CENTRAL MIXEDGRASS PRAIRIE ECOLOGICAL SYSTEM

(CENTRAL SHORTGRASS PRAIRIE ECOREGION VERSION)

ECOLOGICAL INTEGRITY ASSESSMENT

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Table of Contents

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(Central Shortgrass Prairie Ecoregion version)

A. INTRODUCTION

A.1 Classification Summary

CES303.659 - Central Mixedgrass Prairie

Classifiers:

Landcover class:	Herbaceous
Spatial Scale & Pattern:	Matrix
Classification Confidence:	Strong
Required Classifiers:	Natural/Seminatural, Vegetated (> 10% vascular cover), Upland
Diagnostic Classifiers:	
Non-Diagnostic Classifiers:	Lowland Herbaceous Temperate Temperate Continental Shallow Soil Loam Soil Texture Silt Soil Texture Ustic Fire: Medium intensity, Landscape-scale Grazing: High Intensity, Landscape-scale Graminoid

U.S. Distribution: CO, KS, NE, OK, SD, TX
Global Range: This system is found throughout the central and southern areas of the western Great Plains ranging from southern South Dakota into the Rolling Plains and Edwards Plateau of Texas.
Primary Biogeographic Division: 303 – Western Great Plains
TNC Ecoregions:

27	Central Shortgrass Prairie	Predicted or probable
28	Southern Shortgrass Prairie	Predicted or probable
29	Edwards Plateau	Confident or certain
32	Crosstimbers and Southern Tallgrass Prairie	Confident or certain
33	Central Mixed-Grass Prairie	Confident or certain
36	Central Tallgrass Prairie	Confident or certain
37	Osage Plains/Flint Hills Prairie	Predicted or probable

Concept Summary: This mixedgrass prairie system ranges from South Dakota into the Rolling Plains and the Edwards Plateau of Texas. It is bordered by the shortgrass prairie on its western edge and the tallgrass prairie to the east. The loessal regions in west-central Kansas and central Nebraska, the Red Hills region of south-central Kansas and northern Oklahoma are all located within this system. Because of its proximity to other ecoregions, this system contains elements from both shortgrass and tallgrass prairies, which combine to form the mixedgrass prairie ecological system throughout its range. The distribution, species richness and productivity of plant species within the mixedgrass ecological system is controlled primarily by environmental conditions, in particular soil moisture and topography. Grazing and fire are important dynamic processes in this system. The relative dominance of the various grass and forb species within different associations in the system also can strongly depend on the degree of natural or human disturbance. This system can contain grass species such as *Bouteloua curtipendula*, *Schizachyrium scoparium, Andropogon gerardii, Hesperostipa comata, Sporobolus heterolepis*, and *Bouteloua gracilis*, although the majority of the associations within the region are dominated by *Pascopyrum smithii* or *Schizachyrium scoparium*. Numerous forb and sedge species (*Carex* spp.) can also occur within the mixedgrass system in the Western Great Plains. Although forbs do not always significantly contribute to the canopy, they can be very important. Some dominant forb species include *Ambrosia psilostachya, Echinacea angustifolia*, and *Lygodesmia juncea*. Oak species such as *Quercus macrocarp*a can occur also in areas protected from fire due to topographic position. This can cause an almost oak savanna situation in certain areas, although fire suppression may allow for a more closed canopy and expansion of bur oak beyond those sheltered areas. In those situations, further information will be needed to determine if those larger areas with a more closed canopy of bur oak should be considered part of Western Great Plains Dry Bur Oak Forest and Woodland (CES303.667). Likewise, within the mixedgrass system, small seeps may occur, especially during the wettest years. Although these are not considered a separate system, the suppression of fire within the region has enabled the invasion of both exotics and some shrub species such as *Juniperus virginiana* and also allowed for the establishment of *Pinus ponderosa* in some northern areas.

Component Associations – CSP

ALLIANCE/Association name	Element code	G rank
ARTEMISIA TRIDENTATA SSP. WYOMINGENSIS SHRUB HERBACEOUS ALLIANCE		
Artemisia tridentata ssp. *wyomingensis* / Mixed Grasses Shrub Herbaceous Vegetation	CEGL001534	G5
HESPEROSTIPA COMATA - BOUTELOUA GRACILIS HERBACEOUS ALLIANCE		
Hesperostipa comata - Bouteloua gracilis - Carex filifolia Herbaceous Vegetation	CEGL002037	G5
Hesperostipa comata - Carex filifolia Herbaceous Vegetation	CEGL001700	G4
Hesperostipa comata - Carex inops ssp. heliophila Herbaceous Vegetation	CEGL001701	G4
Hesperostipa comata Colorado Front Range Herbaceous Vegetation ???		
KRASCHENINNIKOVIA LANATA DWARF-SHRUB HERBACEOUS ALLIANCE		
Krascheninnikovia lanata / Bouteloua gracilis Dwarf-shrub Herbaceous Vegetation	CEGL001321	G4
PANICUM OBTUSUM HERBACEOUS ALLIANCE	CEGL001573	GNRQ
Panicum obtusum - Buchloe dactyloides Herbaceous Vegetation		
PASCOPYRUM SMITHII HERBACEOUS ALLIANCE		
Pascopyrum smithii - Bouteloua gracilis Herbaceous Vegetation	CEGL001578	G5
Pascopyrum smithii - Hesperostipa comata Central Mixedgrass Herbaceous Vegetation	CEGL002034	G4
Pascopyrum smithii - Nassella viridula Herbaceous Vegetation	CEGL001583	G3G4
Pascopyrum smithii Herbaceous Vegetation	CEGL001577	G3G5Q
POA PRATENSIS SEMI-NATURAL HERBACEOUS ALLIANCE		
Poa pratensis - (Pascopyrum smithii) Semi-natural Herbaceous Vegetation	CEGL005265	GNA
SARCOBATUS VERMICULATUS INTERMITTENTLY FLOODED SPARSELY VEGETATED ALLIANCE		

Sarcobatus vermiculatus / Sporobolus airoides Sparse Vegetation	CEGL001368	G3?
SCHIZACHYRIUM SCOPARIUM - BOUTELOUA CURTIPENDULA HERBACEOUS ALLIANCE		
Schizachyrium scoparium - Bouteloua (curtipendula, gracilis) - Carex filifolia Herbaceous Vegetation	CEGL001681	G3G4
Schizachyrium scoparium - Bouteloua curtipendula - Bouteloua gracilis Central Plains Herbaceous Vegetation	CEGL002246	G2G4
Schizachyrium scoparium - Bouteloua curtipendula - Nassella leucotricha Herbaceous Vegetation	CEGL004070	GNR
Schizachyrium scoparium - Bouteloua curtipendula Chalkflat Herbaceous Vegetation	CEGL002247	G2
Schizachyrium scoparium - Bouteloua curtipendula Loess Mixedgrass Herbaceous Vegetation	CEGL002036	G3?
Schizachyrium scoparium - Bouteloua curtipendula Red Hills Herbaceous Vegetation	CEGL002248	G2Q
Schizachyrium scoparium - Bouteloua curtipendula Western Great Plains Herbaceous Vegetation	CEGL001594	G3
YUCCA GLAUCA SHRUB HERBACEOUS ALLIANCE		
Yucca glauca / Calamovilfa longifolia Shrub Herbaceous Vegetation	CEGL002675	G4
(COMPLEX)		
Blacktailed Prairie Dog Town Grassland Complex	CECX005703	G4

Additional Associations – outside CSP

Cornus drummondii - (Rhus glabra, Prunus spp.) Shrubland
Cynodon dactylon Herbaceous Vegetation
Hesperostipa curtiseta - Elymus lanceolatus Herbaceous Vegetation
Hilaria belangeri - Bouteloua curtipendula Herbaceous Vegetation
Juniperus virginiana var. virginiana / Schizachyrium scoparium - Bouteloua curtipendula Great Plains Herbaceous Vegetation
Juniperus virginiana var. virginiana / Schizachyrium scoparium Forest
Pleuraphis mutica - Buchloe dactyloides Herbaceous Vegetation
Poa palustris Herbaceous Vegetation
Quercus macrocarpa / Mixedgrass Loam Wooded Herbaceous Vegetation
Quercus macrocarpa / Mixedgrass Sand Wooded Herbaceous Vegetation
Quercus macrocarpa / Mixedgrass Shale Wooded Herbaceous Vegetation
Schizachyrium scoparium - Lesquerella gordonii - Castilleja purpurea var. citrina Herbaceous Vegetation

A.2 Ecological System Description

A.2.1 Environment

Although now converted to agricultural uses over much of their former extent, native grasslands once dominated the central portions of North America, from southern Canada to northern Mexico, as well as forming extensive and significant expanses throughout the western portion of the continent (Sims and Risser 2000). The composition of the grasslands of central North America is influenced by a continental climate having both east-west and north-south gradients. Over the central plains, precipitation decreases from east to west, while temperatures and day-lengths increase from north to south. These broad gradients, together with fire and sometimes soils, result in the gradual differentiation of grassland types (Joern and Keeler 1995, Knapp and Seastedt 1998). Although we divide the grasslands of the Great Plains into tall, mixed, and shortgrass prairie types for convenience, the gradients are essentially continuous.

The climate of the Great Plains also exhibits extreme variability both within and between years. Together with a natural fire disturbance regime and the effects of numerous herbivores both large and small, this variability gives rise to spatial and temporal heterogeneity within the broader gradients. Moreover, within the broad continental pattern, local or regional conditions permit the occurrence of anomalous pockets or stringers of grassland types that differ from the surrounding prairie. The Great Plains generally experience windy, dry winters with little snow accumulation. A large proportion of the annual total precipitation (65-80%) falls during the growing season

(April through September). Summer precipitation is primarily from thunderstorm activity and may be extremely heavy (Borchart 1950, Western Regional Climate Center 2004). The annual precipitation gradient ranges from 40-60 inches in eastern tallgrass to 10-15 inches in western shortgrass (Joern and Keeler 1995), with mixedgrass lying between these two extremes. This ecotonal property is also evident at the mountain front, where the sudden change in elevation produces increased precipitation that can support mid- to tallgrasses.

Where the mixedgrass prairie originally occurred in large expanses in the central Great Plains, it was transitional between the tallgrass prairie to the east and shortgrass to the west. This grassland type is a broad and historically shifting ecotone, fluctuating with climatic changes, fire suppression, and changes in grazing frequency and intensity by native and domestic grazers (Sims and Risser 2000). Differences in topography and soil characteristics also occur across the range of this system. It is often characterized by rolling to extremely hilly landscapes with soils developed from loess, shale, limestone or sandstone parent material. Mollisol soils are most prevalent and range from silt loams and silty clay loams with sandy loams possible on the western edge of the range. The Red Hills region of Kansas and Oklahoma, which contains examples of this system, contains somewhat unique soil characteristics and has developed from a diversity of sources including red shale, red clay, sandy shale, siltstone, or sandstone. These soils have developed a characteristic reddish color from the primary material. These soils can consist of silt, loam, or clay and can have textures ranging from a fine sandy loam to a more clayey surface.

Although the greater part of the mixedgrass prairie lies to the east of Colorado, the western extent of this system has probably moved in and out of what is now eastern Colorado during much of the Holocene, as climatic conditions alternated between wetter and drier. In the sandhills of eastern Colorado, mixedgrass prairie dominated large areas in the early years of the 1900s. By the late 1940s, most of these communities had been replaced by shortgrass or sandsage communities, due to the effects of grazing and drought (McGinnies et al. 1991). Under favorable conditions, small to large patches of this type may occur further west, near the mountain front. Branson et al. (1961) found mixedgrass associations on shale-derived soils near the mountain front, adjacent to stony soils of the Rocky Flats alluvium. The mixedgrass system occurred in areas where infiltration rates were on average 1 to 2 inches per hour, while rates in xeric tallgrass associations were 4 to 7 inches per hour.

A.2.2 Vegetation & Ecosystem

Vegetation

John Kirk Townsend, naturalist with the Wyeth expedition of 1834, disparaged the "interminable green plains" encountered by the party as they journeyed along the Platte River (Townsend 1839). Although the prairies appeared monotonous to early explorers, these grasslands are not as structurally simple as they might appear. The native grasslands of central North America are characterized by the dominance of herbaceous plants, with limited contribution from dwarf shrub species and few, if any woody species. The prairies are a mosaic of distinct herbaceous communities including short, medium, tall grasses, a great variety of forbs, and both mesic and xeric environments. In addition, prairie grasslands are repeatedly dissected by thin strips of riparian vegetation along perennial or intermittent streams. On a broad scale, warm-season (C4) grasses dominate in southern latitudes, while cool-season (C3) species dominate further north (Knapp and Seastedt 1998). As a group, grasses are well adapted to both drought and herbivory, and can quickly take advantage of favorable conditions. Grass species may account for less than 20% of the number of species in a prairie, but often just three or four species of grass produce most of the biomass (Sims and Risser 2000). Forbs and some dwarf shrubs may be seasonally important and contribute to the structural complexity of the communities. There are few endemic species of the central prairies, perhaps due to the relatively recent origin of the ecosystem in post-glacial times.

The mixedgrass prairie shares elements with Western Great Plains Shortgrass Prairie and Western Great Plains Foothills and Piedmont Grassland. In the central part of its range, the mixedgrass prairie system typically includes C4 grass species such as *Bouteloua curtipendula, Bouteloua gracilis, Schizachyrium scoparium, Andropogon gerardii, Sporobolus heterolepis,* and the C3 species *Hesperostipa comata*. In the Central Shortgrass Prairie ecoregion, however, the majority of the associations are dominated by *Pascopyrum smithii* (C3), *Hesperostipa comata,* or *Schizachyrium scoparium*. Numerous forb and sedge species (*Carex* spp.) can also occur within the mixedgrass system in the Western Great Plains. Although forbs do not always significantly contribute to the canopy, they can be very important. Some dominant forb species include *Ambrosia psilostachya, Echinacea angustifolia*, and *Lygodesmia juncea*. Shrubland associations can occur in areas protected from fire due to topographic conditions. Where there are shared association types between the mixedgrass prairie and foothills grasslands, those on loamier soils are likely to belong to the mixedgrass prairie type.

The towns of blacktailed prairie dogs (*Cynomys ludovicianus ludovicianus*) occur widely throughout the mixedgrass and shortgrass regions of the Great Plains of the United States and Canada, and this grassland complex ranges from Saskatchewan in Canada south to the southern Great Plains states, including Colorado and Kansas. Currently no plant associations have been directly linked to the prairie dog towns, as, apart from the original mixedgrass or shortgrass prairie communities that were present when the town became established, there are no known descriptions of the various community types that occur on these towns.

Animals

Both the historic and current extent of the blacktailed prairie dog (*Cynomys ludovicianus ludovicianus*) in Central North America have been widely debated (e.g. Knowles et al 2002, Virchow and Hygnstrom 2002, Vermeire et al. 2004, Forrest 2005). Even with large fluctuations due to predator control, drought, and overgrazing, it is thought that blacktailed prairie dog towns historically covered tens of millions of hectares in the Great Plains of the United States and adjacent Canada (Vermeire et al. 2004), and formed an important part of the mixedgrass prairie ecosystem. Although there are no species which are strictly endemic to mixedgrass prairie, grassland birds such as chestnut-collared longspur, lark bunting, Cassin's sparrow, and grasshopper sparrow do use these mid-height grassland for major portions of their life cycle (Knopf 1996), and are indicators of a functioning system.

Biogeochemistry and Productivity

Nutrient cycling in grassland ecosystems is mediated primarily through the assimilation and allocation of carbon and nitrogen by herbaceous plants in relation to precipitation and evapotranspiration rates (Sims and Risser 2000). Water is typically the most limiting factor for plant production; grassland productivity generally increases in a linear fashion with increasing precipitation. Moreover, water availability and use appear to be the fundamental regulators of energy flow in grassland ecosystems (Lauenroth 1979). Due to the semi-arid climate, nutrient availability is typically low, but nutrient mineralization (the transformation by soil bacteria of organic matter into chemical forms usable by plants) increases during periods of wet, relatively warm weather (Wallace and Dyer 1995). Productivity in grassland ecosystems of the North American Great Plains is more easily influenced by variation in annual precipitation than in other ecosystems, and these systems can have dramatic increases in production under unusually high precipitation levels (Knapp and Smith 2001).

In the absence of disturbance such as grazing and fire, dead plant material accumulates on the surface. In comparison with wetter regions, both accumulation and decomposition of litter is slow in these semi-arid grasslands. Wind and water erosion can remove nutrients. Fire quickly returns nutrients to the soil. Herbivory has a much greater influence on energy and nutrient pathways in grasslands than in forests, and a greater proportion of biomass is moving through the grazing pathway in comparison to other ecosystems (Sims and Risser 2000).

A.2.3 Dynamics

Fire, grazing, and drought, and the interactions between them are the primary processes affecting the system. The herbaceous diversity of this mixedgrass system may reflect both the short- and long-term responses of the vegetation to these often concurrent disturbance regimes

Fire

Fire, both aboriginal and lightening-caused, was historically a regular part of this association. Precise information about the size of historic grassland fires is difficult to find, but prairie fires were often said to stretch for miles across the horizon (Moore 1972, Higgens 1986), and fires were reported by early travelers in the region (Bragg 1995). Modern grass fires as large as 110,000 acres have been reported (e.g., Woods County, OK, February 1996), and historical fires could easily have been larger. Seasonality of historic fire is not known, but available information shows that lightning storms occur from March through October, peaking from May to August (Bragg 1995). Fires set by Native Americans of the region appear to have been most frequent in July and August as well (Moore 1972); thus fires may have been common in mid- to late summer (Bragg 1995).

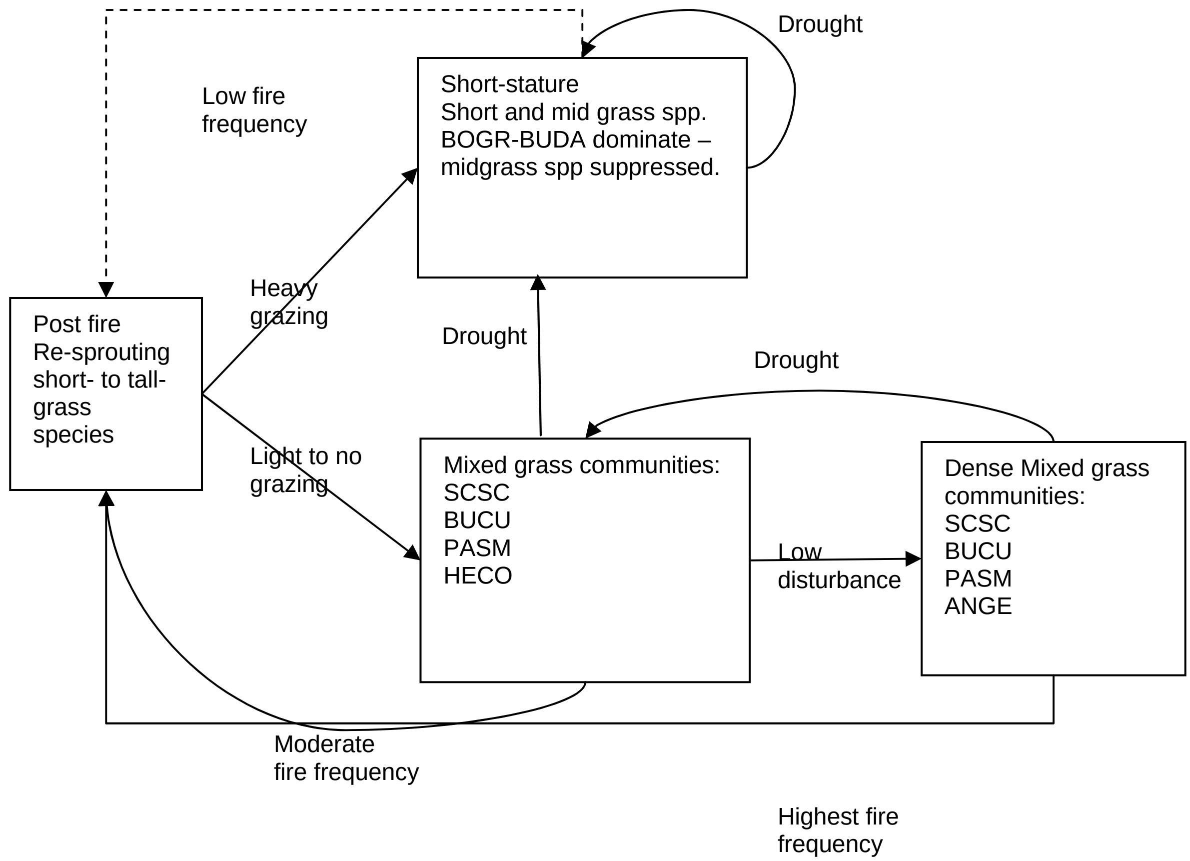
Most of the dominant grass species appear to be somewhat tolerant of fire, although it may take two to three growing seasons for the dominants to recover to preburn cover. Fire return intervals were probably on the order of 5 to 10 years, due to slow litter accumulation (Bragg 1995). Fires burning when plants were green would be of lower intensity. Most burns consume the undecomposed plant matter (litter), releasing moisture to the air and nutrients to the soil. Effects of litter loss are variable but are most pronounced in dry areas where removal of litter results in increased soil surface temperatures (Bragg 1995). Consequences of fire vary with frequency, length of return interval, grazing history, herbicide use, successional stage, weather patterns, edaphic features, and topography (Engle and Bidwell 2001).

Grazing

North American grasslands, including the Central Mixedgrass Prairie, evolved with a diverse herbivore community. Although the post-Pleistocene extinctions greatly reduced the diversity of herbivorous fauna, the presettlement Great Plains retained vast numbers of grazers. Estimates of historic bison numbers prior to settlement range from 20 to 60 million animals (Larson 1940). In addition to bison, there were large numbers of elk, deer, and pronghorn as well as numerous small herbivores, including small mammals, and grasshoppers (Wallace and Dyer 1995). The reduction in diversity of grazers has continued to present times, and current agricultural practice seeks to reduce competition for domestic livestock, and maximize production on a finite parcel in contrast to the large spaces used by native herbivores (Wallace and Dyer 1995). Large ungulates and burrowing animals are often the most obvious herbivores, but many invertebrate species also contribute substantially to the effects of herbivory. Herbivory affects energy and material flow in the system, but may also have differential impacts on life history stages of species. Joern (1995) summarized ways herbivores can influence grasslands in addition to removing plant tissue through feeding, including: altering the physical environment and microtopography through burrowing, changing patch structure in the community through intense, localized grazing (e.g. prairie dogs), affecting nutrient cycling by altering patterns and rates of soil development and nutrient availability, altering plant/soil-water relationships, changing plant species composition, altering gene frequencies with selection for prostrate growth forms in some cases, and changing feeding-site selection by other herbivores.

Drought

Periodic drought is common in the range of the Central Mixedgrass Prairie ecological system, and the occurrence of the most severe droughts is concentrated in the shortgrass and southern mixedgrass prairie regions (Bragg 1995). Drought can have significant effects on the species composition of grasslands, reducing vegetative cover as well as decreasing or eliminating successful reproduction of the component species Response of plants to drought is variable between species, and between microsite conditions. Short-statured grasses such as *Bouteloua gracilis* may be more impacted by blown dust. *Schizachyrium scoparium* is most affected by lack of precipitation, while *Bouteloua curtipendula, Bouteloua gracilis, Hesperostipa comata,* and *Pascopyrum smithii* are better able to withstand or take advantage of drought conditions (Weaver 1954)



Adapted from LANDFIRE R4PRMGs

A.2.4 Landscape

This system evolved as a matrix forming type in the Central Mixedgrass Prairie ecoregion, where landscape context would be less important as a ranking factor. In areas where it is functioning as a large patch type in the Central Shortgrass Prairie ecoregion, landscape context is of increased importance in mitigating for the lack of size in these peripheral occurrences. An occurrence that is embedded in an intact landscape retains connectivity to adjacent and nearby systems that permits species dispersal and recolonization. A surrounding landscape that is composed of natural vegetation in good condition can buffer a small occurrence, provide migration corridors for important species, and serve as refugia for those species in case of widespread disturbance. Similarly, highly modified surrounding landscapes may facilitate the loss of native species from a patch as well as serve as sources of invasive species. Small, fragmented grasslands are likely to be less resistant to colonization by non-native species.

Grasslands are also in part maintained by natural processes such as fire and grazing by large herbivores. If an occurrence is not large enough by itself to support a natural fire and grazing regime where disturbance is patchy and cyclical, a surrounding natural landscape can provide additional area for the operation of these processes.

A.2.5 Size

In the Central Mixedgrass Prairie ecoregion, the midgrass prairie ecological system occurs in very large contiguous areas, and functions as a matrix-forming system. In the Central Shortgrass Prairie ecoregion (and in Colorado), this system is restricted to the large patch type. The range of this system is primarily in the Central Mixedgrass Prairie and Central Shortgrass Prairie ecogregions, although it may be peripheral in a few other ecoregions such as the Dakota Mixedgrass Prairie and Osage Plains/Flint Hills Prairie (Comer et al. 2003). Matrix communities occupy extensive areas, and occur under a broad range of environmental conditions. Large patch communities, although sometimes covering extensive areas, usually have more distinct boundaries, require specific environmental conditions, and are strongly linked to and dependent upon the landscape around them. Like matrix communities, large-patch communities are also influenced by large-scale processes, but these tend to be modified by specific site features that influence the community (Anderson et al. 1999).

Although the mixed-grass prairie system forms the matrix vegetation in parts of the Central Mixedgrass Prairie ecoregion, it is a large patch system in the Central Shortgrass Prairie ecoregion. In regions where this system is matrix forming, a viable example of this system would be large enough that fire and grazing can occur at spatial and temporal scales approaching those at which they naturally occurred, and viable sizes would range from 5000 to over 100,000 acres. In the Central Shortgrass Prairie, occurrences of this size would simply not be found, and size ranking is adjusted accordingly.

Evaluation of the size of an occurrence should consider its current extent in relation to what would be ecologically possible given the precipitation and soils of the area. The natural size of an occurrence of mixedgrass prairie in the western portion of the ecoregion will be determined largely by a site’s topography, soils, and ecosystem processes. If an occurrence has not been reduced in size by human impacts or is surrounded by natural landscape that has not been affected by human disturbances, then size is less important to the assessment of ecological integrity. If, however, human disturbances have decreased the size of the occurrence, or if the surrounding landscape is impacted and has the potential to affect the site, bigger occurrences are able to buffer against these impacts better than smaller sized occurrences due to the fact they generally possess a higher diversity of abiotic and biotic processes allowing them to recover and remain more resilient. Under such circumstances, size may be more important in assessing ecological integrity. Larger occurrences (e.g. >5000 acres) should contain a mosaic of structural and compositional stages with a variety of plant associations and are large enough to support viable populations of grassland birds which use this system for most of their life-cycle needs. Occurrences of this size are large enough to provide refuge for edge sensitive species, and would likely contain sufficient internal variability to capture characteristic biophysical gradients and retain natural geomorphic disturbance. Under such circumstances, size may be an important factor in assessing ecological integrity.

A.3 Ecological Integrity

A.3.1 Threats

Alteration of historic disturbance regime

During its evolutionary history, the Great Plains region experienced heavy grazing pressure, first from the herbivores of the Pleistocene, and then from presettlement herds of bison and pronghorn antelope, as well as numerous prairie dogs and rabbits (Collins and Glenn 1991). Before the advent of cattle ranching, grazing pressure from native herbivores was variable in intensity and seasonality from year to year. Grazing pressure from domestic cattle is typically more homogeneous in timing and intensity (The Nature Conservancy 1998). Historically, soil disturbance was largely the result of occasional concentrations of large native herbivores, or the digging action of fossorial mammals. Prairie dog populations have undergone a decline since settlement, so much of this type could be in various states of secondary succession, returning from a somewhat denuded state and altered composition created by the prairie dogs. Changes in patterns of grazing disturbance have the potential to alter environmental factors such as species composition, soil compaction, nutrient levels, and vegetation structure.

Fire, both aboriginal and lightening-caused, was a regular part of this association. Fire-return intervals have been considerably lengthened since settlement by European-Americans. Fire suppression may allow the invasion of woody species, especially in combination with heavy grazing. Although woodlands and savannas are expected to occur naturally on the landscape, alteration of fire intensity and frequency, grazing, and changes in climate has resulted in various densities of younger trees occurring on sites that were once shrublands or grasslands (West 1999). Ecotonal areas between grassland and ponderosa or juniper savanna may be especially vulnerable to successional changes.

Global warming

Under two widely-used climate change models (National Assessment Synthesis Team 2000), as levels of atmospheric CO_2 increase, the predicted scenario for much of the range of mixedgrass prairie in the Central Shortgrass Prairie Ecoregion is a shift away from grassland to either shrubland/woodland (under increased precipitation conditions) or arid land (under decreased precipitation).

Habitat conversion

Samson et al. (2004) estimated that more than 45% of the native central mixedgrass prairie in the United States has been converted to cropland or pastureland. The current rate of conversion of native grassland to agriculture is low, but is driven in part by market prices, and remains a possibility for some habitat (The Nature Conservancy 1998).

Habitat can also be lost or fragmented by suburban and exurban development, and transportation infrastructure development.

Abiotic resource use
Development of oil and gas resources is ongoing in the Western Great Plains. The Denver-Julesberg basin is an extremely active area in the region in terms of natural gas well permits and production (Colorado Oil and Gas Conservation Commission 2004). Currently most activity in the basin is concentrated in the Wattenberg field in Weld and Yuma counties, in eastern Colorado. The number of inactive wells in the basin show that past drilling activities have probably resulted in habitat alteration for a substantial portion of habitat in northeastern Colorado.

Invasive species
In the Central Shortgrass Prairie Ecoregion invasive species are most prevalent in areas disturbed by cultivation, especially in northeastern Colorado. The Nature Conservancy (1998) identified major problem weeds in grasslands of the Central Shortgrass Prairie Ecoregion as leafy spurge (*Euphorbia esula*), cheatgrass (*Bromus tectorum*), Russian thistle (*Salsola kali*), musk thistle (*Carduus nutans*), Canada thistle (*Cirsium canadensis*), knapweed (*Centaurea* spp.), and toadflax (*Linaria dalmatica*).

A.3.2 Justification of Metrics

As reviewed above, the literature suggests that the following attributes are important measures of the ecological integrity of Central Mixedgrass Prairie grasslands in the Central Shortgrass Prairie ecoregion.

<u>Landscape Context</u>: Land use in the adjacent land as well as in the larger surrounding landscape has important effects on the connectivity and sustainability of many ecological processes critical to this system. The amount and configuration of natural landscape will determine the degree to which natural processes such as fire and species dispersal can function or be simulated by management.

<u>Biotic condition</u>: Species composition and diversity, presence and regeneration of characteristic native plants, invasion of exotics, and structural diversity are important measures of biological integrity.

<u>Abiotic Condition</u>: Ecological processes including the water cycle, energy flow, and nutrient cycling support characteristic plant and animal comunities. Measures of physical components are used as indicators of the integrity of these functions.

<u>Size</u>: Because it is difficult to characterize the potential size of an occurrence of this system in the CSP, size is addressed by evaluating the total area of the occurrence and the area that is in A-ranked biotic and abiotic condition classes

A.3.3 Ecological Integrity Metrics

A synopsis of the ecological metrics and ratings is presented in Table 1. The three tiers refer to levels of intensity of sampling required to document a metric. Tier 1 metrics are able to be assessed using remote sensing imagery, such as satellite or aerial photos. Tier 2 typically require some kind of ground sampling, but may require only qualitative or semi-quantitative data. Tier 3 metrics typically require a more intensive plot sampling or other intensive sampling approach. A given measure could be assessed at multiple tiers, though some tiers are not doable at Tier 1 (i.e., they require a ground visit). The focus for this System is primarily on a Tier 2 approach.

Core and Supplementary Metrics
The Scorecard (see Tables 1 & 2) contains two types of metrics: Core and Supplementary. Separating the metrics into these two categories allows the user to adjust the Scorecard to available resources, such as time and funding, as well as providing a mechanism to tailor the Scorecard to specific information needs of the user.

Core metrics are shaded gray in Tables 1 & 2 and represent the minimal metrics that should be applied to assess ecological integrity. Sometimes, a Tier 3 Core metric might be used to replace Tier 2 Core Metrics. For example, if a Vegetation Index of Biotic Integrity is used, then it would not be necessary to use similar Tier 2 Core metrics such as Percentage of Native Graminoids, Percentage of Native Plants, etc.

Supplementary metrics are those which should be applied if available resources allow a more in depth assessment or if these metrics add desired information to the assessment. Supplementary metrics are those which are not shaded in Tables 1 & 2.

A.4 Scorecard Protocols

For each metric, a rating is developed and scored as A – (Excellent) to D – (Poor). The background, methods, and rationale for each metric are provided in section B. Each metric is rated, then various metrics are rolled together into one of four categories: Landscape Context, Biotic Condition, Abiotic Condition, and Size. A point-based approach is used to roll-up the various metrics into Category Scores.

Points are assigned for each rating level (A, B, C, D) within a metric. The default set of points are A = 5.0, B = 4.0, C = 3.0, D = 1.0. Sometimes, within a category, one measure is judged to be more important than the other(s). For such cases, each metric will be weighted according to its perceived importance. Points for the various measures are then added up and divided by the total number of metrics. The resulting score is used to assign an A-D rating for the category. After adjusting for importance, the Category scores could then be averaged to arrive at an Overall Ecological Integrity Score.

Supplementary metrics are not included in the Rating Protocol. However, they could be incorporated if the user desired.

Table 1. Overall Set of Metrics for the Central Mixedgrass Prairie System in the Central Shortgrass Prairie Ecoregion.

Tier: 1 = Remote Sensing, 2 = Rapid, 3 =Intensive. Shading indicates core metrics.

Category	Essential Ecological Attribute	Indicators / Metrics	Tier
LANDSCAPE CONTEXT	Landscape Composition	Adjacent land use	1
		Buffer width	1
		Connectivity	1
BIOTIC CONDITION	Community Composition	Percent cover of native plant species	2
		Floristic quality index	3
		Presence and abundance of invasive exotics	2, 3
	Patch Diversity	Patch structure - variety	2
		Patch structure - interspersion	2
ABIOTIC CONDITION	Energy/Material Flow	Soil erosion & compaction	2, 3
		Fragmentation – land use within occurrence	1, 2
		Fire condition class	1, 2
SIZE	Size	Total area of system occurrence	1
		Area of system in A-ranked biotic and abiotic condition class	2, 3

Table 2. Metrics and Rating Criteria for the Central Mixedgrass Prairie system in the Central Shortgrass Prairie ecoregion.

Tier: 1 = Remote Sensing, 2 = Rapid, 3 =Intensive. (Alpha-numeric codes in parentheses is reference to the metric ID and corresponds to the section in which the metric is described). Confidence column indicates that reasonable logic and/or data support the index. Shading indicates core metrics.

Category	**Essential Ecological Attributes**	**Indicators/ Metics**	**Tier**	**Metric Ranking Criteria**			
				Excellent (A)	Good (B)	Fair (C)	Poor (D)
LANDSCAPE CONTEXT	Landscape Compostion	Adjacent land use (B.1.1)	1	Average land use score = 1.0 – 0.95	Average land use score = 0.80 – 0.95	Average land use score = 0.40 – 0.80	Average land use score = <0.40
		Buffer width (B.1.2)	1	Wide >500m	Medium 250 – 500m	Narrow 1000 – 50m	Very narrow < 100 m
	Landscape pattern	Percentage of unfragmented landscape within 1 km. (B.1.3)	1	Embedded in 90-100% unfragmented, roadless natural landscape; internal fragmentation absent	Embedded in 60-90% unfragmented natural landscape; internal fragmentation minimal	Embedded in 20-60%% unfragmented natural landscape; Internal fragmentation moderate	Embedded in < 20% unfragmented natural landscape. Internal fragmentation high
BIOTIC CONDITION	Community composition	Percent cover of native plant species (B.2.1)	2	100% cover of native plant specis	85-100%	50-85%	<50%
		Floristic quality index (Mean C) (B.2.2)	3	>4.5	3.5-4.5	3.0-3.5	<3.0
		Presence and abundance of invasive exotic species (B.2.3)	2	System altering invasive species, such as leafy spurge, knapweed species, or yellow toadflax are either not present or occupy less than 1 percent of the occurrence, with no patches larger than 1 acre.	System altering invasive species, such as leafy spurge, knapweed species, or yellow toadflax occupy no more than 1-3% of the occurrence with no patches larger than 1 acre.	System altering invasive species, such as leafy spurge, knapweed species, or yellow toadflax occupy 3-5% of the occurrence, with some patches larger than 1 acre	System altering invasive species, such as leafy spurge, knapweed species, or yellow toadflax occupy >5% of the occurrence.
	Community Extent	Patch structure – variety	2	> 75-100% of possible patch types	> 50-75% of possible patch types	25-50% of possible patch types are	< 25% of possible patch types are

Category	Essential Ecological Attributes	Indicators/ Metics	Tier	Metric Ranking Criteria			
				Excellent (A)	Good (B)	Fair (C)	Poor (D)
		(B.2.5)		are present in the occurrence	are present in the occurrence	present in the occurrence	present in the occurrence
		Patch structure – interspersion (B.2.6)	2	Horizontal structure consists of a very complex array of nested and/or interspersed, irregular biotic/abiotic patches, with no single dominant patch type	Horizontal structure consists of a moderately complex array of nested or interspersed biotic/abiotic patches, with no single dominant patch type	Horizontal structure consists of a simple array of nested or interspersed biotic/abiotic patches.	Horizontal structure consists of one dominant patch type and thus has relatively no interspersion
ABIOTIC CONDITION	Energy/ Material Flow	Soil erosion & compaction (B.3.1)		Score = 4.5-5.0	Score = 3.5-4.4	Score = 2.5-3.4	Score = 1.0-2.4
		Land use within the occurrence (B.3.2)		Average land use score = 1.0 – 0.95	Average land use score = 0.80 – 0.95	Average land use score = 0.40 – 0.80	Average land use score = <0.40
		Fire condition class (B.3.3)	1, 2	FCC score = 4.5-5.0	FCC score = 3.5-4.4	FCC score =2.5-3.4	FCC score =1.0-2.4
SIZE	Size	Total area of system occurrence (B.4.1)	1	> 5000 acres	2,000-5,000 acres	1,000-2,000 acres	< 1,000 acres
		Area of system occurrence in best Biotic and Abiotic Condition class (B.4.2)	1	> 5000 acres	2,000-5,000 acres	1,000-2,000 acres	< 1,000 acres

A.4.1 Landscape Context Rating Protocol

Rate the Landscape Context metrics according to their associated protocols (see Table 2 and details in Section B). Use the scoring table below (Table 3) to roll up the metrics into an overall Landscape Context rating.

Rationale for Scoring: Adjacent land use, buffer width, and connectivity of the occurrence are judged to be more important than the amount of fragmentation within 1 km of the occurrence since an occurrence with no other natural communities bordering it is very unlikely to have a strong biological connection to other natural lands at a further distance.

The following weights apply to the Landscape Context metrics:

Table 3. Landscape Context Rating Calculation.

Measure	Definition	Tier	A	B	C	D	Weight	Score (weight x rating)
Adjacent Land Use (B.1.1)	Addresses the intensity of human dominated land uses within 100 m of the occurrence.	1	5	4	3	1	0.40	
Buffer Width (B.1.2)	Buffers are vegetated, natural (non-anthropogenic) areas that surround an occurrence.	1	5	4	3	1	0.30	
Percentage of unfragmented landscape within 1 km. (B.1.3)	An unfragmented landscape has no barriers to the movement and connectivity of species, water, nutrients, etc. between natural ecological systems.	1	5	4	3	1	0.30	
Landscape Context Rating	A = 4.5 - 5.0 B = 3.5 – 4.4 C = 2.5 – 3.4 D = 1.0 – 2.4							**Total = sum of N scores**

A.4.2 Biotic Condition Rating Protocol

Rate the Biotic Condition metrics according to their associated protocols (see Table 2 and details in Section B). Use the scoring table below (Table 4) to roll up the metrics into an overall Biotic Condition rating.

Rationale for Scoring: The Floristic Quality Index (FQI) metric is judged to be more important than the other metrics as the FQI provides a more reliable indicator of biotic condition.

Scoring for Biotic Condition is a bit more complex. For example, the Floristic Quality Index (FQI) may or may not be assessed, depending on resources (since it is a Tier 3 metric). If it is included then the weights without parentheses apply to the Biotic

Condition metrics. If FQI is not included then the weight in parentheses is used for the Tier 2 metrics.

Table 4. Biotic Condition Rating Calculation.

Measure	Definition	Tier	A	B	C	D	Weight*	Score (weight x rating)
Percent of Cover of Native Plant Species (B.2.1)	Percent of the plant species which are native to the Southern Rocky Mountains.	2	5	4	3	1	0.20 (0.70)	
Floristic Quality Index (Mean C) (B.2.2)	The mean conservatism of all the native species growing in the occurrence.	3	5	4	3	1	0.60 (N/A)	
Presence and abundance of noxious species (B.2.3)	Presence/abundance of invasive exotics with major potential to alter structure and composition of system.						0.20 (0.30)	
Biotic Condition Rating	A = 4.5 - 5.0 B = 3.5 – 4.4 C = 2.5 – 3.4 D = 1.0 – 2.4							**Total = sum of N scores**

* The weight in parentheses is used when metric B.2.2 is not used.

A.4.3 Abiotic Condition Rating Protocol

Rate the Abiotic Condition metrics according to their associated protocols (see Table 2 and details in Section B). Use the scoring table below (Table 5) roll up the metrics into an overall Abiotic Condition rating.

<u>Rationale for Scoring</u>: Quantitative water table data are judged to more reliable than the other metrics for indicating Abiotic Condition (shaded metric in Table 5). However, if such data are lacking then stressor related metrics (Land Use & Hydrological Alterations) are perceived to provide more dependable information concerning Abiotic Condition.

Table 5. Abiotic Condition Rating Calculation.

Measure	Definition	Tier	A	B	C	D	Weight*	Score (weight x rating)
Soil erosion & compaction		2,3	5	5	0	0	0.50	
Disturbance & Fragmentation – land use within occurrence	Addresses the intensity of human dominated land uses within the occurrence.	1, 2	5	4	3	1	0.50	
Abiotic Condition Rating	A = 4.5 - 5.0 B = 3.5 – 4.4 C = 2.5 – 3.4 D = 1.0 – 2.4							**Total = sum of N scores**

A.4.4 Size Rating Protocol

Rate the two measures according to the metrics protocols (see Table 2 and details in Section B). Use the scoring table below (Table 6) to roll up the metrics into an overall Size rating.

Rationale for Scoring: Since the importance of size is contingent on human disturbance both within and adjacent to the occurrence, two scenarios are used to calculate size:

(1) When Landscape Context Rating = "A":
Size Rating = Relative Size metric rating (weights w/o parentheses)

(2) When Landscape Context Rating = "B, C, or D".
Size Rating = (weights in parentheses)

Table 6. Size Rating Calculation.

Measure	Definition	Tier	A	B	C	D	Weight*	Score (weight x rating)
Total size (B.4.1)	The current size of the occurrence	1	5	4	3	1	0.0 (0.40)	
Size of area in best condition (B.4.2)	Area of system occurrence in best Biotic and Abiotic Condition class	1	5	4	3	1	1.0 (0.60)	
Size Rating	A = 4.5 - 5.0 B = 3.5 – 4.4 C = 2.5 – 3.4 D = 1.0 – 2.4							**Total = sum of N scores**

* The weight in parentheses is used when Landscape Context Rating = B, C, or D.

A.4.5 Overall Ecological Integrity Rating Protocol

If an Overall Ecological Integrity Score is desired for a site, then a weighted-point system should be used with the following rules:

1. If Landscape Context = *A* then the Overall Ecological Integrity Rank = **[Abiotic Condition Score *(0.35)] + [Biotic Condition Score *(0.25)] + [Landscape Context Score * (0.25)] + [Size Score * (0.15)]**

2. If Landscape Context is *B*, *C*, or *D* AND Size = *A* then the Overall Ecological Integrity Rank = **[Abiotic Condition Score *(0.35)] + [Biotic Condition Score *(0.25)] + [Size Score * (0.25)] + [Landscape Context Score * (0.15)]**

3. If Landscape Context is *B*, *C*, or *D* AND Size = *B* then the Overall Ecological Integrity Rank = **[Abiotic Condition Score *(0.35)] + [Biotic Condition Score *(0.25)] + [Landscape Context Score * (0.20)] + [Size Score * (0.20)]**

4. If Landscape Context is *B*, *C*, or *D* AND Size = *C* or *D* then the Overall Ecological Integrity Rank = **[Abiotic Condition Score *(0.35)] + [Biotic Condition Score *(0.25)] + [Landscape Context Score * (0.25)] + [Size Score * (0.15)]**

The Overall Ecological Rating is then assigned using the following criteria:

A = 4.5 - 5.0
B = 3.5 – 4.4
C = 2.5 – 3.4
D = 1.0 – 2.4

B. PROTOCOL DOCUMENTATION FOR METRICS

Note: Much of the following discussion is adapted from Rocchio (2006).

B.1 Landscape Context Metrics

B.1.1 Adjacent Land Use

Definition: This metric addresses the intensity of human dominated land uses within 500 m of the occurrence.

Background: This metric evaluates one aspect of the landscape context of an individual occurrrance of the ecological system.

Rationale for Selection of the Variable: The intensity of human activity in the landscape has a proportionate impact on the ecological processes of natural systems. Each land use type occurring in the 500 m buffer is assigned a coefficient ranging from 0.0 to 1.0 indicating its relative impact to the occurrence (Hauer et al. 2002).

Measurement Protocol: This metric is measured by documenting surrounding land use(s) within 500 m of the occurrence. This should be completed in the field if possible, then verified in the office using aerial photographs or GIS. However, with access to current aerial photography and/or GIS data a rough calculation of Land Use can be made without a field visit. Ideally, both field data as well as remote sensing tools are used to identify an accurate % of each land use within 500m of the occurrence.

To calculate a Total Land Use Score estimate the % of the adjacent area within 100 m under each Land Use type and then plug the corresponding coefficient (Table 3) with some manipulation to account for regional application) into the following equation:

Sub-land use score = $\sum$ LU x PC/100

where**:** LU = Land Use Score for Land Use Type; PC = % of adjacent area in Land Use Type.

Do this for each land use within 500 m of the occurrence, then sum the Sub-Land Use Score(s) to arrive at a Total Land Score. For example, if 30% of the adjacent area was under moderate grazing (0.3 * 0.6 = 0.18), 10% composed of unpaved roads (0.1 * 0.1 = 0.01), and 40% was a natural area (e.g. no human land use) (1.0 * 0.4 = 0.4), the Total Land Use Score would = 0.59 (0.18 + 0.01 + 0.40).

Metric Rating: Assign the metric an Excellent, Good, Fair, or Poor rating on the scorecard.

Measure (Metric) Rating

Excellent	Good	Fair	Poor
Average Land Use Score = 1.0-0.95	Average Land Use Score = 0.80-0.95	Average Land Use Score = 0.4-0.80	Average Land Use Score = < 0.4

Data:

Table 7. Current Land Use and Corresponding Land Use Coefficients

Current Land Use	Coefficient
Paved roads/parking lots/residential or commercially developed buildings/gravel pit operation/ Energy development (pumping station/ wind machine farm / strip mine)	0.0
Unpaved Roads (e.g., driveway, tractor trail) / Mining / Energy development (well pad, pipeline, exploration)	0.1
Agriculture (tilled crop production)	0.2
Heavy grazing by livestock / intense recreation (ATV use/camping/popular fishing spot, etc.)	0.3
Logging, chaining, or tree removal with 50-75% of trees >50 cm dbh removed	0.4
Hayed	0.5
Moderate grazing	0.6
Moderate recreation (high-use trail)	0.7
Selective logging or tree removal with <50% of trees >50 cm dbh removed	0.8
Light grazing / light recreation (low-use trail)	0.9
Fallow with no history of grazing or other human use in past 10 yrs	0.95
Natural area / land managed for native vegetation	1.0

based on Table 21 in Hauer et al. (2002)

Scaling Rationale: Land uses have differing degrees of potential impact. Some land uses have minimal impact, such as simply altering the integrity of native vegetation (e.g., recreation and grazing), while other activities (e.g., hay production and agriculture) may replace native vegetation with nonnative or cultural vegetation yet still provide potential cover for species movement. Intensive land uses (i.e., urban development, roads, mining, etc.) may completely destroy vegetation and drastically alter hydrological processes. The coefficients were assigned according to best scientific judgment regarding each land use's potential impact (Hauer et al. 2002).

Confidence that reasonable logic and/or data support the index: Medium.

B.1.2 Buffer Width

Definition: Buffers are vegetated, natural (non-anthropogenic) areas that surround an occurrence. This includes forests, grasslands, shrublands, wetlands, riparian areas, natural lakes and ponds, or streams.

Background: This metric evaluates one aspect of the landscape context of an individual occurrrance of the ecological system.

Rationale for Selection of the Variable: The intensity of human activity in the landscape often has a proportionate impact on the ecological processes of natural systems. The intensity of human activity in the landscape often has a proportionate impact on the ecological processes of natural systems. Buffers are known to reduce potential impacts to wetlands and riparian areas, but their effects on terrestrial ecological systems are less well studied. Although the term "buffer" is retained for this metric, there is insufficient data to confirm that an adjacent natural landscape acts to mitigate the effects of stressors on an occurrence. The relative extent of adjacent natural landscape, however, is potentially important, and is retained until further information is available. This metric may be adequately addressed by the previous metric, or may need to be replaced with some measure of fragmentation.

Measurement Protocol: This metric is measured by estimating the width of the buffer, or adjacent natural landscape surrounding the occurrence. Buffer boundaries extend from the occurrence edge to intensive human land uses which result in non-natural areas. Some land uses such as light grazing and recreation may occur in the buffer, but other more intense land uses should be considered the buffer boundary.

Measurement should be completed in the field then verified in the office using aerial photographs or GIS. Measure or estimate buffer width on four or more sides of the occurrence then take the average of those readings. This may be difficult for large occurrences or those with complex boundaries. For such cases, the overall buffer width should be estimated using best scientific judgment.

Metric Rating: Assign the metric an Excellent, Good, Fair, or Poor rating on the scorecard.

Measure (Metric) Rating			
Excellent	**Good**	**Fair**	**Poor**
Wide > 1000 m	Medium. 500 m to 1000 m	Narrow. 250 m to 500 m	Very Narrow. < 250 m

Data: N/A

Scaling Rationale: Scaling is based on minimum separation distance for an occurrence.

Confidence that reasonable logic and/or data support the index: Medium.

B.1.3 Percentage of Unfragmented Landscape Within One Kilometer

Definition: An unfragmented landscape is one in which human activity has not destroyed or severely altered the landscape. An unfragmented landscape has no barriers to the movement and connectivity of species, water, nutrients, etc. between natural ecological systems. Fragmentation results from human activities such as timber clearcuts, roads, residential and commercial development, agriculture, mining, utility lines, railroads, etc.

Background: This metric evaluates one aspect of the landscape context of an individual occurrrance of the ecological system.

Rationale for Selection of the Variable: The intensity of human activity in the landscape often has a proportionate impact on the ecological processes of natural systems. The percentage of fragmentation (e.g., anthropogenic patches) provides an estimate of connectivity among natural ecological systems. Although related to metric B.1.1 and B.1.2, this metric differs by addressing the spatial interspersion of human land use as well as considering a much larger area.

Measurement Protocol: This metric is measured by estimating the amount of unfragmented area in a one km buffer surrounding the occurrence and dividing that by the total area. This can be completed in the office using aerial photographs or GIS.

Metric Rating: Assign the metric an Excellent, Good, Fair, or Poor rating on the scorecard.

Measure (Metric) Rating			
Excellent	**Good**	**Fair**	**Poor**
Embedded in 90-100% unfragmented, roadless natural landscape; internal fragmentation absent	Embedded in 60-90% unfragmented natural landscape; internal fragmentation minimal	Embedded in 20-60%% unfragmented natural landscape; Internal fragmentation moderate	Embedded in < 20% unfragmented natural landscape. Internal fragmentation high

Data: N/A

Scaling Rationale: Less fragmentation increases connectivity between natural ecological systems and thus allow for natural exchange of species, nutrients, and water. The categorical ratings are based on CNHP (2004).

Confidence that reasonable logic and/or data support the index: Medium.

B.2 Biotic Condition Metrics

B.2.1 Percent of Cover of Native Plant Species

Definition: Percent of the plant species which are native to the Western Great Plains or adjacent Southern Rocky Mountains.

Background: This metric is one aspect of the condition of an individual occurrrance of the ecological system.

Rationale for Selection of the Variable: Occurrences dominated by native species typically have excellent ecological integrity. This metric is a measure of the degree to which native plant communities have been altered by human disturbance. With increasing human disturbance, non-native species invade and can dominate the occurrence.

Measurement Protocol: A qualitative, ocular estimate of cover is used to calculate and score the metric. The entire occurrence of the system should be walked and a qualitative ocular estimate of the total cover of native species growing in the area should be made. Alternatively, if time and resources allow a more quantitative determination of species presence and cover such methods (i.e. Peet et al. 1998) are recommended. The metric is calculated by dividing the total cover of native species by the total cover of all species and multiplying by 100.

Metric Rating: Assign the metric an Excellent, Good, Fair, or Poor rating on the scorecard.

Measure (Metric) Rating			
Excellent	**Good**	**Fair**	**Poor**
100% cover of native plant species	85-< 100% cover of native plant species	50-85% cover of native plant species	<50% cover of native plant species

Data: N/A

Scaling Rationale: The criteria are based on thresholds from CNHP (2004), and best scientific judgment. These are tentative hypotheses as they have not been validated with quantitative data.

Confidence that reasonable logic and/or data support the index: High

B.2.2 Floristic Quality Index (Mean C)

Definition: The mean conservatism of all the native species growing in the occurrence.

Background: This metric is one aspect of the condition of an individual occurrrance of the ecological system.

Rationale for Selection of the Variable: Plants are generally adapted to biotic and abiotic fluctuations associated with the habitat where they grow (Wilhelm and Masters 1995). However, when disturbances to that habitat exceed the natural range of variation (e.g. many human-induced disturbances), only those plants with wide ecological tolerance will survive. In contrast, conservative species (e.g. those species with strong fidelity to habitat integrity) will decline or disappear according to the degree of human disturbance (Wilhelm and Master 1995).

The Floristic Quality Index (FQI) is a vegetative community index designed to assess the degree of "naturalness" of an area based on the presence of species whose ecological tolerance are limited (U.S. EPA 2002). See discussion in Rocchio (2007) for additonal information on this method.

A preliminary FQI for Colorado has been developed (Rocchio 2007). However, calibration of the FQI will likely occur over many years of use and this metric should be updated accordingly.

Measurement Protocol: Species presence/absence data need to be collected from the occurrence area. Although, quantitative measurements are preferred, depending on time and financial constraints, this metric can be measured with qualitative or quantitative data. The two methods are described as follows: (1) Site Survey (semi-quantitative): walk the entire occurrence of the system and make notes of each species encountered. A thorough search of each macro- and micro-habitat is required. (2) Quantitative Plot Data: The plot method described by Peet et al. (1998) is recommended for collecting quantitative data for this metric. This method uses a 20 x 50 m plot which is typically established in a 2 x 5 arrangement of 10 x 10 m modules. However, the array of modules can be rearranged or reduced to meet site conditions (e.g. 1 x 5 for linear areas or 2 x 2 for small, circular sites). The method is suitable for most types of vegetation, provides information on species composition across spatial scales, is flexible in intensity and effort, and compatible with data from other sampling methods.

The metric is calculated by referencing only native species C value from the Colorado FQI Database, summing the C values, and dividing by the total number of native species (Mean C).

Metric Rating: Assign the metric an Excellent, Good, Fair, or Poor rating on the scorecard.

Measure (Metric) Rating			
Excellent	**Good**	**Fair**	**Poor**
> 4.5	3.5-4.5	3.0 – 3.5	< 3.0

Data: Colorado FQI Database (Rocchio 2007).

Scaling Rationale: In the Midwest, field studies using FQI have determined that a site with a Mean C of 3.0 or less is unlikely to achieve higher C values thus this value was used as the Restoration Threshold (between Fair and Poor). In other words, those sites have been disturbed to the degree that conservative species are no longer able to survive and or compete with the less conservative species as a result of the changes to the soil and or hydrological processes on site (Wilhelm and Masters 1995). Sites with a Mean C of 3.5 or higher are considered to have at least marginal quality or integrity thus this value was used as the Minimum Integrity Threshold (between Good and Fair) (Wilhelm and Masters 1995). The threshold between Excellent and Good was assigned based on best scientific judgment upon reviewing the FQI literature. Although it is not know if these same thresholds are true for the Western Great Plains, they have been used to construct the scaling for this metric. As the FQI is applied in this region, the thresholds may change.

Confidence that reasonable logic and/or data support the index: High

B.2.3 Presence and abundance of invasive species.

Definition: This metric estimates the presence and abundance of invasive species with the potential to alter system functioning.

Background: This metric evaluates one aspect of the biotic condition of an individual occurrence of the ecological system.

Rationale for Selection of the Variable: Invasives are introduced species that can thrive in areas beyond their natural range of dispersal. These species are generally adaptable, aggressive, and have a high reproductive capacity, so that in the absence of natural enemies they can increase dramatically and displace native species. The worst invasives can change the character of an entire habitat by affecting ecosystem processes like fire, nutrient flow, flooding, etc

Measurement Protocol: This metric is measured by determining the presence and rough abundance of system altering invasive species in the occurrence. This is completed in the field and ocular estimates are used to match the categorical ratings in the scorecard.

Metric Rating: Assign the metric an Excellent, Good, Fair, or Poor rating on the scorecard.

Measure (Metric) Rating			
Excellent	**Good**	**Fair**	**Poor**
System altering invasive species, such as leafy spurge, knapweed species, or yellow toadflax are either not present or occupy less than 1 percent of the occurrence, with no patches larger than 1 acre.	System altering invasive species, such as leafy spurge, knapweed species, or yellow toadflax occupy no more than 1-3% of the occurrence with no patches larger than 1 acre.	System altering invasive species, such as leafy spurge, knapweed species, or yellow toadflax occupy 3-5% of the occurrence, with some patches larger than 1 acre	System altering invasive species, such as leafy spurge, knapweed species, or yellow toadflax occupy >5% of the occurrence.

Data:

Scaling Rationale: The criteria are based on thresholds from CNHP (2004), and best scientific judgment. These are tentative hypotheses as they have not been validated with quantitative data.

Confidence that reasonable logic and/or data support the index: Medium

B.2.5 Biotic/Abiotic Patch Richness

Definition: The number of biotic/abiotic patches or habitat types present in the occurrence. The metric is not a measure of the spatial arrangement of each patch.

Background: This metric evaluates one aspect of the condition of an individual occurrence of the ecological system.

Rationale for Selection of the Variable: Spatial heterogeneity (i.e., the types and arrangement of habitat patches within a landscape) can strongly influence the abundance and distribution of species that use a particular habitat (Pulliam et al. 1992) Unimpacted sites have an expected range of biotic/abiotic patches. Human-induced alterations can decrease patch richness.

Measurement Protocol: This metric is measured by determining the number of biotic/abiotic patches present at a site and dividing by the total number of possible patches for the specific type (see Table 8). This percentage is then used to rate the metric in the scorecard.

Metric Rating: Assign the metric an Excellent, Good, Fair, or Poor rating on the scorecard.

Measure (Metric) Rating			
Excellent	**Good**	**Fair**	**Poor**
> 75-100% of possible patch types are present in the occurrence	> 50-75% of possible patch types are present in the occurrence	25-50% of possible patch types are present in the occurrence	< 25% of possible patch types are present in the occurrence

Data:

Table 8. Biotic/Abiotic Patch Types in Central Mixedgrass Prairie

Patch Type
Very sparse tree canopy
Shrub canopy
Herbaceous canopy – native bunch grasses
Herbaceous canopy – other graminoid
Herbaceous canopy - forb
Litter cover
Bare soil
Rock outcrop

TOTAL = 8

Scaling Rationale: Simple quartiles were used. Need additional information about appropriate breaks.

Confidence that reasonable logic and/or data support the index: Medium

B.2.6 Interspersion of Biotic/Abiotic Patches

Definition: Interspersion is the spatial arrangement of biotic/abiotic patch types within the occurrence, especially the degree to which patch types intermingle with each other (e.g. the amount of edge between patches).

Background: This metric evaluates one aspect of the condition of an individual occurrence of the ecological system.

Rationale for Selection of the Variable: Spatial heterogeneity (i.e., the types and arrangement of habitat patches within a landscape) can strongly influence the abundance and distribution of species that use a particular habitat (Pulliam et al. 1992)

Measurement Protocol: This metric is measured by determining the degree of interspersion of biotic/abiotic patches present in the occurrence. This can be completed in the field for most sites, however aerial photography may be beneficial for larger sites. The metric is rated by matching site interspersion with the categorical ratings in the scorecard.

Metric Rating: Assign the metric an Excellent, Good, Fair, or Poor rating on the scorecard.

Measure (Metric) Rating			
Excellent	**Good**	**Fair**	**Poor**
Horizontal structure consists of a very complex array of nested and/or interspersed, irregular biotic/abiotic patches, with no single dominant patch type	Horizontal structure consists of a moderately complex array of nested or interspersed biotic/abiotic patches, with no single dominant patch type	Horizontal structure consists of a simple array of nested or interspersed biotic/abiotic patches,	Horizontal structure consists of one dominant patch type and thus has relatively no interspersion

Data: See B.2.3 for list and definitions of Biotic Patches.

Scaling Rationale: In the absence of quantitative data, the scale is based on guidelines for professional judgment.

Confidence that reasonable logic and/or data support the index: Medium

B.3 Abiotic Condition Metrics

B.3.1 Soil erosion & compaction

Definition: An index measure of the degree to which erosion and soil compaction are out of the range of natural variation.

Background: This metric evaluates one aspect of the abiotic condition of an individual occurrence of the ecological system.

Rationale for Selection of the Variable: The functional integrity of this ecological system type is dependent in part on the the conservation of the soil (National Research Council 1994, Smith et al. 1995). The selected variables are part of a more comprehensive assessment of rangeland health (Pellant et al. 1995).

Measurement Protocol: This metric is estimated in the field by observing overland water flow patterns, signs of rill formation and wind scour, the presence of pedestals and terrecettes, drainage patterns, bare ground, and soil compaction.

Metric Rating: Assign each of the six metrics in Table 9 an Excellent, Good, Fair, or Poor rating on the scorecard. Use the scores and weights shown to compile a final score.

Table 9. Soil erosion and compaction scoring.

Metric (weight)	**Excellent** **Score = 5**	**Good** **Score =4**	**Fair** **Score = 3**	**Poor** **Score = 5**	**Score** (weight x rating)
Water patterns (0.10)	Minimal evidence of past or current soil deposition or erosion.	Matches what is expected for the site; erosion is minor with some instability and deposition	More numerous than expected; deposition and cut areas common; occasionally connected.	Water flow patterns may be extensive and numerous; unstable with active erosion; usually connected.	
Rills, wind scour (0.10)	Slight to no evidence	Some evidence of rill formation or accelerated wind scour	Rill formation or accelerated wind scour may be moderately active and well defined throughout most of the occurrence.	Rill formation or accelerated wind scour may be severe and well defined throughout most of the occurrence	
Pedestals and/or Terracets (0.10)	Absent or uncommon.	Occasionally present	Common	Abundant	
Drainages (0.10)	Represented as natural stable channels with no signs of unnatural erosion.	Represented as natural stable channels with only slight signs of unnatural erosion.	Gullies may be present with indications of active erosion; vegetation is intermittent on slopes. Headcuts are active; downcutting is apparent	Gullies common, with indications of active erosion and downcutting; vegetation is infrequent on slopes or bed of gully.	
Bare Ground (0.10)	Bare areas are no higher than	Bare areas are moderately	Bare ground is moderate to much	Much higher than expected	

	expected for the substrate.	larger than expected size and only sporadically connected.	higher than expected for the site. Bare areas are large and may be connected.	for the site. Bare areas are large and generally connected.	
Soil compaction (0.50)	Soils are not compacted and are not restrictive to water movement and root penetration.	Soil compaction moderately widespread and moderately restricts water movement and root penetration.	Soil compaction widespread and greatly restricts water movement and root penetration.	Soil compaction is extensive throughout the occurrence, severely restricting water movement and root penetration	
Final rating:	A = 4.5 - 5.0 B = 3.5 – 4.4 C = 2.5 – 3.4 D = 1.0 – 2.4				**Total = sum of N scores**

Data: Based on Pellant et al. 2005. There is some evidence that soil aggregate stability (AS) could be used as a composite index for this metric (Bestelmeyer et al. 2006), but data collection may be more labor intensive.

Scaling Rationale: In the absence of quantitative data, the scale is based on guidelines for professional judgment.

Confidence that reasonable logic and/or data support the index: High for inclusion of the index. Medium to low for the specific measures and thresholds.

B.3.2 Disturbance and Fragmentation – land use within occurrence

Definition: This metric addresses the intensity of human dominated land uses within the occurrence.

Background: This metric is one aspect of the abiotic condition of an individual occurrence of the ecological system.

Rationale for Selection of the Variable: Fragmentation and disturbance are important factors on the ecological processes of natural systems. Due to the difficulties of applying measures of fragmentation (Hargis et al. 1998, Tischendorf and Fahrig 2000) this variable is measured using the same technique as in Section B.1.1.

Measurement Protocol: This metric is measured by documenting land use(s) withinthe boundaries of the occurrence. This should be completed in the field then verified in the office using aerial photographs or GIS. However, with access to current aerial photography and/or GIS data a rough calculation of Land Use can be made in the office. Ideally, both field data as well as remote sensing tools are used to identify an accurate % of each land use.

To calculate a Total Land Use Score estimate the % of the adjacent area within the occurrence under each Land Use type and then plug the corresponding coefficient (Table 7, section B.1.1) into the following equation:

Sub-land use score = ∑ LU x PC/100

where**:** LU = Land Use Score for Land Use Type; PC = % of total area in Land Use Type.

Do this for each land use within the occurrence, then sum the Sub-Land Use Score(s) to arrive at a Total Land Score. For example, if 30% of the area was under moderate grazing (0.3 * 0.6 = 0.18), 10% composed of unpaved roads (0.1 * 0.1 = 0.01), and 40% was a natural area (e.g. no human land use) (1.0 * 0.4 = 0.4), the Total Land Use Score would = 0.59 (0.18 + 0.01 + 0.40).

Metric Rating: Assign the metric an Excellent, Good, Fair, or Poor rating on the scorecard.

Measure (Metric) Rating			
Excellent	**Good**	**Fair**	**Poor**
Average Land Use Score = 1.0-0.95	Average Land Use Score = 0.80-0.95	Average Land Use Score = 0.4-0.80	Average Land Use Score = < 0.4

Data: See table in section B.1.1.

Scaling Rationale: Land uses have differing degrees of potential impact. Some land uses have minimal impact, such as simply altering the integrity of native vegetation (e.g., recreation and grazing), while other activities (e.g., hay production and agriculture) may replace native vegetation with nonnative or cultural vegetation yet still provide potential cover for species movement. Intensive land uses (i.e., urban development, roads, mining, etc.) may completely destroy vegetation and drastically alter hydrological processes. The coefficients were assigned according to best scientific judgment regarding each land use's potential impact (Hauer et al. 2002).

Confidence that reasonable logic and/or data support the index: Medium.

B.3.3 Fire Condition Class

Definition: The condition class indicates the degree of departure from historic fire regime.

Background: This metric evaluates one aspect of the condition of an individual occurrence of the ecological system.

Rationale for Selection of the Variable: Fire was historically part of this system. Current "condition class" is defined in terms of departure from the historic fire regime, as determined by the number of missed fire return intervals with respect to (1) the historic fire return interval, and (2) the current structure and composition of the system resulting from alterations to the disturbance regime. Under the Fire Regime Condition Class methodology (Hann et al. 2005), this system is in Fire Regime Condition Class II, with a fire return interval of 0-35 years, and stand replacment severity. Because of potential difficulties in measuring this metric, it is non-core.

Measurement Protocol: This metric could be evaluated on a coarse basis by using the LANDFIRE Rapid Assessment GIS coverage, but it is not clear how accurate this is for non-forrested system types. An alternative method would be to use known fire history, in combination with aerial photos or GIS to estimate the percentage of the occurrence falling into each fire condition class.

Metric Rating: Multiply the percent of the occurrence area by the coefficient for its condition class, and sum the scores. Assign the metric an Excellent, Good, Fair, or Poor rating on the scorecard.

Condition Class	**Attributes**	**Coefficient**	**Score** (Coefficient x % of area)
Condition Class 1	• Fire regimes are within or near an historical range. • The risk of losing key ecosystem components is low. • Fire frequencies have departed from historical frequencies by no more than one return interval. • Vegetation attributes (species composition and structure) are intact and functioning within an historical range.	**5**	
Condition Class 2	• Fire regimes have been moderately altered from their historical range. • The risk of losing key ecosystem components has increased to moderate. • Fire frequencies have departed (either increased or decreased) from historical frequencies by more than one return interval. This results in moderate changes to one or more of the following: fire size, frequency, intensity, severity, or landscape patterns. • Vegetation attributes have been moderately altered from their historical range.	**3.5**	
Condition Class 3	• Fire regimes have been significantly altered from their historical range. • The risk of losing key ecosystem components is high. • Fire frequencies have departed from historical frequencies by multiple return intervals. This results in dramatic changes to one or more of the following: fire size, frequency, intensity, severity, or landscape patterns. • Vegetation attributes have been significantly altered from their historical range	**1**	
		A = 4.5 - 5.0 B = 3.5 – 4.4 C = 2.5 – 3.4 D = 1.0 – 2.4	**Total = sum of N scores**

Data:

Scaling Rationale: The present scale is based on professional judgment about thresholds (CNHP 2004).

Confidence that reasonable logic and/or data support the index: Medium.

B.4 Size Metrics

B.4.1 Total size of system occurrence

Definition: This metric assesses the total size of all areas included in the occurrence or stand, i.e., all stands or patches that are close enough together to fall within the same occurrence.

Background: Size (area) of the occurrence has a large effect on the internal heterogeneity and diversity of an occurrence. To define the area, rules are needed to specify when two or more patches or stands are close enough together to belong to the same occurrence.

Rationale for Selection of the Variable: Most ecological function is proportional to size of occurrences, and some is disproportionately related to large occurrences. Some ecological functions occur only, or at much greater levels, in areas in good condition, while other ecological functions may occur even in relatively poor or degraded areas. Some species are specific to habitat in the best condition while others are more tolerant of degraded examples. Other ecological functions may occur in poorer quality areas, but only at a much reduced frequency/intensity, and some species may occur there but only at low density. Poorer areas thus contribute to the ecological significance of occurrences, but to a lesser degree than areas in better condition.

Measurement Protocol: This metric is evaluated by measuring or estimating the total area of the occurrence.

Measure	Definition Tier	A Excellent	B Good	C Fair	D Poor
Total system size	Total area of system within separation distance	>5000 acres	2000-5000 acres	1000-2000 acres	< 1000 acres

Data:

Scaling Rationale: The present scale is based on the range of sizes of occurrences in eastern Colorado and professional judgment about thresholds (CNHP 2004). The range of sizes is expected to be similar throughout the range of the system. The scale could be improved by basing it on the correlation of species presence/richness with size values.

Confidence that reasonable logic and/or data support the index: High.

B.4.2 Size of high quality area

Definition: This metric assesses the size of the area to which the highest condition rating applies.

Background: For occurrences that are heterogeneous with regard to condition, this metric indicates the size of area which is in the best condition class. For homogeneous occurrences, this will be the same as the total system size, but for heterogeneous occurrences it may be smaller.

Rationale for Selection of the Variable: Most ecological function is proportional to size of occurrences, and some is disproportionately related to large occurrences. Some ecological functions occur only, or at much greater levels, in areas in good condition, while other ecological functions may occur even in relatively poor or degraded areas. Some species are specific to habitat in the best condition while others are more tolerant of degraded examples. Other ecological functions may occur in poorer quality areas, but only at a much reduced frequency/intensity, and some species may occur there but only at low density. Because the combined rating for the occurrence is based on a combination of size and condition, the size of the high quality area, the area corresponding to the condition rating, is the most important size measure. However, having large additional areas in poorer condition may compensate to some degree.

Measurement Protocol: This metric is evaluated by measuring or estimating the total area within the occurrence that meets the criteria for the best condition rating score given to the occurrence, the most intact area within the overall occurrence.

Measure	Definition - Tier	A Excellent	B Good	C Fair	D Poor
Size of high quality area	Area of system in best condition class (see rollup of condition metrics) 2, 3	>5000 acres	2000-5000 acres	1000-2000 acres	< 1000 acres

Data:

Scaling Rationale: The present scale is based on the range of sizes of occurrences in eastern Colorado and professional judgment about thresholds (CNHP 2004). The range of sizes is expected to be similar throughout the range of the system. The scale could be improved by basing it on the correlation of species presence/richness with size values.

Confidence that reasonable logic and/or data support the index: High.

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