosevelt National Park range from 585.1 to 883.0 masl. As a whole, the park elevation spans the majority of these elevations ranging from 590.7 to 872.8 masl. Average elevation within the park is 728.8 masl (Figure 6B and Figure 7B). Slopes within Theodore Roosevelt National Park vary from zero to 63.3 degrees and average 12.1 degrees. Slopes within the North Unit are dominated by very high and very low slopes; conversely, in the South Unit, intermediate to very low slopes dominate the landscape (Figure 6C and Figure 7C). Within both units of the park, aspect patterns are visible in conjunction with major stream locations. For example, in the North Unit, the large stream which is known as the Little Missouri River, trends E-W and shows a dominantly southern aspect on the northern bank. The southern bank roughly faces north (Figure 6D). In the South Unit, the Little Missouri trends N-S. The easternmost bank of the stream transitions from a roughly southern aspect to a northern aspect; conversely, the westernmost bank is dominated by an N-NE facing aspect which transitions to an S-SE aspect (Figure 7D). Aside from the slopes of major streams, patterns in aspect are not discernable at TRNP. In general, the North Unit of the park contains a range of lower elevations than the South Unit (Figure 6B and Figure 7B). Distance to streams in Theodore Roosevelt National Park ranges from 0 to 907 meters (Figure 6E and Figure 7E). Mean distance to streams is 212.7 meters within the park.

Wind Cave National Park has elevations that range from 1,083.6 to 1,526.6 masl. Mean elevation within the park is 1,275.3 masl (Figure 8B). Maximum slopes within Wind Cave range from zero to 59.2 degrees and mean slope is 9.8 degrees (Figure 8C). Aspect within the park is highly variable. A series of ridges appear to follow an N-S trend. Areas near the south central park boundary, which extend through the eastern portion of the park, are dominated by south, southeast, and southwest aspects. The resultant aspect of Wind Cave National park is 154.2 degrees and faces in a southeastern direction (Figure 8D). A network of streams spans the park. Areas within the park can be found within 462.6 meters of a stream on average, and distances can range from zero to 1,662.6 meters. Streams intersect and border several prairie dog towns within the park. Many of these transected towns reside in central and north central portions of the park (Figure 8E).

*4.2.2 Soil Order, Taxonomic Particle Size, Vegetation, and Drainage*

Devil's Tower National Monument contains the following three soil orders: Alfisols, Entisols, and Mollisols. In terms of soil order distribution, Alfisols are primarily found in the central and northwestern portion of the park. Mollisols periodically line the exterior boundary of the park; Entisols dominate the southeastern portion of the park, but are also found in the northwest interspersed with Aridisols. Alfisols and Entisols comprise nearly equal portions of the park with 46 and 47 percent respectively. Mollisols account for only seven percent of the total park area (Figure 9A). Taxonomic particle size within the park was limited to the following categories: unknown, clayey, coarse-loamy, coarse-silty, fine, fine-loamy, fine-silty, loamy, loamy-skeletal, and sandy. Of these categories, fine particle size dominated the park with 47 percent. Sandy, clayey, and fine-loamy categories comprised roughly equal proportions of the park with percentages of 14, 13, and 12 respectively. Loamy and coarse-loamy particle sizes comprised the remaining seven percent of the park (Figure 9B).

Nine varieties of vegetation were found in Devil's Tower National Monument. These nine species include the following: *Andropogon gerardii*, *Arctostaphylos uva-ursi*, *Artemsima filifolia*, *Bouteloua curtipendula*, *Bouteloua gracilis*, *Calamovilfa longifolia*, *Carex filifolia*, *Cercocarpus montanus*, and *Pascopyrum smithii*. The top three vegetation types that comprise a total of 88 percent of all vegetation within the park include the following in order according to percentage: *Cercocarpus montanus*, *Pascopyrum smithii*, and *Artemisia filifolia*. All other vegetation comprised the remaining 12 percent in roughly equal amounts (Figure 9C). Devil's Tower was defined by only two drainage classes which include excessively drained and well drained. Drainage during the wettest time of year varies from dominant drainage, because the unknown drainage types are listed as well-drained (Figure 9D and Figure 9E).

Theodore Roosevelt National Park contains the following four soil orders: Alfisols, Entisols, Inceptisols, and Mollisols. TRNP is the only park of the three study sites to contain Inceptisols, which comprise 52 percent of the total park area. Mollisols are the next most abundant soil order with 34 percent of the park. Entisols follow with 13 percent of the park, and Alfisols are the least abundant with only one percent of the park area. As compared to the South Unit, the North Unit excludes Alfisols. Soil order percentages vary dramatically between the North and South Units. In the South Unit Inceptisols and Mollisols dominate the unit with 53 and 35 percent respectively. Within 11 percent of the park Entisols are found sporadically, but Entisols are common in major stream beds. Alfisols are the least predominate soil order represented within the South Unit, comprising only one percent of the unit. In the North Unit, Inceptisols cover half of the park. Entisols and Mollisols comprise roughly equal amounts of the North Unit with 19 and 31 percent, respectively. Continuous areas of Mollisols line the northwest and northeast boundary of the park (Figure 10A and Figure 11A). Eight taxonomic particle size classes were represented at TRNP which include the following: clayey, coarse-loamy, fine, fine-loamy, fine-loamy over fragmental, fine-loamy over sandy or sandy-skeletal, loamy, and sandy-skeletal. Seventy-one percent of TRNP was dominated by the fine-loamy class. The second most prevalent particle size class was fine with 11 percent of the park. Both coarse-loamy and loamy covered eight percent of the park each. The remaining classes represented two percent or less of the total park (Figure 10B and Figure 11B).

Nine types of vegetation were found in Theodore Roosevelt National Park, but only the following six species had scientific names recorded: *Artemisia tridentate*, *Bouteloua gracilis*, *Buchloe dactyloides*, *Calamovilfa longifolia*, *Pascopyrum smithii*, and *Pseudoroegneria spicata spicata*. The remaining vegetation was listed as having unknown scientific names but fell into the following unknown categories: other perennial forbs, prairie junegrass, and winterfat. Unfortunately in both North and South units, vegetation classification was left blank or unknown. Aside from differences in percent park coverage, vegetation in the North Unit excludes *Pseudoroegneria spicata spicata*, which is more commonly known as blue bunch wheatgrass, and the unknown scientific name category was listed as other perennial forbs. The South Unit includes the most unknown species and excludes *Buchloe gracilis* and *Calamovilfa longifolia*, also known as blue grama and prairie sandreed (Figure 10C and Figure 11C). The following four drainage classes define Theodore Roosevelt National Park: excessively drained, somewhat excessively drained, well drained, and moderately well drained. The South Unit appears to have a greater proportion of excessively drained areas than the North Unit. Dominant North Unit drainage is homogenously classified as well drained. Both units contain dominant drainage classification areas that are somewhat excessively drained near the major streams (Figure 10D, Figure 10E, Figure 11D, and Figure 11E).

Wind Cave National Park has the greatest diversity of soil orders. The five orders found within the park include the following: Alfisols, Aridisols, Entisols, Mollisols, and Vertisols. Wind Cave is the only site to contain Vertisols, more commonly known as expandable clay soils. Mollisols are the dominant soil order with an area of 47 percent of the park. Entisols follow closely with an area equal to 34 percent of the park. Aridisols and Alfisols cover roughly equal areas of the park with nine and eight percent respectively. Vertisols account for approximately two percent of the total park area. Alfisols mainly occur along the western portion of the park. Vertisols occur within and outside of prairie dog towns, but appear to only occur in very large towns (Figure 12A). The following taxonomic particle size classes can be found in Wind Cave National Park: coarse-silty, fine, fine-loamy, fine-silty, loamy, sandy-skeletal, and very fine. Large areas of the park are dominated by classes that contain high percentages of larger particles (0.1-74mm); these classes have skeletal in their name (USDA, NRCS 2010). Sixty-five percent of the park is classified as loamy-skeletal. Fine, fine-loamy, loamy, and sandy-skeletal particle size classes account for roughly equal amounts of the park with percentages ranging from six to nine percent (Figure 12B).

Wind Cave National Park has the most diversity of vegetation with the following eleven vegetation types: *Achillea*, *Achillea millefolium var. occidentalis*, *Amelanchier alnifolia*, *Amorpha canescens*, *Andropogon gerardii*, *Artemisia frigida*, *Artemisia tridentate*, *Bouteloua curtipendula*, *Carex*, *Mahonia repens*, and *Pascopyrum smithii*. With coverage of 41 percent of the park, *Pascopyrum smithii*, more commonly known as western wheat grass, spans all areas of the park. *Bouteloua curtipendula*, which is also known as sideoats grama, trends NE-SW through the center of the park. Other vegetation such as *Carex* shows a similar trend. *Amelanchier alnifolia*, known as Saskatoon service berry, is not dominant vegetation in any prairie dog town and is confined to the western portion of the park (Figure 12C). The following three drainage classes occur in Wind Cave National Park: excessively drained, somewhat excessively drained, and well drained. Comprising 76 percent of the park, the well drained class spans the majority of the park. Drainage classes which can be described as somewhat excessively drained and excessively drained cover the remainder of the park and traverse the center of Wind Cave in a NE-SW trend (Figure 12D). During the wettest time of the year, the well drained areas grow to 91 percent and the other drainage classes shrink considerably in size and extent; the somewhat excessively drained areas shrink from 15 to six percent during the wet season. The excessively drained regions in the eastern portion of the park remain relatively stable, but the same drainage class decreases from nine to three percent in the wet season (Figure 12E).

## 4.3 Town Analysis:

### *4.3.1 Trend Analysis along N-S and E-W Transects and Habitat Characteristics:*

Trend analysis within the Devil's Tower National Monument town shows an increase in burrow density to the south and to the west. A containment fence is located along the southwest boundary of the town (Figure 13).

Within Theodore Roosevelt National Park, Towns 1 to 5 are located in the North Unit and Towns 6 to 22 are located in the South Unit. Only fifteen towns in TRNP had large enough sample sizes to plot N-S and E-W trend analyses (Figure 14). Sample sizes within each town range from one to 135. Towns 2, 7, and 9 contained five or less sample points and may be greatly influenced by outliers (Figures 14B, 14D, and 14E). The following towns increased in burrow density to the north and west: Town 1, Town 9, Town 18, and Town 21 (Figures 14A, 14E, 14K, and 14N). Towns 15 and 17 increased to the north and east (Figures 14H and 14J). Burrow density in Town 6 increased to the south and west (Figure 14C). Towns 2 and 22 showed increases in burrow density at the center of the town along the N-S and E-W transects (Figures 14B and 14O). Town 7 reached a maximum burrow density in the center of the town in the E-W direction and remained relatively constant in the N-S direction (Figure 14D). Town 14 showed a maximum burrow density at the town’s center in the N-S direction and a slight increase in burrows to the west (Figure 14G). Town 19 showed a maximum burrow density in the center of the town along the N-S transect was relatively constant in the E-W direction with a slight decrease in burrow density in at the center of the town (Figure 14L). Burrow density in Town 20 increased to the east and remained relatively constant in the N-S direction, with a slight increase toward center of town in the N-S direction (Figure 14M). Burrow densities in Town 10 decreased at the center of town in the N-S direction and maintained relatively constant values along the E-W direction, with slightly lower densities to the west (Figure 14F). Town 16 displayed declining burrow density near the center of town in the E-W direction and increased slightly to the south (Figure 14I).

Trend analysis was performed for 11 towns within Wind Cave National Park (Figure 15). Town 3, 4, 10, 11, 15, and 31 showed maximum burrow densities near the center of town on the N-S transect (Figures 15A, 15B, 15E, 15F, 15G, and 15J). In addition, Towns 3, 11, and 15 also display increased burrow densities to the west. Along the E-W transect, Town 4 increased in burrow density to the east, Town 10 revealed a minimum burrow density near the center of town and Town 31 remains relatively constant. Towns 5 and 17 show maximum burrow densities near the town center along the E-W transect (Figures 15C and 15H). Along the N-S transect, Town 5's burrow density increased to the north and Town 17's burrow density increased to the south. Towns 6 and 23 maintain a relatively constant burrow density along the E-W transect; within Town 6 density increased to the south. Town 23 burrow density increased to the north (Figures 15D and 15I). Burrow density within Town 32 decreased to the north and increased to the east (Figure 15K).

*4.3.2 Habitat Characteristics Using Town Sampling Points:*

In order to summarize the habitat characteristics for the sample points taken in each town, descriptive statistics and frequency information have been described below. Sampling points within the prairie dog town of Devil's Tower National Monument had elevations ranging from 1,178 to 1,189 masl and an average elevation of 1,181 masl. Fifteen sample points were taken for DTNM. Sampling point slopes ranged from zero to 9.3 degrees and averaged 2.2 degrees. The resultant aspect yielded by the points was 73.6 degrees facing northeast. On average, the sampling points were 212.6 meters from streams within the park (Table 7). Within DTNM, sampling points revealed that Entisols extend across 73 percent of the town (Table 8). The most frequent taxonomic particle size classification was fine-loamy with 67 percent of the sample points. The sandy class accounted for seven percent and the remaining were unknown (Table 9). Two plant types were sampled in the park within Town 1. *Bouteloua gracilis*, also known as blue grama, was the most abundant with 67 percent of the sample points. *Artesmisia filifolia*, also known as sand sagebrush, accounted for seven percent, and the remaining were unknown

(Table 10). Both the dominant and the wettest drainage classifications showed that the well-drained class had highest frequency with over 93 percent of the sample points (Table 11 and Table 12). The most frequent aspect direction was to the southeast with 40 percent of the sample points (Table 13).

In Theodore Roosevelt National Park, 520 sample points were taken within prairie dog towns. In accordance with sampling points, elevation ranged from 601.7 to 801 masl for sampling points in TRNP; sampling points also revealed a mean elevation of 737.9 masl. Slopes within the towns averaged 2.7 degrees and ranged from zero to 35.6 degrees. Sampling points were on average 221.2 meters from the nearest stream; this distance ranged from zero to 636.4 meters for all TRNP sampling points (Table 14). Mollisols were the most frequent soil order with 72 percent of the points. Twelve percent of soil orders were unknown at sample points. Entisols occurred in nine percent of the points, and seven percent of points were Inceptisols (Table 15). The fine-loamy taxonomic particle size was found at 49 percent of TRNP sample points. Fine, coarse-loamy, and unknown particle size classes were discovered in 17, 14, and 12 percent of sample points. Fine-loamy oversandy or sandy-skeletal and loamy classes define the remainder of sample points (Table 16). The top three vegetation types found at the TRNP sample points include the following: *Pascopyrum smithii* (western wheatgrass), unknown, and *Artemisia tridentata* (big sagebrush). The aforementioned vegetation types were found in 18, 24, and 10 percent of sampling points respectively (Table 17). Well drained accounted for over 90 percent of drainage classifications for dominant and wet classifications. This percentage increased slightly during the wet season (Table 18 and Table 19). No apparent aspect direction was considered the most prevalent in TRNP sample points (Table 20).

A total of 1,704 sample points were taken in prairie dog towns at Wind Cave National Park. Sampling points in WCNP occurred from 1,107.4 to 1,415.6 masl and averaged 1,281.2 masl. Slopes ranging from zero to 23.2 degrees were represented at WCNP sample points. Average slope within the towns were 4.2 degrees. Resultant aspects faced the southeast. Sampling points within the towns were 505 meters from the nearest stream on average. Distances from points to streams ranged from zero to 1,565.8 meters (Table 21). Sixty-eight percent of points showed Mollisols as the dominant soil order. Aridisols and Entisols accounted for 13 percent each of the sample points. The remaining percentage was defined as Alfisols and Vertisols (Table 22). Loamy-skeletal was the foremost particle size class for 54 percent of all sample points. The fine-loamy classification defined 13 percent of sample points, and the fine-silty defined seven percent (Table 23). The top three vegetation types were as follows: *Bouteloua curtipendula* (sideoats grama), *Pascopyrum smithii* (western wheat grass), and *Amorpha canescens* (lead plant). The vegetation types characterize 39, 28, and 14 percent of WCNP sample points respectively (Table 24). Sample points were described as well-drained in over 90 percent of all sample points in both the dominant and wet classifications. The remaining points were somewhat excessively drained. The percentage of well-drained points increased during the wet season (Table 25 and Table 26). No apparent aspect direction was determined for the WCNP sample points (Table 27).

No significant correlations were found between nominal habitat data and burrow density for DTNM (Table 28). A strong negative correlation was found between burrow density and distance from streams at TRNP (Table 29). Slope and aspect had strong negative correlations with burrow density in WCNP (Table 30). Correlations between burrow density and nominal data such as soil type, vegetation type, taxonomic particle size and drainage were not tested using Pearson's correlation; frequencies of these data were previously described in this section. The data were also explored visually by comparing nominal habitat characteristics and IDW surfaces generated from the sample points. Patterns are listed in the following section.

4.4 Inverse Distance Weighted Surfaces and Erosion Vulnerability Assessment:

Using the sampling points from each town, IDW surfaces were created for DTNM, TRNP, and WCNP (Figure 16; Figure 17; Figure 18). P values for the surfaces ranged from two to six. P values reached a maximum of five and six in TRNP and WCNP respectively. In general, larger values of p were selected for larger towns with more sampling points in order to smooth lines within the surfaces. These surfaces were visually compared to nominal habitat data to look for any correlations. In DTNP, no correlations between burrow density and nominal habitat data were observed. Town 6 and Town 22 in TRNP, showed potential correlations with nominal habitat characteristics. Winterfat vegetation and fine loamy soils occurred with increasing burrow density in Town 6. In Town 22, western wheatgrass, coarse loamy soils, and Mollisols were more prevalent with increasing burrow density. WCNP contained three towns that showed burrow correlations to nominal data. In Town 3, areas containing

*Achillea*, also known as yarrow, and Alfisols displayed the highest burrow density. Western wheatgrass, fine-silty soils, and Mollisols were associated with increasing burrow density in Town 15. Within WCNP, the highest burrow densities in Town 1 were found outside of the park boundary to the north.

Utilizing the inverse distance weighted surfaces and data regarding habitat characteristics, erosion vulnerability was assessed for each park (Figure 16, Figure 17, and Figure 18). Areas within the park that met the following criteria were denoted as vulnerable: burrow density greater than 10 burrows per 30 $m^2$, slopes greater than or equal to 15 degrees, stream distances of 100 meters or less, and contains Entisol or Inceptisol soil orders. Within DTNM areas to the northeast of the town were denoted as vulnerable to erosion (Figure 19). Erosion controls were implemented by the park to the northeast and southwest of the town. TRNP contains six towns near potentially vulnerable areas to erosion in the South Unit (Figure 20). Within the North Unit, the vulnerability criteria were not met, but a large proportion of Entisols were found in Town 2; the highest burrow density in Town 2, which was 14 burrows per 30 $m^2$, intersected the Entisol coverage (Figure 17 and Figure 20). No areas met the stream vulnerability criterion in combination with all other criteria in WCNP. Three towns were classified as vulnerable to erosion with the exclusion of the stream distance and soil type criteria (Figure 21). Areas to the west of Town 3 with Entisols are potentially vulnerable to erosion. Town 23 and 31 show vulnerability in terms of burrow density and slope to the northwest and south respectively, but are not found in within areas which contain Entisols or Inceptisols.

Table 1: Devil's Tower National Monument: Prairie Dog Town Sampling, Burrow Density, and Area.

| Town Label | Town Area ($m^2$) | Total Number of Towns in Park | Number of Towns Too Small to Sample | Number Sample Points per Town | Average Burrow Density of Town (number of burrows/30 meters) | Town Percentage of Park Area (%) | Park Area ($m^2$) |
|---|---|---|---|---|---|---|---|
| 1 | 168,796.9 | 1 | 0 | 15 | 14 | 3.1 | 5,433,415.2 |

Table 2: Excavated Sediment Estimates for Devil's Tower National Monument

| Town Label | Park Area ($m^2$) | Town Area ($m^2$) | Total Area of Towns in Park ($m^2$) | Avg. Burrow Density of Town (Number of burrows/30meters) | MIN Volume of Burrow ($m^3$) | MAX Volume of Burrow ($m^3$) | MIN* Excavated Sediment Per Town ($m^3$) | MAX* Excavated Sediment Per Town ($m^3$) |
|---|---|---|---|---|---|---|---|---|
| 1 | 5,433,415.2 | 168,796.9 | 168,796.9 | 14 | 0.0567512 | 0.4813721 | 4,598.1 | 39,002.0 |
| | | | | | | Total: | 4,598.1 | 39,002.0 |

*Calculated using average burrow density for each town

Table 3: Theodore Roosevelt National Park: Prairie Dog Town Sampling, Burrow Density, and Area.

| Town Label | Town Area ($m^2$) | Total Number of Towns in Park | Number of Towns Too Small to Sample | Number Sample Points per Town | Average Burrow Density of Town (number of burrows/30 meters) | Town Percentage of Park Area (%) | Park Area ($m^2$) |
|---|---|---|---|---|---|---|---|
| 1 | 91,542.3 | 55 | 33 | 7 | 12 | 0.0 | 284,701,149.6 |
| 2 | 86,480.9 | 55 | 33 | 5 | 8 | 0.0 | 284,701,149.6 |
| 3 | 2,335.5 | 55 | 33 | 1 | 2 | 0.0 | 284,701,149.6 |
| 4 | 13,583.7 | 55 | 33 | 1 | 14 | 0.0 | 284,701,149.6 |
| 5 | 4,421.1 | 55 | 33 | 1 | 9 | 0.0 | 284,701,149.6 |
| 6 | 118,766.5 | 55 | 33 | 9 | 11 | 0.0 | 284,701,149.6 |
| 7 | 81,499.5 | 55 | 33 | 4 | 9 | 0.0 | 284,701,149.6 |
| 8 | 18,994.9 | 55 | 33 | 1 | 6 | 0.0 | 284,701,149.6 |
| 9 | 80,248.6 | 55 | 33 | 4 | 7 | 0.0 | 284,701,149.6 |
| 10 | 432,056.2 | 55 | 33 | 33 | 7 | 0.2 | 284,701,149.6 |
| 11 | 50,449.7 | 55 | 33 | 3 | 8 | 0.0 | 284,701,149.6 |
| 12 | 11,919.6 | 55 | 33 | 1 | 9 | 0.0 | 284,701,149.6 |
| 13 | 6,117.6 | 55 | 33 | 1 | 8 | 0.0 | 284,701,149.6 |
| 14 | 1,434,528.6 | 55 | 33 | 135 | 7 | 0.5 | 284,701,149.6 |
| 15 | 603,603.7 | 55 | 33 | 45 | 8 | 0.2 | 284,701,149.6 |
| 16 | 822,665.0 | 55 | 33 | 77 | 8 | 0.3 | 284,701,149.6 |
| 17 | 888,960.5 | 55 | 33 | 71 | 6 | 0.3 | 284,701,149.6 |
| 18 | 177,973.9 | 55 | 33 | 13 | 7 | 0.1 | 284,701,149.6 |
| 19 | 148,742.5 | 55 | 33 | 10 | 10 | 0.1 | 284,701,149.6 |
| 20 | 448,555.7 | 55 | 33 | 42 | 6 | 0.2 | 284,701,149.6 |
| 21 | 93,755.8 | 55 | 33 | 6 | 11 | 0.0 | 284,701,149.6 |
| 22 | 664,145.0 | 55 | 33 | 50 | 8 | 0.2 | 284,701,149.6 |
| NS 1 | 1,412.6 | 55 | 33 | 0 | 7 | 0.0 | 284,701,149.6 |
| NS 2 | 410.1 | 55 | 33 | 0 | 7 | 0.0 | 284,701,149.6 |
| NS 3 | 1,081.7 | 55 | 33 | 0 | 7 | 0.0 | 284,701,149.6 |
| NS 4 | 439.0 | 55 | 33 | 0 | 7 | 0.0 | 284,701,149.6 |
| NS 5 | 1,181.6 | 55 | 33 | 0 | 7 | 0.0 | 284,701,149.6 |

NS: Not Sampled

Table 3: continued

| Town Label | Town Area ($m^2$) | Total Number of Towns in Park | Number of Towns Too Small to Sample | Number Sample Points per Town | Average Burrow Density of Town (number of burrows/30 meters) | Town Percentage of Park Area (%) | Park Area ($m^2$) |
|---|---|---|---|---|---|---|---|
| NS 6 | 632.7 | 55 | 33 | 0 | 7 | 0.0 | 284,701,149.6 |
| NS 7 | 919.3 | 55 | 33 | 0 | 7 | 0.0 | 284,701,149.6 |
| NS 8 | 684.5 | 55 | 33 | 0 | 7 | 0.0 | 284,701,149.6 |
| NS 9 | 4,466.1 | 55 | 33 | 0 | 7 | 0.0 | 284,701,149.6 |
| NS 10 | 4,432.8 | 55 | 33 | 0 | 7 | 0.0 | 284,701,149.6 |
| NS 11 | 1,958.3 | 55 | 33 | 0 | 7 | 0.0 | 284,701,149.6 |
| NS 12 | 1,212.8 | 55 | 33 | 0 | 7 | 0.0 | 284,701,149.6 |
| NS 13 | 1,186.3 | 55 | 33 | 0 | 7 | 0.0 | 284,701,149.6 |
| NS 14 | 399.4 | 55 | 33 | 0 | 7 | 0.0 | 284,701,149.6 |
| NS 15 | 2,017.9 | 55 | 33 | 0 | 7 | 0.0 | 284,701,149.6 |
| NS 16 | 938.0 | 55 | 33 | 0 | 7 | 0.0 | 284,701,149.6 |
| NS 17 | 2,332.5 | 55 | 33 | 0 | 7 | 0.0 | 284,701,149.6 |
| NS 18 | 3,511.6 | 55 | 33 | 0 | 7 | 0.0 | 284,701,149.6 |
| NS 19 | 2,740.6 | 55 | 33 | 0 | 7 | 0.0 | 284,701,149.6 |
| NS 20 | 1,671.1 | 55 | 33 | 0 | 7 | 0.0 | 284,701,149.6 |
| NS 21 | 1,331.3 | 55 | 33 | 0 | 7 | 0.0 | 284,701,149.6 |
| NS 22 | 4,556.8 | 55 | 33 | 0 | 7 | 0.0 | 284,701,149.6 |
| NS 23 | 866.9 | 55 | 33 | 0 | 7 | 0.0 | 284,701,149.6 |
| NS 24 | 464.8 | 55 | 33 | 0 | 7 | 0.0 | 284,701,149.6 |
| NS 25 | 629.4 | 55 | 33 | 0 | 7 | 0.0 | 284,701,149.6 |
| NS 26 | 657.1 | 55 | 33 | 0 | 7 | 0.0 | 284,701,149.6 |
| NS 27 | 869.2 | 55 | 33 | 0 | 7 | 0.0 | 284,701,149.6 |
| NS 28 | 3,711.4 | 55 | 33 | 0 | 7 | 0.0 | 284,701,149.6 |
| NS 29 | 1,229.7 | 55 | 33 | 0 | 7 | 0.0 | 284,701,149.6 |
| NS 30 | 3,435.1 | 55 | 33 | 0 | 7 | 0.0 | 284,701,149.6 |
| NS 31 | 6,061.8 | 55 | 33 | 0 | 7 | 0.0 | 284,701,149.6 |
| NS 32 | 733.2 | 55 | 33 | 0 | 7 | 0.0 | 284,701,149.6 |
| NS 33 | 649.4 | 55 | 33 | 0 | 7 | 0.0 | 284,701,149.6 |

Table 4: Excavated Sediment Estimates for Theodore Roosevelt National Park.

| Town Label | Park Area ($m^2$) | Town Area ($m^2$) | Total Area of Towns in Park ($m^2$) | Avg. Burrow Density of Town (Number of burrows/30$m^2$) | MIN Volume of Burrow ($m^3$) | MAX Volume of Burrow ($m^3$) | MIN* Excavated Sediment Per Town ($m^3$) | MAX* Excavated Sediment Per Town ($m^3$) |
|---|---|---|---|---|---|---|---|---|
| 1 | 284,701,149.6 | 91,542.3 | 6,340,171.9 | 12 | 0.056751238 | 0.481372105 | 2,127.5 | 18,046.0 |
| 2 | 284,701,149.6 | 86,480.9 | 6,340,171.9 | 8 | 0.056751238 | 0.481372105 | 1,341.5 | 11,378.7 |
| 3 | 284,701,149.6 | 2,335.5 | 6,340,171.9 | 2 | 0.056751238 | 0.481372105 | 8.8 | 74.9 |
| 4 | 284,701,149.6 | 13,583.7 | 6,340,171.9 | 14 | 0.056751238 | 0.481372105 | 359.7 | 3,051.4 |
| 5 | 284,701,149.6 | 4,421.1 | 6,340,171.9 | 9 | 0.056751238 | 0.481372105 | 75.3 | 638.5 |
| 6 | 284,701,149.6 | 118,766.5 | 6,340,171.9 | 11 | 0.056751238 | 0.481372105 | 2,521.3 | 21,386.1 |
| 7 | 284,701,149.6 | 81,499.5 | 6,340,171.9 | 9 | 0.056751238 | 0.481372105 | 1,387.6 | 11,769.5 |
| 8 | 284,701,149.6 | 18,994.9 | 6,340,171.9 | 6 | 0.056751238 | 0.481372105 | 215.6 | 1,828.7 |
| 9 | 284,701,149.6 | 80,248.6 | 6,340,171.9 | 7 | 0.056751238 | 0.481372105 | 1,024.7 | 8,691.6 |
| 10 | 284,701,149.6 | 432,056.2 | 6,340,171.9 | 7 | 0.056751238 | 0.481372105 | 5,547.9 | 47,058.1 |
| 11 | 284,701,149.6 | 50,449.7 | 6,340,171.9 | 8 | 0.056751238 | 0.481372105 | 763.5 | 6,476.0 |
| 12 | 284,701,149.6 | 11,919.6 | 6,340,171.9 | 9 | 0.056751238 | 0.481372105 | 202.9 | 1,721.3 |
| 13 | 284,701,149.6 | 6,117.6 | 6,340,171.9 | 8 | 0.056751238 | 0.481372105 | 92.6 | 785.3 |
| 14 | 284,701,149.6 | 1,434,528.6 | 6,340,171.9 | 7 | 0.056751238 | 0.481372105 | 18,734.6 | 158,909.9 |
| 15 | 284,701,149.6 | 603,603.7 | 6,340,171.9 | 8 | 0.056751238 | 0.481372105 | 9,261.6 | 78,558.3 |
| 16 | 284,701,149.6 | 822,665.0 | 6,340,171.9 | 8 | 0.056751238 | 0.481372105 | 12,935.0 | 109,716.5 |
| 17 | 284,701,149.6 | 888,960.5 | 6,340,171.9 | 6 | 0.056751238 | 0.481372105 | 9,332.0 | 79,155.3 |
| 18 | 284,701,149.6 | 177,973.9 | 6,340,171.9 | 7 | 0.056751238 | 0.481372105 | 2,279.0 | 19,331.0 |
| 19 | 284,701,149.6 | 148,742.5 | 6,340,171.9 | 10 | 0.056751238 | 0.481372105 | 2,841.9 | 24,105.5 |
| 20 | 284,701,149.6 | 448,555.7 | 6,340,171.9 | 6 | 0.056751238 | 0.481372105 | 4,768.0 | 40,442.6 |
| 21 | 284,701,149.6 | 93,755.8 | 6,340,171.9 | 11 | 0.056751238 | 0.481372105 | 1,862.3 | 15,796.0 |
| 22 | 284,701,149.6 | 664,145.0 | 6,340,171.9 | 8 | 0.056751238 | 0.481372105 | 10,252.0 | 86,958.6 |
| NA 1 | 284,701,149.6 | 1,412.6 | 6,340,171.9 | 7 | 0.056751238 | 0.481372105 | 19.6 | 166.2 |
| NA 2 | 284,701,149.6 | 410.1 | 6,340,171.9 | 7 | 0.056751238 | 0.481372105 | 5.7 | 48.3 |
| NA 3 | 284,701,149.6 | 1,081.7 | 6,340,171.9 | 7 | 0.056751238 | 0.481372105 | 15.0 | 127.3 |
| NA 4 | 284,701,149.6 | 439.0 | 6,340,171.9 | 7 | 0.056751238 | 0.481372105 | 6.1 | 51.7 |
| NA 5 | 284,701,149.6 | 1,181.6 | 6,340,171.9 | 7 | 0.056751238 | 0.481372105 | 16.4 | 139.1 |
| NA 6 | 284,701,149.6 | 632.7 | 6,340,171.9 | 7 | 0.056751238 | 0.481372105 | 8.8 | 74.5 |
| NA 7 | 284,701,149.6 | 919.3 | 6,340,171.9 | 7 | 0.056751238 | 0.481372105 | 12.8 | 108.2 |
| NA 8 | 284,701,149.6 | 684.5 | 6,340,171.9 | 7 | 0.056751238 | 0.481372105 | 9.5 | 80.6 |
| NA 9 | 284,701,149.6 | 4,466.1 | 6,340,171.9 | 7 | 0.056751238 | 0.481372105 | 62.0 | 525.6 |
| NA 10 | 284,701,149.6 | 4,432.8 | 6,340,171.9 | 7 | 0.056751238 | 0.481372105 | 61.5 | 521.7 |
| NA 11 | 284,701,149.6 | 1,958.3 | 6,340,171.9 | 7 | 0.056751238 | 0.481372105 | 27.2 | 230.5 |
| NA 12 | 284,701,149.6 | 1,212.8 | 6,340,171.9 | 7 | 0.056751238 | 0.481372105 | 16.8 | 142.7 |
| NA 13 | 284,701,149.6 | 1,186.3 | 6,340,171.9 | 7 | 0.056751238 | 0.481372105 | 16.5 | 139.6 |
| NA 14 | 284,701,149.6 | 399.4 | 6,340,171.9 | 7 | 0.056751238 | 0.481372105 | 5.5 | 47.0 |
| NA 15 | 284,701,149.6 | 2,017.9 | 6,340,171.9 | 7 | 0.056751238 | 0.481372105 | 28.0 | 237.5 |
| | | | | | | Subtotal: | 88,246.6 | 748,520.4 |

*Calculated using average burrow density for each town

Table 4: continued

| Town Label | Park Area ($m^2$) | Town Area ($m^2$) | Total Area of Towns in Park ($m^2$) | Avg. Burrow Density of Town (Number of burrows/30$m^2$) | MIN Volume of Burrow ($m^3$) | MAX Volume of Burrow ($m^3$) | MIN* Excavated Sediment Per Town ($m^3$) | MAX* Excavated Sediment Per Town ($m^3$) |
|---|---|---|---|---|---|---|---|---|
| NA 16 | 284,701,149.6 | 938.0 | 6,340,171.9 | 7 | 0.056751238 | 0.481372105 | 13.0 | 110.4 |
| NA 17 | 284,701,149.6 | 2,332.5 | 6,340,171.9 | 7 | 0.056751238 | 0.481372105 | 32.4 | 274.5 |
| NA 18 | 284,701,149.6 | 3,511.6 | 6,340,171.9 | 7 | 0.056751238 | 0.481372105 | 48.7 | 413.3 |
| NA 19 | 284,701,149.6 | 2,740.6 | 6,340,171.9 | 7 | 0.056751238 | 0.481372105 | 38.0 | 322.5 |
| NA 20 | 284,701,149.6 | 1,671.1 | 6,340,171.9 | 7 | 0.056751238 | 0.481372105 | 23.2 | 196.7 |
| NA 21 | 284,701,149.6 | 1,331.3 | 6,340,171.9 | 7 | 0.056751238 | 0.481372105 | 18.5 | 156.7 |
| NA 22 | 284,701,149.6 | 4,556.8 | 6,340,171.9 | 7 | 0.056751238 | 0.481372105 | 63.2 | 536.3 |
| NA 23 | 284,701,149.6 | 866.9 | 6,340,171.9 | 7 | 0.056751238 | 0.481372105 | 12.0 | 102.0 |
| NA 24 | 284,701,149.6 | 464.8 | 6,340,171.9 | 7 | 0.056751238 | 0.481372105 | 6.4 | 54.7 |
| NA 25 | 284,701,149.6 | 629.4 | 6,340,171.9 | 7 | 0.056751238 | 0.481372105 | 8.7 | 74.1 |
| NA 26 | 284,701,149.6 | 657.1 | 6,340,171.9 | 7 | 0.056751238 | 0.481372105 | 9.1 | 77.3 |
| NA 27 | 284,701,149.6 | 869.2 | 6,340,171.9 | 7 | 0.056751238 | 0.481372105 | 12.1 | 102.3 |
| NA 28 | 284,701,149.6 | 3,711.4 | 6,340,171.9 | 7 | 0.056751238 | 0.481372105 | 51.5 | 436.8 |
| NA 29 | 284,701,149.6 | 1,229.7 | 6,340,171.9 | 7 | 0.056751238 | 0.481372105 | 17.1 | 144.7 |
| NA 30 | 284,701,149.6 | 3,435.1 | 6,340,171.9 | 7 | 0.056751238 | 0.481372105 | 47.7 | 404.3 |
| NA 31 | 284,701,149.6 | 6,061.8 | 6,340,171.9 | 7 | 0.056751238 | 0.481372105 | 84.1 | 713.4 |
| NA 32 | 284,701,149.6 | 733.2 | 6,340,171.9 | 7 | 0.056751238 | 0.481372105 | 10.2 | 86.3 |
| NA 33 | 284,701,149.6 | 649.4 | 6,340,171.9 | 7 | 0.056751238 | 0.481372105 | 9.0 | 76.4 |
| | | | | | | Total: | 88,751.5 | 752,803.1 |

*Calculated using average burrow density for each town

Table 5: Wind Cave National Park: Prairie Dog Town Sampling, Burrow Density, and Area.

| Town Label | Town Area ($m^2$) | Total Number of Towns in Park | Number of Towns Too Small to Sample | Number Sample Points per Town | Average Burrow Density of Town (number of burrows/30 meters) | Town Percentage of Park Area (%) | Park Area ($m^2$) |
|---|---|---|---|---|---|---|---|
| 1 | 3,456,248.0 | 39 | 7 | 326 | 5 | 3.0 | 113,773,026.5 |
| 2 | 691,636.8 | 39 | 7 | 65 | 5 | 0.6 | 113,773,026.5 |
| 3 | 594,674.0 | 39 | 7 | 46 | 6 | 0.5 | 113,773,026.5 |
| 4 | 137,510.2 | 39 | 7 | 9 | 5 | 0.1 | 113,773,026.5 |
| 5 | 335,736.0 | 39 | 7 | 28 | 5 | 0.3 | 113,773,026.5 |
| 6 | 300,712.1 | 39 | 7 | 26 | 9 | 0.3 | 113,773,026.5 |
| 7 | 33,725.2 | 39 | 7 | 2 | 3 | 0.0 | 113,773,026.5 |
| 8 | 10,506.1 | 39 | 7 | 1 | 6 | 0.0 | 113,773,026.5 |
| 9 | 18,692.8 | 39 | 7 | 1 | 2 | 0.0 | 113,773,026.5 |
| 10 | 64,172.3 | 39 | 7 | 4 | 5 | 0.1 | 113,773,026.5 |
| 11 | 393,992.3 | 39 | 7 | 36 | 6 | 0.3 | 113,773,026.5 |
| 12 | 14,059.0 | 39 | 7 | 1 | 5 | 0.0 | 113,773,026.5 |
| 13 | 14,849.4 | 39 | 7 | 1 | 3 | 0.0 | 113,773,026.5 |
| 14 | 33,092.6 | 39 | 7 | 2 | 7 | 0.0 | 113,773,026.5 |
| 15 | 554,600.4 | 39 | 7 | 53 | 6 | 0.5 | 113,773,026.5 |
| 16 | 27,318.5 | 39 | 7 | 2 | 1 | 0.0 | 113,773,026.5 |
| 17 | 87,468.5 | 39 | 7 | 7 | 1 | 0.1 | 113,773,026.5 |
| 18 | 29,581.3 | 39 | 7 | 1 | 0 | 0.0 | 113,773,026.5 |
| 19 | 19,925.4 | 39 | 7 | 0 | 2 | 0.0 | 113,773,026.5 |
| 20 | 36,634.7 | 39 | 7 | 3 | 3 | 0.0 | 113,773,026.5 |
| 21 | 10,100.4 | 39 | 7 | 1 | 0 | 0.0 | 113,773,026.5 |
| 22 | 22,636.4 | 39 | 7 | 2 | 7 | 0.0 | 113,773,026.5 |
| 23 | 1,200,927.6 | 39 | 7 | 120 | 5 | 1.1 | 113,773,026.5 |
| 24 | 2,495,329.0 | 39 | 7 | 256 | 5 | 2.2 | 113,773,026.5 |
| 25 | 7,926.4 | 39 | 7 | 1 | 3 | 0.0 | 113,773,026.5 |

Table 5: continued

| Town Label | Town Area ($m^2$) | Total Number of Towns in Park | Number of Towns Too Small to Sample | Number Sample Points per Town | Average Burrow Density of Town (number of burrows/30 meters) | Town Percentage of Park Area (%) | Park Area ($m^2$) |
|---|---|---|---|---|---|---|---|
| 26 | 1,408,792.2 | 39 | 7 | 142 | 5 | 1.2 | 113,773,026.5 |
| 27 | 15,174.9 | 39 | 7 | 1 | 6 | 0.0 | 113,773,026.5 |
| 28 | 5,501.7 | 39 | 7 | 1 | 4 | 0.0 | 113,773,026.5 |
| 29 | 18,825.5 | 39 | 7 | 1 | 15 | 0.0 | 113,773,026.5 |
| 30 | 51,051.7 | 39 | 7 | 4 | 5 | 0.0 | 113,773,026.5 |
| 31 | 5,309,589.5 | 39 | 7 | 556 | 5 | 4.7 | 113,773,026.5 |
| 32 | 72,624.0 | 39 | 7 | 4 | 3 | 0.1 | 113,773,026.5 |
| NS 1 | 4,501.7 | 39 | 7 | 0 | 5 | 0.0 | 113,773,026.5 |
| NS 2 | 1,243.3 | 39 | 7 | 0 | 5 | 0.0 | 113,773,026.5 |
| NS 3 | 5,880.9 | 39 | 7 | 0 | 5 | 0.0 | 113,773,026.5 |
| NS 4 | 3,620.7 | 39 | 7 | 0 | 5 | 0.0 | 113,773,026.5 |
| NS 5 | 4,661.0 | 39 | 7 | 0 | 5 | 0.0 | 113,773,026.5 |
| NS 6 | 2,784.3 | 39 | 7 | 0 | 5 | 0.0 | 113,773,026.5 |
| NS 7 | 6,670.1 | 39 | 7 | 0 | 5 | 0.0 | 113,773,026.5 |

NS: Not Sample

Table 6: Excavated Sediment Estimates for Wind Cave National Park.

| Town Label | Park Area ($m^2$) | Town Area ($m^2$) | Total Area of Towns in Park ($m^2$) | Avg. Burrow Density of Town (Number of burrows/30$m^2$) | MIN Volume of Burrow ($m^3$) | MAX Volume of Burrow ($m^3$) | MIN* Excavated Sediment Per Town ($m^3$) | MAX* Excavated Sediment Per Town ($m^3$) |
|---|---|---|---|---|---|---|---|---|
| 1 | 113,773,026.5 | 3,456,248.0 | 17,502,977.2 | 5 | 0.056751238 | 0.481372105 | 32,811.4 | 278,310.9 |
| 2 | 113,773,026.5 | 691,636.8 | 17,502,977.2 | 5 | 0.056751238 | 0.481372105 | 6,501.6 | 55,147.6 |
| 3 | 113,773,026.5 | 594,674.0 | 17,502,977.2 | 6 | 0.056751238 | 0.481372105 | 7,287.7 | 61,815.5 |
| 4 | 113,773,026.5 | 137,510.2 | 17,502,977.2 | 5 | 0.056751238 | 0.481372105 | 1,416.3 | 12,012.9 |
| 5 | 113,773,026.5 | 335,736.0 | 17,502,977.2 | 5 | 0.056751238 | 0.481372105 | 2,926.1 | 24,819.3 |
| 6 | 113,773,026.5 | 300,712.1 | 17,502,977.2 | 9 | 0.056751238 | 0.481372105 | 4,900.9 | 41,570.5 |
| 7 | 113,773,026.5 | 33,725.2 | 17,502,977.2 | 3 | 0.056751238 | 0.481372105 | 159.5 | 1,352.9 |
| 8 | 113,773,026.5 | 10,506.1 | 17,502,977.2 | 6 | 0.056751238 | 0.481372105 | 119.2 | 1,011.5 |
| 9 | 113,773,026.5 | 18,692.8 | 17,502,977.2 | 2 | 0.056751238 | 0.481372105 | 70.7 | 599.9 |
| 10 | 113,773,026.5 | 64,172.3 | 17,502,977.2 | 5 | 0.056751238 | 0.481372105 | 576.6 | 4,891.0 |
| 11 | 113,773,026.5 | 393,992.3 | 17,502,977.2 | 6 | 0.056751238 | 0.481372105 | 4,161.4 | 35,297.3 |
| 12 | 113,773,026.5 | 14,059.0 | 17,502,977.2 | 5 | 0.056751238 | 0.481372105 | 133.0 | 1,127.9 |
| 13 | 113,773,026.5 | 14,849.4 | 17,502,977.2 | 3 | 0.056751238 | 0.481372105 | 84.3 | 714.8 |
| 14 | 113,773,026.5 | 33,092.6 | 17,502,977.2 | 7 | 0.056751238 | 0.481372105 | 406.9 | 3,451.5 |
| 15 | 113,773,026.5 | 554,600.4 | 17,502,977.2 | 6 | 0.056751238 | 0.481372105 | 6,611.6 | 56,080.3 |
| 16 | 113,773,026.5 | 27,318.5 | 17,502,977.2 | 1 | 0.056751238 | 0.481372105 | 51.7 | 438.3 |
| 17 | 113,773,026.5 | 87,468.5 | 17,502,977.2 | 1 | 0.056751238 | 0.481372105 | 236.4 | 2,005.0 |
| 18 | 113,773,026.5 | 29,581.3 | 17,502,977.2 | 0 | 0.056751238 | 0.481372105 | 0.0 | 0.0 |
| 19 | 113,773,026.5 | 19,925.4 | 17,502,977.2 | 2 | 0.056751238 | 0.481372105 | 75.4 | 639.4 |
| 20 | 113,773,026.5 | 36,634.7 | 17,502,977.2 | 3 | 0.056751238 | 0.481372105 | 231.0 | 1,959.4 |
| 21 | 113,773,026.5 | 10,100.4 | 17,502,977.2 | 0 | 0.056751238 | 0.481372105 | 0.0 | 0.0 |
| 22 | 113,773,026.5 | 22,636.4 | 17,502,977.2 | 7 | 0.056751238 | 0.481372105 | 278.3 | 2,360.9 |
| 23 | 113,773,026.5 | 1,200,927.6 | 17,502,977.2 | 5 | 0.056751238 | 0.481372105 | 10,412.4 | 88,319.8 |
| 24 | 113,773,026.5 | 2,495,329.0 | 17,502,977.2 | 5 | 0.056751238 | 0.481372105 | 22,458.9 | 190,499.9 |
| 25 | 113,773,026.5 | 7,926.4 | 17,502,977.2 | 3 | 0.056751238 | 0.481372105 | 45.0 | 381.6 |
| 26 | 113,773,026.5 | 1,408,792.2 | 17,502,977.2 | 5 | 0.056751238 | 0.481372105 | 12,611.9 | 106,976.3 |
| 27 | 113,773,026.5 | 15,174.9 | 17,502,977.2 | 6 | 0.056751238 | 0.481372105 | 172.2 | 1,461.0 |
| 28 | 113,773,026.5 | 5,501.7 | 17,502,977.2 | 4 | 0.056751238 | 0.481372105 | 41.6 | 353.1 |
| 29 | 113,773,026.5 | 18,825.5 | 17,502,977.2 | 15 | 0.056751238 | 0.481372105 | 534.2 | 4,531.0 |
| 30 | 113,773,026.5 | 51,051.7 | 17,502,977.2 | 5 | 0.056751238 | 0.481372105 | 482.9 | 4,095.8 |
| 31 | 113,773,026.5 | 5,309,589.5 | 17,502,977.2 | 5 | 0.056751238 | 0.481372105 | 46,860.9 | 397,480.5 |
| 32 | 113,773,026.5 | 72,624.0 | 17,502,977.2 | 3 | 0.056751238 | 0.481372105 | 446.5 | 3,787.2 |
| NA 1 | 113,773,026.5 | 4,501.7 | 17,502,977.2 | 5 | 0.056751238 | 0.481372105 | 41.9 | 355.2 |
| NA 2 | 113,773,026.5 | 1,243.3 | 17,502,977.2 | 5 | 0.056751238 | 0.481372105 | 11.6 | 98.1 |
| NA 3 | 113,773,026.5 | 5,880.9 | 17,502,977.2 | 5 | 0.056751238 | 0.481372105 | 54.7 | 464.0 |
| NA 4 | 113,773,026.5 | 3,620.7 | 17,502,977.2 | 5 | 0.056751238 | 0.481372105 | 33.7 | 285.7 |
| NA 5 | 113,773,026.5 | 4,661.0 | 17,502,977.2 | 5 | 0.056751238 | 0.481372105 | 43.4 | 367.8 |
| NA 6 | 113,773,026.5 | 2,784.3 | 17,502,977.2 | 5 | 0.056751238 | 0.481372105 | 25.9 | 219.7 |
| NA 7 | 113,773,026.5 | 6,670.1 | 17,502,977.2 | 5 | 0.056751238 | 0.481372105 | 62.0 | 526.3 |
| | | | | | | Total: | 163,379.7 | 1,385,809.8 |

*Calculated using average burrow density for each town

Table 7: Devil's Tower National Monument: Sampling Point Descriptive Statistics for Habitat Characteristics Part I.

| | N | Range | Minimum | Maximum | Mean | Standard Deviation | Variance | Skewness | | Kurtosis | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Statistic | Std. Error | Statistic | Std. Error |
| Burrow Density (Burrows/30 $m^2$) | 15.0 | 9.0 | 9.0 | 18.0 | 14.4 | 3.0 | 9.3 | -0.5 | 0.6 | -0.6 | 1.1 |
| Elevation (m) | 15.0 | 11.0 | 1,178.0 | 1,189.0 | 1,181.1 | 3.1 | 9.7 | 1.7 | 0.6 | 2.3 | 1.1 |
| Slope (% rise) | 15.0 | 16.3 | 0.0 | 16.3 | 3.9 | 5.2 | 27.5 | 1.5 | 0.6 | 1.6 | 1.1 |
| Slope (degrees) | 15.0 | 9.3 | 0.0 | 9.3 | 2.2 | 3.0 | 8.9 | 1.5 | 0.6 | 1.5 | 1.1 |
| Aspect (degrees) | 15.0 | 162.6 | -1.0 | 161.6 | 73.6 | 73.1 | 5,344.7 | -0.1 | 0.6 | -2.2 | 1.1 |
| Distance to Streams (m) | 15.0 | 180.0 | 120.0 | 300.0 | 212.6 | 50.5 | 2,554.2 | -0.1 | 0.6 | 0.4 | 1.1 |
| Valid N (listwise) | 15.0 | | | | | | | | | | |

Table 8: Devil's Tower National Monument: Sampling Points Soil Order Frequency.

| | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|
| | 4 | 26.7 | 26.7 | 26.7 |
| Entisols | 11 | 73.3 | 73.3 | 100.0 |
| Total | 15 | 100.0 | 100.0 | |

Table 9: Devil's Tower National Monument: Sampling Points Taxonomic Particle Size Frequency.

| | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|
| | 4.0 | 26.7 | 26.7 | 26.7 |
| fine-loamy | 10.0 | 66.7 | 66.7 | 93.3 |
| sandy | 1.0 | 6.7 | 6.7 | 100.0 |
| Total | 15.0 | 100.0 | 100.0 | |

Table 10: Devil's Tower National Monument: Sampling Points Vegetation Frequency.

| | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|
| | 4.0 | 26.7 | 26.7 | 26.7 |
| Artemisia filifolia | 1.0 | 6.7 | 6.7 | 33.3 |
| Bouteloua gracilis | 10.0 | 66.7 | 66.7 | 100.0 |
| Total | 15.0 | 100.0 | 100.0 | |

Table 11: Devil's Tower National Monument: Sampling Points Dominant Drainage Frequency.

| | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|
| Excessively drained | 1.0 | 6.7 | 6.7 | 6.7 |
| Well drained | 14.0 | 93.3 | 93.3 | 100.0 |
| Total | 15.0 | 100.0 | 100.0 | |

Table 12: Devil's Tower National Monument: Sampling Points Wettest Drainage Frequency.

| | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|
| Excessively drained | 1.0 | 6.7 | 6.7 | 6.7 |
| Well drained | 14.0 | 93.3 | 93.3 | 100.0 |
| Total | 15.0 | 100.0 | 100.0 | |

Table 13: Devil's Tower National Monument: Sampling Points Aspect Direction Frequency.

| | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|
| East | 1.0 | 6.7 | 6.7 | 6.7 |
| Flat | 7.0 | 46.7 | 46.7 | 53.3 |
| South | 1.0 | 6.7 | 6.7 | 60.0 |
| South East | 6.0 | 40.0 | 40.0 | 100.0 |
| Total | 15.0 | 100.0 | 100.0 | |

Table 14: Theodore Roosevelt National Park: Sampling Point Descriptive Statistics for Habitat Characteristics Part I.

| | N | Range | Minimum | Maximum | Mean | Standard Deviation | Variance | Skewness | | Kurtosis | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Statistic | Std. Error | Statistic | Std. Error |
| Burrow Density (Burrows/30m$^2$) | 520.0 | 20.0 | 0.0 | 20.0 | 7.3 | 3.1 | 9.7 | 0.1 | 0.1 | 0.7 | 0.2 |
| Elevation (m) | 520.0 | 199.3 | 601.7 | 801.0 | 737.9 | 41.8 | 1,746.9 | -0.7 | 0.1 | -0.4 | 0.2 |
| Slope (% rise) | 520.0 | 71.5 | 0.2 | 71.7 | 4.7 | 6.1 | 37.6 | 4.6 | 0.1 | 34.7 | 0.2 |
| Slope (degrees) | 520.0 | 35.5 | 0.1 | 35.6 | 2.7 | 3.3 | 11.2 | 3.9 | 0.1 | 25.2 | 0.2 |
| Aspect (degrees) | 520.0 | 358.9 | 0.3 | 359.2 | 171.5 | 103.8 | 10,764.4 | 0.1 | 0.1 | -1.2 | 0.2 |
| Distance to Stream (m) | 520.0 | 636.4 | 0.0 | 636.4 | 221.2 | 149.4 | 22,317.7 | 0.6 | 0.1 | -0.5 | 0.2 |
| Valid N (listwise) | 520.0 | | | | | | | | | | |

Table 15: Theodore Roosevelt National Park: Sampling Points Soil Order Frequency.

| | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|
| | 63.0 | 12.1 | 12.1 | 12.1 |
| Entisols | 48.0 | 9.2 | 9.2 | 21.3 |
| Inceptisols | 35.0 | 6.7 | 6.7 | 28.1 |
| Mollisols | 374.0 | 71.9 | 71.9 | 100.0 |
| Total | 520.0 | 100.0 | 100.0 | |

Table 16: Theodore Roosevelt National Park: Sampling Points Taxonomic Particle Size Frequency.

| | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|
| | 63.0 | 12.1 | 12.1 | 12.1 |
| coarse-loamy | 70.0 | 13.5 | 13.5 | 25.6 |
| fine | 89.0 | 17.1 | 17.1 | 42.7 |
| fine-loamy | 257.0 | 49.4 | 49.4 | 92.1 |
| fine-loamy over sandy or sandy-skeletal | 19.0 | 3.7 | 3.7 | 95.8 |
| loamy | 22.0 | 4.2 | 4.2 | 100.0 |
| Total | 520.0 | 100.0 | 100.0 | |

Table 17: Theodore Roosevelt National Park: Sampling Points Vegetation Frequency.

| | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|
| | 122.0 | 23.5 | 23.5 | 23.5 |
| Artemisia tridentata | 54.0 | 10.4 | 10.4 | 33.8 |
| Bouteloua gracilis | 14.0 | 2.7 | 2.7 | 36.5 |
| Pascopyrum smithii | 250.0 | 48.1 | 48.1 | 84.6 |
| Pseudoroegneria spicata ssp. spicata | 44.0 | 8.5 | 8.5 | 93.1 |
| unknown scientific name | 36.0 | 6.9 | 6.9 | 100.0 |
| Total | 520.0 | 100.0 | 100.0 | |

Table 18: Theodore Roosevelt National Park: Sampling Points Dominant Drainage Frequency.

| | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|
| | 17.0 | 3.3 | 3.3 | 3.3 |
| Excessively drained | 2.0 | 0.4 | 0.4 | 3.7 |
| Somewhat excessively drained | 4.0 | 0.8 | 0.8 | 4.4 |
| Well drained | 497.0 | 95.6 | 95.6 | 100.0 |
| Total | 520.0 | 100.0 | 100.0 | |

Table 19: Theodore Roosevelt National Park: Sampling Points Wettest Drainage Frequency.

| | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|
| Excessively drained | 2.0 | 0.4 | 0.4 | 0.4 |
| Moderately well drained | 34.0 | 6.5 | 6.5 | 6.9 |
| Well drained | 484.0 | 93.1 | 93.1 | 100.0 |
| Total | 520.0 | 100.0 | 100.0 | |

Table 20: Theodore Roosevelt National Park: Sampling Points Aspect Direction Frequency.

| | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|
| East | 80.0 | 15.4 | 15.4 | 15.4 |
| North | 64.0 | 12.3 | 12.3 | 27.7 |
| North East | 77.0 | 14.8 | 14.8 | 42.5 |
| North West | 44.0 | 8.5 | 8.5 | 51.0 |
| South | 64.0 | 12.3 | 12.3 | 63.3 |
| South East | 46.0 | 8.8 | 8.8 | 72.1 |
| South West | 75.0 | 14.4 | 14.4 | 86.5 |
| West | 70.0 | 13.5 | 13.5 | 100.0 |
| Total | 520.0 | 100.0 | 100.0 | |

Table 21: Wind Cave National Park: Sampling Points Descriptive Statistics for Habitat Characteristics Part I.

| | N | Range | Minimum | Maximum | Mean | Standard Deviation | Variance | Skewness | | Kurtosis | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Statistic | Std. Error | Statistic | Std. Error |
| Burrow Density (Burrows/30m$^2$) | 1,704.0 | 18.0 | 0.0 | 18.0 | 4.9 | 2.9 | 8.3 | 0.6 | 0.1 | 0.4 | 0.1 |
| Elevation (m) | 1,704.0 | 308.1 | 1,107.4 | 1,415.6 | 1,281.2 | 69.9 | 4,887.8 | -0.8 | 0.1 | 0.4 | 0.1 |
| Slope (% rise) | 1,704.0 | 42.8 | 0.0 | 42.9 | 7.4 | 5.8 | 34.1 | 1.7 | 0.1 | 3.6 | 0.1 |
| Slope (degrees) | 1,704.0 | 23.2 | 0.0 | 23.2 | 4.2 | 3.3 | 10.8 | 1.6 | 0.1 | 3.2 | 0.1 |
| Aspect (degrees) | 1,704.0 | 359.7 | 0.1 | 359.9 | 152.1 | 91.0 | 8,273.4 | 0.5 | 0.1 | -0.5 | 0.1 |
| Distance to Stream (m) | 1,704.0 | 1,565.8 | 0.0 | 1,565.8 | 505.0 | 341.6 | 116,656.4 | 0.3 | 0.1 | -1.0 | 0.1 |
| Valid N (listwise) | 1,704.0 | | | | | | | | | | |

Table 22: Wind Cave National Park: Sampling Points Soil Order Frequency.

| | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|
| | 54.0 | 3.2 | 3.2 | 3.2 |
| Alfisols | 3.0 | 0.2 | 0.2 | 3.3 |
| Aridisols | 226.0 | 13.3 | 13.3 | 16.6 |
| Entisols | 215.0 | 12.6 | 12.6 | 29.2 |
| Mollisols | 1,151.0 | 67.5 | 67.5 | 96.8 |
| Vertisols | 55.0 | 3.2 | 3.2 | 100.0 |
| Total | 1,704.0 | 100.0 | 100.0 | |

Table 23: Wind Cave National Park: Sampling Points Taxonomic Particle Size Frequency.

| | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|
| | 54.0 | 3.2 | 3.2 | 3.2 |
| coarse-silty | 27.0 | 1.6 | 1.6 | 4.8 |
| fine | 226.0 | 13.3 | 13.3 | 18.0 |
| fine-loamy | 246.0 | 14.4 | 14.4 | 32.5 |
| fine-silty | 116.0 | 6.8 | 6.8 | 39.3 |
| loamy | 54.0 | 3.2 | 3.2 | 42.4 |
| loamy-skeletal | 926.0 | 54.3 | 54.3 | 96.8 |
| very-fine | 55.0 | 3.2 | 3.2 | 100.0 |
| Total | 1,704.0 | 100.0 | 100.0 | |

Table 24: Wind Cave National Park: Sampling Points Vegetation Frequency.

| | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|
| | 54.0 | 3.2 | 3.2 | 3.2 |
| Achillea | 3.0 | 0.2 | 0.2 | 3.3 |
| Achillea millefolium var. occidentalis | 172.0 | 10.1 | 10.1 | 13.4 |
| Amorpha canescens | 240.0 | 14.1 | 14.1 | 27.5 |
| Andropogon gerardii | 92.0 | 5.4 | 5.4 | 32.9 |
| Artemisia frigida | 10.0 | 0.6 | 0.6 | 33.5 |
| Bouteloua curtipendula | 663.0 | 38.9 | 38.9 | 72.4 |
| Pascopyrum smithii | 470.0 | 27.6 | 27.6 | 100.0 |
| Total | 1,704.0 | 100.0 | 100.0 | |

Table 25: Wind Cave National Park: Sampling Points Dominant Drainage Frequency.

| | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|
| Somewhat excessively drained | 114.0 | 6.7 | 6.7 | 6.7 |
| Well drained | 1,590.0 | 93.3 | 93.3 | 100.0 |
| Total | 1,704.0 | 100.0 | 100.0 | |

Table 26: Wind Cave National Park: Sampling Points Wettest Drainage Frequency.

| | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|
| Somewhat excessively drained | 40.0 | 2.3 | 2.3 | 2.3 |
| Well drained | 1,664.0 | 97.7 | 97.7 | 100.0 |
| Total | 1,704.0 | 100.0 | 100.0 | |

Table 27: Wind Cave National Park: Sampling Points Aspect Direction Frequency.

| | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|
| East | 333.0 | 19.5 | 19.5 | 19.5 |
| North | 165.0 | 9.7 | 9.7 | 29.2 |
| North East | 253.0 | 14.8 | 14.8 | 44.1 |
| North West | 90.0 | 5.3 | 5.3 | 49.4 |
| South | 286.0 | 16.8 | 16.8 | 66.1 |
| South East | 278.0 | 16.3 | 16.3 | 82.5 |
| South West | 206.0 | 12.1 | 12.1 | 94.5 |
| West | 93.0 | 5.5 | 5.5 | 100.0 |
| Total | 1,704.0 | 100.0 | 100.0 | |

Table 28: Devil's Tower National Monument: Test for Correlation.

| | | Burrow Density | Elevation (m) | Slope (% rise) | Slope (degrees) | Aspect (degrees) | Distance to Streams (m) |
|---|---|---|---|---|---|---|---|
| Burrow Density | Pearson Correlation | 1.000 | 0.032 | -0.104 | -0.105 | -0.310 | 0.168 |
| | Sig. (2-tailed) | | 0.911 | 0.714 | 0.710 | 0.260 | 0.551 |
| | N | 15.000 | 15.000 | 15.000 | 15.000 | 15.000 | 15.000 |
| Elevation (m) | Pearson Correlation | 0.032 | 1.000 | .929** | .928** | .517* | 0.504 |
| | Sig. (2-tailed) | 0.911 | | 0.000 | 0.000 | 0.049 | 0.056 |
| | N | 15.000 | 15.000 | 15.000 | 15.000 | 15.000 | 15.000 |
| Slope (% rise) | Pearson Correlation | -0.104 | .929** | 1.000 | 1.000** | .722** | 0.413 |
| | Sig. (2-tailed) | 0.714 | 0.000 | | 0.000 | 0.002 | 0.126 |
| | N | 15.000 | 15.000 | 15.000 | 15.000 | 15.000 | 15.000 |
| Slope (degrees) | Pearson Correlation | -0.105 | .928** | 1.000** | 1.000 | .724** | 0.414 |
| | Sig. (2-tailed) | 0.710 | 0.000 | 0.000 | | 0.002 | 0.125 |
| | N | 15.000 | 15.000 | 15.000 | 15.000 | 15.000 | 15.000 |
| Aspect (degrees) | Pearson Correlation | -0.310 | .517* | .722** | .724** | 1.000 | 0.483 |
| | Sig. (2-tailed) | 0.260 | 0.049 | 0.002 | 0.002 | | 0.068 |
| | N | 15.000 | 15.000 | 15.000 | 15.000 | 15.000 | 15.000 |
| Distance to Stream (m) | Pearson Correlation | 0.168 | 0.504 | 0.413 | 0.414 | 0.483 | 1.000 |
| | Sig. (2-tailed) | 0.551 | 0.056 | 0.126 | 0.125 | 0.068 | |
| | N | 15.000 | 15.000 | 15.000 | 15.000 | 15.000 | 15.000 |

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 29: Theodore Roosevelt National Park: Test for Correlation.

| | | Burrow Density | Elevation (m) | Slope (% rise) | Slope (degrees) | Aspect (degrees) | Distance to Streams (m) |
|---|---|---|---|---|---|---|---|
| Burrow Density | Pearson Correlation | 1.000 | -0.019 | 0.004 | 0.007 | -0.006 | -.132** |
| | Sig. (2-tailed) | | 0.658 | 0.921 | 0.877 | 0.894 | 0.002 |
| | N | 520.000 | 520.000 | 520.000 | 520.000 | 520.000 | 520.000 |
| Elevation (m) | Pearson Correlation | -0.019 | 1.000 | -.102* | -.106* | 0.004 | .290** |
| | Sig. (2-tailed) | 0.658 | | 0.020 | 0.016 | 0.923 | 0.000 |
| | N | 520.000 | 520.000 | 520.000 | 520.000 | 520.000 | 520.000 |
| Slope (% rise) | Pearson Correlation | 0.004 | -.102* | 1.000 | .998** | .134** | -.237** |
| | Sig. (2-tailed) | 0.921 | 0.020 | | 0.000 | 0.002 | 0.000 |
| | N | 520.000 | 520.000 | 520.000 | 520.000 | 520.000 | 520.000 |
| Slope (degrees) | Pearson Correlation | 0.007 | -.106* | .998** | 1.000 | .138** | -.244** |
| | Sig. (2-tailed) | 0.877 | 0.016 | 0.000 | | 0.002 | 0.000 |
| | N | 520.000 | 520.000 | 520.000 | 520.000 | 520.000 | 520.000 |
| Aspect (degrees) | Pearson Correlation | -0.006 | 0.004 | .134** | .138** | 1.000 | -0.028 |
| | Sig. (2-tailed) | 0.894 | 0.923 | 0.002 | 0.002 | | 0.529 |
| | N | 520.000 | 520.000 | 520.000 | 520.000 | 520.000 | 520.000 |
| Distance to Stream (m) | Pearson Correlation | -.132** | .290** | -.237** | -.244** | -0.028 | 1.000 |
| | Sig. (2-tailed) | 0.002 | 0.000 | 0.000 | 0.000 | 0.529 | |
| | N | 520.000 | 520.000 | 520.000 | 520.000 | 520.000 | 520.000 |

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 30: Wind Cave National Park: Test for Correlation.

| | | Burrow Density | Elevation (m) | Slope (% rise) | Slope (degrees) | Aspect (degrees) | Distance to Stream (m) |
|---|---|---|---|---|---|---|---|
| Burrow Density | Pearson Correlation | 1.000 | -0.007 | -.101** | -.101** | -.054* | 0.040 |
| | Sig. (2-tailed) | | 0.768 | 0.000 | 0.000 | 0.027 | 0.102 |
| | N | 1,704.000 | 1,704.000 | 1,704.000 | 1,704.000 | 1,704.000 | 1,704.000 |
| Elevation (m) | Pearson Correlation | -0.007 | 1.000 | 0.045 | 0.045 | -0.035 | .136** |
| | Sig. (2-tailed) | 0.768 | | 0.066 | 0.063 | 0.152 | 0.000 |
| | N | 1,704.000 | 1,704.000 | 1,704.000 | 1,704.000 | 1,704.000 | 1,704.000 |
| Slope (% rise) | Pearson Correlation | -.101** | 0.045 | 1.000 | 1.000** | -0.020 | .102** |
| | Sig. (2-tailed) | 0.000 | 0.066 | | 0.000 | 0.401 | 0.000 |
| | N | 1,704.000 | 1,704.000 | 1,704.000 | 1,704.000 | 1,704.000 | 1,704.000 |
| Slope (degrees) | Pearson Correlation | -.101** | 0.045 | 1.000** | 1.000 | -0.021 | .102** |
| | Sig. (2-tailed) | 0.000 | 0.063 | 0.000 | | 0.388 | 0.000 |
| | N | 1,704.000 | 1,704.000 | 1,704.000 | 1,704.000 | 1,704.000 | 1,704.000 |
| Aspect (degrees) | Pearson Correlation | -.054* | -0.035 | -0.020 | -0.021 | 1.000 | 0.003 |
| | Sig. (2-tailed) | 0.027 | 0.152 | 0.401 | 0.388 | | 0.906 |
| | N | 1,704.000 | 1,704.000 | 1,704.000 | 1,704.000 | 1,704.000 | 1,704.000 |
| Distance to Stream (m) | Pearson Correlation | 0.040 | .136** | .102** | .102** | 0.003 | 1.000 |
| | Sig. (2-tailed) | 0.102 | 0.000 | 0.000 | 0.000 | 0.906 | |
| | N | 1,704.000 | 1,704.000 | 1,704.000 | 1,704.000 | 1,704.000 | 1,704.000 |

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

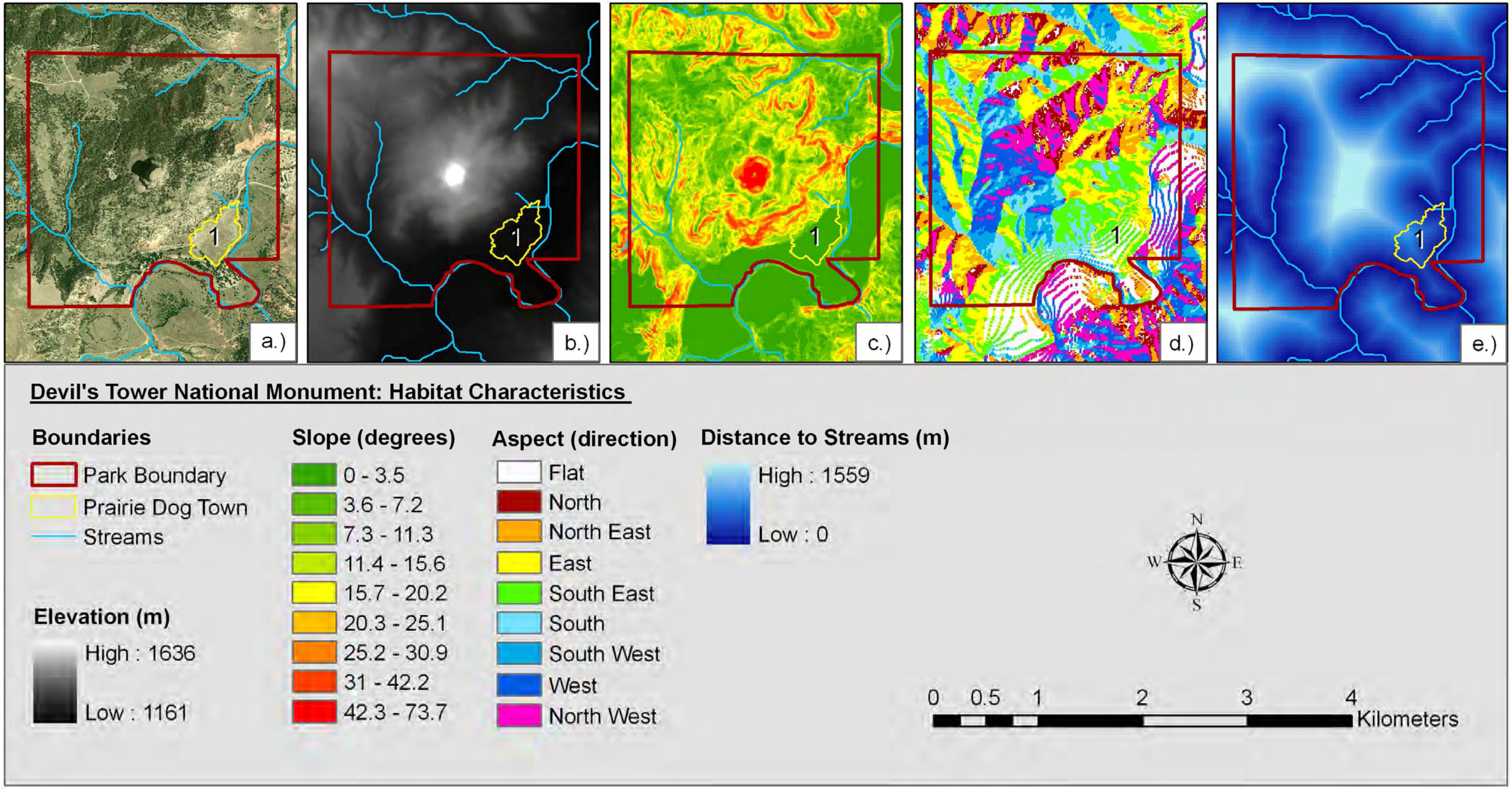


Figure 5: Devil's Tower National Monument: Habitat Characteristics Part I. a.) Aerial Imagery b.) Digital Elevation Model c.) Slope in Degrees d.) Aspect e.) Distance to Streams.

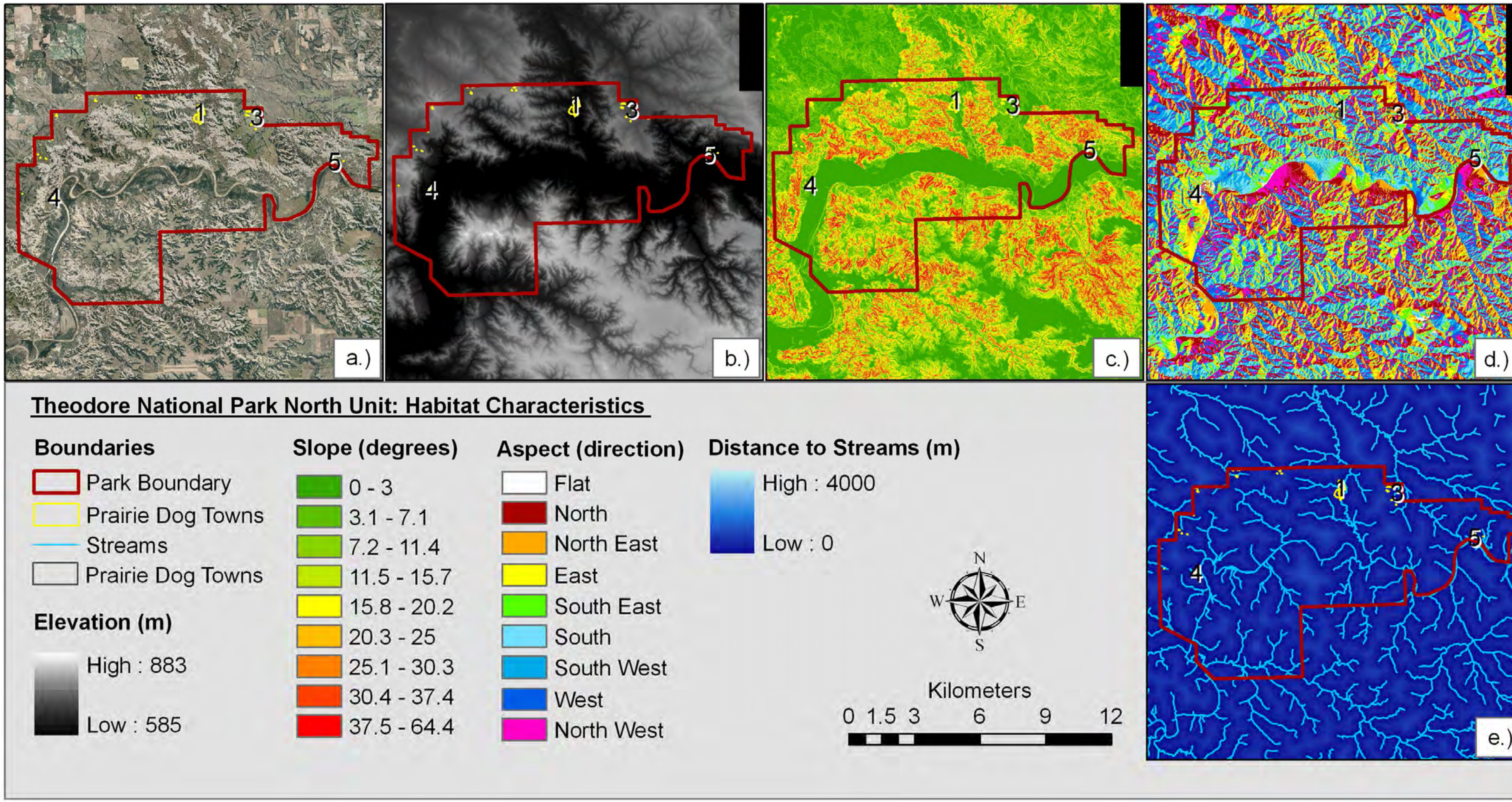


Figure 6: Theodore Roosevelt National Park: North Unit Habitat Characteristics Part I. a.) Aerial Imagery b.) Digital Elevation Model c.) Slope in Degrees d.) Aspect e.) Distance to Streams.

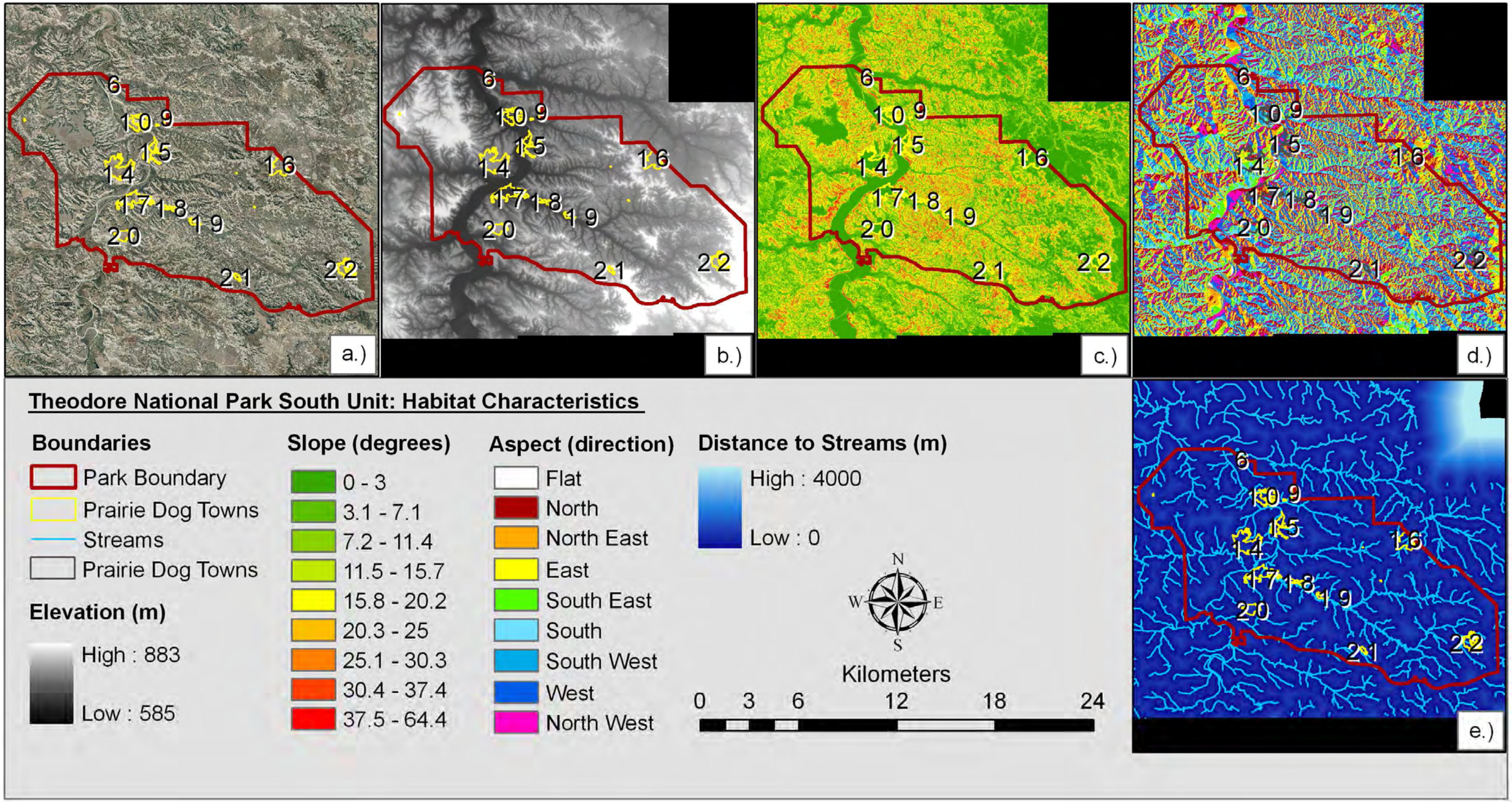


Figure 7: Theodore Roosevelt National Park: South Unit Habitat Characteristics Part I. a.) Aerial Imagery b.) Digital Elevation Model c.) Slope in Degrees d.) Aspect e.) Distance to Streams.

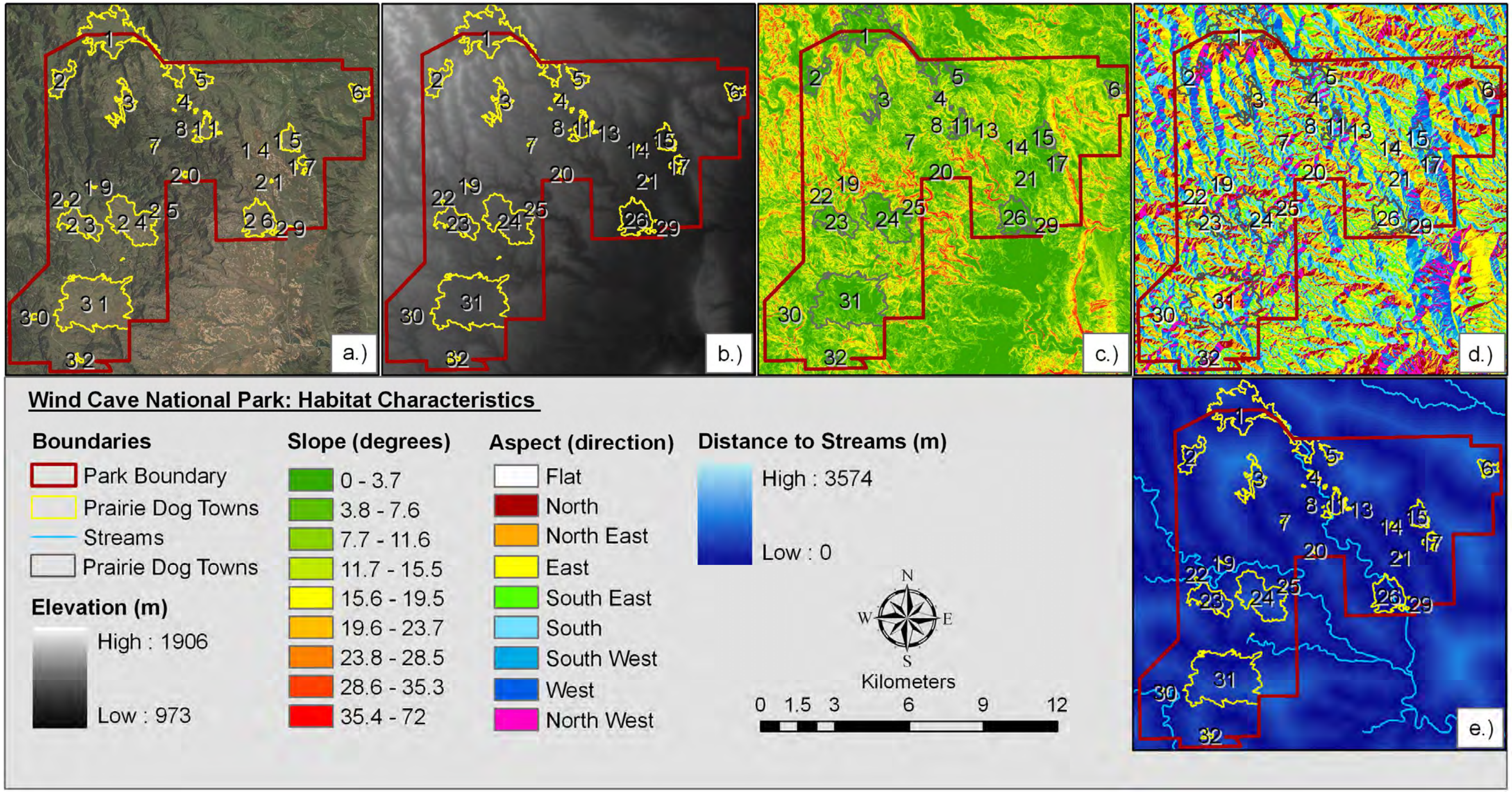


Figure 8: Wind Cave National Park: Habitat Characteristics Part I. a.) Aerial Imagery b.) Digital Elevation Model c.) Slope in Degrees d.) Aspect e.) Distance to Streams.

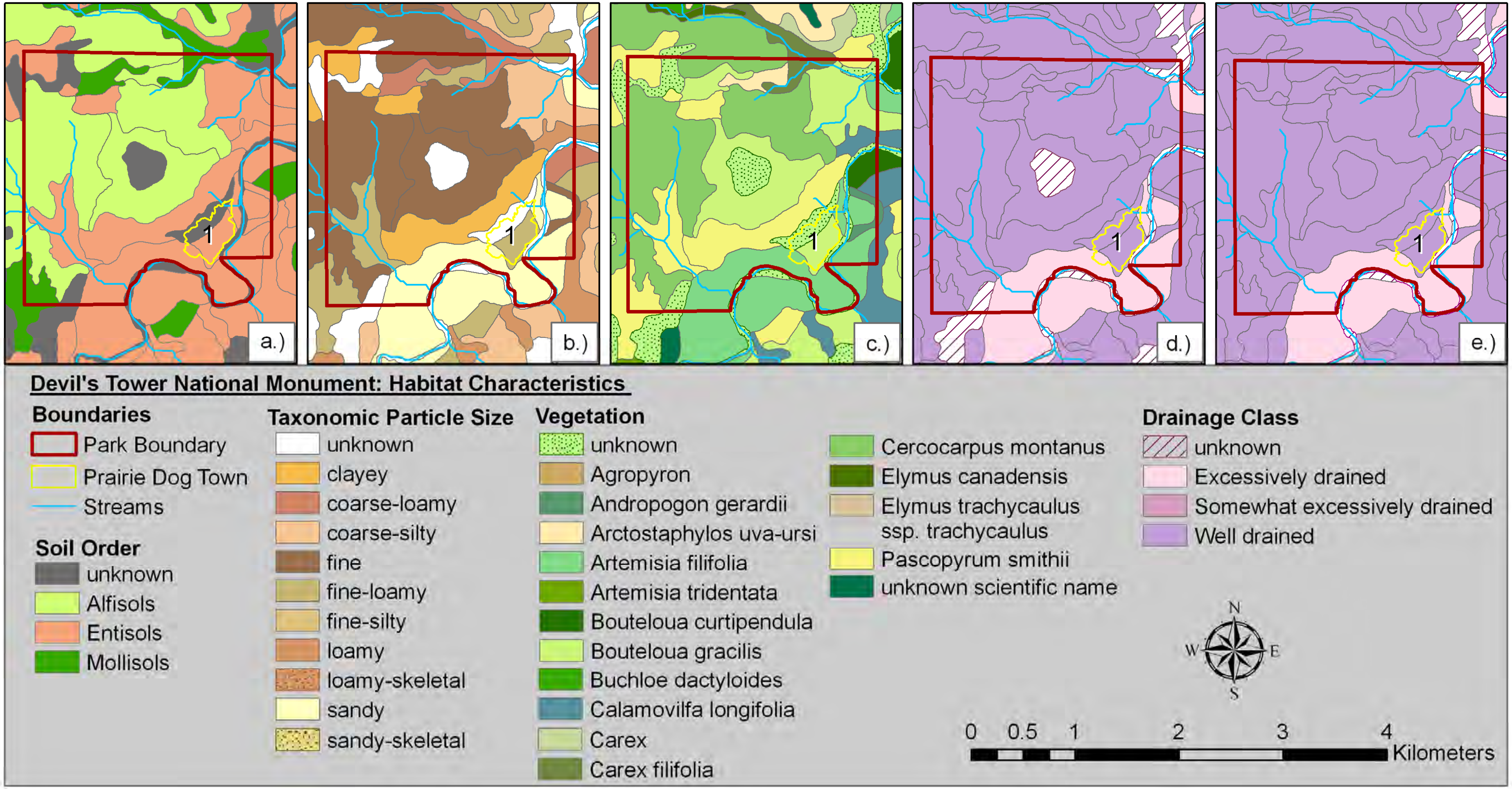


Figure 9: Devil's Tower National Monument: Habitat Characteristics Part II. a.) Soil Order b.) Taxonomic Particle Size c.) Vegetation d.) Dominant Drainage Class e.) Wettest Drainage Class.

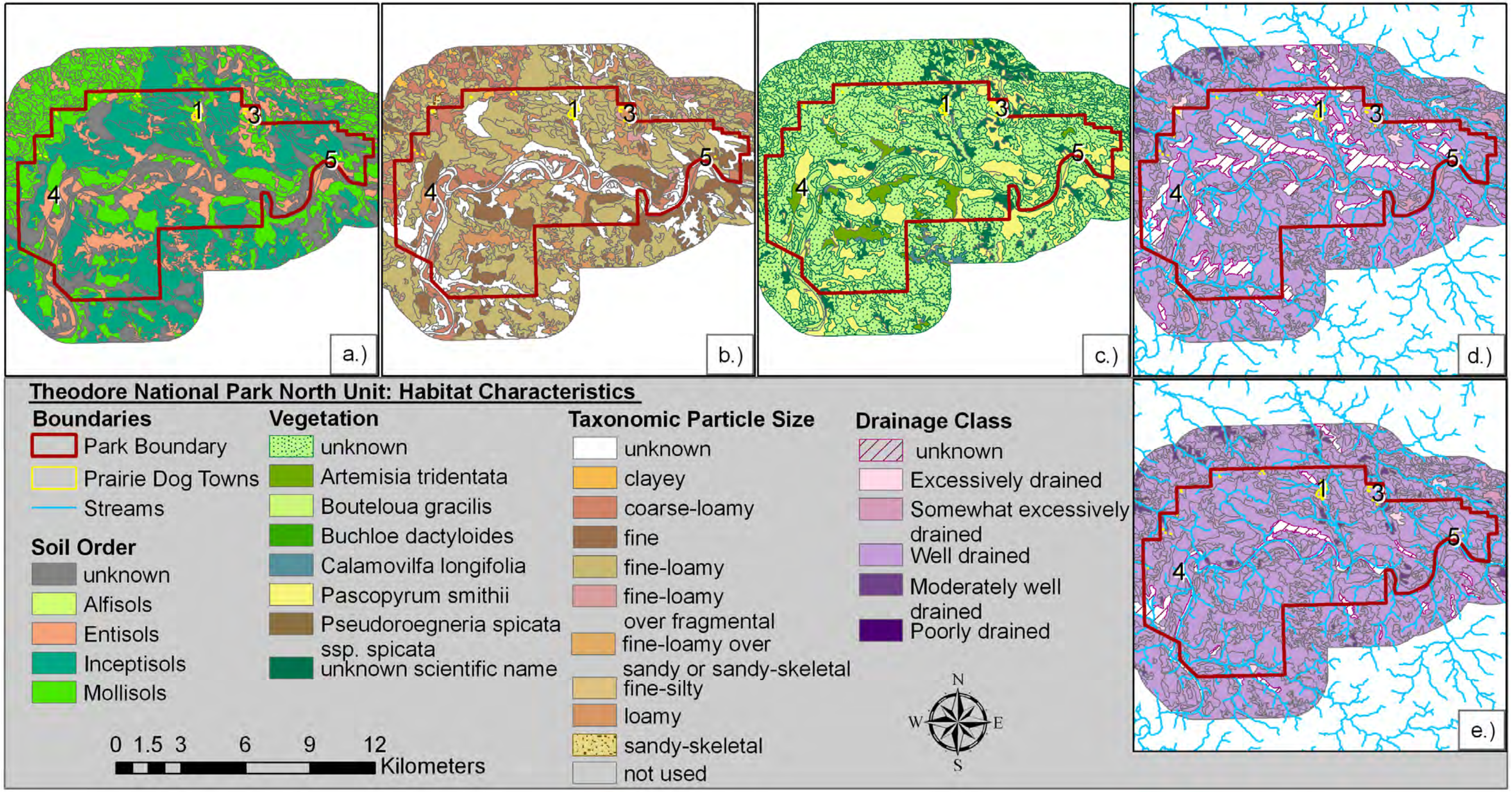


Figure 10: Theodore Roosevelt National Park: North Unit Habitat Characteristics Part II. a.) Soil Order b.) Taxonomic Particle Size c.) Vegetation d.) Dominant Drainage Class e.) Wettest Drainage Class.

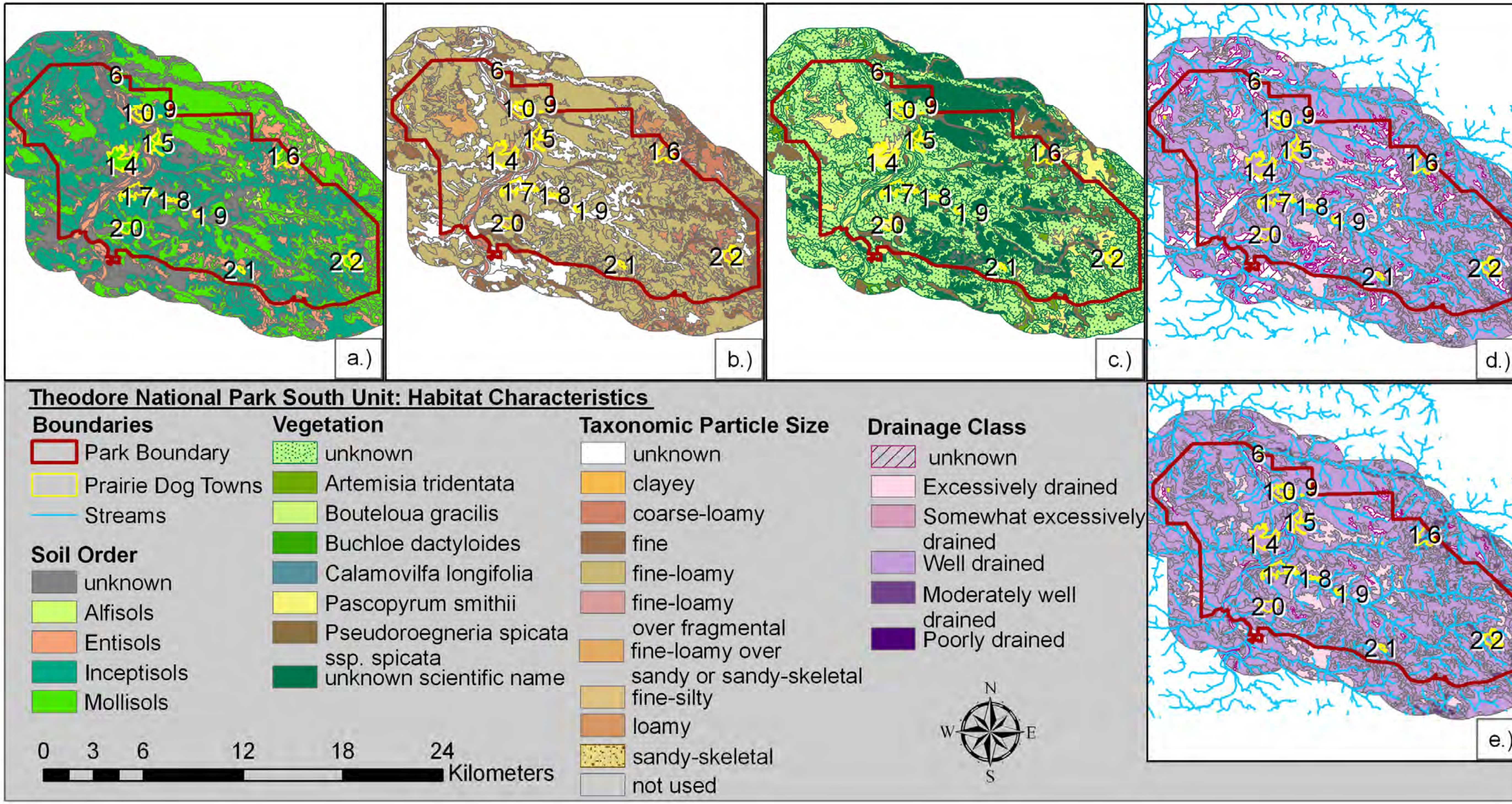


Figure 11: Theodore Roosevelt National Park: South Unit Habitat Characteristics Part II. a.) Soil Order b.) Taxonomic Particle Size c.) Vegetation d.) Dominant Drainage Class e.) Wettest Drainage Class.

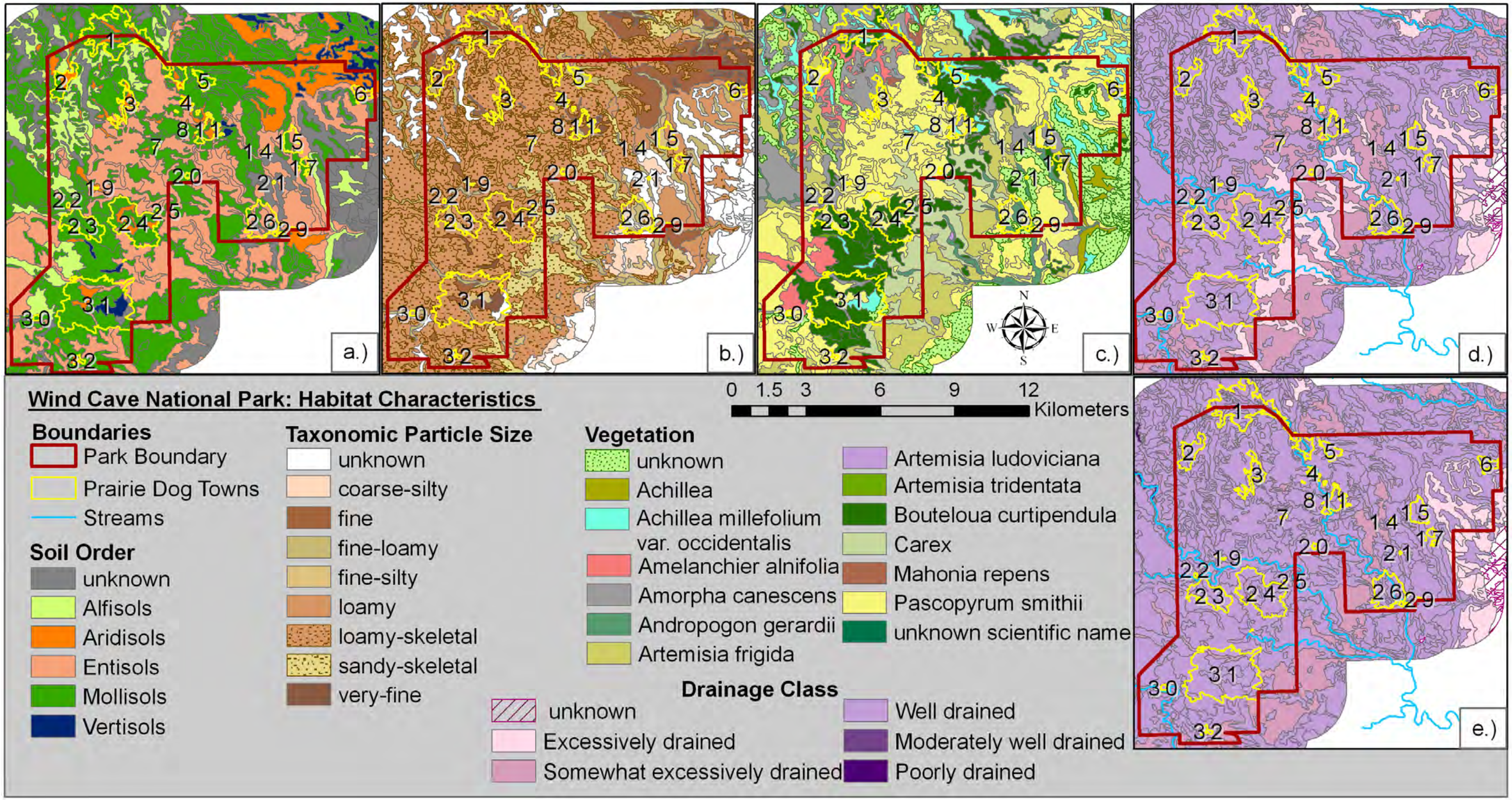


Figure 12: Wind Cave National Park: Habitat Characteristics Part II. a.) Soil Order b.) Taxonomic Particle Size c.) Vegetation d.) Dominant Drainage Class e.) Wettest Drainage Class.

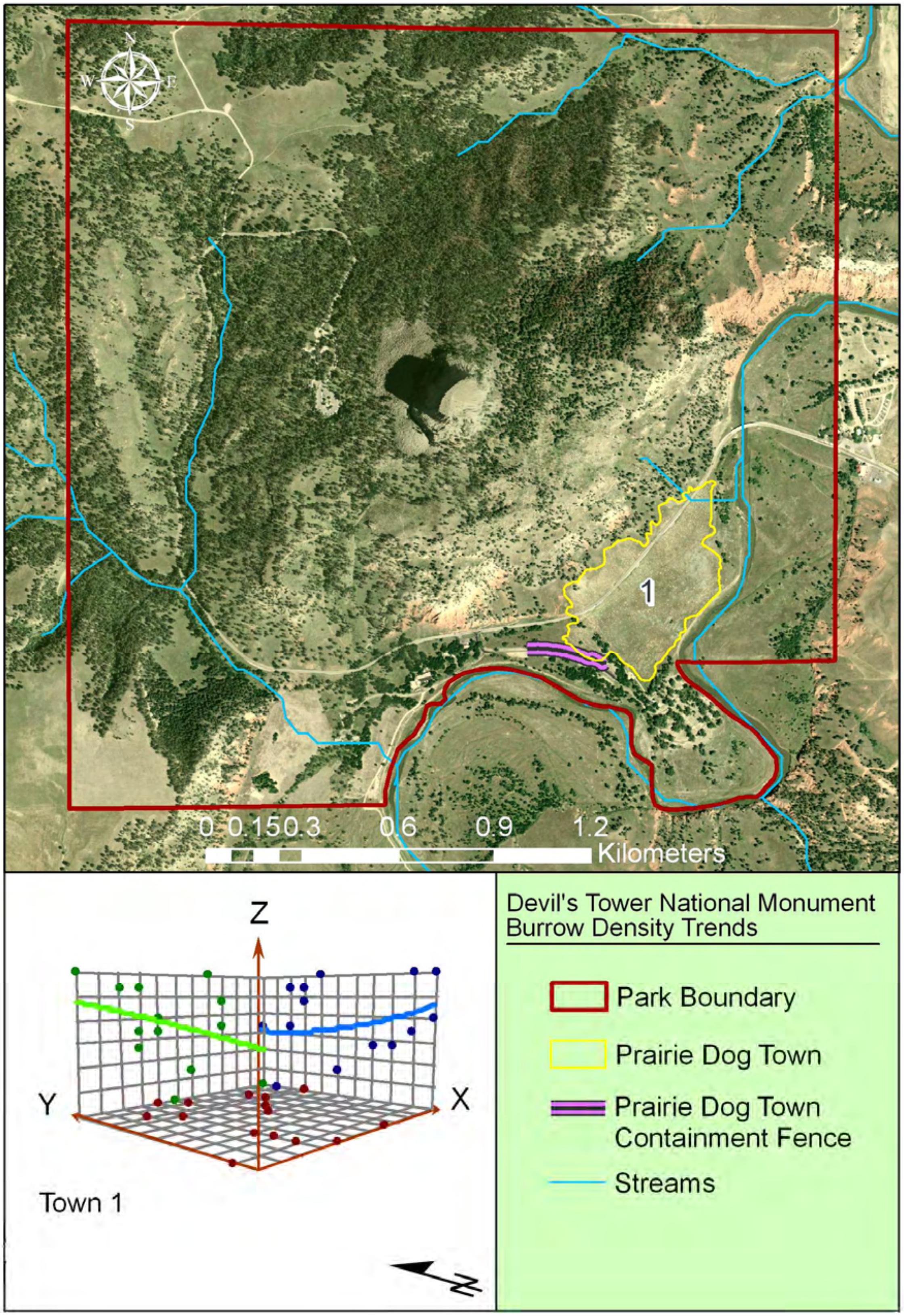


Figure 13: Devil’s Tower National Monument: N-S E-W Trends in Burrow Density.

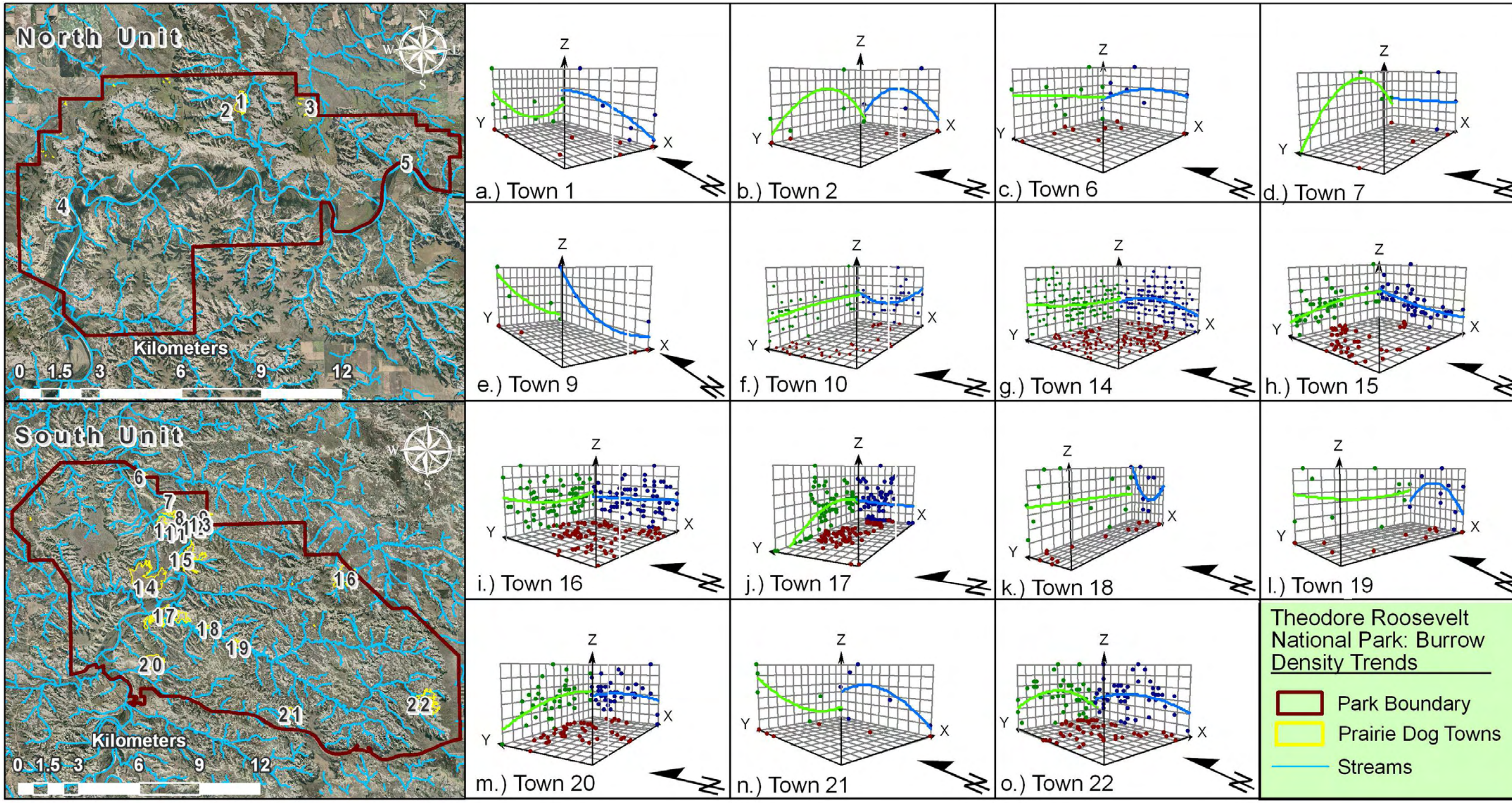


Figure 14: Theodore Roosevelt National Park: N-S E-W Trends in Burrow Density. a-f include towns with five or more sampling points.

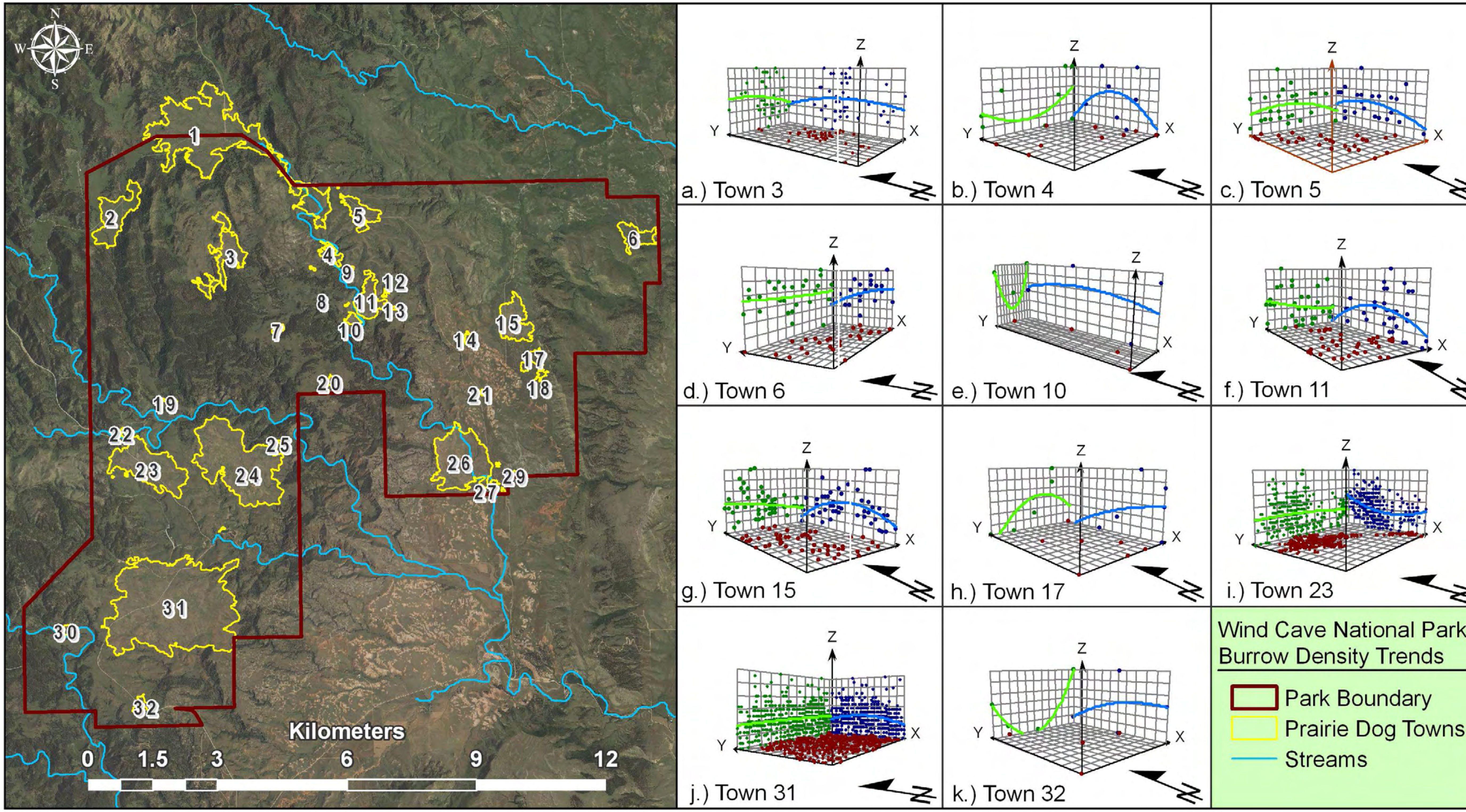


Figure 15: Wind Cave National Park N-S E-W Trends in Burrow Density. a-k include towns with five or more sampling points.

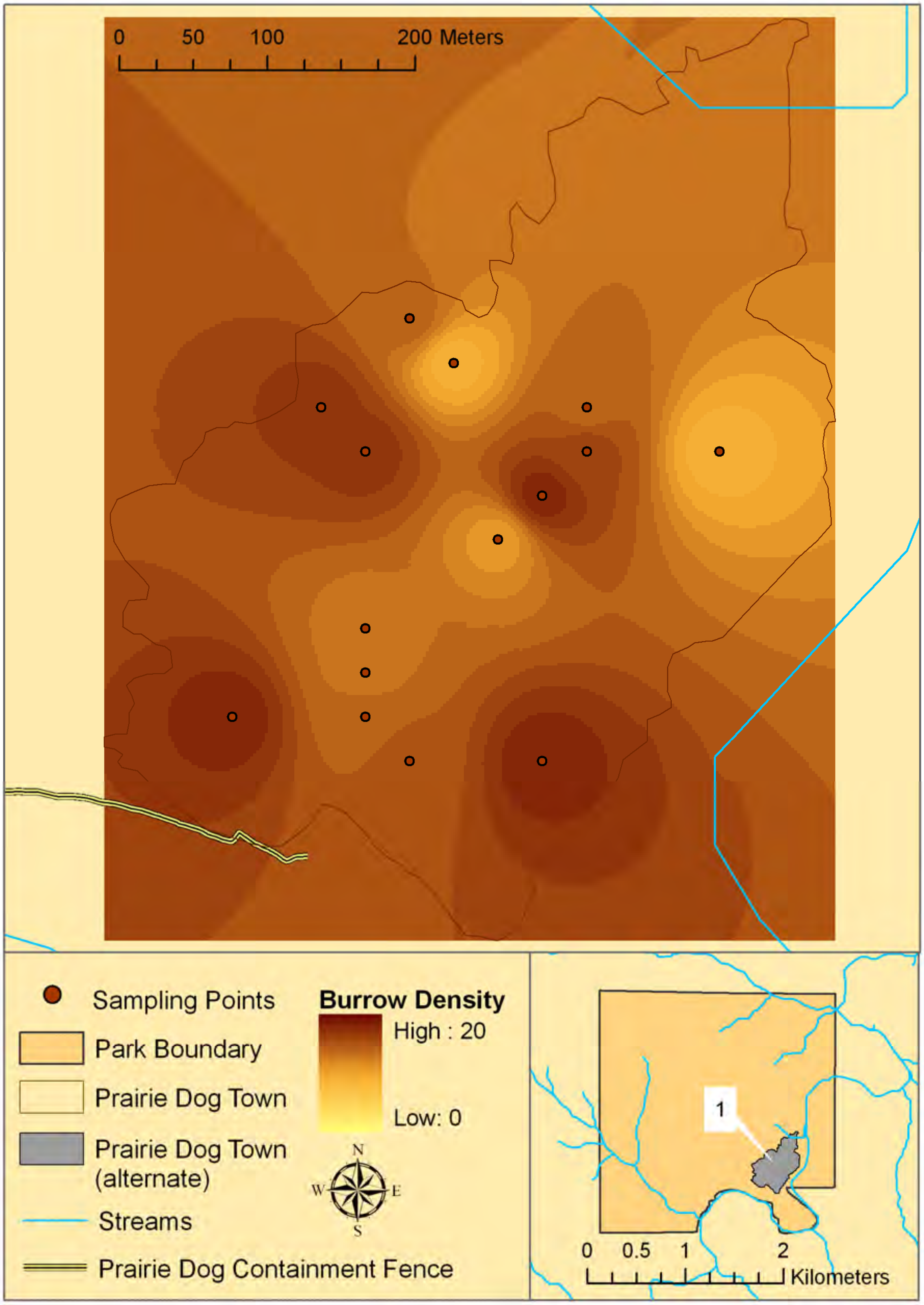


Figure 16: Devil's Tower National Monument: Inverse Distance Weighted Surface.

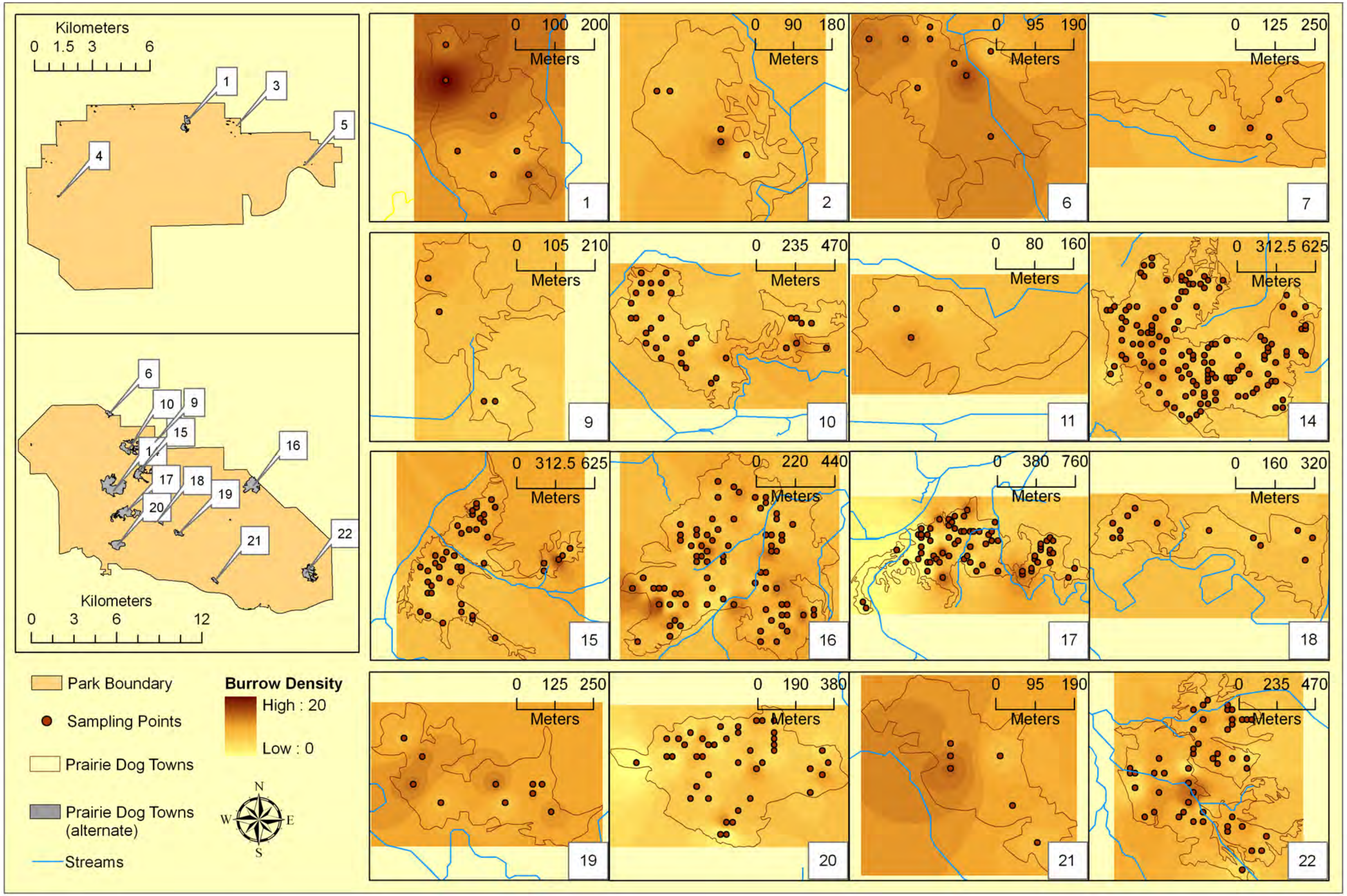


Figure 17: Theodore Roosevelt National Park: Inverse Distance Weighted Surface.

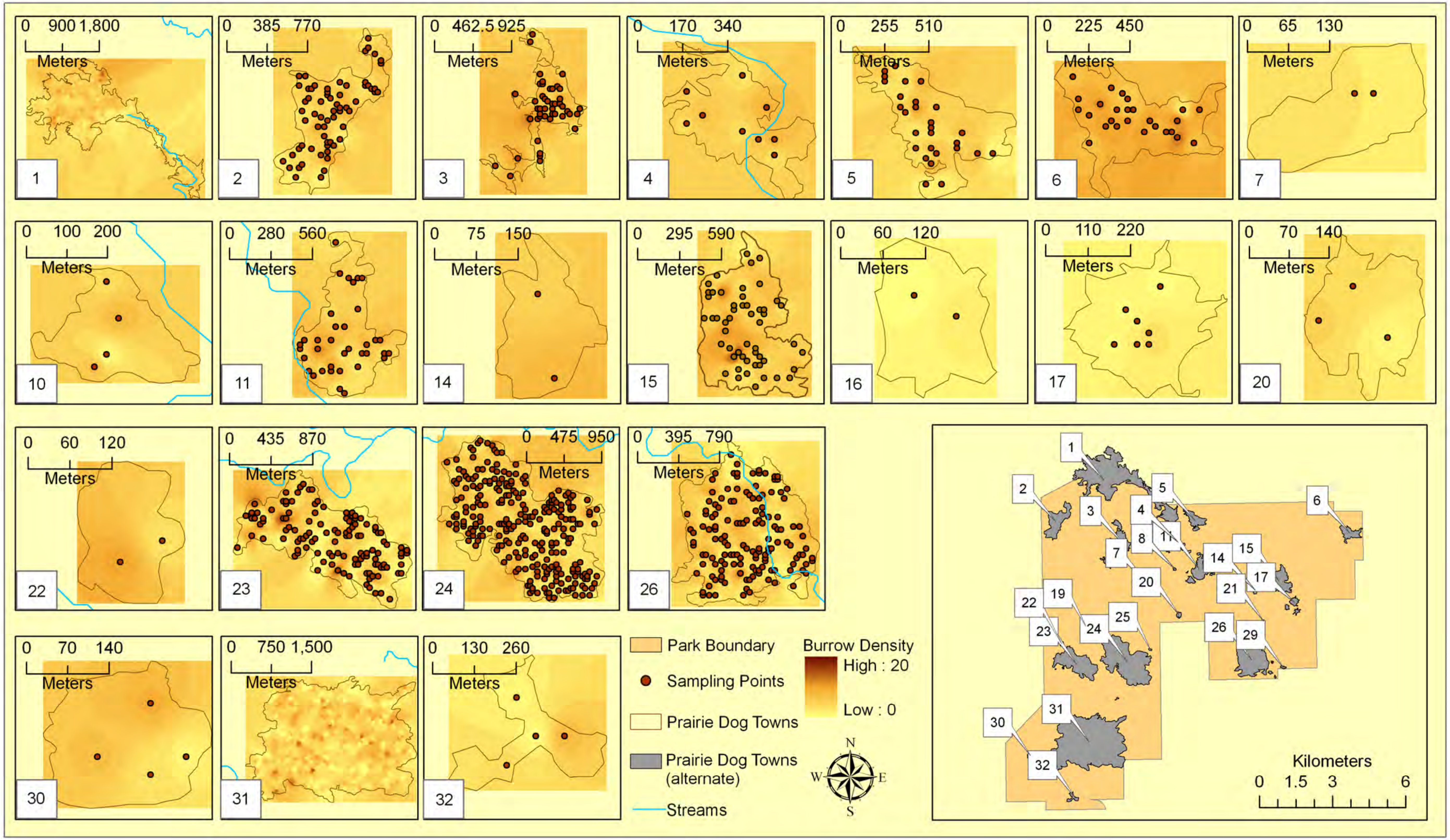


Figure 18: Wind Cave National Park: Inverse Distance Weighted Surface.

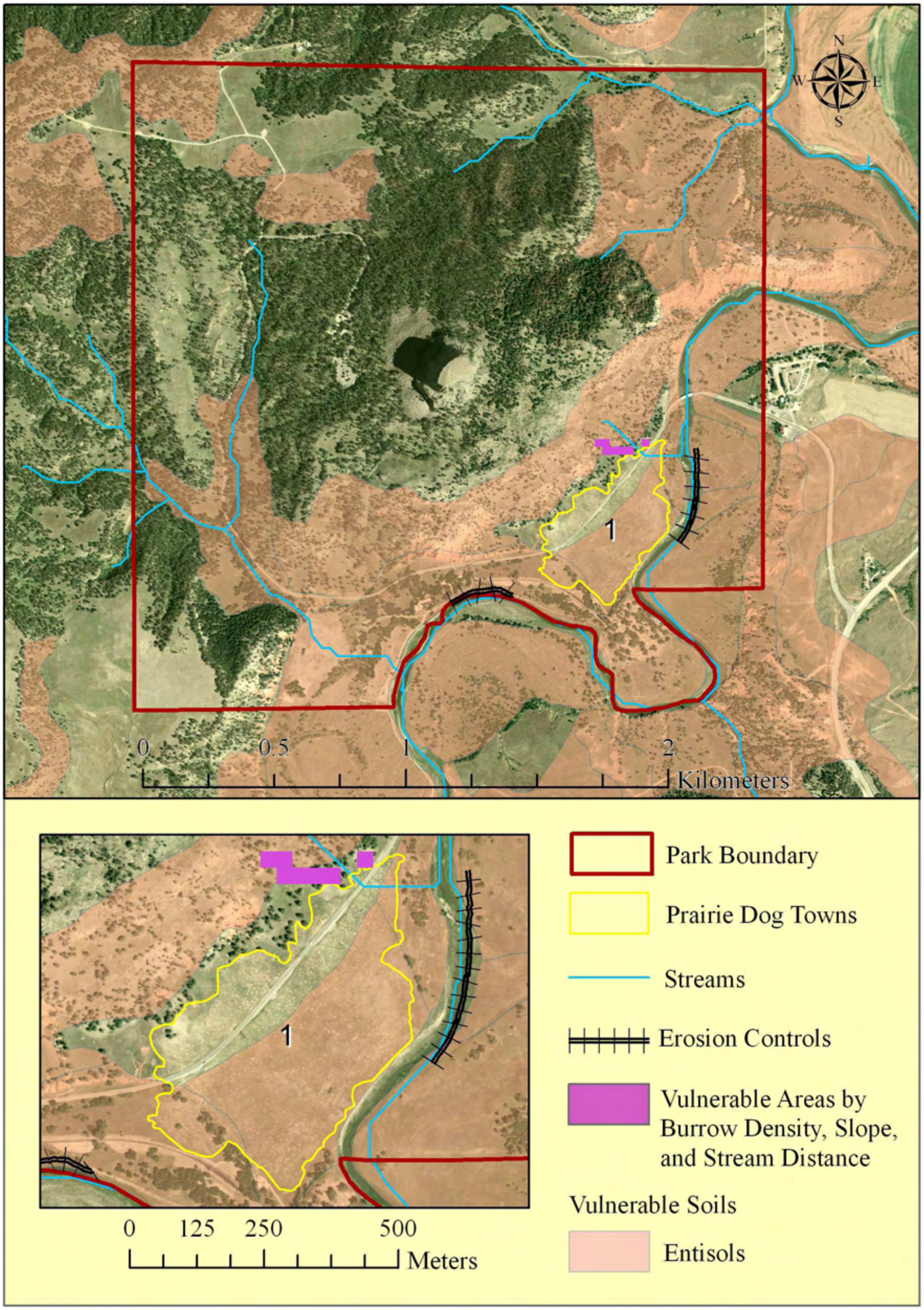


Figure 19: Devil’s Tower National Monument: Vulnerability to Erosion.

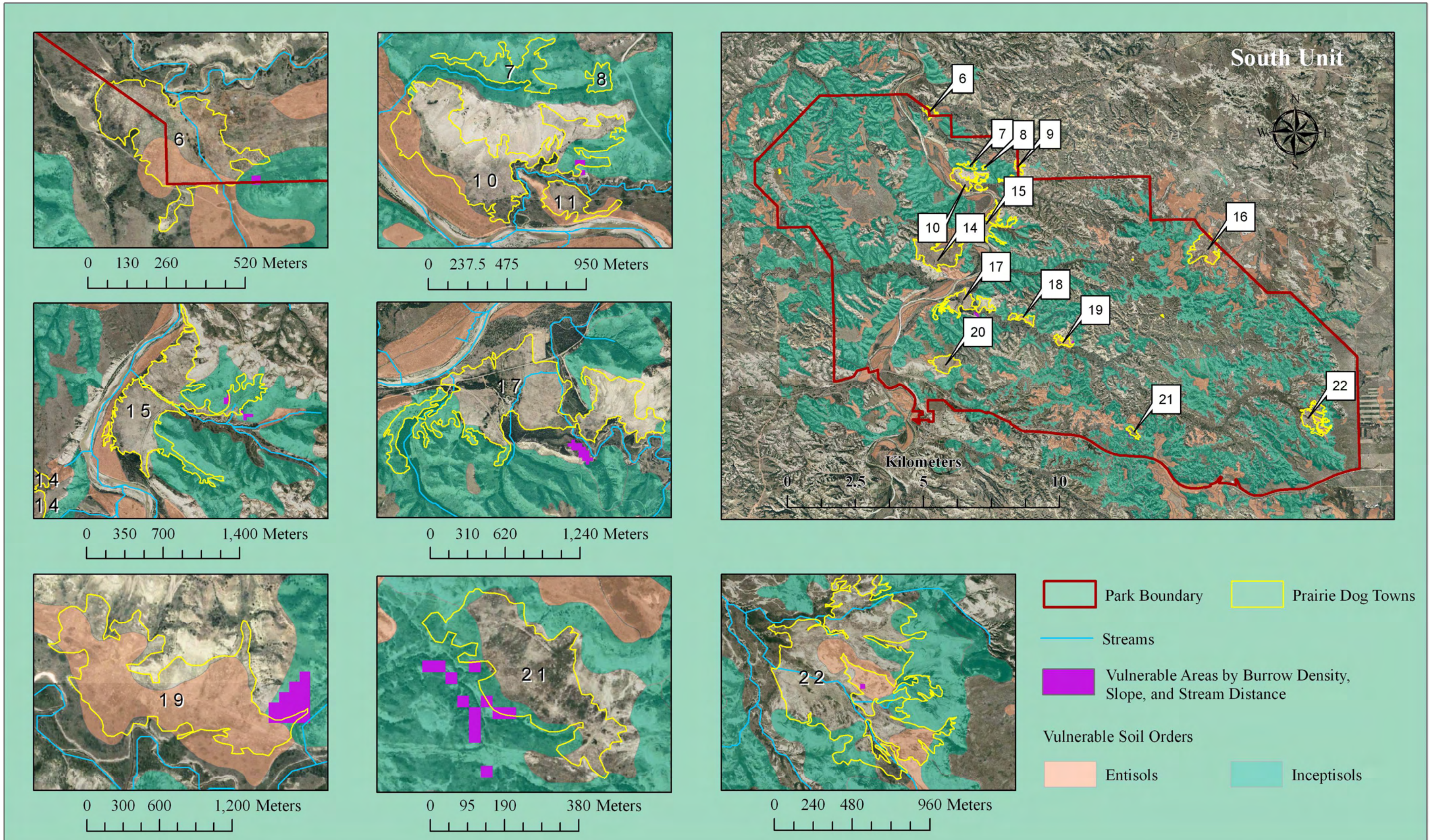


Figure 20: Theodore Roosevelt National Park: Vulnerability to Erosion.

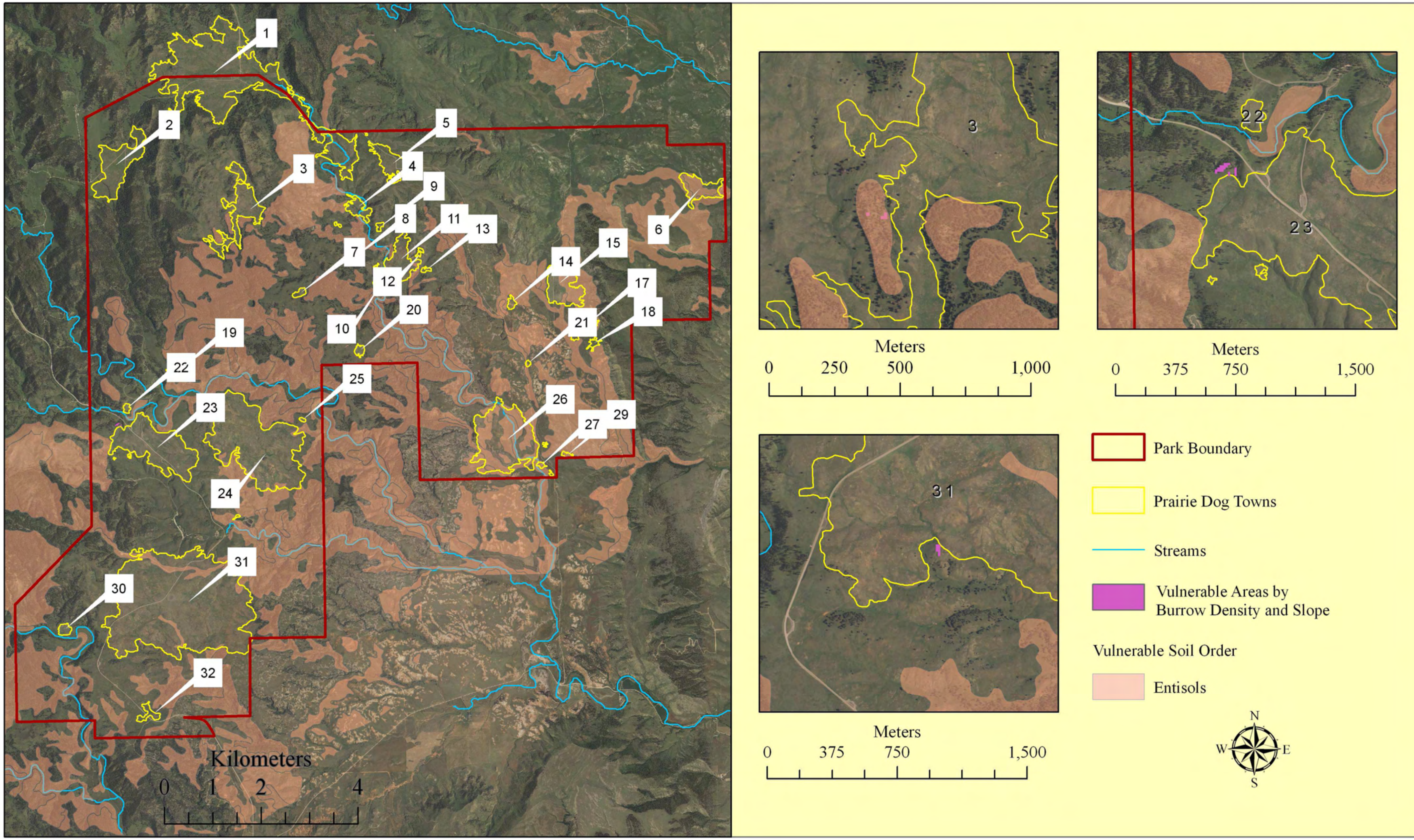


Figure 21: Wind Cave National Park: Vulnerability to Erosion.

# CHAPTER V

## DISCUSSION

Excavated sediment estimates for Wind Cave National Park were larger than any other site. Theodore Roosevelt National Park had the second largest volume of excavated sediment; Devil's Tower National Monument had the least excavated sediment. In terms of park size, Wind Cave National Park is less than half the size of TRNP, but has more than double excavated sediment. Prairie dog towns within Wind Cave National Park cover 13.7 percent of the park, and towns within TRNP only cover 2.2 percent of the park. Average town sizes are four times larger in Wind Cave National Park than at TRNP. The town in Devil's Tower is slightly larger than the average sized town at WCNP. In terms of park size, Wind Cave National Park is more than twenty-times larger than Devil's Tower and contains four times the area of prairie dog town coverage.

Wind Cave National Park is a medium-sized park, which contains relatively high percentages of prairie dog towns. Towns within Wind Cave are large and have the lowest average burrow density of all parks. However, WCNP has the highest volume of excavated sediment. Although burrow density ranges and averages are similar within TRNP and WCNP, the size and abundance of prairie dog towns vary. In accordance with research by Lomolino et al., it is reasonable to assume that towns within WCNP are more stable than those of TRNP based on town size (2003). Several towns within WCNP are adjacent to one another and most likely follow the adjacency pattern which was beneficial to town persistence prior to plaque epizootics observed in black-tailed prairie dog populations in Oklahoma (Lomolino et al. 2003). It is reasonable to assume that park size limits the amount of excavated sediment within DTNM. However, the size of the town in DTNM and its epizootic history may indicate that spatial isolation was beneficial to the town post-exposure to the plague (Lomolino et al. 2003). Theodore Roosevelt National Park is the largest park, but contains less excavated sediment than Wind Cave National Park. Habitat characteristics and management style could explain these differences. In addition to these variables, difficulty with town delineation in TRNP may also explain variations in town size, abundance, and excavated sediment. The badlands within TRNP made it difficult to delineate prairie dog towns at a macroscale; differences between prairie dog burrows and the surrounding badlands were not always apparent in aerial photos.

Overall, Wind Cave National Park contains higher range and mean elevations, shows south facing aspect, and is located farther from streams on average than Theodore Roosevelt National Park. Within prairie dog towns, Wind Cave National Park shares similar percentages of Mollisols, but lacks Inceptisols. Soils within WCNP have a greater percentage of rock fragments and slightly higher amounts of clay as compared to TRNP. Secondary frequencies of particle size decrease in the percentage of clay for both WCNP and TRNP. WCNP has greater vegetation diversity and the largest percentage of sideoats grama. The percentage of western wheat grass was relatively the same within towns of both parks. Perhaps contrasting habitat characteristics explain differences in prairie dog town size and abundance between the two parks. Towns within both parks are considered well-drained in 90 percent of sample points.

In addition to potential differences in management style, plague exposure may account for differences in the volume of excavated sediment. Through park policy, Wind Cave National Park actively manages black-tailed prairie dogs to maintain town size and population viability. Policy within Theodore Roosevelt National Park manages prairie dog populations indirectly by improving habitat for endangered species and species of focus within the park (USDI, NPS 1986). Perhaps, the species specific management style of Wind Cave National Park is the most beneficial for town size, abundance, and ultimately excavated sediment.

Past research suggests that black-tailed prairie dogs are found at elevations ranging from 1,300 to 2,000 masl, on slopes ranging from 0 to 4.5 percent slopes, and in well-drained loamy soils (Hollister 1916, Clark et al. 1971, and Pizzimenti 1975 in Hoogland 1996; Assal and Lockwood 2007). In addition, black-tailed prairie dogs prefer short perennial grasses (Koford 1958; Wuerthner 1997). Elevation ranges and averages of sampling points within Devil's Tower National Monument are slightly below the elevation range mentioned in past research. Theodore Roosevelt is well below the range listed in past research. The maximum elevation found in WCNP town sampling points falls within the range of elevation. The WCNP sampling point average elevation is just below the range from past research. The average slopes of sampling points within Devil's Tower National Monument and Theodore Roosevelt National Park agree with the aforementioned research; slope values for these parks are 3.9 percent rise and 4.7 percent rise respectively. With an average slope of 7.4 percent rise, sampling points within Wind

Cave National Park do not coincide with previous slope data (Table 21). All towns show a dominant drainage class of well-drained and coincide with past research. Sampling points from DTNM and TRNP denoted fine-loamy as the majority particle size. The majority of sample points within WCNP were designated as loamy-skeletal (Table 9, Table 16, and Table 23). These particle size classifications concur with past research. The top three vegetation types found at all sites are perennial vegetation (Table 10, Table 17, and Table 24). Blue grama only reaches a maximum of 0.3 m in height. Western wheatgrass only reaches a height of 0.6 m and big sagebrush and sideoats grama reach a maximum of 0.9 m (USDA 2010).

Burrow trends show strong negative correlations with increasing distance from streams in TRNP. Within TRNP, the only shallow sloping areas are near flood plains. This explains the negative correlation. Burrow density increases in two of the towns based on vegetation, taxonomic particle size, and soil order. Similar correlations between burrow density, western wheatgrass, and Mollisols were found in WCNP for one town. Slope and aspect were negatively correlated to burrow density in WCNP. As in TRNP, prairie dogs within WCNP burrow more actively in shallow sloping areas. In terms of aspect in WCNP, prairie dogs burrow more in east facing slopes than in west facing slopes. In WCNP, burrow density increases as the degree of aspect decreases. Areas with the largest burrow density face to the northeast. Areas of the lowest burrow density face to the northwest. As seen in Figure 8C and 8D, the more mountainous regions of WCNP trend roughly N-S. More prairie dog activity is evident on the eastern side of the mountains which face the morning sun. The highest burrow density occurs to the northeast which faces the morning sun and receives the most sunlight throughout the day.

In terms of erosion vulnerability, the South Unit of Theodore Roosevelt National Park is the most vulnerable. Six of the sampled 17 towns in the South Unit displayed vulnerability to all of the vulnerability criteria. Three of the 32 towns in WCNP were somewhat vulnerable to erosion, but did not meet all of the vulnerability criteria. Town 3 met all of the vulnerability criteria except for stream distance and the other two towns only met burrow density and slope criteria for vulnerability. The town in Devil's Tower National Monument showed erosion vulnerability to the northeast of the town in proximity to the intersection of the road and stream. However, erosion controls were installed by the park southeast and southwest of the town where they prevent the excavated sediment transport into the stream. If the installation of erosion controls was reactive rather than proactive, then the controls suggest different erosion areas. Perhaps, the burrowing activity of prairie dogs in DTNM has a more immediate fluvial impact, and the high slope and high burrow densities of the northeast portion of the town aid in sediment transport to the stream. One result of this project was to pinpoint areas with very high burrow densities that may need erosion controls set in place for the future. By considering burrow density as a factor in erosion vulnerability, the zoogeomorphic effects of prairie dogs can be managed more effectively. The discrepancies in burrow density described below may alter the erosion control suggestions of this study. It is possible that the vulnerability criteria selected do not accurately reflect the most influential criteria.

Past research determined that burrow density within prairie dog towns can range from 10 to 300 burrows/10,000 $m^2$. When converted to the scale of this project, past research shows 0 to 0.9 burrows per 30 $m^2$. This number varies greatly from the average burrow densities determined via point counting in this project. WCNP and TRNP have burrow densities of five and seven burrows per 30 $m^2$ respectively. These convert to 1,667 and 2,333 burrows/10,000 $m^2$ respectively. Devil's Tower has the highest average burrow density which is 14 burrows/30 $m^2$ or 4,667 burrows/10,000 $m^2$. Differences between burrow density calculations of DTNM versus the other study sites may be attributed to low sample sizes and increased influence of outlier points. Koford noted that DTNM may have larger burrow densities because tourist feed the prairie dogs. His estimates showed a burrow density of 100 burrows/10,000 $m^2$ in DTNM, which are much lower than those measured in this study (1958).

Burrow density was responsible for differences between excavated sediment estimations of this study and Butler's estimations of mixed sediment (2006). Sediment estimations of this study were two to five times larger than Butler's estimations (2006). Unfortunately, Whicker and Detling did not mention the soil density value used to calculate kilograms of mixed soil per prairie dog burrow (1988). This study used the lowest soil density for soils with a loamy texture to convert minimum burrow volume estimates to kilograms. The converted value was three times lower than the value listed by Whicker and Detling for mixed soil (1988). It is possible that the estimates of mixed sediment, which was measured using primarily mound material, may be larger than estimates of excavated sediment. Mound material is deposited on the surface and is compacted by prairie dogs for flood prevention. Material on the surface may come from other burrows or other sources. These differences are slight when compared to differences in burrow density.

Potential causes for discrepancies in burrow density of this study can be attributed to a variety of sources. Variability in methodology used to calculate town area could cause discrepancies in burrow density. In an effort to determine if town area is the cause of density conflicts, area calculations from this study were compared to historic town area data from Dalsted et al. 1981. Using a map of Wind Cave, the corresponding towns were defined for this study (Dalsted, et al. 1981). Ten of the 11 towns were paired together. Town area data from Dalsted et al. was plotted from 1964 to 1978 for each town. After fitting linear trend lines to each town, an $R^2$ value was determined (Table 31). Town area from this study was added to Dalsted's data and a new $R^2$ value was calculated (1981). Using SPSS, a paired sample t-test was performed and revealed that there was no significant difference between the $R^2$ value of the trend line for Dalsted et al. data and the data of this study at a confidence of 95 percent (Table 32). This information suggests that town delineation methodology within this study is sound.

With improved management techniques and changes in prairie dog perception, towns and ultimately populations of prairie dogs can stabilize and grow. As towns grow, the number of burrows increases. Changes in town growth and population stability may also contribute to inconsistencies in burrow density data. Additionally, rebound from population declines associated with the sylvatic plague may contribute to burrow increases. Assuming sufficient food sources, towns which are especially confined physically may experience burrow density increases. However, the differences in density are too large to attribute this solely to town confinement.

Perhaps, the latest public aerial imagery does not have sufficient resolution to accurately interpret and count prairie dog burrows. It may have been beneficial to sample larger percentages of each town to decrease the influence of outliers on burrow density. Disparity in excavated sediment estimations was only compounded by using average burrow density instead of the predicted burrow density of the IDW surface. By ground truthing burrow locations in the field, the cause of burrow differences may be better understood. Other factors of burrow discrepancies include counting burrows of other animals mistakenly and counting all mounds of soil as burrow entrances. Within the aerial images, areas covered by vegetation with contrasting colors of soils provided the best conditions to count burrows. Areas of bare ground were difficult to interpret and may have contributed to burrow density overestimates.

Intrinsic biases exist within this study that may have further introduced error into burrow density counts, town delineations, and the interpretation of habitat characteristics. Dome craters were preferentially counted because they have the largest diameter of burrows on the surface. The resolution of aerial images used to delineate and point count towns in Theodore Roosevelt was lower than in DTNM and WCNP. Thus, a bias existed regarding higher resolution imagery and consequently an extent ratio of 1:1,800 meters. In addition, surface deposits at TRNP made it difficult to delineate towns and count burrows. Because point counting was based on sampling percentages, larger towns had more sampling points and more influence on frequency and statistical data which was used to describe habitat characteristics. Small towns were more influenced by outliers. Towns with ornate perimeters were at a disadvantage when clipping grid cells prior to point counting. Towns with simple perimeters were more likely to contain grid cells and therefore more likely to be sampled completely.

Although this study attempted to reveal site specific estimates of the volume of excavated sediment generated during the creation of black-tailed prairie dog towns, it failed to imply the rate of sediment deposition. Burrow density estimates only represent a moment in time. No differentiation was made regarding newly created burrows, recently maintained burrows, and abandoned burrows. This oversight limits temporal conclusions which can be drawn about the degree of zoogeomorphic effects over time. Past research has suggested that after a burrow is abandoned, it can take up to three years to disappear from the surface (Butts and Lewis 1982). Temporal information on the rate of sediment excavation can be explored in future work by comparing changes in burrow density across a three year time span.

Even if a prairie dog burrow is inactive and unmaintained, it can express similar zoogeomorphic effects as active burrows in terms of surface and subsurface drainage. For this reason, it should not be excluded from excavated sediment estimations. Regardless of the organisms which inhabit prairie dog burrows, the introduction of sediment into the surrounding environment will continue with burrow maintenance and construction. With shared burrows, it is difficult to attribute all excavated sediment to black-tailed prairie dogs. Future field work can confirm the proportion of this effect which is caused by black-tailed prairie dogs.

Once burrow density estimation issues are resolved, excavated sediment volumes can also be used interchangeably as an estimate of burrow water capacity. Rates of excavated sediment may also vary based on dynamic environmental factors such as dispersion of offspring, decreased food supply, predation pressures, and town reconstruction following burrow collapse or flooding. Prairie dog populations pre-European contact were larger and more expansive than populations occurring post-contact. Excavated sediment estimations, which more accurately reflect burrow density, can be extrapolated to represent the pre-contact geographic range and population numbers of black-tailed prairie dogs in the Great Plains.

Table 31: Wind Cave National Park: Town Area Comparisons to Dalsted et al. (1981).

| Town Name* | Town Number | Town Area (hectares) by Year | | | | | | | | | | | | $R^2$ Without 2008 Data | $R^2$ With 2008 Data |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1961* | 1963* | 1964* | 1966* | 1967* | 1970* | 1971* | 1974* | 1975* | 1977* | 1978* | 2008 | | |
| Shirttail | 30 | | 8.8 | | 8.9 | | 13 | | | | 11.5 | 14.1 | 5.1 | 0.655 | 0.271 |
| Bison Flats | 31 | 62.3 | 83.6 | | | 99.3 | | 165.6 | | | 225.2 | 246.4 | 531.0 | 0.980 | 0.995 |
| Norbeck | 23 | 27.5 | 34 | | 38 | | | 51.4 | | | | 62.5 | 120.1 | 0.988 | 0.998 |
| Research Reserve | 24 | | 25.5 | | | | 64.6 | | | | | 108.7 | 249.5 | 1.000 | 0.998 |
| Pringle | 2 | | | | | | | 8.9 | 16.2 | 21.6 | | 29 | 69.2 | 0.986 | 0.977 |
| Sanctuary | 3 | | | 49.7 | | 61.1 | 71.3 | | | | | 54.8 | 59.5 | 0.009 | 0.002 |
| Highland | 11 | | | | | | 4 | | | | | 12.2 | 39.4 | 1.000 | 1.000 |
| Southeast | 26 | | | 23.3 | 26.5 | | 49.9 | | | | | 59.4 | 140.9 | 0.887 | 0.988 |
| Northeast | 6 | | | | | | | 1.6 | | | 15.8 | 13.8 | 30.1 | 0.932 | 0.855 |
| North | 1 | | | | | | | 6.4 | | | | 10.7 | 345.6 | 1.000 | 0.972 |

*Dalsted et al. 1981

Table 32: Wind Cave National Park: Town Area Comparison Paired t-test Results.

| Pair 1 | Paired Differences | | | | | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|---|
| | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference | | | | |
| | | | | Lower | Upper | | | |
| R2 Without 2008 Data - R2 With 2008 Data | 0.03815 | 0.129356 | 0.040906 | -0.054385933 | 0.130685933 | 0.9326247 | 9 | 0.375355925 |

# CHAPTER VI

## CONCLUSIONS

In conclusion, this study provided site-specific estimates of excavated sediment generated during the creation of existing towns within Devil's Tower National Monument, Theodore Roosevelt National Park, and Wind Cave National Park. Discrepancies in burrow density caused potential overestimates in excavated sediment, despite lower values in soil mass as compared to Whicker and Detling (1988). Because the burrow densities did not coincide with past research, excavated sediment estimations must be further explored. Based on comparisons with historic data from Dalsted et al., town delineation techniques of this study are considered sound. Assuming that the imagery and methodology used in this study equally estimated burrow densities of each site, descriptions and potential causes of these differences have been described in the paragraphs to follow. In the future it may be more advantageous to estimate excavated sediment using the IDW surfaces generated from the sample points rather than average burrow density.

Differences in the volume of excavated sediment between each study site were attributed to differences in park size, prairie dog town size and abundance, select habitat characteristics, management styles, and exposure to epizootic diseases. By far, Wind Cave National Park had the greatest percentage of prairie dog towns and consequently the largest volume of excavated sediment. The town within Devil's Tower National

Monument had the highest burrow density of all three sites and was excluded from sediment comparisons on the basis of park size. Theodore Roosevelt National Park was the largest park, but contained less than half of the excavated sediment of Wind Cave National Park. Discrepancies in excavated sediment values between the study sites may be attributed to more favorable habitat conditions at Wind Cave National Park. In general, WCNP includes higher compositions of lithic and clay contents in soil, greater vegetation diversity, and higher elevations. In comparison to the more general management style of TRNP, Wind Cave has a management plan specific to prairie dogs with defined goals and restrictions; perhaps management style has allowed prairie dog towns to flourish in WCNP (USDI, NPS 1986; USDI, NPS 2006). It is also possible that exposure to the sylvatic plague decreased prairie dog populations in TRNP to an extent that they could not recover.

In addition to attempting to provide estimates of excavated sediment, information regarding the spatial organization of prairie dog towns was explored. The highest burrow densities in TRNP were found at short distances from streams, along shallow-sloping floodplains. Within WCNP, the highest burrow densities were also found on shallow slopes. The roughly N-S trending mountains of WCNP, in addition to maximum access to sunlight, may have influenced burrow densities in the park. Soil texture, vegetation, and taxonomic particle size influenced burrow density in a few towns within TRNP and WCNP. By utilizing the select habitat characteristics in conjunction with burrow density, areas of potential erosion were designated. The South Unit of Theodore Roosevelt National Park was established as the most vulnerable to erosion according to the selected vulnerability requirements. In addition to resolving burrow density estimates, future work should include the verification and measurement of erosion in the South Unit.

With few exceptions, past research regarding habitat preferences of black-tailed prairie dogs were confirmed using data from this study. Town elevations within DTNM and TRNP fell outside of the documented elevation range for black-tailed prairie dogs. Slopes within WCNP were higher than the documented range.

After burrow density discrepancies have been resolved, future work should include temporal studies of burrow excavation and maintenance. The areas defined as vulnerable to erosion should be validated via ground truthing in future studies. It would be extremely beneficial to monitor burrow density as town size and shape change. As always future collaborations with the park staff would be extremely beneficial to all parties involved; it would especially provide insight into the interworkings of management techniques within each study site. If the rate of sediment excavation is quantified in future work, then landscape change in past and present environments can be explored. When excavated sediment values are extrapolated across space and time, then it will be possible to better describe the impact of prairie dog removal and consequent agricultural and urban land conversion on the grasslands of the Great Plains.

Although estimations of excavated sediment calculated by this study require additional research, habitat characteristics were confirmed in accordance with past research. New methodologies such as IDW surfaces, macro-scale burrow trend analysis, and erosion vulnerability assessments were applied to black-tailed prairie dog populations. Difficulties encountered in this study may serve to strengthen future attempts to quantify the zoogeomorphic effects of burrowing mammals at a macroscale.

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## VITA

Shelley D. Miller was born in Knoxville, Tennessee, on February 7, 1983, the daughter of Maggie J. Miller and Darrell L. Miller. From the age of 15 until her mid-20s, Shelley worked for the Clinch River Environmental Studies Organization to explore and document the ecology of Anderson County Tennessee. This program fostered her love of the outdoors and laid the foundation for future work in science. After completing her work at Clinton High School in 2001, she entered the University of Tennessee Knoxville. She graduated in the summer of 2005 with the degree of Bachelor of Science in Honors Geology from the University of Tennessee. She submitted a senior thesis in conjunction with the Honor’s Program regarding olivine accumulation in Hawaiian basalts. With the thoughtful guidance of Dr. Harry Y. McSween, this project was Shelley’s first formal experience with point counting. Over the next few years, Shelley struggled to find a job in geology and worked for a variety of employers. One of the most influential of these jobs was a job with the Tennessee Valley Authority (TVA) in Clinton, TN. It was at TVA that Shelley worked as a student generating plant operator. Although this job utilized Shelley’s analytical skills and provided insight into power plant mechanics, steam production, and industrial systems, it was also the turning point in her career. In search of a more suitable career path, she entered the Graduate College at Texas State University-San Marcos in the fall of 2007. In the summer of 2009 Shelley began employment for the Balcones Canyonlands Preserve in Austin, Texas. This job opportunity utilized her knowledge of geology, animal ecology, and GIS.  As part of this organization, Shelley provides input on karst environments and the endangered species contained therein.  She is currently seeking permanent employment.

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