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Black-tailed Prairie Dog (Cynomys ludovicianus) State-and-Transition Model for Loamy Ecological Sites in MLRA 62 in Custer State Park, South Dakota

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BLACK-TAILED PRAIRIE DOG (*CYNOMYS LUDOVICIANUS*) STATE-AND-TRANSITION MODEL FOR LOAMY ECOLOGICAL SITES IN MLRA 62 IN CUSTER STATE PARK, SOUTH DAKOTA

BY

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This thesis is approved as a creditable and independent investigation by a candidate for the Master of Biological Sciences degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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CONTENTS

ABBREVIATIONS

AP – Above average precipitation

BM – Brush management

BT – Below average temperatures

BW – Bison wallow

CNW – Control noxious weeds

CSLG – Continuous season-long grazing

D – Drought

FSD – Frequent and severe defoliation

HCSG – Heavy continuous seasonal grazing

HCSLG – Heavy continuous season-long grazing

IN- invasion of non-native cool-season grasses (ex. Kentucky bluegrass, smooth brome, annual brome, etc.)

LB – Litter buildup

LTLG – Long-term light grazing

LTPD - Long term prairie dog occupation,

LTPG – Long-term prescribed grazing

MR – Mechanical renovation

NF – No fire

NG – No grazing

NP – Normal precipitation

NW - Noxious weeds

PD – Prairie dogs

PDC – Treat entire colony, remove prairie dogs from site

PDE – Prairie dog establishment

PDM – Reduce prairie dog density

PF – Prescribed fire

S – Seeding

WC – Weed control

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ABSTRACT

BLACK-TAILED PRAIRIE DOG (*CYNOMYS LUDOVICIANUS*) STATE-AND-TRANSITION MODEL FOR LOAMY ECOLOGICAL SITES IN MLRA 62 IN CUSTER STATE PARK, SOUTH DAKOTA

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Black-tailed prairie dogs (*Cynomys ludovicianus*) are native burrowing rodents that occupy large areas in the shortgrass and mixed-grass prairies of the Northern Great Plains. They are an important component of these prairie systems due to their impacts on plant communities. Currently State-and-Transition models (STMs) for grassland Ecological Site Descriptions (ESDs) address grazing by livestock as a major factor affecting states and phases within states. Impacts from other grazers, such as prairie dogs, are either not addressed directly, or are included only in a transition to a generalized early seral state. There are, however, dramatic differences in plant communities within prairie dog towns associated with time of prairie dog occupancy as well as other biotic and abiotic factors. These differences are not captured by current STMs. For managers who are tasked with managing prairies occupied by prairie dogs, current STMs do not provide the needed conceptual framework for understanding spatial variation and temporal changes to grassland vegetation affected by prairie dogs, nor do they provide information on management practices and strategies needed to manage these lands effectively.

This study was conducted in Custer State Park in southwestern South Dakota. The goal was to develop a state-and-transition model for prairie dog towns on the Loamy Ecological Site (ES) in Major Land Use Area (MLRA 62). Cover data of plant species was collected on and off of prairie dog towns in 2014 and 2015. These data were used to identify 5 distinct vegetation states associated with prairie dog colonies using a combination of Nonmetric Multidimensional Scaling (NMS) Ordination and Cluster analysis. The 5 states are: State 2, Native Invaded; State 3, Kentucky Bluegrass Dominated; State 4, Shortgrass Sod; State 5, Early Seral; and State 6, Fringed Sage Dominated. These 5 states are influenced by the interactions of fire, grazing by prairie dogs and large ungulates, presence of invasive plant species, and climatic factors (e.g. wet/dry cycles and temperature), all of which were used to describe transition pathways between states and community pathways within states. The resulting prairie dog state-and-transition model allows managers to determine the status and health of plant communities on prairie dog towns on the Loamy ES in MLRA 62. It will also help land managers understand vegetation variations across colonies, identify early warning signs that an undesirable transition is likely to occur, and provide potential restoration options that might be able to return a site to a more desirable plant community for management purposes.

INTRODUCTION

Ecological sites (ES) are “a distinctive kind of land with specific physical characteristics (climate, soils, topography) that differs from other kinds of land in its ability to produce a distinctive kind and amount of vegetation and in its response to management” (SRM 1998). Each ecological site has the capacity to produce a distinct array of plant communities resulting from the interaction of biotic, physical, and disturbance factors (Interagency Ecological Site Handbook for Rangelands 2013). In an ecological site description (ESD), the continuum of plant communities are organized into stable, long term “states” that represent the range of variability in plant communities associated with disturbance (Interagency Ecological Site Handbook for Rangelands 2013). State-and-transition models (STMs) provide a diagram and explanation of the states that are supported by an ES, variability between phases within a state, shifts between states (transitions), and causal processes (Interagency Ecological Site Handbook for Rangelands 2013). They also indicate the natural- and human-induced drivers that can result in a plant community crossing a threshold to a new state, from which a return to the previous state is unlikely or takes considerable time, energy and expense. STMs provide a conceptual framework for understanding spatial variation and temporal changes in grassland vegetation as well as implications of management practices and strategies (e.g. Bestelmeyer et al. 2009; Augustine et al. 2014). Development of effective ESDs is a critical feature of STMs because the descriptions provide the interpretive information associated with these models (Briske et al. 2005). These descriptions define the different vegetation states, transitions, and thresholds that may occur on a site in response to natural and management events (Pyke et al. 2002).

STMs for grassland ESDs address grazing by livestock as a major factor affecting states and phases within states. Impacts from other grazers, such as prairie dogs, are either not addressed directly, or are included only in a transition to an early seral state. For example, the STM for R062XC010SD in Major Land Resource Area (MLRA) 62 puts all prairie dog plant communities into a single state: "State 4 Early Seral" (USDA NRCS 2018). Other Loamy STMs in MLRAs 055C (USDA NRCS 2010a), 058D (USDA NRCS 2010b), 061X (USDA NRCS 2011b), 063A (USDA NRCS 2016), and 063B (USDA NRCS 2011c) also limit rodent affected vegetation communities (i.e. prairie dogs) to one community within one state. The Loamy STM in MLRA 53C (USDA NRCS 2011a) limits prairie dogs to 2 states, "State 3 Degraded and State 4 Invaded". As currently described, this early seral state has to encompass all prairie dog associated plant communities for that ecological site. This is an issue because there is considerable variability in plant communities associated with prairie dog occupation within an ecological site (Gabrielson 2009). Some plant communities on prairie dog towns (e.g. at the town edge) provide good ground cover and species richness/diversity (Lehman et al. 2009); others are characterized by considerable bare ground and limited plant species diversity (e.g. in the town core) (Baker et al. 2013). Because current STMs do not allow land managers to distinguish between different plant communities, understand transitions between those plant communities, or identify plant community thresholds associated with prairie dog occupation, they are of very limited value for use on prairie dog occupied rangelands. This is of special concern for land managers who want to avoid specific plant communities on prairie dog towns that are undesirable for their management goals.

Incorporation of specific plant community phases and/or states for prairie dogs in STMs is important for the Northern Great Plains (NGP) due to the extent of both their current and potential habitat. Black-tailed prairie dogs (*Cynomys ludovicianus*) are native to the shortgrass and mixed-grass prairie. Historical estimates of the area occupied by prairie dogs range from 31 million hectares (ha) (Vermeire et al. 2004) to 100 million ha (Miller et al. 1994) in the mixed-grass and shortgrass prairie. The United States Fish and Wildlife Service (USDI FWS 2009), estimated that black-tailed prairie dogs occupied approximately 1 million ha (2.4 million acres (ac)) of their suitable range in 2009. Prairie dogs occupy private, state, and federal lands managed by Federal agencies (e.g. U.S. Forest Service (USFS), Bureau of Land Management (BLM), National Park Service (NPS)), state agencies, tribal land agencies, non-governmental organizations (NGOs), and ranchers.

The goal of this project was to develop an STM specifically for plant communities occurring on prairie dog occupied areas within the context of the existing STM for an ecological site. The objective was to develop a “prairie dog STM” for a specific ecological site (Loamy ES, MLRA 62) found in Custer State Park (CSP) in the southern Black Hills in southwestern South Dakota. The expected result was a prairie dog STM that specifically identified 1) the plant community associations (states) and phases within states that can occur on prairie dog colonies, 2) the transitions/thresholds linking states, and 3) the causal processes for those transitions.

There are several expected benefits to this project. The most immediate will be an STM that will be useful to CSP Resource Staff for future management of prairie dog colonies on Loamy ESs in the Park. Because the STM will have been generated using local data from prairie dog colonies in CSP, application in CSP should be seamless. Another benefit of this study is it provides evidence of the feasibility of developing STMs specifically for prairie dog towns on other ESs. If prairie dog STMs are developed for other ecological sites throughout the range of the prairie dog as a result of this study, the greatest benefit at the landscape scale is the value these prairie dog state-and-transition models can provide to land managers in understanding the plant community variations across colonies, the processes that lead to transitions, early warning signs of undesirable thresholds, and restoration requirements to return to a desired state.

LITERATURE REVIEW

State-and-Transition Model Literature Review

History of Range Condition Theory

Change in plant communities on rangelands has been studied for well over 100 years. Early models to explain changes on the landscape were based on the Clementsian theory of succession (Clements 1916) that portrayed succession as an orderly, linear process with a stable, predictable endpoint (climax plant community). Sampson (1917, 1919) related the stages of secondary succession based on Clements' (1916) model to range condition classes. He suggested that retrogression due to heavy grazing was the linear, predictable reverse of Clementsian succession (Smith 1988, Westoby et al. 1989). While the Clementsian model of succession provided a framework for evaluating rangelands, it was recognized that better definitions of range condition were needed, as were classification criteria (Smith 1988). Efforts to do so in the 1940's and early 1950's led to 2 major approaches, the productivity approach and the climax approach (Smith 1988).

The productivity approach, espoused by Humphrey (1945) and others evaluated range condition based only on the amount of forage currently produced compared to the amount expected under good management. The climax approach instead tied range condition to successional status (Smith 1988). The version of the climax approach developed by Dyksterhuis (1949), called the Quantitative Climax Method, or QCM, created condition classes defined by the current composition of vegetation (percent composition by weight of species/groups) as compared to that expected in the climax plant community. This approach was adopted by the Soil Conservation Service (now known as the Natural Resources Conservation Service (NRCS)), the BLM, and some other agencies (Smith 1988); it became the standard for evaluation of range condition until the end of the 20th century.

Rangeland management professionals recognized numerous problems with the concepts and applicability of the standard/traditional approach to range condition assessment. These concerns have been documented by numerous authors including a task group assembled by the Society for Range Management (SRM UCT Task Group 1995). Concerns include the fact that grazing is not the only disturbance that can lead to vegetation change, and return to the “climax” plant community may not be possible when woody species are a component of the plant community (SRM UCT Task Group 1995). In addition, while the traditional range condition approach could explain changes to grasslands and semi-arid rangelands, it was not appropriate for other grazing lands, including annual grasslands, planted pastures, grazing woodlands, and sites invaded by non-native species (Holechek et al. 2004).

Over the last 2 or 3 decades, the concept of range condition has changed radically. The profession has adopted an alternative model proposed by Westoby et al. (1989), the State-and-Transition Model (STM). This model utilizes “states” to describe distinct plant communities on a site and pathways (“transitions”) between those states. The model does not depend on a single climax community, nor does it require plant community change to proceed linearly or to follow any theoretical models of vegetation dynamics (Westoby et al. 1989).

STMs provide a conceptual framework within which changes in vegetation can be described and the management practices causing those changes can be understood (Westoby et al. 1989). STMs identify several relatively stable states for each Ecological Site. Within each state there may be one to several plant communities (phases). Transitions may be easily reversible (i.e. phase shifts within a state) or not easily reversible (i.e. transitions between stable states) (Briske et al. 2005; Augustine et al. 2014). The challenge, as STMs are developed, is to identify which conditions, processes, and interactions induce phase shifts and which induce state transitions (Augustine et al. 2014).

Ecological Sites, ESDs and STMs

Rangeland ecosystems are divided into Ecological Sites (ES), which are "a kind of land with specific physical characteristics which differs from other kinds of land in its ability to produce distinctive kinds and amounts of vegetation and in its response to management" (SRM 1998). Each ecological site has the capacity to produce a distinct array of plant communities resulting from the interaction of biotic, physical, and disturbance factors (Interagency Ecological Site Handbook for Rangelands 2013). For understanding and management of ESs, it is critical to know not only what plant communities can exist on a site, but also what factors cause shifts between those plant communities and the relative permanence of those changes.

Ecological site descriptions (ESD) have been developed for most ESs (Interagency Ecological Site Handbook for Rangelands 2013). Information on location, soils, climate, and other factors affecting plant communities on an ES are detailed in each ESD. Critical to the value of each ESD is the organization of plant communities into stable, long term “states” that represent the range of variability in plant communities associated with disturbance (Interagency Ecological Site Handbook for Rangelands 2013). A State-and-transition model (STMs) is included in the ESD developed for each ES, including a diagram and explanation of the states found in an ES, the plant communities within each state (phases), the variability between phases within a state (community pathways), transitions that can happen between states, and the factors (causal processes) associated with transitions (Interagency Ecological Site Handbook for Rangelands 2013). A feature of STMs is the listing of the natural- and human-induced drivers that can lead to a plant community crossing a threshold to a new state. Thresholds are major shifts between states; a return to the previous state is generally considered unlikely or takes considerable time and expense.

STMs provide an overview of the various states that can occur on an ES (Fig. 1), as well as how a site will respond to management (Bestelmeyer et al. 2009; Augustine et al. 2014). The ESD provides a detailed explanation of the STM and includes a listing of species present along with their expected biomass in each defined state (Briske et al. 2005). ESD descriptions allow land managers to make informed decisions because the states, transitions and thresholds inform them how the ES will respond to natural influences or management decisions (Pyke et al. 2002).

One component of STMs, thresholds, has generated considerable debate and research. A threshold is a transition between stable states. It is not considered to be easily reversed. Transitions or thresholds can be caused by biotic and abiotic factors, including fire, severe climatic events, grazing, long-term rest from grazing or fire suppression, and interactions of these and other factors (Briske et al. 2005). Crossing a threshold changes future vegetation trajectories for an ES, and removal of the causal factors typically does not result in a reversal to the previous state (Briske et al. 2005). While thresholds were not identified as such by Westoby et al. (1989), they have become a major focus in the application of STMs.

Thresholds were not always included in early STM development because of the lack of knowledge (Stringham et al. 2003). Early on, what were described as thresholds were often phase shifts (Stringham et al. 2003). Archer (1989) explained qualitative transitional thresholds as changes in vegetational groups. Whisenant (1999) used ecological processes to explain changes in thresholds among states. These differences in threshold criteria varied considerably until clarification was provided and adopted. Stringham et al. (2003) provided clarification and definitions for STM development including thresholds and transitions.

ESDs and STMs are used by the NRCS, BLM, USFS, ranchers, NGOs, state agencies and many others involved in rangeland management decisions. ESDs provide considerable information on an ES, including descriptions and tables detailing the plant communities in each state. One of the states included in each ESD is the historic plant community, which was defined in the traditional range model, and is used in the ESD as an ecological reference community (Briske et al. 2005). The other plant communities detailed in an ESD can serve as alternative reference points for situations where the desired plant community for management is not the historic plant community (Briske et al. 2005). Practitioners collect vegetation biomass for each species in the field and compare current species composition to the information provided by the appropriate ESD. This provides not only information on which state the site fits into, but also information on how the ES will respond to various types of disturbances (e.g. drought, fire). Use of the information found in the ESD is particularly important for long term planning and monitoring; it can be used to define management strategies to effect change toward the plant community desired for management objectives. STMs are beneficial because they explain what management options are available to restore or maintain a desirable ES. They also depict the natural range of variability that can occur on an ES based on abiotic or management factors (Interagency Ecological Site Handbook for Rangelands 2013).

STM Terminology

Standardized STM definitions are discussed by Stringham et al. (2003), The Society for Range Management Task Group on Unity in Concepts and Terminology (SRM UCT Task Group 1995) and Interagency Ecological Site Handbook for Rangelands (2013). The definitions listed below are the 5 components all STMs must include.

State (large boxes in Fig. 1), “is a suite of community phases that interact with the environment to produce a characteristic composition of plant species, functional and structural groups, soil functions, and a characteristic range of variability. The state is defined with reference to community phases, dynamic soil properties, and animal populations that are linked to one another via feedback mechanisms.” (Interagency Ecological Site Handbook for Rangelands 2013).

Transitions (arrows starting with “T”, Fig. 1), “describe the biotic or abiotic variables or events, acting independently or in combination, that contribute directly to loss of state resilience and result in shifts between states. A transition can be triggered by natural events (e.g. climatic events or fire), management actions (e.g. grazing, burning, fire suppression, recreational use) or both.” (Interagency Ecological Site Handbook for Rangelands 2013).

Restoration pathways (arrows starting with “R”, Fig. 1), “describe the environmental conditions and practices that are required to recover a state that has undergone a transition.” “Practices include significant management inputs (e.g. chemical/mechanical treatments or planting) coupled to facilitating and management practices (e.g. prescribed fire, wildland fire managed for resource benefit, fencing, and grazing management prescriptions).” (Interagency Ecological Site Handbook for Rangelands 2013).

Community phases (small boxes within states, Fig. 1), “are unique assemblages of plants and associated dynamic soil property levels that can occur over time within a state.” “Community phases included in a single state may have similar floristic or functional groups, but may differ in dominant or subordinate species.” (Interagency Ecological Site Handbook for Rangelands 2013).

Community pathways (arrows between community phases within a state, Fig. 1), “describe the causes of shifts between community phases.” They “…can be used to represent both linear and non-linear plant community changes.” The “…shifts in community phases are easily reversed due to succession, natural disturbances, short-term climatic variation, and facilitating practices such as grazing management.” (Interagency Ecological Site Handbook for Rangelands 2013).

STMs and Prairie Dog Towns

STMs for grassland ESDs address grazing by livestock as a major factor affecting states, phases within states, and transitions. Impacts from other grazers, such as prairie dogs, are either not addressed directly, or are included only in a transition to an early seral state. For example, the STM for R062XC010SD in MLRA 62 puts all prairie dog plant communities into a single state: "State 4 Early Seral" (USDA NRCS 2018). Other Loamy STMs in MLRAs 055C (USDA NRCS 2010a), 058D (USDA NRCS 2010b), 061X (USDA NRCS 2011b), 063A (USDA NRCS 2016), and 063B (USDA NRCS 2011c) also limit rodent affected vegetation communities (i.e. prairie dogs) to one community within one state. As currently described, this early seral state has to encompass all prairie dog associated plant communities for that ecological site. This is an issue because there is considerable variability in plant communities associated with prairie dog occupation within an ecological site (Gabrielson 2009). Some plant communities on prairie dog towns, such as at the town edge, provide good ground cover and species richness/diversity (Lehman et al. 2009); others are characterized by considerable bare ground and limited plant species diversity, such as in the town core (Baker et al. 2013). Because current STMs do not allow land managers to distinguish between different plant communities, understand transitions between those plant communities, or identify plant community thresholds associated with prairie dog occupation, they are of very limited value for use on prairie dog occupied rangelands. This is of special concern for land managers who want to avoid specific plant communities on prairie dog towns that are undesirable for achieving their management goals.

The goal of this project was to evaluate the types of plant communities associated with prairie dog towns on one ES (MLRA 62 Loamy) and, if possible, develop an STM specific to sites on that ES that are occupied by prairie dogs. The resulting STM would be very useful for management of Custer State Park (South Dakota) mixed grass prairie areas with prairie dog towns. The CSP management plan includes management of prairie dog towns. An expectation of that management is that plant communities on the prairie dog towns will maintain good cover by vegetation and not become refuges for noxious weeds. The STM generated by this study will provide managers with the information needed to identify potential changes in plant communities that are undesirable and to develop management strategies that prevent those changes from occurring.

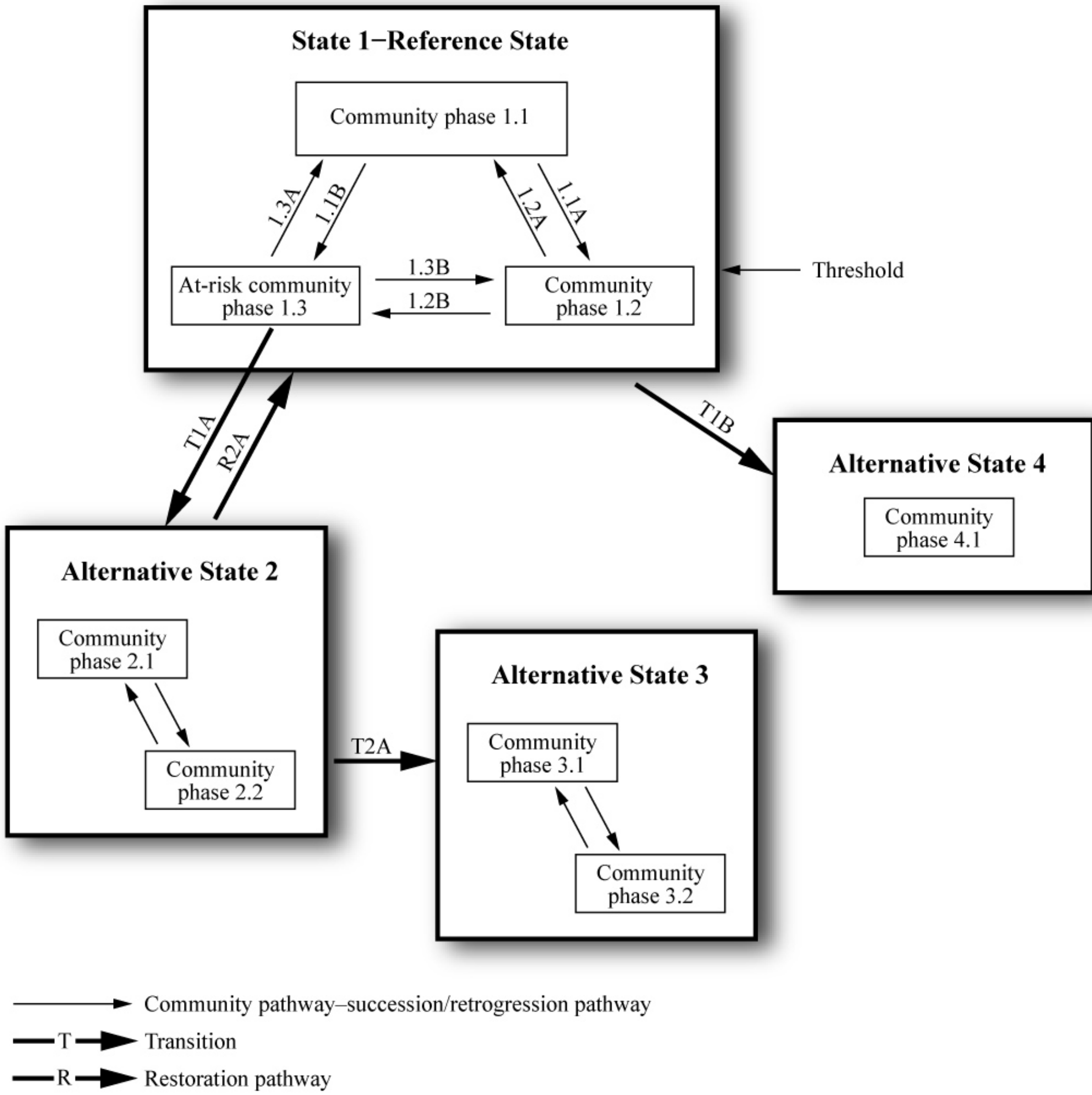

Figure 1. Example of a state-and-transition model for an ecological site (Interagency Ecological Site Handbook for Rangelands 2013).

Black-tailed Prairie Dog Literature Review

Black-tailed prairie dogs are a native colonial burrowing rodent. Historical estimates of the area occupied by prairie dogs range from 31 million hectares (ha) (Vermeire et al. 2004) to 100 million ha (Miller et al. 1994) in the mixed-grass and shortgrass prairies. The shortgrass and mixed-grass prairie area consists of 118 million ha (Vermeire et al. 2004); of that area, prairie dog occupation is limited to suitable ecological sites (ES) (e.g. loamy, sands, sandy, clayey, clay pan and shallow to gravel). Prairie dogs typically colonize soils that are located on gentle slopes with minimal flooding potential (Koford 1958).

The United States Fish and Wildlife Service (USDI FWS 2009), estimated that black-tailed prairie dogs occupied approximately 1 million ha (2.4 million acres (ac)) of their suitable range in 2009. Prairie dogs occupy private, state, and federal lands that are managed by Federal agencies (e.g. USFS, BLM, NPS), state agencies, tribal land agencies, NGOs, and ranchers. Prairie dogs are an important component of shortgrass and mixed-grass prairies due to their impacts on ecosystems and the extent of both their current and potential habitat.

Plant communities prairie dogs occupy vary from the Sandsage prairie on the Cimarron National Grassland in southwest Kansas (VanNimwegen et al. 2008) to the northern mixed-grass prairie in north central Montana (Johnson-Nistler et al. 2004). Prairie dogs alter the vegetation of communities they occupy. Several factors influence the impact of prairie dogs on rangeland production, including location, ecological site, dominant grass species, grazing intensity, and age of the prairie dog town (Johnson-Nistler et al. 2004).

Prairie dogs are ecosystem regulators (Baker et al. 2013); they manipulate the soil, and impact plant (Gabrielson 2009) and animal communities (Agnew et al. 1986). At the landscape scale, complexes of prairie dog colonies increase the patchiness or heterogeneity and increase habitat diversity (Breland et al. 2014). The role prairie dogs have in total system function is unclear, but it is evident they influence the soil they occupy (Barth et al. 2014) along with abundance and species composition of reptiles and amphibians (Kretzer & Cully 2001), vegetation (Johnson-Nistler et al. 2004), birds (Augustine & Baker 2013), mammals (Stapp 2007; Chipault and Detling 2013), and invertebrates (Deisch et al. 1989).

Prairie dogs increase the amount of bare ground on their colonies by digging underground burrows and building mounds. The bare soil around the mounds has an increase in nutrients compared to off-mound sites due to the urine and feces deposited around the burrow mound. Soil infiltration rates are also higher on burrows compared to off-mound locations (Barth et al. 2014).

Continuous clipping by prairie dogs reduces vegetation production and cover of cool-season grasses such as western wheatgrass (*Pascopyrum smithii* [Rydb.] A. Love) and green needlegrass (*Nassella viridula* [Trin.] Barkworth) and warm-season grasses such as big bluestem (*Andropogon gerardii* Vitman) and little bluestem (*Schizachyrium scoparium* [Michx.] Nash), while increasing cover and production of annuals and less desirable perennial species (e.g. purple threeawn (*Aristida purpurea Nutt.*) (Fahnestock and Detling 2002). Vegetation production is also reduced since tall grass species (e.g. big bluestem) and mid-height species (e.g. western wheatgrass) are replaced by short warm-season species (e.g. blue grama (*Bouteloua gracilis* [Willd. Ex Kunth] Lag. Ex Griffiths)) (Johnson-Nistler et al. 2004; Coppock et al. 1983b). Fahnestock and Detling (2002) found that forbs represented nearly 90% of the biomass and cover on prairie dog towns compared to less than 10% in off-town sites in Badlands National Park. They also suggest that exotic species may exploit prairie dog towns as they provide areas for establishment and seed reserves.

Species composition of areas within prairie dog towns varies based on length of prairie dog occupation (Coppock et al. 1983a). Species diversity is greatest on newly colonized areas while diversity is lowest on the “core” or longest occupied area (Coppock et al. 1983a). As time since occupation by prairie dogs increases on a site, species composition changes. In a study by Coppock et al. (1983a), newly colonized (2 years or less) areas of prairie dog towns maintained plant communities similar to those of nearby off-town areas. For areas occupied for 3 - 8 years, cool-season and warm-season grasses continued to dominate, however forb species biomass increased. Coppock et al. (1983a) determined that plant species diversity was greatest for areas of prairie dog towns that were at this stage. For sites occupied by prairie dogs for greater time periods (> 26 years), grasses were reduced, shrubs and forbs co-dominated the sites, and species diversity declined (Coppock et al. 1983a). Johnson-Nistler et al. (2004) found that, on private land grazed by cattle, species richness declined with prairie dog colonization. They also found that long-term prairie dog occupation of mixed-grass prairie sites in northeastern

Montana resulted in reduced litter and increased bare ground and fringed sage (*Artemisia frigida* Willd.) cover.

Prairie dogs, through their activities, create biological niches for many mammals, birds, reptiles, and other animals. Of the 332 terrestrial wildlife species in western South Dakota, 40% (134) are found on prairie dog towns: 88 birds, 36 mammals, 6 reptiles, and 4 amphibians (Sharps and Uresk 1990). Prairie dog colonies enhance habitat for pronghorn (*Antilocapra americana*) (Lehman et al. 2009) and burrowing owls (*Athene cunicularia*) (MacCracken et al. 1985) while providing food for predators such as black-footed ferrets (*Mustela nigripes*) and badgers (*Taxidea taxus*) (Eads et al. 2013). Prairie dog towns, compared to adjacent grasslands, show an increased density of small mammals, such as deer mice (*Peromyscus maniculatus*) and grasshopper mice (*Onochomys leucogaster*) (Agnew et al. 1986). Prairie dog towns also provide habitat for 5 classes, 13 orders and 39 families of invertebrates (Deisch et al. 1989).

Numerous studies have compared vegetation on colonized and uncolonized sites (e.g. Coppock et al. 1983a,b, Fahnestock and Detling 2002, and Stoltenberg 2004), however, as pointed out by Gabrielson (2009), many studies either failed to verify that the sites were on comparable soils/ecological sites (e.g. Cid et al. 1991) or reported comparisons between sites with known soil differences (e.g. Klatt and Hein 1978). Because soils play such an important role in determining the kinds of plant communities that can exist on a site and the responses of plant communities to disturbances (Interagency Ecological Site Handbook for Rangelands 2013), it is essential that comparisons between colonized and uncolonized sites be done on similar soils/ecological sites. Only then is it possible to determine whether a difference in vegetation is due to prairie dog activity or an edaphic factor.

There is compelling evidence that suggests that vegetation alternations caused by prairie dogs are different than those caused by cattle or bison. Prairie dog occupation reduces grass cover and production while increasing forbs (Fahnestock and Detling 2002). Graminoid production following 26 years of prairie dog occupation was less than 3% in a study by Coppock et al. (1983a). Lightly stocked bison grazing alone does not change species composition and only has a minimal impact on grass biomass on the mixed-grass prairie (Fahnestock and Detling 2002). Heavy grazing by cattle will, however, cause a shift from mid-height species to shortgrass species (Lewis et al. 1959) but it does not increase the amount of bare soil to the extent found on prairie dog towns. Native shortgrasses have a greater grazing and drought tolerance than mid-height grasses (Milchunas et al. 2008); as a result they often persist on sites affected by long-term heavy grazing.

Fahnestock and Detling (2002) found that, when bison and prairie dogs occupied the same area, no additive effects occurred. Gabrielson (2009) determined that, in the mixed-grass prairie, prairie dogs clip or consume 4 times more vegetation on-town than cattle. In her study, prairie dogs removed over 70% of on-town vegetation. Cattle in that study removed only half as much vegetation on-town compared to the same ecological sites off-town.

MATERIAL AND METHODS

Study Area

This study was conducted in 2014 and 2015 in Custer State Park (CSP), in the southern Black Hills in southwest South Dakota. CSP encompasses 28,537 ha (70,516 ac). Steep granite spires characterize the northwest portion of CSP, rolling forested hills dominate the central portion, and mixed-grass prairie dominates the eastern and southern portions. Elevations in CSP range from 1,146 to 2,042 m (3759 to 6699 ft) (CSP 2010).

Approximately 73% of CSP is dominated by ponderosa pine (*Pinus ponderosa* Lawson & C. Lawson) and 2% by deciduous forest on valley loam soils with stands of bur oak (*Quercus macrocarpa* Michx.) and paper birch (*Betula papyrifera* Marshall). The remaining 25% can be characterized as northern mixed-grass prairie (CSP 2010). The dominant cool-season species in the CSP mixed-grass prairie is western wheatgrass; warm-season species include big bluestem, little bluestem, blue grama, and sideoats grama (*Bouteloua curtipendula* [Michx.] Torr.) (CSP 2010). Common shrub species include leadplant (*Amorpha canescens* Pursh), western snowberry (*Symphoricarpos occidentalis* Hook.), wild raspberry (*Rubus idaeus* L.), and prairie rose (*Rosa arkansana* Porter); (Keller 2011). An introduced grass, Kentucky bluegrass (*Poa pratensis* L.), is commonly found throughout the Black Hills including CSP.

Rangeland and woodland areas of CSP are located in 2 NRCS MLRAs, 61 and 62. Rangeland and woodland sites can be divided into 12 ecological sites (currently provisional) identified by the NRCS (Table 1). An additional 3 sites were derived from NRCS woodland sites by CSP park managers to accommodate sites with steep slopes (Table 1). Forage production was determined in 2008 for the 15 range and woodland sites

(Keller 2011) (Table 1). My study was conducted in the southern portion of CSP on Loamy Ecological Sites (Loamy ES), which represent only 3% of CSP but are common to many of the CSP prairie dog towns.

The closest weather station to the study sites is the USGS weather station near the CSP Wildlife Visitor Center (43°40’02.73” N 103°21’46.13” W). All study sites are located within 10 km of this weather station. Long-term (Custer State Park Climate Data 2018) average annual precipitation is 466 mm (Table 2). Over 75% of the moisture in the area falls between April and September, with almost half the annual precipitation falling April-June. May is the wettest month (Table 2). Average snowfall for the southern Black Hills is 320 mm; March is the snowiest month with an average snowfall of 180 mm. Average annual, summer and winter temperatures in CSP are 6.7° C, 16° C, and –5° C, respectively (CSP 2010). Water year precipitation (October – September) during the years of the study (2014 and 2015) was 644 mm and 442 mm, respectively (Table 2).

Study Sites

This study was conducted on mixed-grass prairie sites in the southern part of CSP on active black-tailed prairie dog towns and on non-colonized rangeland surrounding prairie dog towns. Of the 22 prairie dog towns in CSP (Table 3), 18 are in MLRA 62; 4 are in MLRA 61. Soils and ecological sites on the prairie dog towns vary, however the majority of the towns include some component of the Loamy Ecological Site (Loamy ES). Initial criteria for selection of prairie dog towns for inclusion in this study were 1) towns were in MLRA 62 and 2) ecological sites on towns included > 18 ha of Loamy ES. These criteria ensured comparisons were based on adequate areas for data collection on the same ecological site on all prairie dog towns. Sizes of the 3 towns meeting the criteria varied from 21 to 243 hectares. The 3 prairie dog towns are Cow Camp (C), Hay Flats (H), and North Lame Johnny (N). Each prairie dog town was paired to a nearby off-town site that was 100 – 150 m away and ≥ 2 ha in area. Off-town areas were selected based on ecological site suitability (Loamy ES), and distance from associated prairie dog towns (closest edge of off-town area ≥ 100 m from prairie dog town edge) using ArcGIS (ESRI 2013). The 3 off-town sites varied from 2 to 10 hectares, depending on area of contiguous Loamy ES hectares. Loamy ES soils were field verified by Jim Westerman, NRCS Soil Specialist, June 24 and July 8, 2014.

Mapping: Prairie dog towns and the surrounding off-town rangelands were mapped in 2013 using a DeLorme Earthmate PN-60 GPS (PN-60); waypoints were imported into ArcGIS (ESRI 2013) using DNR Garmin 5.4.1 (DNR Garmin 2008). The boundary of each town was mapped by travelling on ATV between the outermost active mounds on the town. Active mounds were defined as mounds with actively clipped adjacent vegetation. This eliminated outpost mounds. Vegetation between boundary mounds did not have to be clipped. Greatest distance travelled between mounds was limited to 50 m; when the distance between 2 outermost mounds was greater than 50 m, they were connected via travel to intermediate mounds located closer to the interior of the town. The boundaries of the off-town sites were mapped using Custer State Park's soils layers in ArcGIS (ESRI 2013). The size of the Loamy ES off-town sites were ≥2 ha.

Prairie Dog Town Areas

Sampling for this study occurred on the 3 prairie dog towns and in the associated off-town sites. Two distinct areas on each prairie dog town were identified for targeted sampling: core and edge. The remainder of each prairie dog town (general interior) was included in sampling to describe overall prairie dog town variability. Associated off-town areas were also sampled. Definitions/descriptions of sampling locations include the following:

Prairie dog town core: We defined the areas of a prairie dog town that were occupied ≥ 25 years prior to our study as the core. This was accomplished by mapping prairie dog town areas visible on available aerial photograph images from 1978 and 1990. Each of the 3 towns on CSP in this study, Cow Camp, Hay Flats, and North Lame Johnny, was old enough to have a core area (Table 3). Thus the core area for this study is the town origin or longest occupied area within the prairie dog colony. It should be noted here that the core, as defined in this study, is the oldest occupied area of the town; it may not, however, totally encompass all of the areas of the town that have vegetation characteristics typically associated with long-term heavy use.

Prairie dog town edge: The prairie dog town edge area was defined as the area within 30 m interior of the boundary.

Prairie dog town general interior: This encompasses the interior of a prairie dog town not included in the core or edge of a town.

Nearby off-town sites: Off-town sites associated with prairie dog towns were defined as areas that meet the following criteria: 1) located on Loamy ES, 2) occupy an area ≥ 2 ha., 3) are not occupied by prairie dogs, and 4) the edge closest to the associated prairie dog town is 100 - 150 m from the prairie dog town boundary.

Sampling Strategy

The goal of this study is to develop a STM for prairie dog towns on the Loamy ES in MLRA 62. Thus all prairie dog towns, and associated off-town areas are located in MLRA 62 and all sampling in this study was confined to sites that are Loamy ES.

The sampling strategy for this study was designed to develop a description and evaluation of the vegetation found on the core, edge, and general interior areas of prairie dog towns and on nearby off-town areas. The data generated was used to define these specific plant communities and provide the basis for developing a state-and-transition model for prairie dog towns that can be used to determine the status and health of plant communities on prairie dog towns on Loamy ES in MLRA 62. Sampling was confined to the 3 large prairie dog towns because of the availability of adequately sized areas of core, edge, and associated off-town plant communities.

General interior of the prairie dog town was sampled to collect data on the transition zone between the core and edge. General interior of the prairie dog towns occupies the largest area of the prairie dog towns in the study. Transect lengths for the general interior of the towns were longer (100 m in length vs. 50 m for the core, edge, and off-town areas) to capture more of the prairie dog town variability and determine different phases and states found in the general interior.

Transects

Transect Design: Transects used in this study were belt transects that were 10 m wide and either 50 m or 100 m long, depending on specific data collection (see details, below). Within each belt transect, a central line transect was placed that runs the length of the belt transect (Fig. 2). In all sampling situations using the belt transects, 3 belt transects were established adjacent to each other (Fig. 2). To make sure line transects 1, 2 and 3 were accurately spaced 10 m apart, two 30 m tapes were run from the start and end of the line transects (0 and 50 or 100 m) perpendicular to transects 1, 2 and 3. Plots (0.25 m^2, round) were established within each belt transect:

- Line transect plots were established along the line transect at 10 m intervals beginning 5 m from the beginning of the line transect and ending 5 m from the end of the line transect (Fig. 2). This resulted in 5 plots for each 50 m line transect and 10 plots for each 100 m line transect.
- Belt plots were established on both sides of the line transect, at a distance of 2.5 m from the line transect, beginning 2.5 m from the beginning of the belt transect and continuing at 5 m intervals. This resulted in 20 plots in each 50 m belt transect and 40 plots in each 100 m belt transect.

Each belt transect was subdivided into adjacent 10m X 10m “main plots”. Each main plot included 1 line transect plot and associated 4 belt plots within each 10 x 10 m area (Fig. 2). This resulted in 5 main plots for each 50 m belt transect and 10 for each 100 m belt transect.

The beginning and end of every line transect was permanently marked with a 20 cm long nail through a 7.62 cm diameter washer (both painted red) driven into the ground; GPS coordinates were taken at the start and end of every transect to assist in future relocation. GPS coordinates were uploaded into ArcGIS (ESRI 2013)and saved for future use. Relocation of individual plots was accomplished using distance measurements on transects.

<u>50 Meter Transect Locations</u>: Three adjacent 10 m X 50 m permanent belt transects were placed in each of the core, edge, and off-town areas of each of the 3 prairie dog towns in the study in 2014.

Core: The location of the beginning of Belt Transect 1 in the core of prairie dog towns was randomly selected on ArcGIS (ESRI 2013). The beginning of Transect 1 coincided with the random ArcGIS (ESRI 2013) location; the orientation of Transect 1 was a randomly generated direction (0 - 360 degrees). The entire area of the 3 adjacent belt transects was required to be within the Loamy ES of the core. If placement of the belt transects based on the first random point did not accomplish this, additional random starting points were generated until the 3 adjacent transects were wholly within the Loamy ES of the core area. Direction of placement of the core belt transects from the starting point to the transect end (to the left or right when facing the center of the town core) was also randomly chosen.

Edge: The edge is defined as the area beginning at the boundary and extending 30 m toward the interior of the town. Thus, belt transects in the edge area began at random locations along the boundary. The nearest clipped edge prairie dog mound to the randomly generated boundary point was designated as the beginning of the edge of Belt Transect 1. The edge of Belt Transect 1 was placed along the town boundary by stretching a 50 m tape from that random starting point and pivoting it until it ran along the boundary of the prairie dog town (based on location of nearest boundary mound to the end of the 50 m tape). A 30 m tape was stretched toward the interior of the town and perpendicular to the boundary edge of Belt Transect 1. The beginning of Line Transect 1 was located 5 m interior of the boundary. Belt Transect 2 was placed adjacent to the interior edge of Belt Transect 1; Belt Transect 3 was placed adjacent to the interior edge of Belt Transect 2. Direction of placement of edge belt transects from starting point to the transect end (to the left or right when facing the center of the town) was randomly chosen.

Off-town sites: The location of the beginning of Transect 1 (Fig. 2) was selected randomly within the Loamy ES within the off-town areas; orientation of Transect 1 was based on a randomly generated direction. The entire area of the 3 adjacent belt transects was required to be within the Loamy ES of the off-town area. If placement of the belt transects based on the first random point did not accomplish this, additional random starting points were generated until the 3 adjacent transects were wholly within the Loamy ES of the off-town area. Direction of placement of the off-town belt transects from the starting point to the transect end was a randomly generated direction (0 - 360 degrees).

100 m Transects to Capture Interior Variability

On each of the 3 prairie dog towns, 2 locations within the general interior on Loamy ES were randomly selected. Time allowed a third set of transects to be sampled in the general interior of the North Lame Johnny prairie dog town. At each location, 3 adjacent 10 m X 100 m permanent belt transects (Fig. 2) were established in a randomly chosen direction. If any part of the 100 m adjacent transects was located < 10 m from the edge of the Loamy ES, an alternate location was used. These random samples were used to capture interior prairie dog town variability.

Data Collection on Transects

All plots were sampled in summer 2014 (July 2 to August 29) except for North Lame Johnny random 3 (10/1/2014) and again in summer 2015 (June 17 to July 21). In order to include both early- and late-season species in each plot, plots were sampled early in one year and later in the other year. Data collected in each plot in each year included:

Species list: A complete list of plant species present in each plot was recorded.

Cover: Percent cover of current year vegetation was estimated for each species present in each plot using a modification of Daubenmire (Daubenmire 1959) cover classes: T = trace (<1%), 1= 1-5%, 2= 6-25%, 3= 26-50%, 4= 51-75%, 5= 76-95%, and 6= >95%. Mid-point for all cover classes was used to estimate mean percent cover for data analysis (T = 0.5%, 1 = 2.5%, 2 = 15%, 3 = 37.5%, 4 = 62.5%, 5 = 85%, 6 = 97.5%. Total current year vegetation cover, litter (must be detached, horizontal to the soil surface), bare soil, and rock were estimated using the same cover classes for each 0.25m^2 circular plot. Sum of the cover values for plant species typically exceeded 100% because of overlapping canopies. Vegetation rooted outside plot with aerial coverage in the plot was included.

Photographs

Landscape Photos: Landscape photos were taken at the start (looking toward the end) and end (looking toward the start) of each line transect. Landscape photo board information included: location (e.g. prairie dog town name), line transect number, direction, location of photo (start (S) or end (E)) on transect, and date.

Plot Photos: Three line plot photos were taken at plots located 5, 45 and 95 m from the beginning of each 100 m interior line transect. Two line plot photos were taken at plots located 5 and 45 m from the beginning of 50 m line transects on core, edge, and off-town areas. Plot photos were taken centered above the plots at a height of approximately 1.5 m. A photo board was included in each photo to provide information on data collected. Line plot photo board information included: location (e.g. prairie dog town name), transect number, plot information (distance from transect origin (ex. 5, 45, or 95 m)), and date.

Analyses

Vegetation cover data collected in 2014 and 2015 from the 3 prairie dog colonies, including their associated off-town sites, were entered by plot and species into Excel (Microsoft 2010). Data were then organized by main plot (1 line plot and 4 belt plots per main plot) and a standardized species list with cover data for each prairie dog area (core, edge, interior, and off-town) was created. Similarity index scores for the 2014 and 2015 plot cover data were calculated to determine whether or not years should be evaluated separately. Similarity index scores were ≥ 0.69 (Table 4). As a result, the 2014 and 2015 species cover data for each plot were combined by averaging them in SAS (SAS 2000). All data were combined into one data set with 6 columns: colony ID, prairie dog town area (core, edge, interior [separated into interior transects, R1-R3], and off-town), belt transect number, main plot number, species code (USDA NRCS 2014), and percent cover. Two data sets were then created: 1) the main matrix, which contained species cover data; and 2) the second matrix, which contained percent cover by species, percent bare soil, percent total foliar cover, percent litter, and colony ID (categorical data).

The 2 matrices were imported into PC-ORD 7 (v7; McCune and Mefford 2016). Inclusion of the secondary matrix enhances the system's analytical capabilities (McCune and Mefford 2016). Only species that occurred in 3 or more main plots across all colonies were retained. Main matrix cover values were modified by multiplying by 0.01 (to yield values between 0 and 1). These values were arcsine squareroot transformed to reduce the impact of high values while compacting middle values (McCune and Grace 2002). All modifications only occurred in the main matrix.

Nonmetric Multidimensional Scaling (NMS) ordination was initially run for each colony using autopilot mode, slow and thorough, with Sorensen (Bray-Curtis) distance measurement to check for patterns among the core, edge, off-town, and interior sampling locations. The analyses were run 2 additional times to compare the results for consistency of interpretation, taking into account % variance (r^2), stress scores, and axes. Output (not shown) indicates consistent groupings of main plots within each prairie dog town sampling area for each town studied. Plots showed that sampling areas were largely distinct for the Cow Camp prairie dog town; some of the interior sampling areas for the Hay Flats and North Lame Johnny towns overlapped with core and/or edge sampling areas. Cluster analysis of the data was also conducted in PC-ORD to help interpret NMS ordination. Cluster analyses used Sorensen (Bray-Curtis) distance measurement with Flexible Beta group linkage. The dendrograms were cut at natural breaks, resulting in 7 clusters for Cow Camp and 5 clusters each for Hay Flats and North Lame Johnny. Cow Camp clusters had adequate distance between groups until 7 groups were displayed; at 7 groups the cluster analysis split off 4 main plots from the edge and 7 main plots from R1. Hay Flats and North Lame Johnny did not have adequate distance between groups to consider more than 5 groups.

Cluster group membership variables were added to the NMS secondary matrix, and ordination was run as before on each individual prairie dog town and on the combined data. The cluster and ordination analyses are related only in that they use the same distance measure. The NMS ordination uses the distance of each plot in relation to all the other plots to place that plot in a multi-dimensional space (if needed), while the cluster analysis uses the distance to combine plots (and groups of plots) until all are combined.

Table 1. Ecological sites in Custer State Park (CSP), including type (rangeland, woodland, altered), total area (ha), and percent of CSP total area. Ecological sites include 12 provisionally identified by the NRCS[1] and 3 derived from NRCS woodland sites by CSP park managers[2] to accommodate sites with steep slopes.

Ecological Site	Type	Total Area (ha)	Cover %
Rocky Side Slope[1]	Woodland	10,788	38
Steep Rocky Side Slope[2]	Woodland	6,101	21
Cool Slope[1]	Woodland	1,120	4
Warm Slope[1]	Woodland	1,164	4
Steep Warm Slope[2]	Woodland	950	3
Shallow Ridge[1]	Woodland	784	3
Steep Cool slope[2]	Woodland	226	1
Silty Footslope[1]	Woodland	88	< 0.5
Stony Hills[1]	Rangeland	3,507	12
Overflow[1]	Rangeland	1,097	4
Loamy[1]	Rangeland	1,164	4
Clayey[1]	Rangeland	567	2
Shallow Loamy[1]	Rangeland	406	1
Savannah[1]	Rangeland	483	2
Thin Upland[1]	Rangeland	18	< 0.1
Altered Sites[3]	Developed	74	< 0.4

[1] Provisional ecological sites identified by NRCS (USDA NRCS 2018).

[2] CSP-created sites on steep terrain.

[3] Sites with dams, lakes, campgrounds and or buildings.

Table 2. Water year (October – September) precipitation data (mm) collected at the Custer State Park Wildlife Station Visitor Center weather station[1] including long-term (1984-2015) average monthly precipitation and monthly precipitation for the 2014[2] and 2015[3] water years (Custer State Park Climate Data 2018).

Month	Long term Ave. Monthly Precipitation (mm)	2014 Precipitation (mm)	Actual Precipitation (mm) 2015
October	34	109	23
November	14	6	4
December	7	5	0
January	7	0	0.5
February	13	2	0.5
March	22	3	1
April	52	29	28
May	84	114	145
June	81	118	151
July	70	97	42
August	44	44	33
September	38	117	14
Total	466	644	442

[1]URL for Custer State Park Wildlife Station Visitor Center weather station water-year summary https://waterdata.usgs.gov/sd/nwis/wys_rpt/?site_no=434002103214500.

[2]URL for 2014 data is https://waterdata.usgs.gov/nwis/wys_rpt?dv_ts_ids=222992&wys_water_yr=2014&site_no=434002103214500&agency_cd=USGS&adr_water_years=2006%2C2007%2C2008%2C2009%2C2010%2C2011%2C2012%2C2013%2C2014%2C2015%2C2016%2C2017&referred_module=.

[3]URL for 2015 data is https://waterdata.usgs.gov/nwis/wys_rpt?dv_ts_ids=222992&wys_water_yr=2015&site_no=434002103214500&agency_cd=USGS&adr_water_years=2006%2C2007%2C2008%2C2009%2C2010%2C2011%2C2012%2C2013%2C2014%2C2015%2C2016%2C2017&referred_module=.

Table 3. Size (ha), area (ha) designated as Loamy Ecological Site, NRCS Major Land Resource Area (MLRA), and estimated date of establishment of prairie dog towns that were active in Custer State Park in 2013.

Prairie Dog Town	**Total Area (ha)[1]**	**Loamy Ecological Site Area (ha)[2]**	**MLRA[3]**	**Estimated Date of Establishment[4]**
Cow Camp	243	121	62	1978
Hay Flats	51	45	62	1978
North Lame Johnny	21	19	62	1989
4 Mile Road	9	4	62	1989
Swint Town	8	7	62	2008
Fisherman Flats	7	6	62	2008
Korthaus	6	2	62	2005
Wind Cave Corral Gate	6	6	62	2008
Racetrack	4	4	62	2005
Lower French Creek	3	3	62	
Bluebell	3	0	62	
4 Mile Draw	2	2	62	
Tea Kettle	2	2	62	
Bachelor Draw	2	2	62	
Robbers Roost	1	2	62	
Section 2	1	0	62	
Shepard Draw	1	0	62	
Flynn Creek Fire Rd.	1	1	62	
Red Valley	23	14	61	2005
VC Mineral Lick	4	0	61	
South Viewing	3	3	61	2006
East Trap	2	2	61	

[1]Prairie dog colony area (ha) mapped in 2013.

[2]Area of loamy ES soils for each prairie dog colony, determined in GIS by overlaying NRCS soils data with mapped prairie dog colonies.

[3] https://efotg.sc.egov.usda.gov/references/public/SD/MLRA_boudaries.pdf.

[4]Based on presence/absence in available Custer State Park aerial photos; For prairie dog colonies with no date included, date of establishment is unknown.

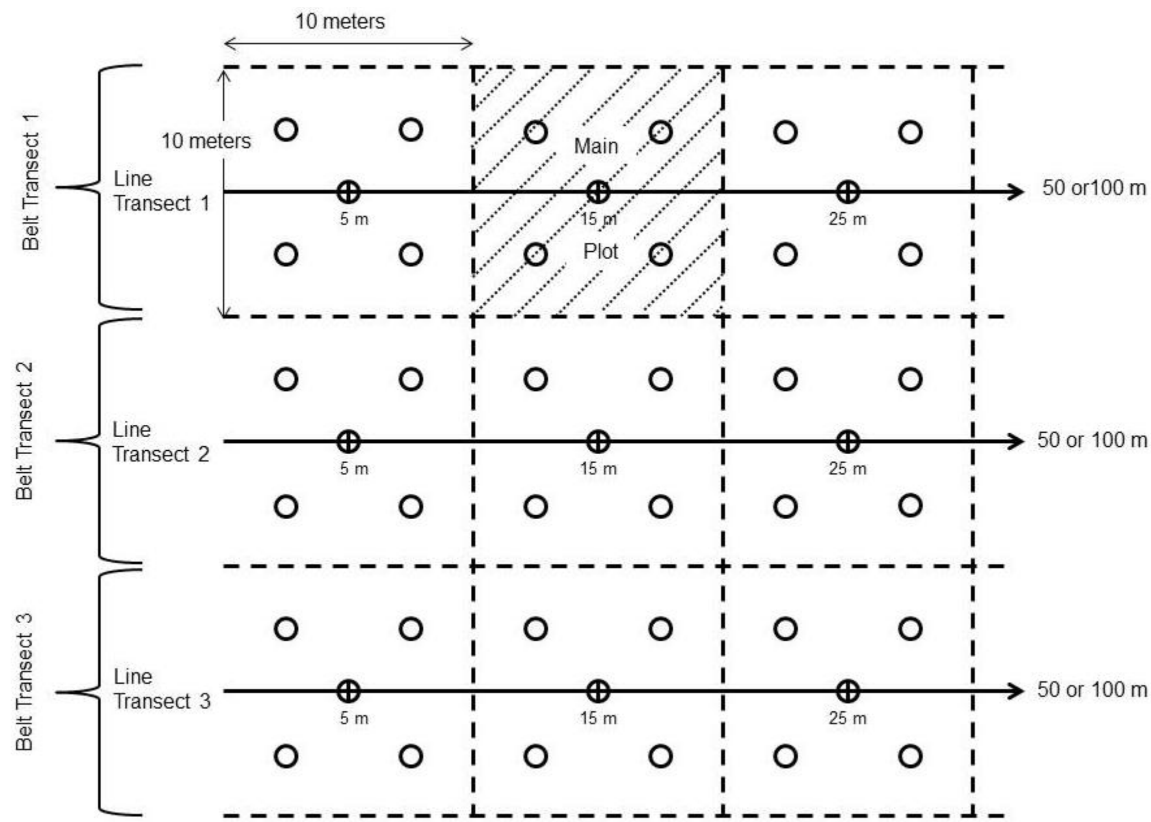

Figure 2. Schematic of 3 adjacent belt transects as they were used in this study. Fifty and 100 m transects were set up the same; the only difference was length. Solid lines represent line transects, horizontal dashed lines represent boundaries of the belt transects (5 m on both sides of each line transect). At each sampling location, 3 belt transects were placed adjacent to each other sharing belt boundaries. Line transect plots (⊕) were located at 10 m intervals starting 5 m from the beginning point of each line transect. Belt plots (○) were located 2.5 m on either side of each line transect; these plots begin 2.5 m from the beginning of the belt transect and occur at 5 m intervals. All plots were $0.25 m^2$ circular plots. Each 10 m length (indicated by vertical dashed lines) of a belt transect was designated as a main plot (example indicated by diagonal hatching), containing one line transect plot and 4 evenly spaced belt plots within the $100 m^2$ (10 m X 10 m) area.

Table 4. Similarity index score by colony and prairie dog area, comparing 2014 and 2015 main plot species cover data.

	Similarity Index Comparing 2014 and 2015 Species Cover Data					
Colony	Core	Edge	OFT[1]	R1[2]	R2[3]	R3[4]
Cow Camp	0.7	0.75	0.69	0.79	0.69	N/A
Hay Flats	0.75	0.72	0.87	0.73	0.82	N/A
N. Lame Johnny	0.74	0.77	0.85	0.77	0.83	0.66

[1]Associated off-town site.

[2]Data from first randomly placed transects in the interior of a prairie dog town.

[3]Data from second randomly placed transects in the interior of a prairie dog town.

[4]Data from third randomly placed transects in the interior of a prairie dog town (only for N. Lame Johnny prairie dog town).

RESULTS

Ordination and Cluster Analyses

Two axis solutions were recommended when running NMS ordination on Cow Camp (final minimum stress of 12.9 and r^2 of 0.89 for 2 axes), Hay Flats (final minimum stress of 16 and r^2 of 0.80 for 2 axes) and North Lame Johnny (final minimum stress of 14 and r^2 of 0.79 for 2 axes). Once the 3 colonies were combined, a final minimum stress of 11.952 and r^2 of 0.871 was obtained for 3 axes.

The congruence of the 2 analyses (ordination and cluster) demonstrates distinct differences in vegetation on all colonies between the core, edge and off-town areas (Figs. 3-8). In general, shorter vegetation (e.g. shortgrasses), weedy forbs (e.g. fetid marigold (*Dyssodia papposa* [Vent.] Hitchc.)), and fringed sage were most influential in separating the core from other areas on-town. This is consistent with the findings of Johnson-Nistler et al. (2004), Coppock et al. (1983a), and Baker et al. (2013) that found forbs and dwarf shrubs are common in long-term occupied areas. Off-town areas are separated from on-town areas in ordination analyses by having more Kentucky bluegrass, native mid-height grasses (e.g. needleandthread (*Hesperostipa comata* [Trin. & Rupr.] Barkworth)) and litter. This is consistent with vegetation expected on the loamy ES under moderate to light utilization (USDA NRCS 2018) with the exception of the inclusion of Kentucky bluegrass, which has been increasing in CSP (Keller 2011). The edge of the prairie dog towns, however, appears to be intermediate in character between the core of a prairie dog town and the associated off-town site, with less litter than off-town, but with a mix of grasses and forbs that occur in both. This is consistent with the findings of Coppock et al. (1983a) who demonstrated that vegetation of recently colonized areas of prairie dog towns, such as the edge; include species/species groups representative of both the off-town and on-town areas.

The vegetation of the general interior areas (R1, R2) of the Cow Camp (C) prairie dog town (Fig. 3) appears to represent plant associations that are intermediate between the core and edge, and include a variety of weedy forbs (R1 having Canada thistle (*Cirsium arvense* [L.] Scop.) and houndstongue (*Cynoglossum officinale* L.) and R2 having tumblegrass (*Schedonnardus paniculatus* [Nutt.] Trel.) and woolly plantain (*Plantago patagonica* Jacq.)). The vegetation from one of the transects (R1) of the general interior area of the Hay Flats (H) prairie dog town (Fig. 5) is distinct from the core and edge; tumblegrass appears to be an important component of the vegetation in that area. The other transect of Hay Flats (R2), largely overlaps the core. This suggests that, while the core is the oldest part of the Hay Flats prairie dog town, the area sampled by R2 has been occupied long enough to support vegetation similar to that found on the core. The general interior areas of the North Lame Johnny (N) prairie dog town (Fig. 7) represent the continuum between the core (overlapped by R3) and the edge (overlapped by R2); with one transect (R1) overlapping both. This suggests that 1) the town has been occupied long enough that some non-core areas have developed plant communities similar to the core; 2) the interior depth of the edge is greater than 30 m and/or there are areas interior of the edge that have only recently been affected by prairie dog herbivory; and 3) the area between the core and the edge in this prairie dog town represents a fairly tight transition zone.

Ordination of the combined dataset (Cow Camp, Hay Flats, and North Lame Johnny combined) resulted in a 3-dimensional plot (Fig. 9). One very striking observation about that plot is that, while there is overlap between the plant communities of the 3 towns, there are also considerable differences in the plant communities occurring on these 3 towns on the Loamy ES. This suggests that the array of plant communities possible on prairie dog towns in one ecological site may be much more diverse than is represented by any one town. Any state-and-transition model (STM) developed for prairie dog towns of the Loamy ES in MLRA 62 must, then, account for this variety of plant communities.

NMS ordination of the data for each individual prairie dog town grouped plots based on similar vegetation composition (Figs. 3, 5, 7). For all 3 towns, the core, edge, and off-town plots divided into separate groups. General interior plots appeared either as separate groups or in combination with the core, edge, or off-town plots, depending on similarity of vegetation. NMS ordination of the combined data for the 3 prairie dog towns (Fig. 9) indicated that while there is some similarity between them, the 3 towns were largely distinct. Cluster analysis of the combined data resulted in 16 clusters (Fig. 10), most of which are very similar to the groups from the individual towns. At the level where the dendrogram was cut, individual clusters did not represent plots from different prairie dog towns. This suggests, as did the ordination analysis, that the array of plant communities possible on prairie dog towns on the Loamy ES in MLRA 62 is much more diverse than can be portrayed by any one town. This also suggests that there are a number of fairly distinctive plant communities that can be found on these prairie dog towns and their off-town counterparts, each resulting from different levels of disturbance.

State-and-Transition Model Overview

The great value of ordination and cluster analysis in this study is in identifying distinct plant communities that can exist on prairie dog towns of the Loamy ES in MLRA 62. Determination of the pathways by which plant communities shift from one to another is not, however, generally evident in either the ordination plots or the cluster analysis dendrograms. Organization of plant communities into state-and-transition models requires a combination of analyzed field data and professional expertise (Interagency Ecological Site Handbook 2013). The latter is required to understand/describe the dynamics of an ecological site, including the shifts between plant communities and the causes of those changes. Knowledge of the effects of climatic events (e.g. drought, precipitation amounts and timing, temperatures, etc.), grazing (including presence/absence, timing, severity, and frequency of defoliation), fire, weed introductions, and other factors and their interactions is essential to understand how vegetation changes as well as the timeframes over which those changes occur. The professional expertise that has been applied to the interpretation of the field data from this study comes largely from Dr. Jack Butler (USFS), who has 35 years of experience studying the ecology and management of Northern Great Plains vegetation, and myself (Mark Hendrix), with 6 years of experience. Additional rangeland professionals who helped in interpreting the data and developing the STM for the Loamy ES for MLRA 62 include Dr. Patricia Johnson (SDSU), Dr. Roger Gates (SDSU-Retired), and Dr. Gary Brundige (SD GF&P- Retired).

Development of the STM for prairie dog towns on the Loamy ES of MLRA 62 began with an evaluation of the 16 vegetation communities identified by the cluster analysis of the 3 combined prairie dog towns of this study (Fig. 10; Table 5). The plant communities were evaluated for and grouped using key vegetation, soil cover and litter factors that would determine how plant communities would change in response to management (Table 6). These were then grouped into 6 states: State 1, Reference State; State 2, Native Invaded; State 3, Kentucky Bluegrass Dominated; State 4, Shortgrass Sod; State 5, Early Seral; and State 6, Fringed Sage Dominated. States 2 - 6 are characterized by modern day plant communities that resulted from the alteration of the reference state by (1) changes in grazing patterns, (2) fire suppression, and (3) introduction and expansion of aggressive, non-native perennial cool-season grasses (USDA NRCS 2018). A short description of the organization of the 16 vegetation communities into these states follows. Detailed descriptions of each state and phase within states then follows in the subsection titled “State-and-Transition Model Description”.

State 1: Reference State

The Reference State (State 1) has been identified by the provisional STM (USDA NRCS 2018) as best represented by Plant Community Phase 1.1: Rhizomatous wheatgrass-Needlegrass-Bluestem/Snowberry. This state has been identified as the reference/historic plant community. According to the NRCS Ecological Site Description (ESD) R062XC010SD (USDA NRCS 2018), potential vegetation is about 75% grasses or grass-like plants, 15% forbs, and 5% shrubs and 0 to 2% trees. The community is dominated by cool-season grasses; warm-season grasses are subdominants.

State 2: Native Invaded

The cluster **C** (Fig. 10; Tables 5 and 6) plant community had large percentage cover of big bluestem and is more similar than any of the other clusters to the community identified on the Loamy ESD (USDA NRCS 2018) as the reference state (State 1). In this community, big bluestem is the dominant warm-season grass, and includes a mixture of other warm-season and cool-season grasses. **C** has, however, been invaded by Kentucky bluegrass (Table 5). Thus, this community was designated as representing a phase of State 2, designated as Community Phase 2.1 (Table 6).

Western wheatgrass dominates clusters **H** and **O**, with no big bluestem or little bluestem and with some Kentucky bluegrass invasion (Table 5). These 2 clusters were separated into Phase: 2.2 (**H**) and Phase 2.3: (**O**) based on shortgrass cover found in cluster **O** (Table 6).

State 3: Kentucky Bluegrass Dominated

Kentucky bluegrass dominates clusters **E**, **F, D**, **G**, and **N** in association with western wheatgrass and a minimal contribution by big bluestem and shortgrasses (Table 5). Clusters **E** and **F** are very similar, and will likely respond to disturbances similarly, so they were combined as Community Phase 3.1 (Table 6). Clusters **D** and **G** are very similar in terms of the major species likely to influence responses to management and disturbances (e.g. Kentucky bluegrass and western wheatgrass), and were combined into one phase: 3.2 (Table 6). Cluster **N**, however, differs from clusters **E**, **F, D,** and **G** with respect to the large component of shortgrasses in the community. As a result, cluster **N** was designated as phase 3.3 (Table 6). Kentucky bluegrass increases with long-term non-use, lack of fire, and an increase in litter. Native mixed-grass species cover is reduced as

Kentucky bluegrass increases, which in turn negatively influences species diversity and vegetation production (Toledo et al. 2014).

State 4: Shortgrass Sod

Clusters **K, L, M, and P** are all dominated by shortgrasses with a large component of western wheatgrass; Kentucky bluegrass is present but in relatively small amounts (Table 5). These clusters were designated as belonging to State 4. Cluster **P** has much higher shortgrass cover compared to **L**, **M**, and **K**; it also has no fringed sage. Thus **P** was designated as a separate phase within State 4: phase 4.1 (Table 6). Clusters **K, L**, and **M** are very similar in terms of cover of shortgrasses, western wheatgrass and Kentucky bluegrass. Cluster **K**, however, has only a small amount of fringed sage and no Annual brome, setting it apart from clusters **L** and **M** which have much greater fringed sage and substantial Annual brome. The potential influence of those species on responses to disturbances, climate, and management resulted in Cluster **K** being designated as a separate phase in State 4: phase 4.2 (Table 6). Clusters **L** and **M** are very similar to each other in terms of the major species likely to influence responses to management and disturbance (e.g. shortgrasses, western wheatgrass, and fringed sage cover) (Table 5); they were thus combined into one phase of State 4: phase 4.3 (Table 6).

State 5: Early Seral

Clusters **J**, **B** and **I** share several similarities: they have no Kentucky bluegrass, annual brome, or little bluestem and the combined shortgrass and western wheatgrass component is moderate (40 – 58% cover) (Table 5). The lack of a Kentucky bluegrass component coupled with a substantial presence of native shortgrasses and western wheatgrass are important factors affecting the trajectories of vegetation change likely for these clusters; thus they have been grouped into State 5. Each of these clusters, however, have vegetation differences that will modify those trajectories. Cluster **J** has relatively equal amounts of shortgrasses and western wheatgrass with no annual exotic species; native perennial grasses in cluster **B** are made up almost entirely of western wheatgrass, and there is a large component of annual exotic species; and cluster **I** has a good component of western wheatgrass and shortgrasses with no annual exotic species, but it also has a relatively high cover of fringed sage. Because these differences are likely to generate different responses to disturbances and management, the 3 clusters have been designated as separate phases within State 5. Cluster **J** was designated as phase 5.1, **B** as phase 5.2, and **I** as phase 5.3 (Table 6).

State 6: Fringed Sage Dominated

Cluster **A** is made up entirely by plots found on the core of the Cow Camp prairie dog town (Figure 31). The vegetation is dominated by fringed sage interspersed with fetid marigold and other annuals; shortgrasses are absent and western wheatgrass makes only a minimal (3% cover) contribution (Table 5). Cluster A was designated as State 6. The plant community represented by Cluster **A** is the result of long-term heavy defoliation; it is likely that considerable time and inputs may be required to affect a shift toward greater components of native perennial grasses representative of other states.

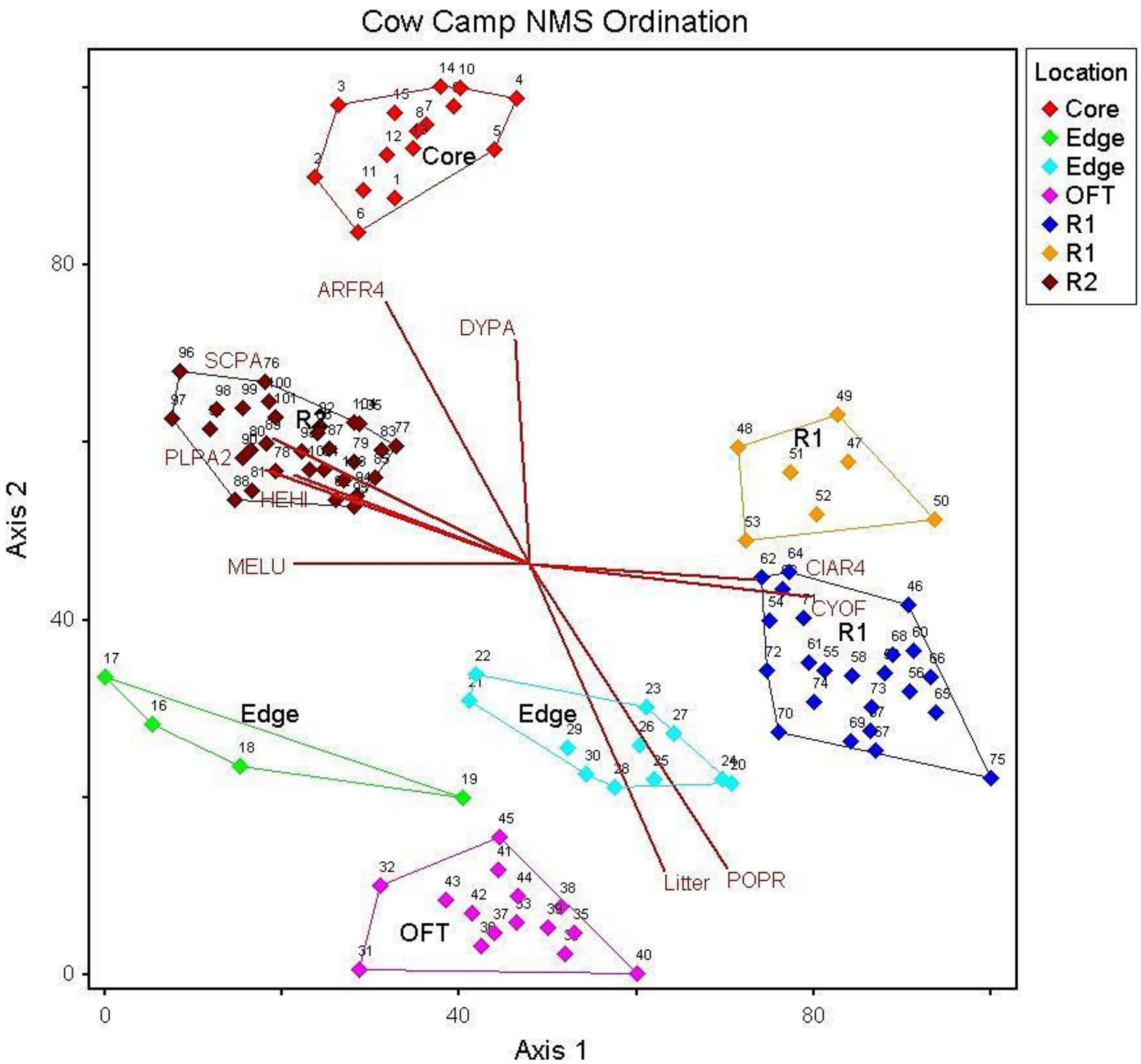

Figure 3. NMS 2 dimensional ordination plot for the Cow Camp prairie dog town, with a final minimum stress of 12.9 and r^2 of 0.89 for 2 axes. Main plots are designated by small diamonds with corresponding ID number; locations of plots on prairie dog town sampling areas are indicated by color of diamonds and polygon. Ordination plot reflects 7 groupings, including Core, Edge (divided into 2 groupings), OFT (off-town), R1 (Random Interior #1; divided into 2 groupings), and R2 (Random Interior #2). Line overlays indicate influence of vegetation species correlations; species shown have an $r^2 \geq 0.50$ and are the most influential species for each of the sampling locations. Axis 1 ($r^2 = 0.410$) is related to cover of tumblegrass (SCPA), woolly plantain (PLPA2), rough false pennyroyal (HEHI), black medic (MELU), Canada thistle (CIAR4), and houndstongue (CYOF). Axis 2 ($r^2 = 0.475$) is related to cover of Kentucky bluegrass (POPR), litter, fringed sagewort (ARFR4), and fetid marigold (DYPA) (see Appendix Table A.1 for species codes and common and scientific names).

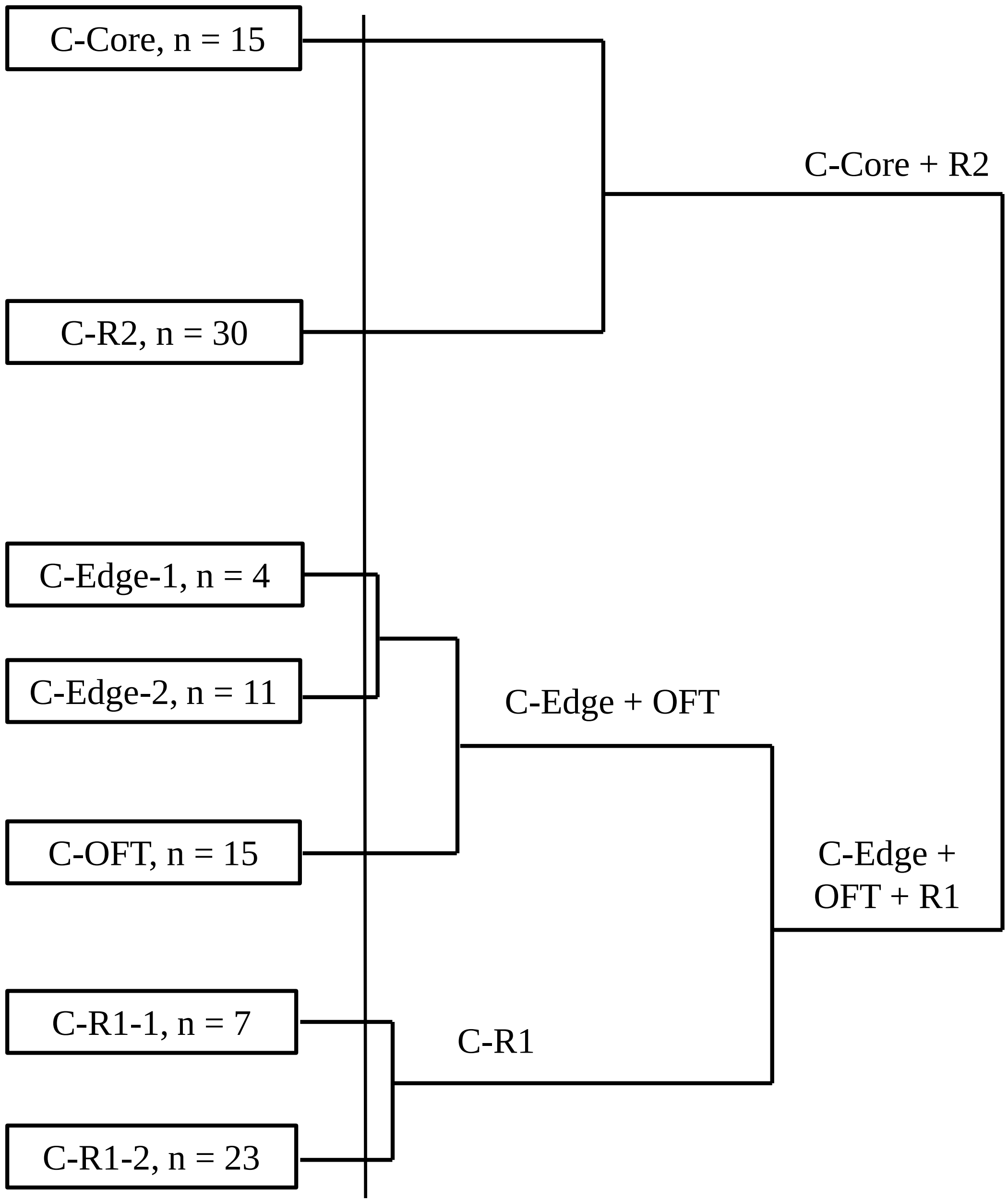

Figure 4. Cluster analysis dendrogram for plots on the Cow Camp (C) prairie dog town, with percent chaining of 0.99%. Dendrogram was cut vertically, with 55% information explained by the resulting 7 clusters (individual main plots (MPS) within clusters not shown for clarity of presentation). Each cluster is named to reflect prairie dog town (C), locations of MPS contained therein (i.e. Core, Edge, R1, R2, and OFT (off-town)); location and the number of MPS (n) included in the cluster are identified on the left side of the dendrogram. Note: MPS initially identified as representing "Edge" were divided into 2 clusters (Edge-1, Edge-2); MPS initially identified as representing R1 were also divided into 2 clusters (R1-1, R1-2).

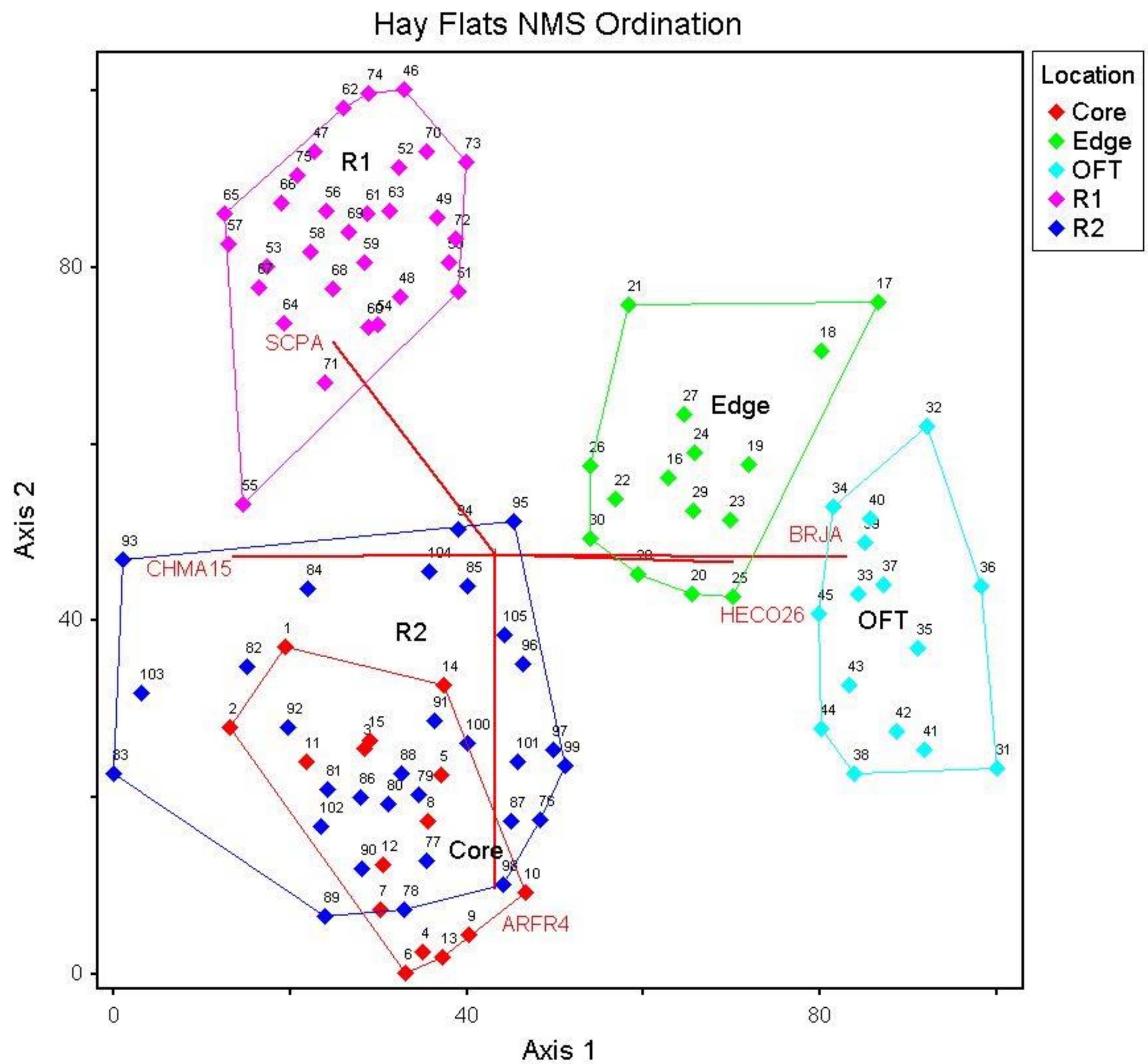

Figure 5. NMS 2 dimensional ordination plot for the Hay Flats prairie dog town, with a final minimum stress of 16 and r^2 of 0.80 for 2 axes. Main plots are designated by small diamonds with corresponding ID number; locations of plots on prairie dog town sampling areas are indicated by color of diamonds and polygon. Ordination plot reflects the original 5 sampling locations: Core, Edge, OFT (off-town), R1 (Random Interior #1), and R2 (Random Interior #2). Line overlays indicate influence of vegetation species correlations; species shown have an $r^2 \geq 0.50$ and are the most influential species for each of the sampling locations. Axis 1 ($r^2 = 0.441$) is related to cover of annual brome (AB), needleandthread (HECO26), and prostrate spurge (CHMA15). Axis 2 ($r^2 = 0.357$) is related to cover of fringed sagewort (ARFR4) and tumblegrass (SCPA) (see Appendix Table A.1 for species codes and common and scientific names).

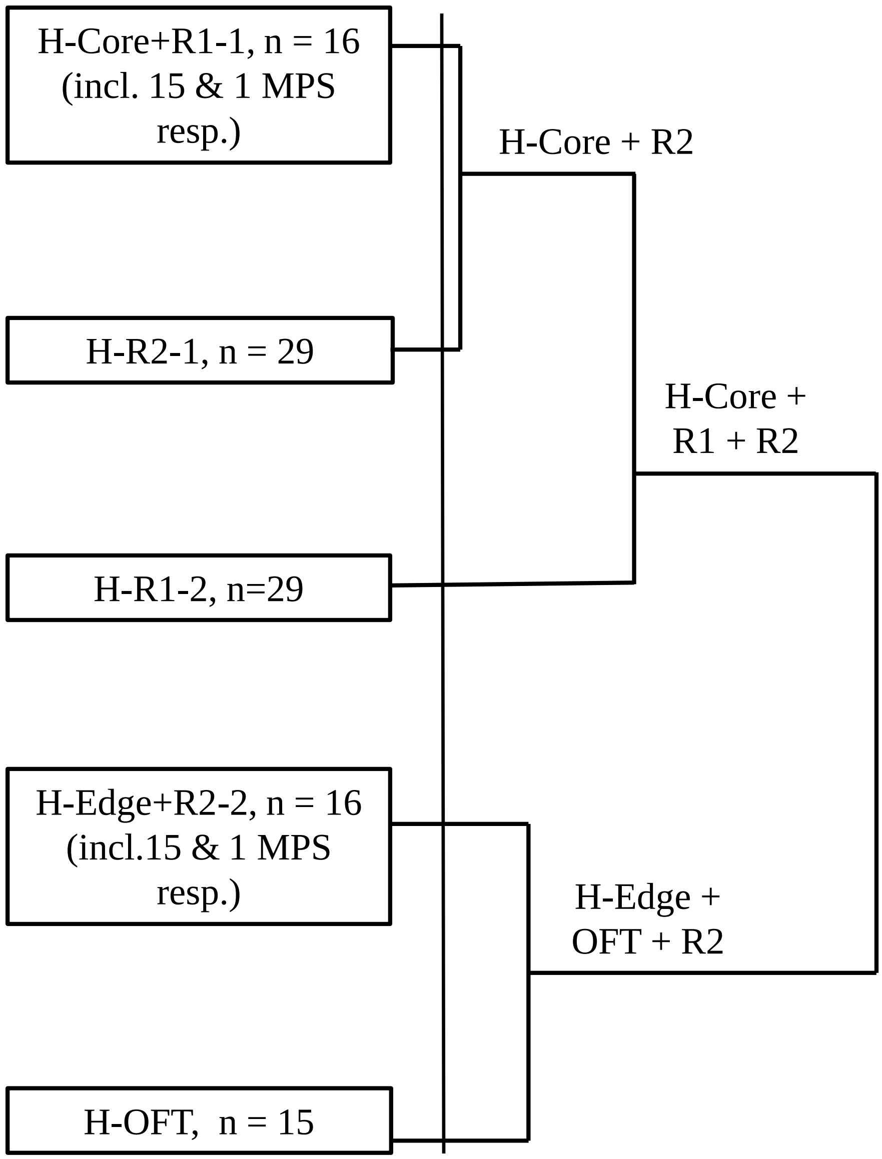

Figure 6. Cluster analysis dendrogram for plots on the Hay Flats (H) prairie dog town, with percent chaining of 1.15%. Dendrogram was cut vertically, with 75% information explained by the resulting 5 clusters (individual main plots (MPS) within clusters not shown for clarity of presentation). Each cluster is named to reflect prairie dog town (H), locations of MPS contained therein (i.e. Core, Edge, R1, R2, and OFT (off-town)). One MPS from R1-1 clustered with the Core plots. Similarly, one MPS from R2-2 clustered with the Edge plots. Location and the number of MPS (n) included are identified on the left side of the dendrogram.

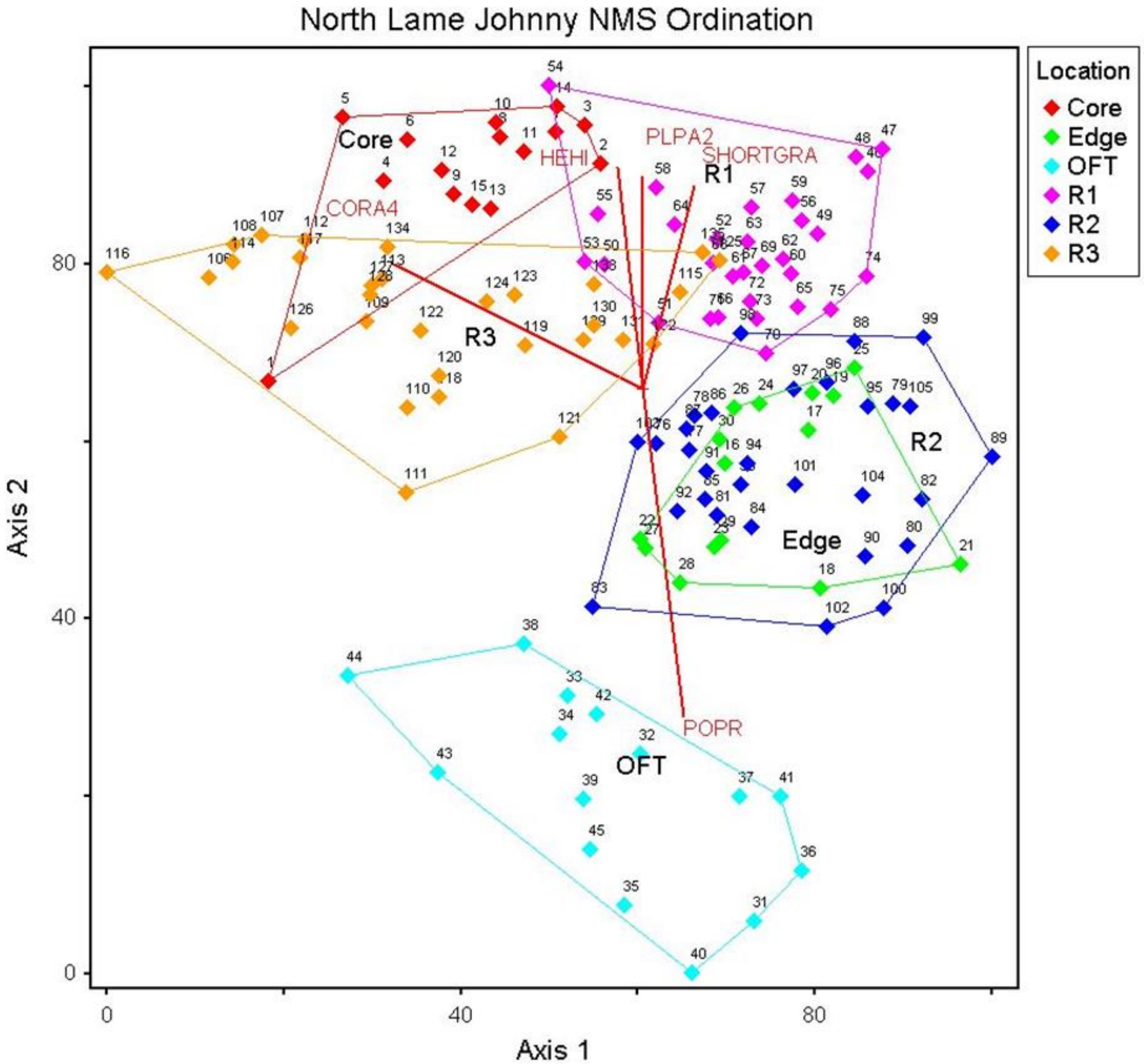

Figure 7. NMS 2 dimensional ordination plot for the North Lame Johnny prairie dog town, with a final minimum stress of 14 and r^2 of 0.79 for 2 axes. Main plots are designated by small diamonds with corresponding ID number; locations of plots on prairie dog town sampling areas are indicated by color of diamonds and polygon. Ordination plot reflects the original 6 sampling locations: Core, Edge, OFT (off-town), R1 (Random Interior #1), R2 (Random Interior #2), and R3 (Random Interior #3). Line overlays indicate influence of vegetation species correlations; species shown have an $r^2 \geq 0.45$ and are the most influential species for each of the sampling locations. Axis 1 ($r^2 = 0.441$) is related to cover of dwarf horseweed (CORA4). Axis 2 ($r^2 = 0.357$) is related to cover of Kentucky bluegrass (POPR), woolly plantain (PLPA2), rough false pennyroyal (HEHI) and Shortgrasses (SHORTGRA) (see Appendix Table A.1 for species codes and common and scientific names).

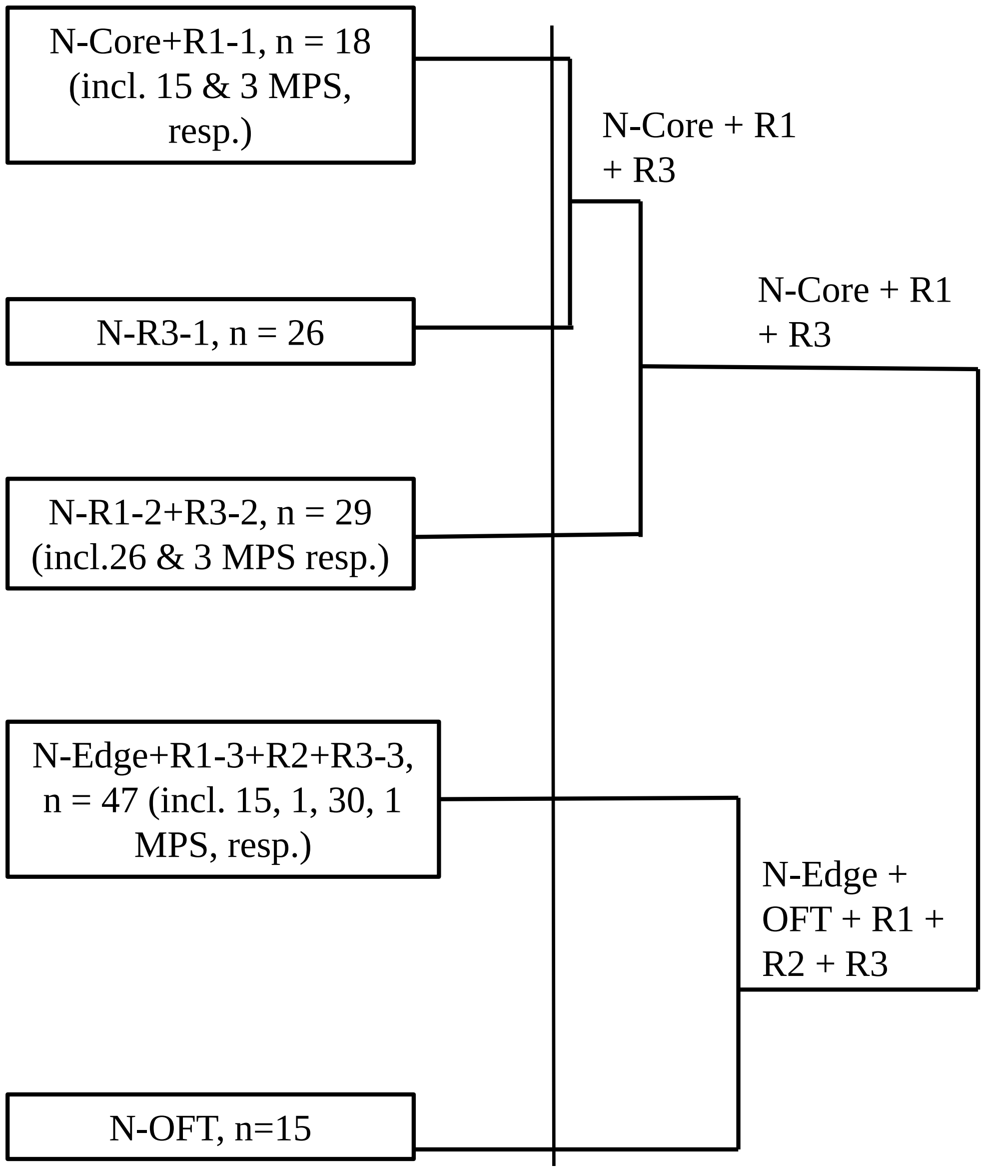

Figure 8. Cluster analysis dendrogram for plots on the North Lame Johnny (N) prairie dog town, with percent chaining of 1.28%. Dendrogram was cut vertically, with 80% information explained by the resulting 5 clusters (individual main plots (MPS) within clusters not shown for clarity of presentation). Each cluster is named to reflect prairie dog town (N), and locations of MPS contained therein (i.e. Core, Edge, R1, R2, R3, and OFT (off-town)). Three MPS from R1-1 clustered with the Core plots. Similarly, 3 MPS from R3-2 clustered with the R1 plots. All Edge and R2 MPS clustered with 1 MPS each from R1-3and R3-3. Location and the number of MPS (n) included are identified on the left side of the dendrogram.

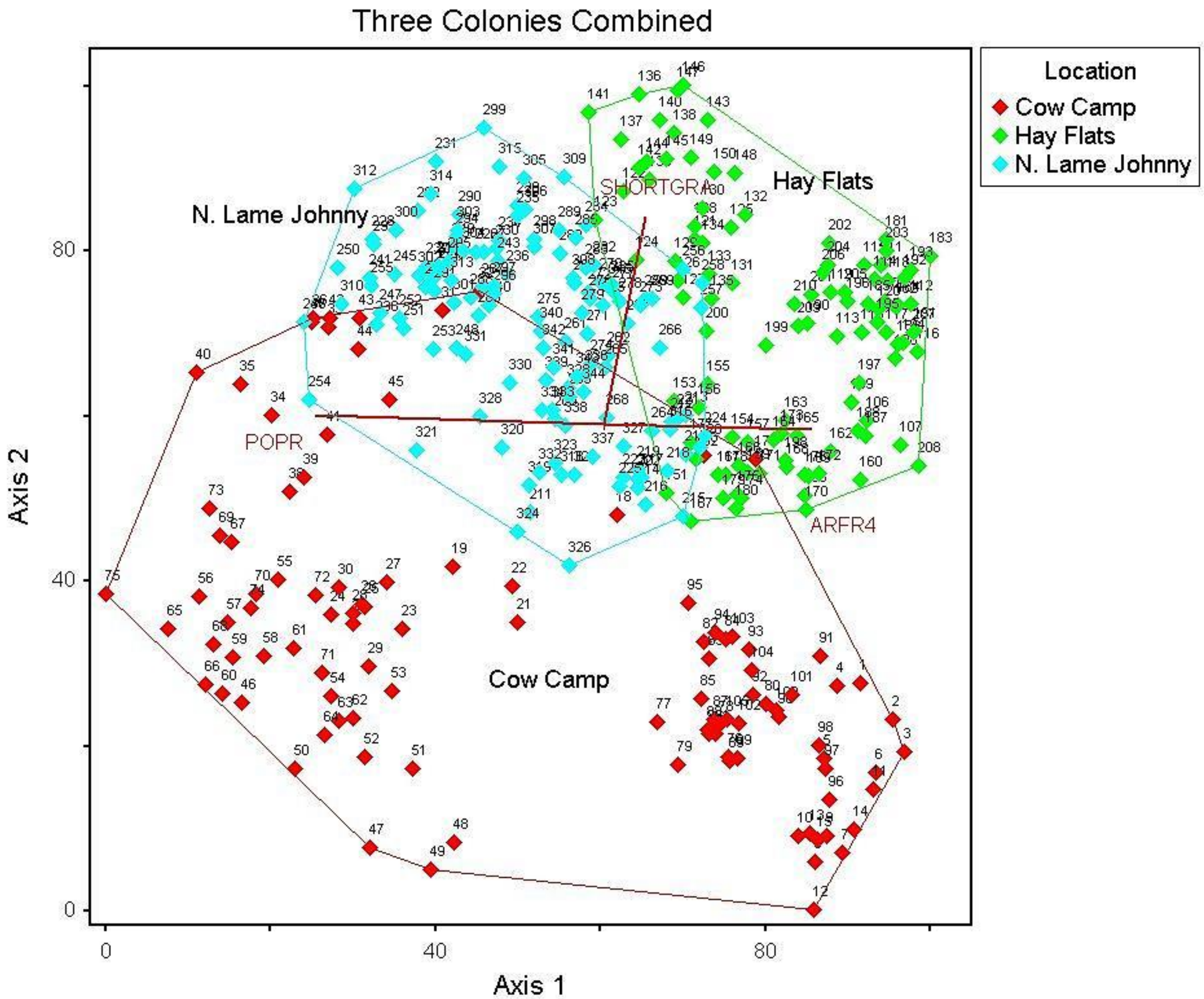

Figure 9. NMS three dimensional ordination plot (Axis 3 not shown) for the Cow Camp (C), Hay Flats (H), and North Lame Johnny (N) prairie dog towns, with a final minimum stress of 11.952 and r^2 of 0.871 for 3 axes. Main plots are designated by small diamonds with corresponding ID number (C 1-105; H 106-210; and N 211-345); locations of plots on prairie dog colonies are indicated by color of diamonds and polygons. Line overlays indicate influence of vegetation species correlations; species shown have an $r^2 \geq 0.50$ and are the most influential species for each of the sampling locations. Axis 1 ($r^2 = 0.490$) is related to the cover of Kentucky bluegrass (POPR), and fringed sagewort (ARFR4). Axis 2 ($r^2 = 0.272$) is related to the cover of shortgrasses (SHORTGRA), woolly verbena (VEBR) and fetid marigold (DYPA) Axis 3 (not shown) ($r^2 = 0.109$) is related to the cover of big bluestem (ANGE), field cottonrose (LOAR5), and western ragweed (AMPS) (see Appendix Table A.1 for species codes and common and scientific names).

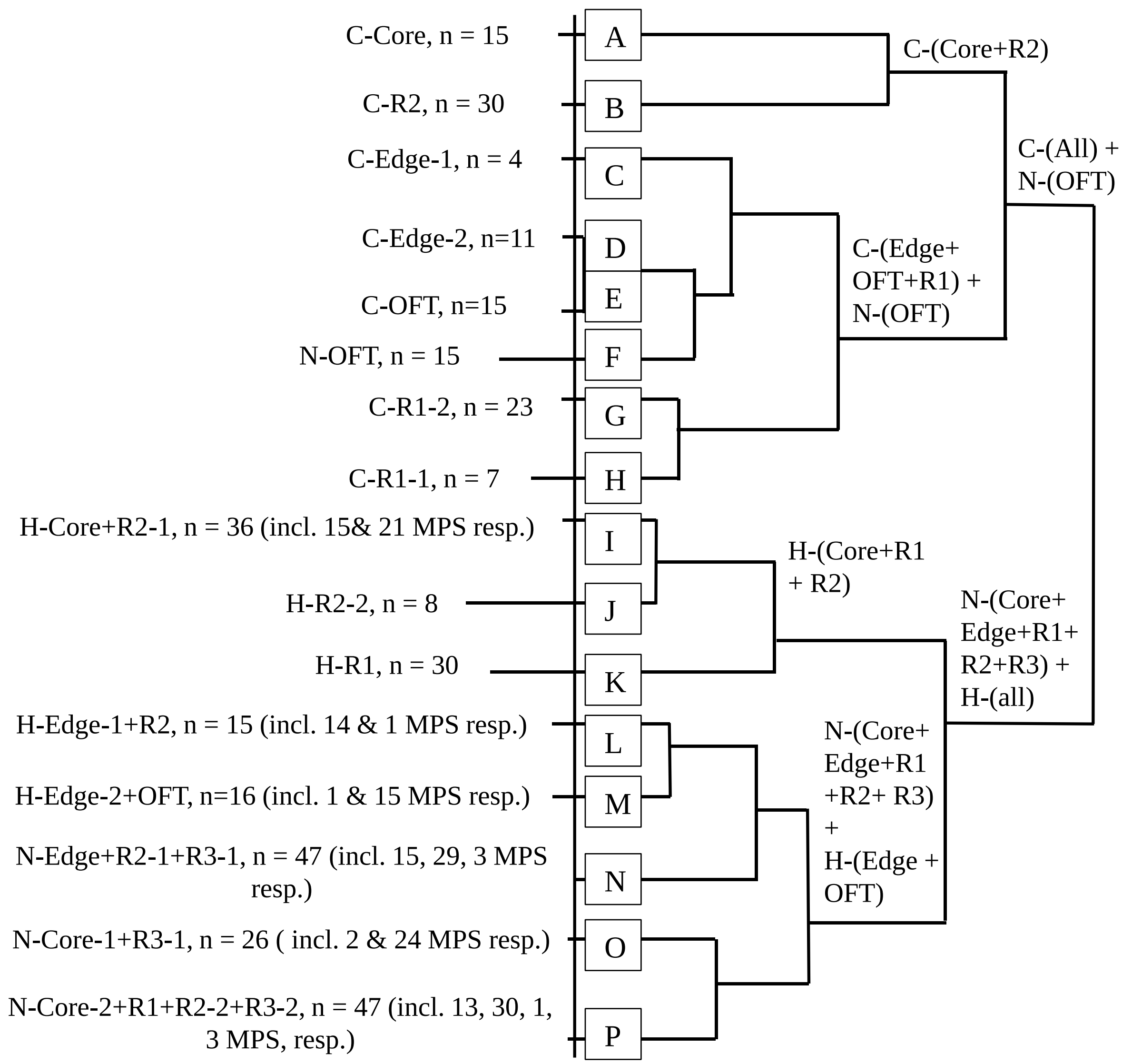

Figure 10. Cluster analysis dendrogram for plots on the Cow Camp (C), Hay Flats (H), and North Lame Johnny (N) prairie dog towns, with percent chaining of 0.36%. Dendrogram was cut vertically, with 58% information explained by the resulting 16 clusters (individual main plots (MPS) within clusters not shown for clarity of presentation). Each cluster is named to reflect prairie dog town (C, H, and N) and locations of MPS contained therein (i.e. Core, Edge, R1, R2, R3, and OFT (off-town)). Cluster location and the number of MPS (n) included are identified on the left side of the dendrogram. Letters in boxes on the right side of the division line provide a simpler naming system for the 16 clusters and will be used exclusively in subsequent tables, figures, and text. Key species cover values and associated ground cover can be found in Table 5.

Table 5. Cluster analysis dendrogram results (Figure 10) in table format. Included for each of the 16 Clusters are associated bare soil, foliar, litter, and key species/species groups[1] cover values that likely influence vegetation change on the Loamy ES in MLRA 62. See Appendix Table A.1 for species codes and common and scientific names.

Cluster	Bare Soil	Foliar	Litter	Ann Exotic	Ann Forb	Ann Native	Per Exotic	Per Native	AB	ANGE	ARFR	PASM	POPR	SHORT GRASS
C	6	90	43	12	26	14	5	30	0	38	7	8	16	21
H	12	84	46	2	16	14	19	16	1	0	0	56	8	0
O	10	87	42	20	41	21	5	15	12	0	0	44	8	27
F	2	96	64	12	12	0	10	56	2	6	1	29	54	8
E	1	91	63	32	33	1	19	62	13	7	2	29	56	2
D	4	93	36	20	25	5	24	26	0	7	0	62	54	0
G	1	96	54	2	4	2	40	8	1	1	0	63	50	0
N	3	94	54	15	17	2	6	21	42	1	0	33	37	44
P	3	94	52	22	62	40	4	23	29	0	0	40	5	64
K	3	94	44	0	26	26	3	35	0	0	2	41	9	34
M	2	95	63	2	5	3	7	39	64	0	10	49	7	39
L	4	91	53	1	7	7	2	37	17	0	17	38	15	39
J	12	85	34	0	10	10	1	82	0	0	17	26	0	26
B	6	92	26	51	97	46	4	24	0	0	11	39	0	1
I	11	86	25	0	6	6	1	70	0	0	36	18	0	40
A	16	81	11	5	17	12	27	87	0	0	55	3	0	0

[1]Key species/species groups were: Ann Exotic=exotic (non-native) annuals; Ann Forbs=annual forbs; Ann Native= native annuals; Per Exotic=exotic (non-native) perennial; Per Native= native perennial; AB=Annual brome; ANGE=big bluestem; ARFR=fringed sage; PASM=western wheatgrass; POPR=Kentucky bluegrass; Shortgrass=blue grama, hairy grama, and buffalo grass.

Table 6. Cover of bare soil, total foliar, litter, and key species/species groups[1] for the 16 clusters resulting from the final cluster analysis dendrogram (Figure 10). Three pairs of those clusters (E/F, D/G, and L/M)[2] were combined because of similarities in species composition that impact management implications. The final 13 clusters were organized into states and phases within the Custer State Park Prairie Dog State-and-Transition model for the Loamy Ecological Site in MLRA 62.

State. Phase	Clu-ster	Bare Soil	Foliar	Litter	Ann Exotic	Ann Forbs	Ann Native	Per Exotic	Per Native	AB	ANGE	ARFR	PASM	POPR	SHORT GRASS
2.1	C	6	90	43	12	26	14	5	30	0	38	7	8	16	21
2.2	H	12	84	46	2	16	14	19	16	12	0	0	56	8	0
2.3	O	10	87	42	20	41	21	5	15	12	0	0	44	8	27
3.1	E/F	2	93	64	22	22	0	15	59	7	6	2	29	55	5
3.2	D/G	3	95	45	11	15	4	32	17	1	4	0	62	52	0
3.3	N	3	94	54	15	17	2	6	21	42	1	0	33	37	44
4.1	P	3	94	52	22	62	40	4	23	29	0	0	40	5	64
4.2	K	3	94	44	0	26	26	3	35	0	0	2	41	9	34
4.3	L/M	3	93	58	1	6	5	5	38	40	0	13	43	11	39
5.1	J	12	85	34	0	10	10	1	82	0	0	17	26	0	26
5.2	B	6	92	26	51	97	46	4	24	0	0	11	39	0	1
5.3	I	11	86	25	0	6	6	1	70	0	0	36	18	0	40
6.1	A	16	81	11	5	17	12	27	87	0	0	55	3	0	0

[1]Key species/species groups were: Ann Exotic=exotic (non-native) annuals; Ann Forbs=annual forbs; Ann Native= native annuals; Per Exotic=exotic (non-native) perennial; Per Native= native perennial; AB=Annual brome; ANGE=big bluestem; ARFR=fringed sage; PASM=western wheatgrass; POPR=Kentucky bluegrass; Shortgrass=blue grama, hairy grama, and buffalo grass.

[2]Clusters that were combined were: E and F due to similar western wheatgrass (56 and 54) and Kentucky bluegrass (29 and 29) percent cover; D and G due to similar western wheatgrass (62 and 63) and Kentucky bluegrass (54 and 50) percent cover; and L and M due to similar shortgrass (39 and 39) and western wheatgrass (38 and 49) percent cover.

DISCUSSION

State-and-Transition Model

State-and-transition models (STMs) are much more than a simple listing of the states and phases within states that can exist on an ES. They must include transitions or pathways of change that can occur, with information on the conditions, disturbances, and management that cause those changes. It is critical to understand the differences between changes in a plant community within a state and changes between states, and the processes that lead to both. Changes in plant community composition between plant communities (phases) within a state are considered to be fairly easy to reverse in a reasonable timeframe. Thresholds, where a plant community shifts to another state, are, however, often viewed as permanent, or at least are considered very difficult and/or time consuming to reverse.

The Prairie Dog STM for the Loamy ES of MLRA 62 in Custer State Park developed through this project follows. States, phases, pathways within states, transitions and restorations between states included in the STM diagram (Fig. 4) are described. It is important to note that the STM described in this study is specific to prairie dog affected sites of the Loamy ES in MLRA 62. It shares one phase (1.1) within the Reference State (State 1.0) of the STM described in the Loamy 62C ESD (USDA NRCS 2018). There are also some similarities between state 2 of the NRCS STM and state 2 of The STM developed in this study, however, should be considered a stand-alone STM that captures the unique processes, states, and phases associated with prairie dog activity on the Loamy ES in MLRA 62. Thus, except for state 1 (and possibly state 2), the states, phases, pathways, and transitions of the Prairie Dog STM for the Loamy ES of MLRA 62 are separate from the STM for the Loamy ES of MLRA 62.

State 1: Reference State

Prior to European settlement and the introduction and spread of non-native forage grasses, grasslands were maintained by repeated drought, sporadic natural or Native American caused wildfire (usually of light intensities), light to severe grazing by bison and other large native ungulates, insects, small mammals, and other biotic and abiotic factors that influenced soil and site development (USDA NRCS 2018). Prior to settlement of the Black Hills, fire was ecologically important because it influenced the composition and structure of all plant communities (Shepperd and Battaglia 2002). The pre-settlement fire return interval for the southern Black Hills with ponderosa pine and mixed-grass prairie ecotone, similar to the areas studied in CSP, was 10 to 12 years (Brown and Sieg 1999). The historic fire regime of the Black Hills resulted in open savanna ponderosa pine stands scattered among northern mixed-grass prairie dominated areas (Shepperd and Battaglia 2002). Laurenroth and Milchunas (1989) suggest bison moved in large herds, grazing or trampling most things in their path. Large ungulate use at the time was heavy, but the large herds would not return for a few years, allowing plant communities to recover (Laurenroth and Milchunas 1989). Encroachment of ponderosa pine can occur on this ES in the absence of low intensity fires that naturally thin small seedlings (USDA NRCS 2018).

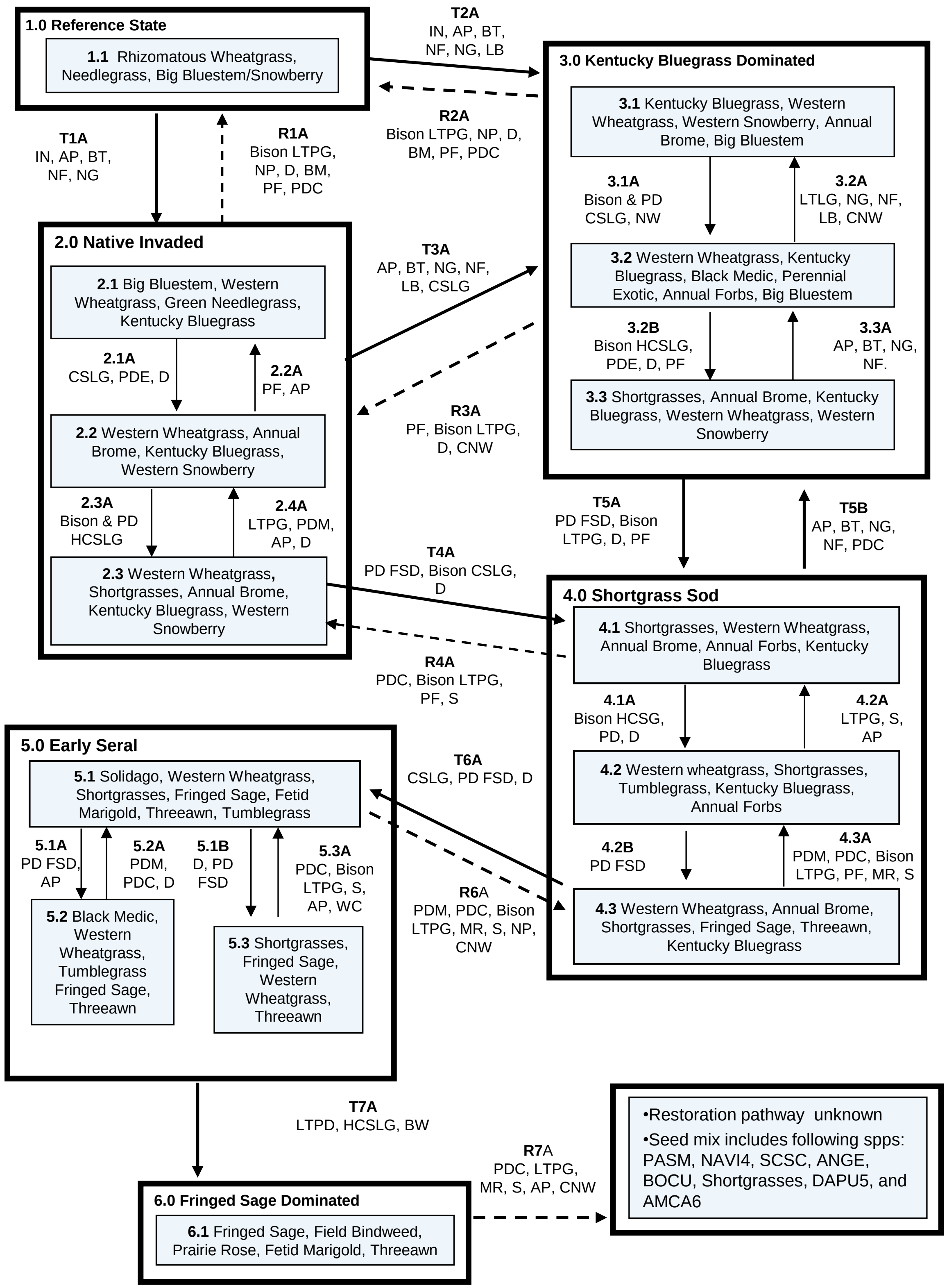

Figure 11. State-and-transition model for the Loamy MLRA 62 Prairie dog ecological site. For a detailed description and photographs of each state, plant community phase, community phase pathway, transition, and restoration, refer to the discussion section. SEE LIST OF ABBREVIATIONS FOR STM (pg. v).

Community Phase 1.1: Rhizomatous wheatgrass-Needlegrass-Bluestem/Snowberry

The Reference State (State 1) has been identified by the provisional STM (USDA NRCS 2018) as best represented by Plant Community Phase 1.1: Rhizomatous wheatgrass-Needlegrass-Bluestem/Snowberry. This state has been identified as the reference/historic plant community. According to the NRCS Ecological Site Description (ESD) R062XC010SD (USDA NRCS 2018), potential vegetation is about 75% grasses or grass-like plants, 15% forbs, and 5% shrubs and 0 to 2% trees. The community is dominated by cool-season grasses; warm-season grasses are subdominants. Major cool-season grass species include: western wheatgrass, slender wheatgrass (*Elymus trachycaulus* (Link) Gould ex Shinners), needleandthread, and porcupinegrass (*Hesperostipa spartea* (Trin.) Barkworth). Dominant warm-season grasses include: big bluestem, little bluestem, and sideoats grama. Other grasses or grass-like species include: prairie dropseed (*Sporobolus heterolepis* [A. Gray] A. Gray), tall drop seed (*Sporobolus compositus* (Poir.) Merr.), blue grama, plains muhly (*Muhlenbergia cuspidata* [Torr. ex Hook.] Rydb.), and threadleaf sedge (*Carex filifolia* Nutt.). Western snowberry is the dominant shrub.

The reference/historical plant community is resilient and well adapted to the Northern Great Plains fire regime and climatic conditions that are somewhat modified by the ecotone overlap of the prairie and the Black Hills. The diversity in plant species promotes high drought tolerance. This is a sustainable plant community in regards to site, soil stability, watershed function, and biologic integrity (USDA NRCS 2018).

State 2: Native Invaded

Native perennial grasses such as western wheatgrass and big bluestem, dominate this state, however Kentucky bluegrass has become established along with some annual grasses and forbs. Native species limit the expansion of non-native species by utilizing nutrients, moisture and sunlight. Invasive Kentucky bluegrass has become established at the expense of native, cool-season grasses due to ecological, morphological, and physiological similarities. Ecologically, both western wheatgrass and Kentucky bluegrass are well adapted to loamy soils. Physiologically, western wheatgrass and Kentucky bluegrass are cool-season species that grow in spring and, if moisture is sufficient, fall; thus they compete directly for limited resources. Morphologically, western wheatgrass and Kentucky bluegrass are both cool-season, rhizomatous, mid-height, sod forming perennial grasses (Johnson and Larson 2007). Combined bison and prairie dog use characterize the native invaded state. According to ESD R062XC010SD this plant community is resilient and well adapted to the Northern Great Plains climatic conditions. Diversity in plant species promotes high drought tolerance. This is a sustainable plant community regarding site/soil stability, watershed function, and biologic integrity (USDA NRCS 2018). Presence of Kentucky bluegrass is a primary management concern. According to Toledo et al. (2014), Kentucky bluegrass negatively alters the landscape following establishment by altering nutrient flow, hydrology, soil surface structure, soil stability and genetic diversity. Management prescriptions must include strategies that limit or prevent significant increases in Kentucky bluegrass or risk transition to State 3.0 (Kentucky Bluegrass Dominated).

Community Phase 2.1: Big Bluestem, Western Wheatgrass, Green Needlegrass, Kentucky Bluegrass (Figure 12)

Potential vegetation is about 70% grasses or grass-like plants, 25% forbs, and 5% shrubs. Community 2.1 is dominated by native warm-season grasses with native cool-season grasses as subdominants. Maintenance of warm-season grasses in this state is affected by climatic events such as spring drought which, in the northern mixed-grass prairie, typically results in a shift from cool-season to warm-season grass production (Heitschmidt et al. 2005). Sites on which this phase was based occurred on the prairie dog town edge, and may be representative of the transition of Kentucky bluegrass invaded plant communities associated with recently initiated prairie dog activity (Fig. 12). Major grasses (with associated percent foliar cover values) on the sites on which this phase was based (Table 6) include: big bluestem (38), shortgrasses (21), little bluestem (12), needleandthread (15), Kentucky bluegrass (16), western wheatgrass (8), and green needlegrass (6).

Figure 12. Example photograph of a transect in plant community phase 2.1.

Community Phase 2.2: Western Wheatgrass, Annual Brome, Kentucky Bluegrass, Western Snowberry (Figure 13)

Potential vegetation is about 75% grasses or grass-like plants, 20% forbs, and 5% shrubs. Community 2.2 is dominated by native cool-season grasses. The sites on which this phase was based occurred on the prairie dog town interior. Major species (with associated percent foliar cover values) on the sites on which this phase was based (Table 6) include: western wheatgrass (56), annual brome (12), Kentucky bluegrass (8), Canadian horseweed (*Conyza canadensis* [L.] Cronquist) (5) and western snowberry (2). Big bluestem and little bluestem cover values have been reduced to 5% or less, likely due to prairie dog activity. Prairie dog activity may also be keeping Kentucky bluegrass cover to relatively low levels. Non-native annuals and cool-season perennials have taken advantage of the space and resources available with the reduction in late seral native warm-season grass species.

Figure 13. Example photograph of a transect in plant community phase 2.2.

Community Phase 2.3: Western Wheatgrass, Shortgrasses, Annual Brome, Kentucky Bluegrass, and Western Snowberry (Figure 14)

Potential vegetation is about 70% grasses or grass-like plants, 25% forbs, and 5% shrubs. Community 2.3 is dominated by cool-season grasses with short warm-season grasses as subdominants. The sites on which this phase was based occurred on the prairie dog town interior. Major species (with associated percent foliar cover values) on the sites on which this phase was based (Table 6) include: western wheatgrass (44), shortgrasses

(27), annual brome (12), Kentucky bluegrass (8), woodsorrel (*Oxalis* L.) (4), prostrate knotweed (*Polygonum aviculare* L.) (2) and western snowberry (1). The warm-season tall and mid-height species of big bluestem and little bluestem have been replaced by warm-season shortgrasses, likely due to prairie dog activity. Prairie dog activity may also be keeping Kentucky bluegrass cover to relatively low levels. Non-native annual forbs and graminoids take advantage of the space and resources available with the reduction in native species.

Figure 14. Example photograph of a transect in plant community phase 2.3.

State 3: Kentucky Bluegrass Dominated

Kentucky bluegrass dominates this site. This is at least partly due to climatic conditions that favor their expansion in the Black Hills compared to the prairies in

MLRA 61, such as cooler spring and fall periods and greater precipitation (USDA NRCS 2018). Kentucky bluegrass is a grazing-tolerant C_3 perennial invader that is displacing native C_3 grasses in the Northern Great Plains (Toledo et al. 2014). It also changes ecosystem services and community function at the landscape level (Toledo et al. 2014). Sites with native prairie grasses have a higher carbon: nitrogen ratio compared to Kentucky bluegrass dominated sites (Wedin and Tilman 1990). Increase in available nitrogen gives Kentucky bluegrass an advantage against native C_3 grasses that evolved with a lower nitrogen requirement (Wedin and Tilman 1990). An increase in nitrogen is caused by litter buildup from Kentucky bluegrass and limited biomass storage in its shallow root system (Wedin and Tilman 1990).

Community Phase 3.1: Kentucky Bluegrass, Western Wheatgrass, Western Snowberry, Annual Brome and Big Bluestem (Figure 15)

Potential vegetation is about 70% grasses or grass-like plants, 20% forbs, and 10% shrubs. Community 3.1 is dominated by invasive cool-season grasses while native cool-season and warm-season grasses are subdominants. Major species (with associated percent foliar cover values) on the sites on which this phase was based (Table 6) include: Kentucky bluegrass (55), western wheatgrass (29), western snowberry (8), annual brome (7), big bluestem (6), and shortgrasses (5). Aggressive non-native perennial grasses, especially Kentucky bluegrass, have displaced native cool-season and warm-season species, substantially reducing western wheatgrass cover and leaving only remnant populations of shortgrasses and big bluestem. The sites on which this phase was based were located off-town, having no prairie dog activity.

Figure 15. Example photograph of a transect in plant community phase 3.1.

Community Phase 3.2: Western Wheatgrass, Kentucky Bluegrass, Black Medic, Perennial Exotic, Annual Forbs, and Big Bluestem (Figure 16)

Potential vegetation is about 69% grasses or grass-like plants, 30% forbs, and 1% shrubs. Community 3.2 co-dominates include Kentucky bluegrass and western wheatgrass. Major species (with associated percent foliar cover values) on the sites on which this phase was based (Table 6) include: western wheatgrass (62), Kentucky bluegrass (52), black medic (*Medicago Lupulina* L.) (17), annual forbs (15), Canada thistle (10), big bluestem (4), and houndstongue (5). Native late successional species are present but they are being displaced by aggressive non-native species. Canada thistle and houndstongue, not present in phase 3.1, are well established on this site. The sites on which this phase was based were located in areas of prairie dog towns that are accessible to, and grazed to some extent by prairie dogs: on a town edge or within the town boundary. Grazing by prairie dogs and bison and weed control strategies are essential to prevent increases in non-native perennial grasses and forbs on this site.

Figure 16. Example photograph of a transect in plant community phase 3.2.

Community Phase 3.3: Shortgrasses, Annual Brome, Kentucky Bluegrass, Western Wheatgrass and Western Snowberry (Figure 17)

Potential vegetation is about 80% grasses or grass-like plants, 15% forbs, and 5% shrubs. Major species (with associated percent foliar cover values) on the sites on which this phase was based (Table 6) include: shortgrasses (44), annual brome (42), Kentucky bluegrass (37), western wheatgrass (33), western snowberry (3) and big bluestem (1). The sites on which this phase was based were located in areas of prairie dog towns that are accessible to, and grazed by prairie dogs: on a town edge or within the town boundary. The effects of prairie dog use is more pronounced than was seen in Phase 3.2, especially with the reduction in cover of western wheatgrass, Kentucky bluegrass, and big bluestem. Shortgrasses and annual brome are common and widespread. Canada thistle and houndstongue, which were present in phase 3.2, are reduced or lacking in Phase 3.3.

Figure 17. Example photograph of a transect in plant community phase 3.3.

State 4: Shortgrass Sod

Shortgrasses are a dominant feature of this state; western wheatgrass is found as either a co-dominant or a major contributing species in the plant communities. Continuous season-long grazing and/or heavy continuous grazing of bison and prairie dogs without adequate recovery periods favor the shortgrass species and have eliminated native tall grass species. Kentucky bluegrass, while present, is a minor component, suggesting it is not able to withstand the amount of disturbance associated with this state. Fringed sage is fairly common, and annual forb and grass cover may be substantial. The dominance of shortgrasses in these plant communities impacts the hydrological cycle; increased runoff and reduced infiltration can be expected compared to States 1, 2 and 3 (Facelli and Pickett 1991).

Community Phase 4.1: Shortgrasses, Western Wheatgrass, Annual Brome, Annual Forbs, and Kentucky Bluegrass (Figure 18)

Potential vegetation is about 70% grasses or grass-like plants, 30% forbs, and 1% shrubs. Community 4.1 is dominated by warm-season grasses with western wheatgrass as a subdominant. Major species (with associated percent foliar cover values) on the sites on which this phase was based (Table 6) include: shortgrasses (64), western wheatgrass (40), annual brome (29), woolly plantain (15), Canadian horseweed (7), rough false pennyroyal (*Hedeoma hispida* Pursh) (7), and Kentucky bluegrass (5). The sites on which this phase was based were located in the interior of prairie dog towns, with substantial grazing by prairie dogs. Plant communities include a large component of annual forbs; in dry years with poor conditions for annual forb germination, bare soil will be higher.

Figure 18. Example photograph of a transect in plant community phase 4.1.

Community Phase 4.2: Western Wheatgrass, Shortgrasses, Tumblegrass, Kentucky Bluegrass, and Annual Forbs (Figure 19)

Potential vegetation is about 80% grasses or grass-like plants, 15% forbs, and 5% shrubs. Community 4.2 is dominated by western wheatgrass with shortgrasses and tumblegrass as subdominants. Major species (with associated percent foliar cover values) on the sites on which this phase was based (Table 6) include: western wheatgrass (41), shortgrasses (34), tumblegrass (30), Kentucky bluegrass (9), rough false pennyroyal (8), Canadian horseweed (7), and dwarf horseweed (*Conyza ramosissima* Cronquist) (4). The sites on which this phase was based were located in the interior of prairie dog towns, with substantial grazing by prairie dogs. Tumblegrass expansion has displaced annual forbs and shortgrasses; fringed sage is a minor component of the plant communities.

Figure 19. Example photograph of a transect in plant community phase 4.2

Community Phase 4.3: Western Wheatgrass, Annual Brome, Shortgrasses, Fringed Sage, Threeawn, and Kentucky Bluegrass (Figure 20)

Potential vegetation is about 80% grasses or grass-like plants, 5% forbs, and 15% shrubs. Community 4.3 is dominated by western wheatgrass, annual brome, and shortgrasses. Major species (with associated percent foliar cover values) on the sites on which this phase was based (Table 6) include: western wheatgrass (43), annual brome (40) shortgrasses (39), fringed sage (13), threeawn (*Aristida purpurea* Nutt.) (6) and, Kentucky bluegrass (11). The sites on which this phase was based were located on the edge and in the interior of prairie dog towns, with substantial grazing by prairie dogs; some sites were also located off-town. Fringed sage is well-established in this phase. Deep roots, drought and grazing resistance, reproduction from both seed and roots, and limited use by most herbivores make fringed sage very competitive with other native species (Johnson and Larson 2007).

Figure 20. Example photograph of a transect in plant community phase 4.3.

State 5: Early Seral

The plant communities representative of this state are found in the interior areas of prairie dog colonies and developed under heavy continuous grazing. Kentucky bluegrass is not present; it may not be able to survive continuous clipping by prairie dogs combined pronghorn and bison grazing pressure. Bare soil has increased compared to

Shortgrass Sod (State 4). Western wheatgrass and shortgrasses are present, but at reduced levels compared to Shortgrass Sod (State 4). Common perennial forbs are Missouri goldenrod (*Solidago missouriensis* Nutt.) and black medic. Fringed sage and other forbs attract grazing by pronghorn (*Antilocapra Americana*), mule deer (*Odocoileus hemionus*) and elk (*Cervus elaphus*). Prairie dog occupation is similar between all 3 phases. Differences are caused by changes in species composition and the varying degree of prairie dog disturbance to the ES.

Community Phase 5.1: Solidago, Western Wheatgrass, Shortgrasses, Fringed Sage, Fetid Marigold, Threeawn, and Tumblegrass (Figure 21)

Potential vegetation is about 40% grasses or grass-like plants, 40% forbs, and 20% shrubs. Community 5.1 is dominated by Missouri goldenrod; grasses are sub-dominants with annual forbs and perennial shrubs present. Major vegetation species (with associated percent foliar cover values) on the sites on which this phase was based (Table 6) include: Missouri goldenrod (47), western wheatgrass (26), shortgrasses (26), fringed sage (17), fetid marigold (4), threeawn (4), and tumblegrass (3). The sites on which this phase was based were located on the interior of prairie dog towns, where there is substantial grazing by prairie dogs.

Figure 21. Example photograph of a transect in plant community phase 5.1.

Community Phase 5.2: Black Medic, Western Wheatgrass, Tumblegrass, Fringed Sage, and Threeawn (Figure 22)

Potential vegetation is about 40% grasses or grass-like plants, 50% forbs, and 10% shrubs. Community 5.2 is dominated by black medic; western wheatgrass is subdominant. Annual native and exotic species are a major component of this community, replacing many native perennials. Major vegetation species (with associated percent foliar cover values) on the sites on which this phase was based (Table 6) include: black medic (49), western wheatgrass (39), tumblegrass (17), fringed sage (11), and threeawn (4). The sites on which this phase was based were located on the interior of prairie dog towns, with substantial grazing and disturbance by prairie dogs.

Figure 22. Example photograph of a transect in plant community phase 5.2.

Community Phase 5.3: Shortgrasses, Fringed Sage, Western Wheatgrass, and Threeawn (Figure 23)

Potential vegetation is about 60% grasses or grass-like plants, 5% forbs, and 35% shrubs. Community 5.3 is co-dominated by shortgrasses and fringed sage. Western wheatgrass is only a minor component, especially as compared to Phases 5.1 and 5.2; fringed sage and threeawn are major components of the plant community. Major vegetation species (with associated percent foliar cover values) on the sites on which this phase was based (Table 6) include: shortgrasses (40), fringed sage (36), western wheatgrass (18), and threeawn (14). Bare soil is relatively high (11%) and annuals make up only a minor component of the plant community. Fringed sage cover (36%) well exceeds that found in Phases 5.1 and 5.2. The sites on which this phase was based occurred on the prairie dog town “core” or origin and interior of a prairie dog town. It is representative of the area within the colony that has had the longest occupation and/or the most severe disturbance. Difference between phase 5.3 and 6.1 is the severity of prairie dog disturbance.

Figure 23. Example photograph of a transect in plant community phase 5.3.

State 6: Fringed Sage Dominated

The plant communities representative of this state are found in the interior areas of prairie dog colonies and developed under heavy continuous grazing. Kentucky bluegrass is absent from this highly disturbed State. Bare soil is high compared to Early Seral (State 5). Grasses and grass-like cover is low (10%). Potential soil erosion is high and infiltration low due to large area of bare soil and minimal litter cover. Fringed sage dominates this state. Pronghorn are regularly seen grazing fringed sage; prairie rose, and associated forbs in this heavily disturbed area.

Community Phase 6.1: Fringed Sage, Field Bindweed, Prairie Rose, Fetid Marigold, and Threeawn (Figure 24)

Potential vegetation is about 10% grasses or grass-like plants, 30% forbs, and 60% shrubs. Community 6.1 is dominated by fringed sage; forbs are subdominants. Shortgrasses are not present and western wheatgrass has been nearly eliminated, and replaced by fringed sage, prairie rose and field bindweed (*Convolvulus arvensis* L.). Major vegetation species (with associated percent foliar cover values) on the sites on which this phase was based (Table 6) include: fringed sage (55), field bindweed (26), prairie rose (12), fetid marigold (6), threeawn (4), tumblegrass (4) and western wheatgrass (3). This plant community is typically found on the “core” or origin of a prairie dog town. It is representative of the area within the colony that has had the longest occupation and/or the most severe disturbance. The core plant community typically differs in appearance from other interior parts of the prairie dog colony; graminoid cover is sparse and bare soil has increased.

Figure 24. Example photograph of a transect in Plant community phase 6.1.

Transitions and Restorations

Transition T1A (IN, AP, BT, NF, NG) (Figure 25)

Invasion of State 1 by Kentucky bluegrass is the most significant characteristic of the transition from State 1 to State 2. While there may be some management factors that increase the chances that Kentucky bluegrass will invade, retention of native species as a major component of this state suggests that non-management factors may be the most important in this transition. The presence of Kentucky bluegrass in the area serves as a source of invasion (IN), and above average precipitation (AP) and cooler spring and fall temperatures (BT) favor the encroachment and expansion of Kentucky bluegrass (USDA NRCS 2018) into plant communities on this ES. Suppression of natural fire events (NF), and/or no grazing (NG) also favor Kentucky bluegrass invasion (USDA NRCS 2018), however their role in this transition is minor. Fire and grazing play a much more major role in the T2A transition (see below) to the Kentucky Bluegrass Dominated State (State 3) where Kentucky bluegrass becomes the dominant species in the community. Both fire suppression and no grazing lead to litter buildup resulting in increased soil moisture retention and lower soil temperature. It is likely, however, that reduced fire frequency increases opportunities for snowberry to expand. Snowberry can trap snow and delay snow melt in the spring, which facilitates its expansion. Slow snow melt associated with snowberry also favors expansion of Kentucky bluegrass and annuals with short roots. Delayed moisture release allows shallow rooted plants to utilize soil surface moisture.

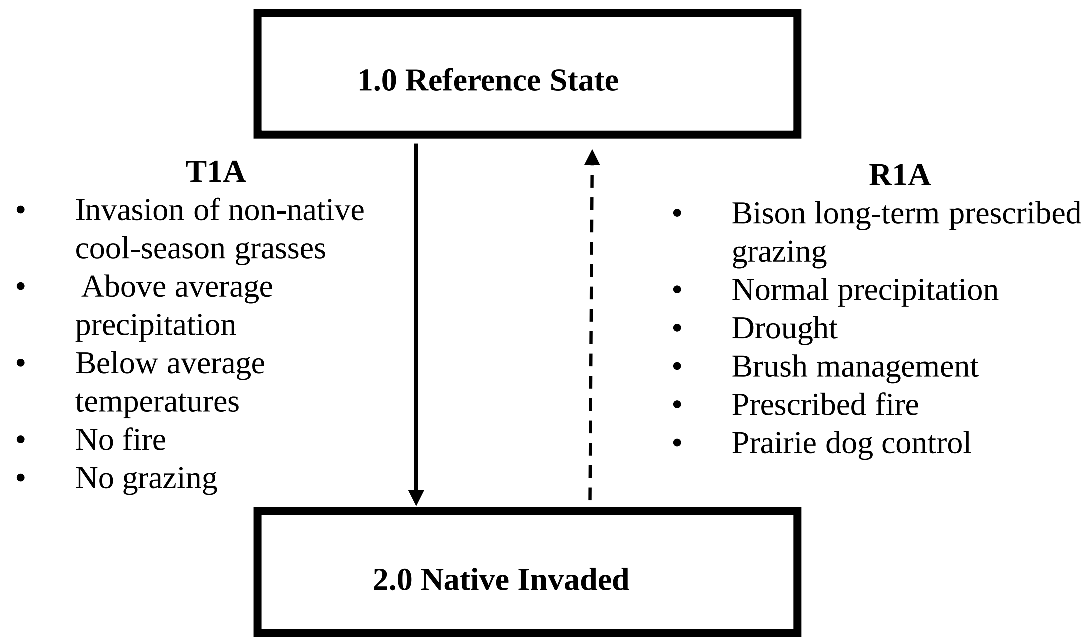

Figure 25. Transition from the Reference State (State 1) to Native Invaded (State 2) and restoration pathway to return to the Reference State.

Restoration R1A (Bison LTPG, NP, D, BM, PF, PDC) (Figure 25)

Restoration of a site from Native Invaded (State 2) to Reference State (State 1) will be extremely difficult and time-consuming. This transition requires the elimination of Kentucky bluegrass from the plant community. Restoration will likely require long-term prescribed grazing (LTPG) of bison, normal precipitation (NP) or drought (D), brush management (BM), and prescribed fire (PF). Altering duration and season of use by bison to early spring or fall during cool-season growth will limit both native and non-native cool-season species. Western wheatgrass is a major component of the State 2 plant communities, and, while heavy grazing in the cool-season will reduce its cover, its rhizomatous habit will allow expansion after restoration is complete. Deferment of bison grazing during the warm-season and prairie dog control (PDC) will reduce grazing pressure on native warm-season species. Restoration of this ES from State 2 to State 1, however, will be very difficult without warmer and drier climatic conditions. Kentucky bluegrass is not as drought tolerant as the native grasses, thus drought may reduce its presence in the communities. Fire will favor native warm-season species and reduce litter buildup, limiting opportunity for Kentucky bluegrass encroachment and expansion. Brush management using prescribed fire and or chemical treatments may be needed to control western snowberry.

Transition T2A (IN, AP, BT, NF, NG, LB) (Figure 26)

As was the case for T1A, invasion of State 1 by Kentucky bluegrass is the most significant characteristic of the transition from State 1 to State 3. In this transition, however, Kentucky bluegrass quickly dominates the plant communities, displacing native warm and cool-season species. The presence of Kentucky bluegrass in the area serves as a source of invasion (IN), and above average precipitation (AP) and cooler spring and fall temperatures (BT) favor the encroachment and expansion of Kentucky bluegrass (USDA NRCS 2018) into plant communities on this ES. Management factors that increase Kentucky bluegrass invasion and expansion and reduce the presence of native species are also very important in this transition. Suppression of natural fire events (NF), and/or no grazing (NG) favor Kentucky bluegrass invasion (USDA NRCS 2018). Both fire suppression and no grazing lead to litter buildup (LB), resulting in increased reflective solar radiation, increased soil moisture retention, and lower soil temperature (Facelli and Pickett 1991). These conditions favor Kentucky bluegrass expansion and limit growth of native warm-season grasses as they affect germination, establishment, and changes in resource availability (Facelli and Pickett 1991). Vegetation production in unburned sites are light– and carbon-limited rather than nitrogen-limited for new shoot growth, forcing plants to alter resource allocation and biomass (Johnson and Matchett 2001). Fire suppression affects more than just the above ground vegetation; it affects below ground processes, insects, animals, and plants adapted to frequent fire (Vale 2002). Litter provides a microhabitat for annual brome grass to germinate in the fall, giving non-native species the competitive advantage in the spring to complete their lifecycle. Fire suppression also increases opportunities for snowberry to expand. Snowberry can trap snow and delay snow melt in the spring, which further facilitates its expansion as well as that of Kentucky bluegrass and annuals with short roots.

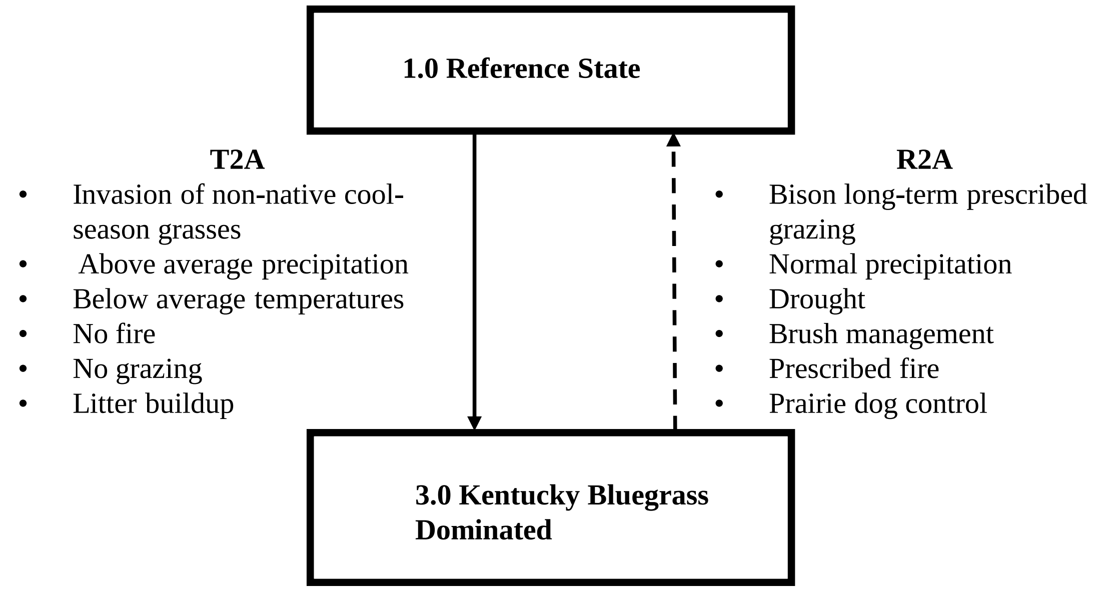

Figure 26. Transition from the Reference State (State 1) to Kentucky Bluegrass Dominated (State 3) and restoration pathway to return to the Reference State.

Restoration R2A (Bison LTPG, NP, D, BM, PF, PDC) (Figure 26)

Restoration of a site from Kentucky Bluegrass Dominated (State 3) to Reference State (State 1) will be even more difficult and time-consuming than is required for Restoration R1A. This is due to the more extensive presence of Kentucky bluegrass in State 3. This transition requires the elimination of Kentucky bluegrass from the plant community, as well as other non-native cool-season species including smooth brome (*Bromus inermis* Leyss.) and annual brome. Restoration will likely require long-term prescribed grazing (LTPG) of bison, normal precipitation (NP) or drought (D), brush management (BM), and prescribed fire (PF). Altering duration and season of use for bison to early spring or fall during cool-season growth limits cool-season species. Prairie dog control (PDC) and deferment of bison grazing during the warm-season will reduce grazing pressure on native warm-season species. Native vegetation is well adapted to normal precipitation (NP) and periods of drought (D). Kentucky bluegrass is not; however, as drought tolerant as the native grasses, thus drought may reduce its presence in the communities. Fire to reduce litter buildup will limit opportunity for further Kentucky bluegrass encroachment and expansion. Consecutive years of prescribed fire may be needed in the spring to reduce Kentucky bluegrass. Brush management using prescribed fire and or chemical control is needed to control western snowberry.

Transition T3A (AP, BT, NG, NF, LB, CSLG) (Figure 27)

The transition from Native Invaded (State 2) to Kentucky bluegrass Dominated (State 3) is triggered by factors that 1) encourage Kentucky bluegrass (already present in State 2) to expand and dominate a site and 2) reduce native species presence. These factors include above average precipitation (AP) and cooler spring and fall temperatures (BT), both of which favor Kentucky bluegrass and other non-native cool-season species. No grazing (NG) and lack of natural and prescribed fire (NF) lead to litter buildup (LB), which also favors Kentucky bluegrass and other non-native cool-season species. Long-term continuous season long grazing (CSLG) by ungulates can reduce the cover of the taller native warm-season grasses such as big bluestem. CSLG also reduces vegetation biomass and species diversity (Fahnestock and Detling 2002) and favors cool-season invasive species (USDA NRCS 2018). Late seral species begin to be replaced by state and local noxious weeds such as Canada thistle.

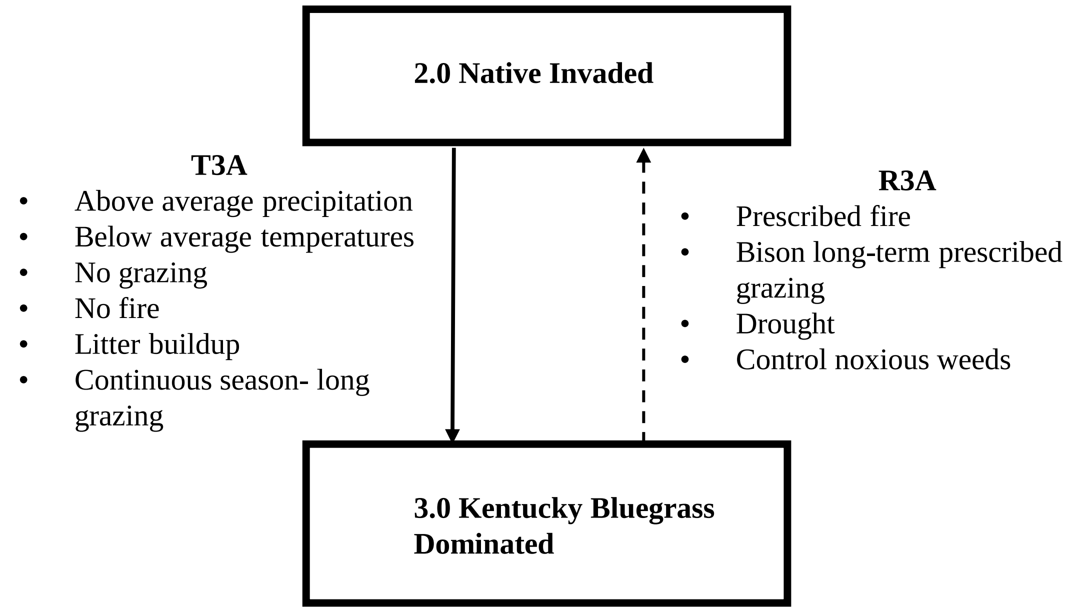

Figure 27. Transition from Native Invaded (State 2) to Kentucky Bluegrass Dominated (State 3) and restoration pathway to return to the Native Invaded State.

Restoration R3A (PF, Bison LTPG, D, CNW) (Figure 27)

Restoring Kentucky Bluegrass Dominated (State 3) to Native Invaded (State 2) will be difficult as it requires creation of conditions that reduce Kentucky bluegrass and favor native warm and cool-season species. Prescribed fire (PF) can be useful in reducing litter, resulting in warmer, dryer soils that favor warm-season species while potentially reducing the abundance of Kentucky bluegrass. Energy absorption of solar radiation warms the soil temperature 2.8 to 15.6 degrees C on burned sites (Wright and Bailey 1982). Warm soil increases nutrient cycling and causes warm-season species to begin growth 2 weeks earlier than unburned areas (DeBano et al. 1998). Native cool-season species, such as western wheatgrass, may also benefit because they are very tolerant of fire. Heavy grazing by bison (Bison LTPG) in spring may also make conditions less favorable for Kentucky bluegrass; however important cool-season species such as western wheatgrass may also be reduced. While weather cannot be controlled, periods of drought (D) could provide opportunity to accelerate control of Kentucky bluegrass through strategic use of fire and spring grazing. Control of noxious weeds (CNW), such as Canada thistle and houndstongue, may also be needed to transition to State 2. Fire, biological control, chemical control, and other options should be considered, depending on the species of concern.

Transition T4A (Prairie dog FSD, Bison CSLG, D) (Figure 28)

The dominance of shortgrasses is the most significant characteristic of the transition from Native Invaded (State 2) to Shortgrass Sod (State 4). The transition from State 2 to State 4 can result from frequent and severe defoliation (FSD) of vegetation by prairie dogs combined with continuous season long grazing (CSLG) by bison. Heavy grazing eliminates tall stature species, such as the bluestems and needlegrasses, favoring more grazing tolerant species such as the shortgrasses and western wheatgrass. Shortgrasses evolved under heavy grazing (Milchunas et al. 2008), developing a short stature that provides protection of growing points from defoliation. Western wheatgrass has been shown to develop short-statured “grazing morphs” under long-term heavy defoliation, providing that species with protection of meristematic tissue from grazing damage (Briske and Richards 2004). Drought (D) accelerates a shift to shortgrass and western wheatgrass dominance due to their greater tolerance of drought compared to native tallgrasses and Kentucky bluegrass.

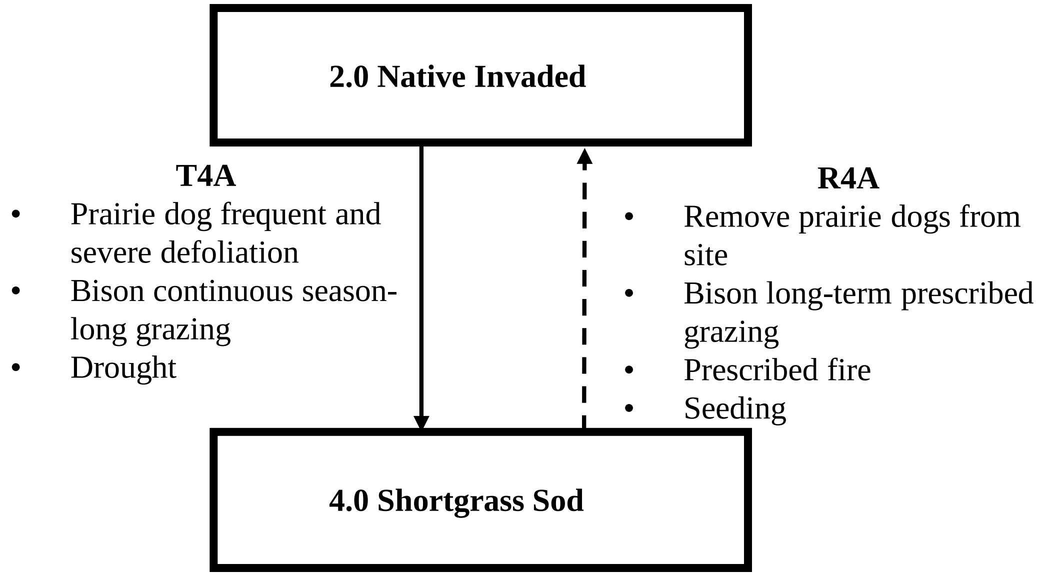

Figure 28. Transition from Native Invaded (State 2) to Shortgrass Sod (State 4) and restoration pathway to return to the Native Invaded State.

Restoration R4A (PDC, Bison LTPG, PF, S) (Figure 28)

Restoring Shortgrass Sod (State 4) to Native Invaded (State 2), will be very difficult, and require considerable time for native late-seral species to recover. Recovery strategies must favor the taller native grass species (e.g. bluestems and needlegrasses) without encouraging an expansion of Kentucky bluegrass. Strategies to accomplish this likely include prairie dog control (PDC). Prairie dogs defoliate year-round, which favors shortgrasses over the taller native grasses. Releasing these sites from prairie dog use could, however, lead to greater Kentucky bluegrass cover. Heavy cool-season grazing by bison (Bison LTPG) can be used effectively to control Kentucky bluegrass, but will also reduce western wheatgrass cover. Western wheatgrass is a major component of the State 2 plant communities, and, while heavy grazing in the cool-season will reduce its cover, its rhizomatous habit will allow expansion after restoration is complete. Some alteration of duration and season of use by bison may be required to maintain and increase western wheatgrass in the system. Prescribed fire (PF) in spring will be a useful tool for reducing

Kentucky bluegrass presence and opening the canopy for the taller warm-season native grasses to establish and/or expand. It may be necessary to seed (S) the taller bluestems and needlegrasses if they have been entirely eliminated from the site.

Transition T5A (PD FSD, Bison LTPG, D, PF) (Figure 29)

A shift toward dominance of shortgrasses and reduction in Kentucky bluegrass is the most significant characteristic of the transition from Kentucky Bluegrass Dominated (State 3) to Shortgrass Sod (State 4). Prairie dog frequent severe defoliation, (PD FSD) will reduce cover of Kentucky bluegrass and favor expansion of shortgrasses. Heavy grazing by bison (Bison LTPG) in spring may also make conditions less favorable for Kentucky bluegrass; however important cool-season species such as western wheatgrass may also be reduced. While weather cannot be controlled, periods of drought (D) could provide opportunity to accelerate control of Kentucky bluegrass in conjunction with strategic use of fire (PF) and spring grazing. Drought and grazing stress favor expansion of grazing and drought tolerant species such as shortgrasses and western wheatgrass. Prescribed fire can be useful in reducing litter, resulting in warmer, dryer soils that favor warm-season species.

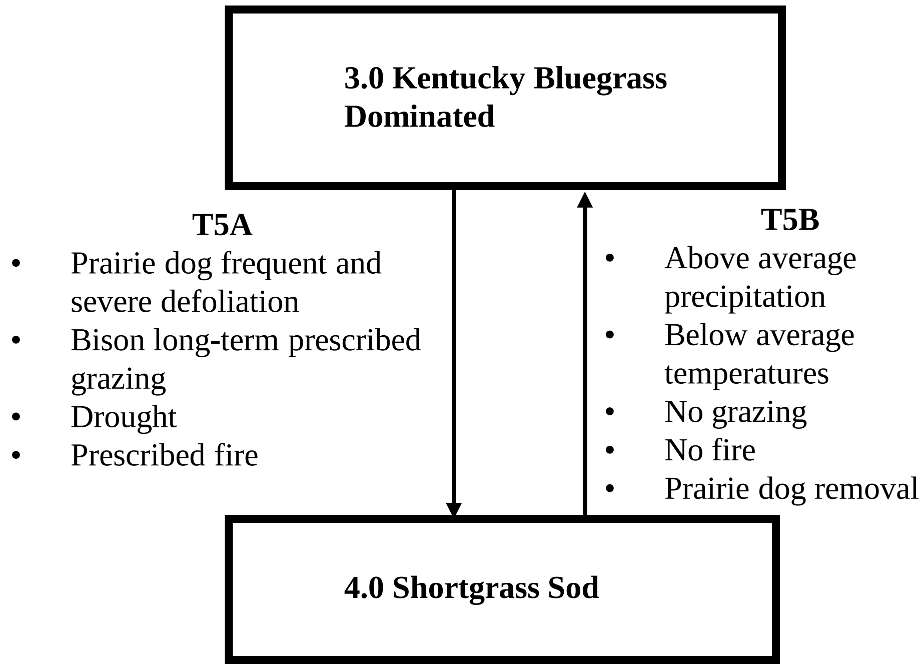

Figure 29. Transition from Kentucky Bluegrass Dominated (State 3) to Shortgrass Sod (State 4) and transition pathway to return to the Kentucky Bluegrass Dominated State.

Transition T5B (AP, BT, NG, NF, PDC) (Figure 29)

This plant community shift is labeled a transition and not a restoration because State 3 is not a desirable state and can occur if the ES is not managed properly. The transition from Shortgrass Sod (State 4) to Kentucky bluegrass Dominated (State 3) is triggered by factors that 1) encourage Kentucky bluegrass, which is already present in State 4, to expand and dominate a site as well as 2) factors that reduce native warm-season shortgrass presence. These factors include above average precipitation (AP) and cooler spring and fall temperatures (BT), both of which favor Kentucky bluegrass, other non-native cool-season species, and western wheatgrass (a major component of State 3). No grazing (NG) and lack of natural and prescribed fire (NF) lead to litter buildup, which also favors Kentucky bluegrass and other non-native cool-season species. Prairie dog control (PDC) will also favor Kentucky bluegrass and reduce the cover of shortgrasses.

Transition T6A (CSLG, Prairie dog FSD, D) (Figure 30)

The dominance of early seral species, reduction in shortgrasses, and reduction/elimination of Kentucky bluegrass are the most significant characteristics of the transition from Shortgrass Sod (State 4) to Early Seral (State 5). The transition from State 4 to State 5 can occur as a result of continuous season-long grazing (CSLG) by multiple species and frequent severe defoliation by prairie dogs (Prairie Dog FSD). These disturbances lead to reduced native species cover, increased annuals and bare soil, and reduced vegetation production, all of which impact soil temperature, infiltration, evaporation, and runoff. Periods of drought (D) will accelerate this transition.

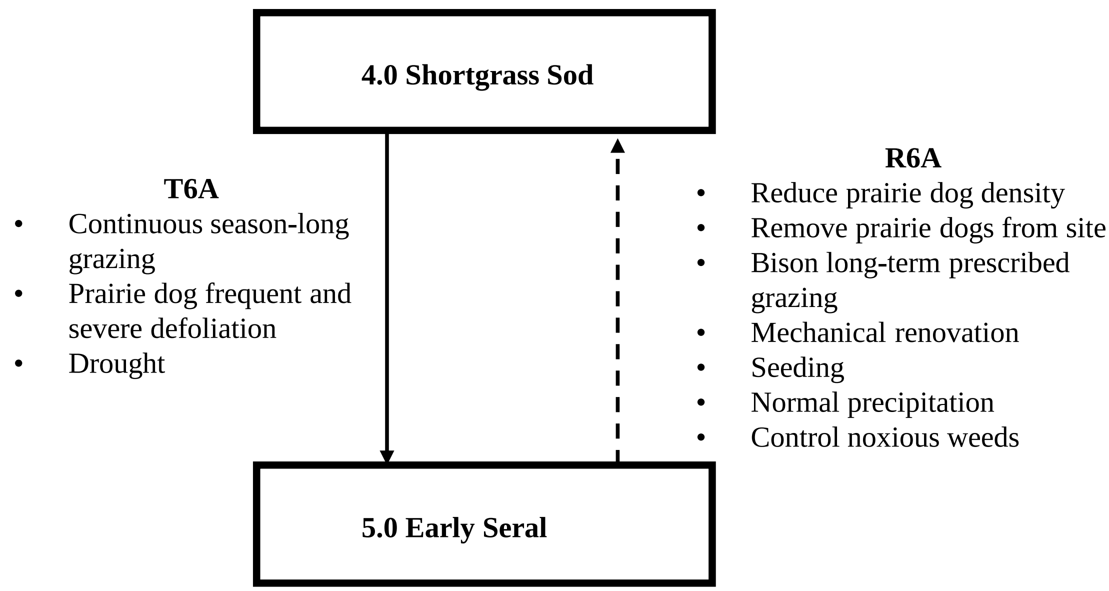

Figure 30. Transition from Shortgrass Sod (State 4) to Early Seral (State 5) and restoration pathway to return to the Shortgrass Sod State.

Restoration R6A (PDM, PDC, Bison LTPG, MR, S, NP, CNW) (Figure 30)

Restoring Early Seral (State 5) to Shortgrass Sod (State 4) will be difficult as it requires considerable amounts of inputs and time. Depending on the status of the vegetation in State 5, prairie dogs will need to be either reduced (PDM) or removed from the site (PDC). Strategic grazing by bison (Bison LTPG) to encourage native grass (e.g. shortgrasses and western wheatgrass) expansion will be needed. It will be important, however, to not encourage Kentucky bluegrass invasion. This will likely require an emphasis on heavy grazing in the cool-season. Mechanical renovation (MR), including using a disk to knock down prairie dog mounds and to smooth out the old prairie dog town, may be required. Seeding (S) using a no-till drill or broad cast seeder could be used if native species do not respond to rest. Above normal (AP) or normal precipitation (NP) would be beneficial in allowing seeded species the opportunity to germinate and complete their life cycle. Fringed sage is the biggest obstacle and may need to be controlled with herbicides (CNW).

Transition T7A (LTPD, HCSLG, BW) (Figure 31)

A shift toward dominance of fringed sage is the most significant characteristic of the transition from Early Seral (State 5) to Fringed Sage dominated (State 6). Long-term (greater than thirty years) prairie dog occupation (LTPD), heavy continuous season-long grazing (HCSLG) by multiple species, and bison wallow (BW) disturbance are all factors that can lead to a threshold being crossed to the Fringed Sage Dominated state (State 6). Bare soil has increased (16%) and native late seral grass species are sparse (western wheatgrass 3%). Bison enjoy the increase in bare soil for wallowing. Wallows are utilized by multiple bison year after year.

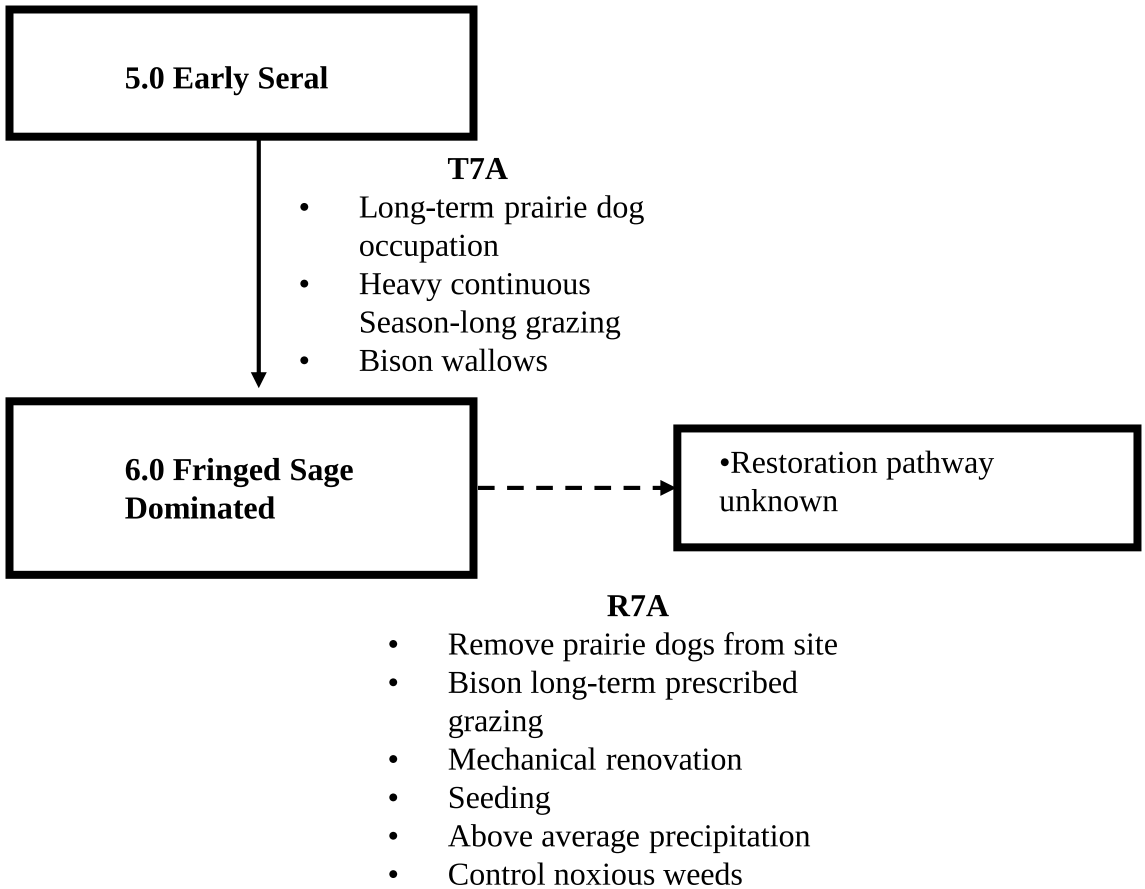

Figure 31. Transition from Early Seral (State 5) to Fringed Sage Dominated (State 6), restoration pathway is unknown so the restoration arrow is not connected to another State.

Restoration R7A (PDC, LTPG, MR, S, AP, CNW) (Figure 31)

Restoration of the Fringed Sage Dominated state (State 6) will be difficult, and require extensive time and inputs. Restoration is not connected to another State since results of restoration are uncertain. Potential strategies may include prairie dog control (PDC), long-term prescribed grazing (LTPG) by bison, and mechanical renovation (MR). Seeding (S) using broadcast seeding or no-till drill will likely be required. A native seed mix could include: western wheatgrass, green needlegrass, little bluestem, big bluestem, side oats grama, blue grama, hairy grama, buffalo grass, purple prairie clover (*Dalea purpurea* Vent.) and leadplant. Above average precipitation (AP) would be helpful so seeded species have sufficient moisture to germinate and establish. Control of local and state noxious weed species (CNW) is important during native species establishment.

<u>Community Phase Pathways (see Fig. 11):</u>

Community Phase Pathway 2.1A (CSLG, PDE, D)

Continuous season-long grazing (CSLG) by bison and introduction or an increase in prairie dog density (PDE) on the site will reduce big bluestem cover. Drought (D) will favor western wheatgrass, as will bison grazing and prairie dog clipping. During drought prairie dog colonies expand, since vegetation growth is limited by moisture (J. Butler, Pers. Comm.). Prairie dogs spend less time clipping to see predators and more time expanding their colony.

Community Phase Pathway 2.2A (PF, AP)

A shift from community phase 2.2 to 2.1 requires conditions favorable for big bluestem regeneration and a reduction in western wheatgrass and western snowberry. Strategies include prescribed fire (PF) in spring to control invasive cool-season grass species and reduce snowberry. Average to below average precipitation (AP) is more detrimental to Kentucky bluegrass because of its shallow root and intolerance to heat and drought stress (Toledo et al. 2014). Prescribed fire when Kentucky bluegrass is actively growing has the greatest impact on reducing Kentucky bluegrass. While native cool-season species may also be reduced, warm-season species like big bluestem benefit from prescribed fire.

Community Phase Pathway 2.3A (Bison & PD HCSLG)

Heavy continuous season-long grazing (HCSLG) by bison and prairie dogs reduces tall and medium height vegetation, while favoring shortgrasses. Abundance and distribution of blue grama, hairy grama and buffalo grass, as a result, will increase. Annual brome and other annual species increase under this management strategy.

Community Phase Pathway 2.4A (LTPG, PDM, AP, D)

A shift from phase 2.3 to 2.2 requires reduction in cover of shortgrasses and annuals. Strategies to effect this change include long-term prescribed grazing by bison (LTPG) and, possibly, reduction in prairie dog density (PDM) to reduce grazing pressure that favors shortgrasses. Average to above average precipitation (AP) may make this shift occur more quickly. Drought (D), however, limits invasion of non-native cool-season grasses (Hockensmith et al. 1997). Moisture used by non-native cool-season grasses is not available for native perennials. Normal precipitation during May, June, and July would benefit native cool-season and warm-season species.

Community Phase Pathway 3.1A (Bison & PD CSLG, NW)

A shift from phase 3.1 to 3.2 results from management that leads to increased western wheatgrass cover as well as increases in annual and perennial weedy species. Continuous season-long grazing (CSLG) by bison and prairie dogs will, over time, reduce vegetation biomass and species diversity (Fahnestock and Detling 2002). Late seral species will be replaced by Canada thistle (NW) a South Dakota statewide noxious weed. houndstongue, a Custer county local noxious weed, may also be present.

Community Phase Pathway 3.2A (LTLG, NG, NF, LB, CNW)

Long-term light grazing (LTLG) or no grazing (NG) combined with no fire (NF) will result in litter buildup (LB). Litter increases reflective solar radiation, thus reducing evaporation and keeping soil temperature cooler while retaining soil moisture (Facelli and Pickett 1991). Such changes affect germination, establishment, and changes in resource availability (Facelli and Pickett 1991) giving non-native species the competitive advantage. Control of state and local noxious weeds (CNW) may be required for this phase shift to occur.

Community Phase Pathway 3.2B (Bison HCSLG, PDE, D, PF)

A shift from phase 3.2 to 3.3 results in increased shortgrasses and annual brome and decreases in big bluestem, western wheatgrass and Kentucky bluegrass. Management strategies leading to this shift include heavy continuous season-long grazing (HCSLG) by bison and colonization/expansion of prairie dogs (PDE). Grazing by bison and prairie dogs during drought (D) increases the amount of bare soil which alters the plant community. Drought favors a community phase shift with an increase in drought-tolerant shortgrasses and a decline in Kentucky bluegrass which is not tolerant to heat or drought stress (Hockensmith et al. 1997). Prescribed fire (PF) reduces litter, resulting in warmer, dryer soils that favor warm-season species.

Community Phase Pathway 3.3A (AP, BT, NG, NF)

The shift from phase 3.3 to 3.2 is supported by above average precipitation (AP) and cooler spring and fall temperatures (BT) that favor the expansion of Kentucky bluegrass (USDA NRCS 2018) on this ES. No grazing (NG) encourages increases in western wheatgrass and Kentucky bluegrass. The lack of natural and prescribed fire (NF) leads to litter buildup, which in turn will favor Kentucky bluegrass and other non-native cool-season species.

Community Phase Pathway 4.1A (Bison HCSG, PD, D)

The shift from phase 4.1 to 4.2 results from heavy continuous seasonal grazing by bison (Bison HCSG) and/or prairie dogs (PD). Shortgrasses as well as annual grasses and forbs are replaced by an unpalatable warm-season grass, tumblegrass. Drought (D) increases stress and competition among plants.

Community Phase Pathway 4.2A (Bison LTPG, S, AP)

The shift from phase 4.2 to 4.1 requires reduction of heavy grazing by bison and prairie dogs. This can be accomplished using long-term prescribed grazing by bison (Bison LTPG) of including growing season deferment. Reduction in the prairie dog population (PDM) may reduce the tumblegrass patches; chemical control may be required if tumblegrass does not respond adequately to grazing management changes. Native species may need to be seeded (S) following treatment of tumblegrass if the seed bank lacks viable native seeds and or buds. Above normal or normal precipitation (AP) would be useful in facilitating germination of planted seeds and viable seeds remaining in the seed bank.

Community Phase Pathway 4.2B (Prairie Dog FSD)

The shift from phase 4.2 to 4.3 occurs as a result of frequent and severe defoliation by prairie dogs (Prairie Dog FSD). Continuous prairie dog clipping of native vegetation favors expansion of fringed sage and threeawn within the shortgrass-dominated plant community. This heavy disturbance regime also favors an increase in annual brome.

Community Phase Pathway 4.3A (PDM, PDC, Bison LTPG, PF, MR, S)

The shift from phase 4.3 to 4.2 may require reduction in grazing intensity by prairie dogs, either through partial or complete prairie dog control (PDM, PDC). Other management strategies likely to effect this change include eliminating bison grazing during the growing season (Bison LTPG) and prescribed fire to reduce annual brome and fringed sage. Prescribed fire (PF) during spring may allow warm-season species present in the seed bank to re-establish. Treatment of fringed sage and threeawn is critical to return to phase 4.2, and could include mechanical and/or chemical treatments (MR) in addition to natural or prescribed fire. Treated areas may need to be seeded (S) with a mix of native cool-season and warm-season species if the seed bank is depleted of native propagules.

Community Phase Pathway 5.1A (Prairie Dog FSD, AP)

The shift from phase 5.1 to 5.2 is characterized by a substantial reduction in shortgrasses and increases in bare ground, black medic, and tumblegrass. Continued heavy grazing by prairie dogs (Prairie Dog FSD) can lead to losses in shortgrass cover. Above average precipitation (AP) allows western wheatgrass, black medic, and tumblegrass to take advantage of resources freed by declining shortgrass cover, resulting in substantial increases in each of these species .

Community Phase Pathway 5.2A (PDM, PDC, D)

It is likely that a reduction in grazing by prairie dogs, either through partial or complete colony control (PDM, PDC) is important in the shift from phase 5.2 to 5.1. This, combined with drought (D) may reduce the cover of black medic, tumblegrass, and other annuals, leading to an increase in bare soil.

Community Phase Pathway 5.1B (D, Prairie Dog FSD)

The combination of drought (D) and frequent and severe defoliation by prairie dogs (Prairie Dog FSD) are important in the shift from phase 5.1 to 5.3. These factors favor shortgrasses since they have a greater drought and grazing tolerance. Thus, abundance and distribution of blue grama, hairy grama and buffalo grass will increase. Bare soil increases because vegetation production is limited to viable buds. Fringed sage cover increases as graminoid cover decreases on this ES.

Community Phase Pathway 5.3A (PDC, Bison LTPG, S, AP, WC)

The shift from phase 5.3 to 5.1 requires a substantial reduction in grazing pressure, especially during the growing season. This can be accomplished by removing the grazing disturbance of prairie dogs (PDC) and by limiting bison grazing to the non-growing season (Bison LTPG). The area may need to be seeded (S) if the seed bank is void of viable native propagules (seeds, buds) resulting from multiple years of frequent and severe defoliation. Above average precipitation (AP) is desired to facilitate restoration as moisture is important for seed bank germination and expansion of current vegetation. If fringed sage cover does not decline as native late seral species cover increases, it will need to be controlled with herbicide (WC).

CONCLUSION AND MANAGEMENT IMPLICATIONS

In the Custer State Park resource management plan (CSP 2010), the park allows prairie dogs to occupy 364 ha on rangeland Ecological Sites. CSP currently manages 22 prairie dog towns that range in size from 1 to 243 ha. The State-and-Transition Model created by this project will be used for future management of prairie dog colonies in CSP. It is the desire of CSP managers that prairie dog towns be changed to or maintained in States 1 through 4. Vegetation in States 5 (Early Seral) and 6 (Fringed Sage Dominated) are considered undesirable for management due to the loss of native grasses, increased bare ground (and potential for erosion), and extensive presence of exotic species. This STM will be used to assess and document status and changes in prairie dog town vegetation over time. Most importantly it will be used to identify prairie dog town areas that are at risk of crossing a threshold to another less desirable state. Less time and fewer inputs are needed to maintain an ES in a desirable State than to restore an ES that has already crossed the threshold to a less desirable state. If restoration of a prairie dog town on loamy ES needs to occur, the restoration pathway described in the STM will be followed.

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APPENDIX TABLE

Table A.1. Plant species found on plots sampled in 2014 and 2015.

CODE	COMMON NAME	SCIENTIFIC NAME
ACMI2	Yarrow	Achillea millefolium
AGCR	crested wheatgrass	Agropyron cristatum
AGGL	False dandelion	*Agoseris glauca*
AGSC5	Ticklegrass	*agrostis scabra*
AGST2	Redtop	*Agrostis stolonifera*
ALLIU	Onion	*Allium*
ANGE	Big bluestem	*Andropogon gerardii*
AMAR2	annual ragweed	*Ambrosia artemisiifolia*
AMBL	Prostrate pigweed	*Amaranthus blitoides*
AMCA6	Leadplant	*Amorpha canescens*
AMPS	Westwern ragweed	*Ambrosia psilostachya*
AMRE	Redroot pigweed	*Amaranthus retroflexus*
ANCY	Candle anemone	*Anemone cylindrica*
ANMU	cutleaf anemone	*Anemone multifida*
ANEMO	Anemone	*Anemone spp.*
ANTEN	Pussytoes	*Antennaria*
ARABI2	Rockcress	*Arabis*
ARDR4	Green sagewort	*Artemisia dracunculus*
ARFR4	Fringed sagewort	*Artemisia frigida*
ARGL	tower rockcress	*Arabis glabra*
ARLU	White sagewort	*Artemisia ludoviciana*
ARMI2	Common burdock	*Arctium minus*
ARNIC	Arnica	*Arnica*
ARPO2	Crested pricklypoppy	*Argemone polyanthemos*
ARPU9	Purple threeawn	*Aristida purpurea*
ASLA27	Standing milkvetch	*Astragalus laxmannii*
ASCR2	Groundplum milkvetch	*Astragalus crassicarpus*
ASSP	showy milkweed	*Asclepias speciosa*
ASPU	Plains milkweed	*Asclepias pumila*
ASTRA	Milkvetch	*Astragalus spp.*
ASVI	Green milkweed (narrowleaf)	*Asclepias viridiflora*
BOCU	sideoats grama	*Bouteloua curtipendula*
BOGR2	blue grama	*Bouteloua gracilis*
BOHI2	hairy grama	*Bouteloua hirsuta*
BORAG	Borage	*Boraginaceae*
BRASS2	Mustard	*Brassica*
BREU	False boneset	*Brickellia eupatorioides*

Table A.1 Continued

BRIN2	Smooth brome	*Bromus inermis*
BRJA	Japanese brome	*Bromus japanicus*
BRTE	Cheatgrass/Downy brome	*Bromus tectorum*
BUDA	Buffalograss	*Buchloe dactyloides*
CABU2	Shepard's purse	*Capsella bursa-pastoris*
CAFI	Threadlead sedge	*Carex filifolia*
CAMI2	Littlepod false flax	*Camelina microcarpa*
CARO2	Harebell	*Campanula rotundifolia*
CAREX	Sedge	*Cares spp.*
CASE5	downey paintbrush	*Castilleja sessiliflora*
CASE12	yellow evening primrose	*Calylophus serrulatus*
CEAR4	field chickweed	*cerastium arvense*
CEBR3	shortstalk chickweed	*Cerastium brachypodum*
CHAL7	Lambsquaters	*Chenopodium album*
CHMA15	Prostrate spurge	*Chamaesyce maculata*
CHENO	Goosefoot	*Chenopodiaceae*
CHJU	rush skeletonweed	*Chondrilla juncea*
CIAR4	Canada thistle	*Cirsium arvense*
CIUN	Waveyleaf thistle	*Cirsium undulatum*
CIFL	Flodman's thistle	*Cirsium flodmanii*
CIVU	bull thistle	*Cirsium vulgare*
COAR4	Field bindweed	*Convolvulus arvensis*
COCA5	Horseweed	*Conyza canadensis*
COLI2	Slenderleaf collomia	*Collomia linearis*
CORA4	dwarf horseweed	Conyza ramosissima
CYOF	Houndstongue	*Cynoglossum officinale*
CYXA2	Carelessweed/Giant sumpweed	*Cyclachaena xanthiifolia*
DAPU5	Purple prairie clover	*Dalea purpurea*
DASP2	poverty oatgrass	*Danthonia spicata*
DESO	flixweed	*Descurainia sophia*
DILE2	Leiburg's panicum	*Dichanthelim leibergii*
DIOLS	Scribner's Dichanthelium	*Dichanthelium oligosanthes var. scribnerianum*
DRABA	Mustard	*Draba spp.*
DYPA	Fetid marigold	*Dyssodia papposa*
ECAN2	Purple coneflower	*Echinacea angustifolia*
ECCR	Barnyardgrass	*Echinochloa crus-galli*
ELCA4	Canada wildrye	*Elymus canadensis*

Table A.1 Continued

ELEL5	Squirreltail	*Elymus elymoides*
ELEOC	Spikerush	*Eleocharis*
ELTRS	Bearded slender wheatgrass	*Elymus trachycaulus ssp. subsecundus*
ELTR7	Slender wheatgrass	*Elymus trachycaulus*
EQLA	smooth horsetail	*Equisetum laevigatum*
ERAS2	Western wallflower	*Erysimum asperum*
ERCA4	hoary fleabane	*Erigeron canus*
ERCI	Stink grass	*Eragrostis cillaris*
ERFO3	beautiful fleabane	*Erigeron formosissimus*
ERFL	Trailing fleabane	*Erigeron flagellaris*
ERIGE2	Fleabane	*Erigeron spp.*
ERSP	Purple lovegrass	*Eragrostis spectabilis*
ERSU2	threenerve fleabane	*Erigernon subtrinervis*
EUDE4	toothed spurge	*Euphorbia dentata*
EUES	Leafy spurge	*Euphorbia esula*
FABACEAE	Legume, pea family	*Fabaceae*
FESA	Rocky mtn. fescue	*Festuca saximontana*
GALIU	Bedstraw	*Galium spp.*
GAPA6	Velvetweed	*Gaura parviflora*
GACO5	Scarlet guara	*Gaura coccinea*
GLEE3	American licorice	*Glycyrrhiza lepidota*
GLGR	American Mannagrass	*Glyceria grandis*
GRASSLIKE		
GRSQ	Curlycup gumweed	*Grindellia squarrosa*
GUSA2	broom snakeweed	*Gutierrezia sarothrae*
HECO26	Needleandthread	*Hesperostipa comata*
HEAN3	Annual sunflower	*Helianthus annuus*
HEHI	Rough false pennyroyal	*Hedeoma hispida*
HELIA3	Sunflower	*Helianthus*
HEPA19	stiff sunflower	*Helianthus pauciflorus*
HEVI4	Hairy goldaster	*Heterotheca villosa*
HOJU	Foxtail barley	*Hordeum jubatum*
IRMI	Rocky Mountain iris	*Iris missouriensis*
JUNCU	Rush	*Juncus*
KOMA	Prairie Junegrass	*Koelaria macrantha*
LAMIACEAE	Mint	*Lamiaceae spp.*
LAOC3	Flatspine stickseed	*Lappula occidentalis*
LASE	Prickly lettuce	*Lactuca serriola*
LATA	Blue lettuce	*Lactuca tatarica*

Table A.1 Continued

LEDE	Pepperweed	*Lepidium densiflorum*
LEMO4	Common starlily	*Leucocrinum montanum*
LEVU	oxeye daisy	*Leucanthemum vulgare*
LIIN2	Narrowleaf stoneseed	*Lithospermum incisum*
LIPU	Dotted gayfeather	*Liatris punctata*
LITHO	Stoneseed	*Lithospermum*
LOAR5	Field Cottonrose	*Logfia arvensis*
LOUN	deervetch	*Lotus unifoliolatus*
LYJU	Rush skeletonplant	*Lygodesmia juncea*
MADI6	Pineapple weed	*Matricaria discoidea*
MAPI	lacy tansyaster	*Machaeranthera pinnatifida*
MAVI8	Pincushion cacti	*Mammillaria vivipara*
MELU	Black medic	*Medicago lupulina*
MEAL2	White Sweetclover	*Melilotus alba*
MELA3	Prairie bluebells	*Mertensia lanceolata*
MEOF	yellow sweetclover	*Melilotus officianlis*
MILI3	Narrowleaf four o'clock	*Mirabilis linearis*
MOFI	Wild bergamont	*Monarda fistulosa*
MONU	Nutall's poverty weed	*Monolepis nuttalliana*
MUCU3	Plains muhly	*Muhlenbergia cuspidata*
MURA	Green muhly	*Muhlenbergia racemosa*
MUSQ3	false buffalograss	*Munroa squarrosa*
NAVI4	Green needlegrass	*Nasella viridula*
NECA2	Catnip	*Nepeta cataria*
OECO2	Combleaf evening primrose	*Oenothera cronopifolia*
OLRI	stiff goldenrod	*Oligoneuron rigidum*
ONBE	False gromwell	*Onosmodium bejarense*
OPFR	Brittle pricklypear	*Opunita fragilis*
OPMA2	Bigroot pricklypear	*Opunita macrorhiza*
OPUNT	Cactus	*Opuntia*
ORFA	clustered broomrape	*Orobanche fasciculata*
ORLU2	Owl clover	*Orthocarpus luteus*
OXALI	Woodsorrel	*Oxalis*
OXLA3	Purple locoweed	*Oxytropis lambertii*
PACA6	Witch grass	*Panicum capillare*
PASM	western wheatgrass	*Pascopyrum smithii*
PAVI2	switchgrass	*Panicum virgatum*
PEAL2	White beardtongue	*Penstemon albidus*
PEAR6	Silver scurfpea	*Pediomelum argophyllum*
PEGL3	Smooth beardtounge	*Penstemon glaber*

Table A.1 Continued

PEGR5	Slender beardtongue/penstemon	*Penstemon gracillis*
PENST	Beardtongue	*Penstemon spp.*
PHLOX	Phlox	*Phlox spp.*
PHPR3	Timothy	*Phleum pratense*
PHVI5	Virginia Groundcherry	*Physalis virginiana*
PLMA2	Common plantain	*Plantago major*
PIOP	Opposite leaf bahia	*Picradeniopsis oppositifolia*
PIPO	Ponderosa Pine	*Pinus ponderosa*
PLANT	Plantain	*Plantago spp.*
PLPA2	Woolly plaintain	*Plantago patagonica*
POAC3	leathery knotweed	*Polygonum cf. achoreum*
POAR7	Tall cinquefoil	*Potentilla arguta*
POAV	Prostrate knotweed	*Polygonum aviculare*
POAL4	white milkwort	*Polygala alba*
POCO	Canada bluegrass	*Poa compressa*
PODO4	Douglas knotweed	*Polygonum douglasii*
POHI6	Wooly cinquefoil	*Potentilla hippiana*
POLYG4	Knotweed	*Polygonum*
PONO3	Norwegian cinquefoil	*Potentilla norvegica*
PORE5	Sulphur cinquefoil	*Potentilla recta*
POTEN	Potentialla	*Cinquefoil*
POPE8	Pensylvania cinquefoil	*Potentilla pensylvanica*
POPR	Kentucky bluegrass	*Poa pratensis*
POVE	whorled milkwort	*Polygala verticillata*
PSMA11	Macoun's cudweed	*Pseudognaphalium macounii*
PSTE5	Slim Flower Scurfpea	*Psoralidium tenuiforum*
RACO3	Prairie cone flower	*Ratibida columnifera*
RIBES	Currant	*Ribes spp.*
ROAR3	Prairie rose	*Rosa arkansana*
ROCK	Rock	
RUAC3	common sheep sorrel	*Rumex acetosella*
RUCR	Curly dock	*Rumex crispis*
RUOC3	Western dock	*Rumex occidentalis*
RUHI2	Blackeyed Susan	*Rudbeckia hirta*
SALVI	Salvi family	*Lamiaceae squarestem*
SARE3	lanceleaf sage	*Salvia reflexa*
SATR12	Russian thistle	*Salsola tragus*
SCLA	lanceleaf figwort	*Scrophularia lanceolata*
SCPA	Tumblegrass	*Schedonnardus paniculatus*

Table A.1 Continued

SCSC	Little bluestem	*Schizachyrium scoparium*
SEDE2	Lesser spike moss (club moss)	*Selaginella densa*
SHORTGRASSES	blue grama, hairy grama, buffalo grass	
SIAL2	Tall tumblemustard	*Sisymbrium atlissimum*
SIPR4	White campion	*Silene pratensis*
SILO3	Tall hedgemustard	*Sisymbrium loeselii*
SIMO2	blue-eyed grass	*Sisyrinchium montanum*
SINO	Nightflowering catch fly	*Silene noctiflora*
SIVU	Bladder campion	*Silene vulgaris*
SOLAN	nighshade	*Solanum*
SOLID	goldenrod	*Solidago spp.*
SOMI2	Missouri goldenrod	*Solidago missouriensis*
SOMO	Velvet goldenrod	*Solidago mollis*
SOSP2	showy goldenrod	*Solidago speciosa*
SOTR	Cutleaf nightshade	*Solanum trifolum*
SPAS	Tall dropseed	*Sporobolus asper*
SPCO	Scarlet globemallow	*Sphaeralcea coccinea*
SPCO16	Tall dropseed	*Sporobolus compositus*
SPCR	Sand dropseed	*Sprobolus cryptandrus*
SPHE	prairie dropseed	*Sporobolus heterolepis*
SPPE	prairie cordgrass	*Spartina pectinata*
SYCI	Lindley's aster	*Symphyotrichum ciliolatum*
SYFA	White Prairie aster	*Sympyotrichum falcatum*
SYOB	aromatic aster	*Sympyotrichum oblongifolium*
SYOC	Western snowberry	*Symphoricarpos occidentalis*
TAOF	Dandelion	*Taraxacum officinale*
TEAC	Stemless hymenoxys	*Tetraneuris acaulis*
THAR5	Field pennycress	*Thlaspi arvense*
THIN6	intermediate wheatgrass	*Thinopyrum intermedium*
TORY	Poison ivy	*Toxicodendron rydbergii*
TRBR	Bracted spiderwort	*Tradescantia bracteata*
TRDU	yellow salsify	*Tragopogon dubius*
TRIFO	clover	*Trifolium*
TRLE3	slimpod Venus' looking-glass	*Triodanis leptocarpa*
TROC	Prairie spiderwort	*tradescantia occidentalis*
TRPE4	Clasping Venus' looking-glass	*Triodanis perfoliata*
TRPR2	Red clover	*Trifolium pratense*
TRRE3	White clover	*Trifolium repens*
URDI	Stinging nettle	*Urtica dioica*

Table A.1 Continued

VEBR	Bigbract verbena	*Verbena bracteata*
VEPE2	Neckweed	*Veronica peregrina*
VEST	Hoary verbena	*Vesrbena stricta*
VETH	Mullein	*Verbascum Thapsus*
VIAM	American vetch	*Vicia americana* var. *minor*
VIVI	hairy vetch	*Vicia americana*
VIPE2	prairie violet	*Viola pedatifida*
VUOC	Sixweeks fescue	*Vulpia octoflora*
ZIVE	Deathcamus	*Zigadenus venenosus*

[1] NOMENCLATURE FOLLOWS USDA PLANTS DATA BASE (USDA NRCS 2014)