United States Department of Agriculture

Ecological Site Description

Major Land Resource Area 105

Northern Mississippi Valley Loess Hills

Dolomite Colluvium Bluff Prairie

Leadplant / Little Bluestem – Prairie Dropseed

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Front cover: Top photo is of a Dolomite Colluvium Bluff Prairie reference state taken at Rush Creek State Natural Area, Crawford County, Wisconsin. Bottom left photo is of a rocky soil surface on a Dolomite Colluvium Bluff Prairie two months after a spring prescribed burn, taken at Pleasant Valley Conservancy State Natural Area, Dane County, Wisconsin. Bottom right photo is of a timber rattlesnake (*Crotalus horridus*) on a piece of dolomite colluvium, taken in Winona County, Minnesota. All three photos are by Peter Hartman, formerly USDA-NRCS.

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General Information

Ecological Site Name

Abiotic: Dolomite Colluvium Bluff Prairie

Biotic: Leadplant / Little Bluestem – Prairie Dropseed
Amorpha canescens / Schizachyrium scoparium – Sporobolus heterolepis

Ecological Site ID: 105XY001

Hierarchical Framework Relationships

Major Land Resource Area (MLRA): Northern Mississippi Valley Loess Hills (105)

USFS Subregions: North-Central U.S. Driftless and Escarpment Section (222L); Mississippi-Wisconsin River Ravines (222Lc), Kickapoo-Wisconsin River Ravines (222Ld), and Western Paleozoic Plateau (222Lf) Subsections

MLRA Notes

The Northern Mississippi Valley Loess Hills includes parts of four US states, including Wisconsin, Iowa, Minnesota, and Illinois (Figure 1). The region is often referred to informally as the "Driftless Area," because it was not glaciated during the most recent Wisconsin aged glacial period, and some areas have never been glaciated. Another commonly used name is the "Paleozoic Plateau," because the region is a deeply dissected ancient plateau, composed of bedrock formations primarily from the Paleozoic Era. These bedrock layers are mostly sedimentary dolomites and sandstones from the Ordovician and Cambrian Periods, along with some shale. The area consists mostly of gently sloping to rolling summits with steeper valley walls that join small to very large floodplains. Wisconsin aged loess covers much of the area, adding to the fertility and productivity of many soils. Valley bottoms are deeply filled by glacially derived outwash, or more recent erosional sediments. Steep valley sides are covered by colluvium (i.e., slope alluvium, or hillslope sediments) and can have prominent cliffs. The climate is warm in the summer and very cold in the winter. Two-thirds or more of the precipitation falls during the growing season. The soil temperature regime is mesic (i.e., mean annual soil temperature between

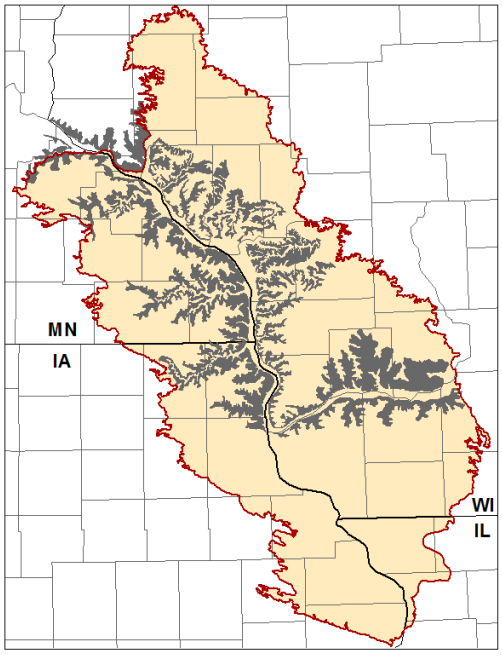


Figure 1. Potential distribution of Dolomite Colluvium Bluff Prairie in MLRA 105.

46 and 59°F) and the soil moisture regime is udic, implying a humid climate with well distributed rainfall. Historic vegetation of the region was principally comprised of savannas, woodlands, prairie and scattered mesic forests (Shea et al., 2014). Bur oak (*Quercus macrocarpa*), white oak (*Q. alba*), and black oak (*Q. velutina*) were the major tree species.

Ecological Site Concept

The central concept of the Dolomite Colluvium Bluff Prairie (DCBP) ecological site is dry-mesic to dry prairie natural communities in a landscape that typically supports forest ecosystems, occurring on bluffs and valley sides in deeply dissected terrain. Soils are formed in loamy-skeletal colluvium (>35 percent rock fragments), and are derived from the Oneota or St. Lawrence bedrock Formation. Slope, aspect, and hillslope position are the main environmental factors that affect the composition and structure of the vegetation on these prairies (Kraszewski and Waller, 2008 and Weaver, 1968). These sites are commonly known as “goat” prairies, implying that they are so steep that “a goat can climb them with more ease than a man” (Thomson, 1940).

Aspect ranges that produce comparatively hotter and drier site conditions (SSE to W facing) is the most important site factor. Other important, but secondary factors include: slope steepness, available water capacity in the soil, and slope shape. Slopes are mostly steep to very steep (20 to 100 percent slopes). Soils are Mollisols with low available water capacity, due to the fact that these sites are somewhat excessively to excessively drained and have a loamy-skeletal soil texture. Quite distinctive for upland soils in this region – these dry soils maintain carbonates at or near the surface, whereas carbonates in other geomorphically related soils are leached deep into subsurface horizons. Slope shape is generally convex, both up and across slopes, adding to the droughty nature of these sites.

DCBP consists of dry-mesic to dry prairie plant species that tolerate droughty, exposed conditions (Curtis, 1959). Vegetation is generally dense, with very little bio-crust or bare soil present (except in the case of recent prescribed burns). Grasses dominate these sites, and consist of a mix of short, mid height, and tall grass species with a percent cover ratio of 20-60-20, respectively. Short grasses usually are around 20 percent of grass cover, and may include sideoats grama (*Bouteloua curtipendula*), hairy grama (*Bouteloua hirsuta*), or long-stalked panic grass (*Dichanthelium perlongum*). Mid height grasses range from 25 to greater than 75 percent, including species like little bluestem (*Schizachyrium scoparium*) and prairie dropseed (*Sporobolus heterolepis*). Tall

grasses are also around 20 percent, and include a mix of species like big bluestem (*Andropogon gerardii*), Indian grass (*Sorghastrum nutans*), and switch grass (*Panicum virgatum*). There are a many dozens of forbs common to the site. Species occurring at most or all locations include: stiff tickseed (*Coreopsis palmata*), flowering spurge (*Euphorbia corollata*), skyblue aster (*Symphyotrichum oolentangiense*), fewleaf sunflower (*Helianthus occidentalis*), and compassplant (*Silphium laciniatum*). Small shrubs, like lead plant (*Amorpha canescens*) and smooth sumac (*Rhus glabra*) can also be common. Large, mature trees normally do not occur, but smaller trees can become established if the site has not been burned recently. Although these sites are naturally droughty and have a long history of prairie vegetation, they need fire to maintain their quality. Without regular burning, these plant communities become invaded by woody species like eastern redcedar (*Juniperus virginiana*) and/or various deciduous shrub and tree species (Shea et al., 2014).

Many established classification systems refer to bluff prairies being on landforms that are shallow to bedrock with thin soils (NatureServe, 2014; WI DNR, 2014; Landfire, 2009; and MN DNR, 2005). In fact, landforms that DCBP occur on generally are not shallow to bedrock. Shallow to bedrock soils can occur in complex with DCBP on high elevation shoulder slopes, narrow ridges, or near of ledges and cliffs, but these areas are minor in context to the broader bluff prairie landform. A majority of bluff prairie natural areas in the MLRA consist primarily of soils deep or very deep to bedrock, including: King and Queen's Bluff Scientific and Natural Area (SNA) in Winona County, MN; Mound Prairie SNA in Houston County, MN; Blue River Bluffs State Natural Area (NA) in Grant County, WI; Rush Creek NA in Crawford County, WI; and Spring Green Preserve NA in Sauk County, WI.

Physiographic Features

This ecological site is located on the steep bluffs and valley sides of the river hills and breaks landscapes of the Paleozoic Plateau (e.g., Mississippi, Wisconsin, Root, and Upper Iowa River Valleys; Table 1). The Oneota-Jordan-St. Lawrence geologic sequence is the most common stratigraphy for bluff prairie landforms in the MLRA, particularly along the Mississippi River and its tributaries in the northern two-thirds of the MLRA (Figure 2). A majority of the DCBP ecological sites are associated with the Oneota dolomite Formation. The Oneota dolomite typically is on upper backslopes, shoulder slopes, and summits. The Jordan sandstone Formation lies directly beneath the Oneota, typically near the middle backslope. Loamy-skeletal colluvium from the Oneota may cover part or all of the Jordan sandstone (Figure 3). The St. Lawrence dolomite Formation (including dolomitic siltstone) is below the Jordan sandstone, typically on the lower backslope above the river valley. The St. Lawrence is also associated with the DCBP ecological site. Often, loamy-skeletal colluvium from the Oneota Formation completely covers the Jordan sandstone, thereby creating an entire hillslope that is dominated by DCBP, across all three bedrock geologies. If the Jordan sandstone is not covered by at least 12 inches of loamy-skeletal colluvium, it supports a different and unique ecological site: 105XY002 Sandstone Colluvium Bluff Prairie (SCBP). DCBP can occur on other dolomite bedrock types, such as the Platteville Formation. However, at this time it is thought that the dolomite from the Galena Formation develops a unique ecological site, forming a higher proportion of shallow to bedrock soils. This change in bluff prairie geology from the Oneota to the Galena Formation occurs approximately 10 miles south of the confluence of the Mississippi and Wisconsin Rivers. Further soil and plant community relationship studies are needed for bluff prairies underlain by Galena dolomite.

Aspect, slope steepness, slope shape, and soil interact to characterize this ecological site, making this site drier and more exposed to climatic extremes than adjacent sites. Aspect is the most defining parameter, and typically ranges from south to west. South-southeast aspects can occur on the uppermost backslopes and shoulders, but are less common on lower backslopes. The longest slope lengths within a DCBP ecological site occur on southwest and south aspects. Slopes generally are steep to very steep, ranging from 20 to 100 percent slopes. Shoulders often are the steepest and occur just below the summit, or where there are changes in bedrock lithology. Less steep slopes (i.e., 6 to 20 percent) do occur on narrow summits, but are of small extent. The predominant slope shape is convex both up slope and across slope. This is particularly true on

bluffs, which occur either at the end of a ridge or at the corner of a valley side. Slope shape can also be linear, but it is typical to have at least one component of slope shape be convex. If concavities do exist, either up or across slope, it is most likely part of a different ecological site. For example, a narrow drainageway that is linear upslope, and concave across, is likely a different ecological site (e.g., oak savanna).

The topography of a given location can include dolomite bedrock outcrops, ledges and/or cliffs. These are a unique ecological site. Because outcrops and cliffs have a small horizontal surface area and are so intermingled with the rest of this ecological site, they are considered to be a normal component of the site. Across the distribution of DCBP, elevation ranges from 700 to 1300 feet. However, on any given bluff prairie site, the elevation from the top to bottom of the landform will only range 200-300 feet. Runoff is high. These sites do not flood or pond.

Table 1. Physiographic features of DCBP.
(Data and information presented here were obtained from the National Soil Information System and NRCS integrated plot data.)

	Minimum	Maximum
Elevation (ft.)	700	1,300
Slope (percent)	20	100
Aspect (degrees)	168	270
Water Table Depth (in.)	60	80+
Flooding	none	none
Ponding	none	none
Runoff Class	high	high

Aspects (arranged by importance): SSW, S, WSW, W, and SSE
Landforms: bluffs and valley sides
Hillslope Positions: lower backslopes, upper backslopes, and shoulder slopes
Slope Shape: convex to linear (up slope), convex to linear (across slope)

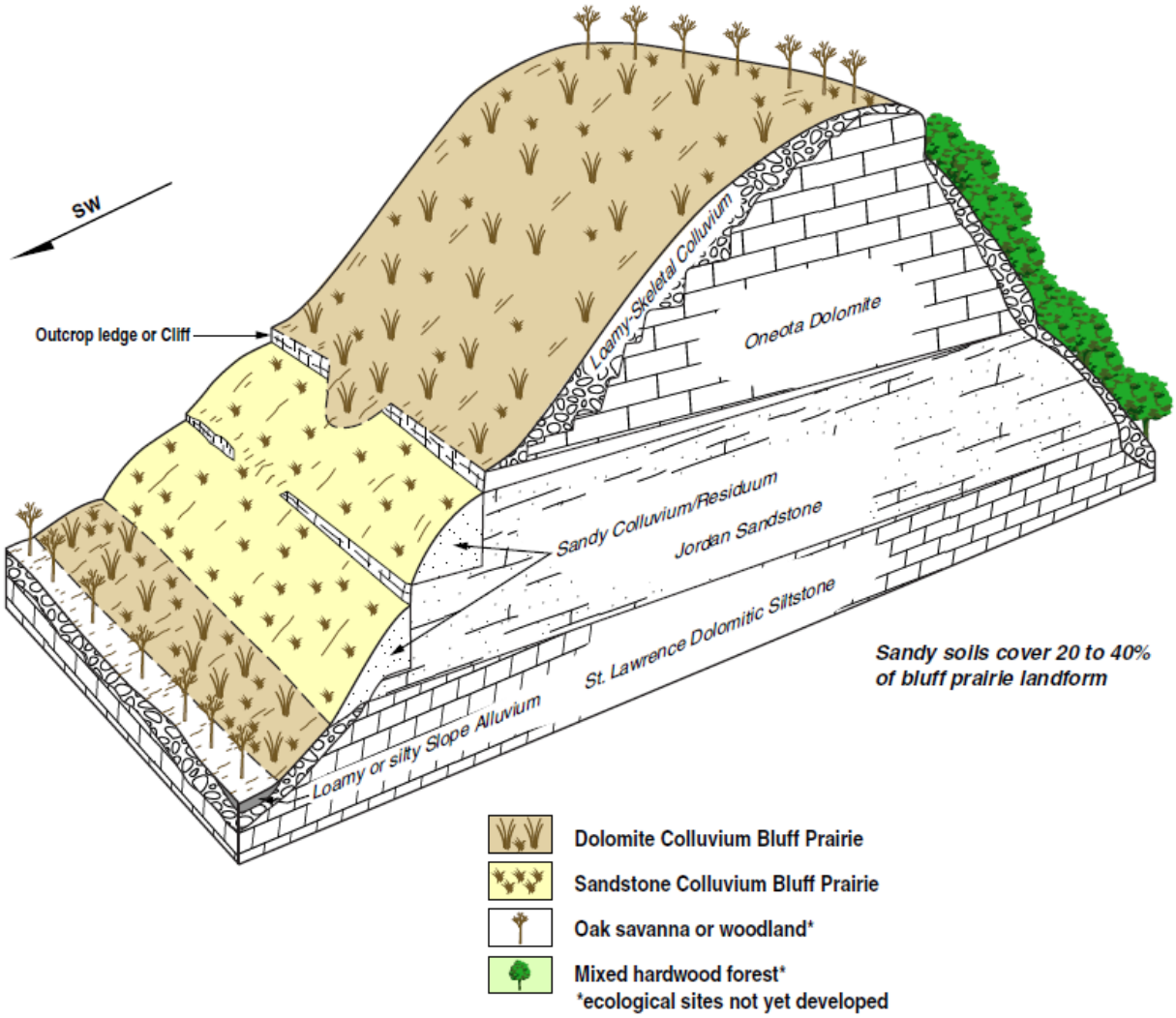


Figure 2. Block diagram representing typical bluff prairie landform with 70 percent DCBP (occurring on both the Oneota and St. Lawrence Formations) and 30 percent Sandstone Colluvium Bluff Prairie (occurring on the Jordan Formation).

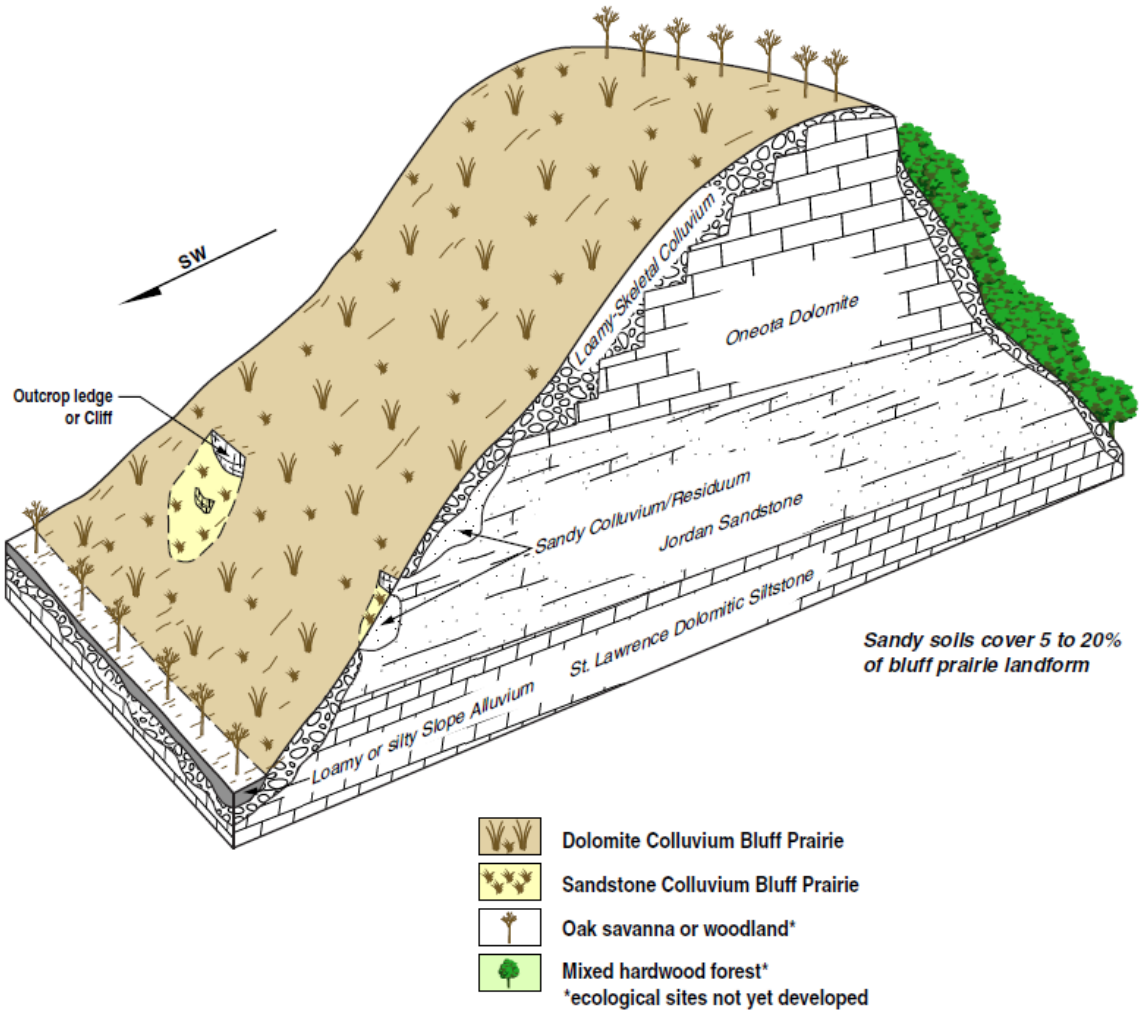


Figure 3. Block diagram representing typical bluff prairie landform with 90 percent DCBP (occurring on all Formations) and only 10 percent SCBP (occurring only beneath outcrops of the Jordan Formation). Loamy-skeletal colluvium buries most of the sandy soils derived from the Jordan Formation.

Climatic Features

The average freeze-free period of this ecological site is about 162 days, and ranges from 145 to 205 days (Table 2). Average annual precipitation is 38 inches, which includes rainfall plus the water equivalent from snowfall (Table 3). Two-thirds or more of the precipitation falls during the growing season. The majority of rainfall occurs as high intensity, convective thunderstorms during the summer months. Most of the spring snowmelt runs off the steeply sloping or high relief surfaces into high gradient drainageways and then into large floodplains. The average annual temperature is 35.6 to 56.1°F. These data are derived from 30-year averages gathered from seven National Oceanic and Atmospheric Administration (NOAA) weather stations contained within the range of this ecological site (Table 4), but were not necessarily located on soil map units correlated to DCBP.

Bluff prairies have a harsher environment than what is characteristic for other ecological sites in the MLRA. They are subject to fluctuating extremes of temperature and moisture because of their aspect and hillslope positon. For example, bluff prairies have an aspect exposed to the full drying effect of the sun and a bluff setting exposed to prevailing winds, which combine to enhance evapotranspiration compared to surrounding sites. Also, although DCBP occurs in a humid climate, soils are calcareous soil at or near the surface, indicating greater evapotranspiration than precipitation. Another example of how DCBP is more climatically extreme comes from their soil temperature class, which categorizes physiographic areas based on mean annual soil temperature. The soil temperature regime of MLRA 105 is classified as mesic (i.e., mean annual soil temperature between 46 and 59°F). However, when looking at the average soil temperature of bluff prairie sites by season, they are more similar to thermic (i.e., between 59 and 72°F) in the summer, and frigid (i.e., between 32 and 46°F) in the winter (USDA-NRCS, unpublished data).

Table 2. Frost-free and freeze-free days.
(Data were obtained from NOAA weather stations within the range of this ecological site, using 30-year averages.)

	Average days
Frost-free period (32.5°F or greater, 90% probability)	141
Freeze-free period (Less than 28.5 °F, 90% probability)	162

Table 3. Monthly and annual precipitation and temperature of DCBP area.
(Data were obtained from NOAA weather stations within the range of this ecological site, using 30-year averages.)

Monthly Moisture (Inches) and Temperature (°F) Distribution					
	----------Precipitation----------			----------Temperature----------	
	Low	**Med**	**High**	**Average Low**	**Average High**
January	0.61	0.93	1.33	7.1	25.6
February	0.51	0.93	1.41	11.4	31.0
March	1.10	1.80	2.52	23.2	43.0
April	2.27	3.09	4.78	35.8	58.0
May	2.46	3.76	4.99	46.5	68.9
June	2.87	4.05	6.59	56.7	78.5
July	2.73	4.05	5.80	61.0	82.4
August	2.94	4.14	5.45	59.0	80.2
September	1.91	2.94	5.06	49.7	72.4
October	1.18	2.19	3.29	37.9	59.9
November	1.29	1.87	2.97	25.9	43.5
December	0.67	1.19	1.96	12.4	29.3
Annual	-	37.57	-	35.6	56.1

Table 4. NOAA climate stations used for data analysis, located within the range of DCBP.

Station ID	Location (County)	From	To
POSTVILLE [USC00136766]	Allamakee (IA), 52162	1981	2010
CALEDONIA [USC00211198]	Houston (MN), 55921	1981	2010
THEILMAN 1SSW [USC00218227]	Wabasha (MN), 55945	1981	2010
PRAIRIE DU CHIEN [USC00476827]	Crawford (WI), 53821	1981	2010
RICHLAND CTR [USC00477158]	Richland (WI), 53581	1981	2010
VIROQUA [USC00478827]	Vernon (WI), 54665	1981	2010
LA CROSSE MUNI AP [USW00014920]	La Crosse (WI), 54603	1981	2010

Influencing Water Features

This ecological site is not influenced by wetland or riparian water features.

Representative Soil Features

The parent material for these soils is mostly dolomite colluvium (Table 5). There are also silts, clays, and very fine sands which came from loess that was being deposited while the colluvium was forming. Typically on DCBP sites the loess and dolomite rock fragments that formed the colluvium are thoroughly mixed. Rock fragments are typically abundant on the surface, indicating that the colluvium processes were active throughout the loess deposition. These soils usually are very deep (>60 inches to bedrock), but can also include deep soils (40-60 inches to bedrock). Drainage class is typically somewhat excessively drained, but can be excessively drained on the most convex, steepest, and highest hillslope positions, such as shoulder slopes. The soil family particle size class is loamy-skeletal, having more than 35 percent rock fragments by volume, typically from dolomite. These soils often are mildly alkaline in the surface horizon (i.e., A horizon) and moderately alkaline in the rest of the soil profile. There is never a saturated zone in the upper 80 inches. Typical soil textures include: flaggy, very flaggy, extremely flaggy, or channery and cobbly analogues of loam, fine sandy loam, very fine sandy loam, silt loam, or sandy loam. Sub-horizons that have <35% rock fragments can occur, especially in the surface. The A horizon typically is 10 to 20 inches thick with dark, Mollic colors (e.g., 10YR 2/1), and is relatively high in organic matter, which increases the fertility and available water capacity of these soils significantly. Soil order is typically Mollisol (e.g., Entic Hapludolls), but includes Inceptisols (e.g., Humic Eutrudepts) as well. The Brodale soil series is representative of the soils found on this ecological site.

Table 5. Representative soil features of DCBP.
(Data and information presented here were obtained from the National Soil Information System and NRCS integrated plot data.)

	Minimum	Maximum
Surface Fragments less than 3" (percent cover)	10	44
Surface Fragments greater than 3" (percent cover)	6	36
Subsurface Fragments less than 3" (percent volume)	40	70
Subsurface Fragments greater than 3" (percent volume)	5	30
Drainage Class	Somewhat excessively	excessively
Permeability Class (most limiting layer)	moderate	moderately rapid
Soil Depth	40	80+
Soil Reaction/pH (1:1 water)	6.6	8.4
Available Water Capacity (inches in 60")	2.03	5.26
Calcium carbonate equivalent	0	60
Parent Material – Kind: colluvium		
Parent Material – Origin: Oneota Formation (dolomite)		
Surface Texture: loam, fine sandy loam, or sandy loam		
Surface Texture Modifier: very gravelly, fine gravelly, or gravelly		
Subsurface Group: loamy-skeletal		
Soil Series: Brodale		

States and Community Phases

Ecological Dynamics

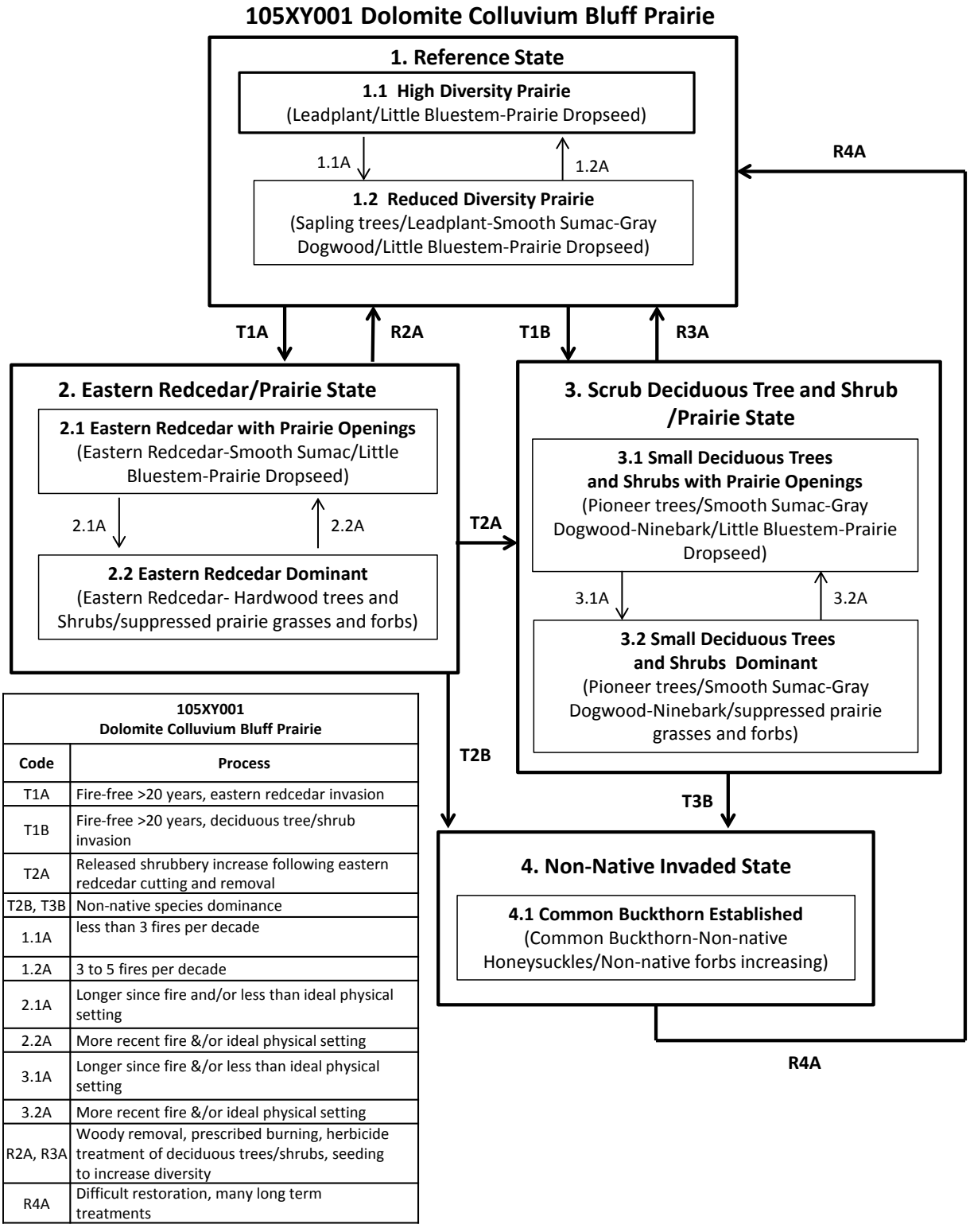
Dolomite Colluvium Bluff Prairies are open areas on steep, exposed slopes in an otherwise forested landscape. Herbaceous plants that can tolerate droughty, rocky soil conditions dominate the site. Bluff prairie plants in general possess many adaptations enabling them to survive in a harsh environment, often subject to widely fluctuating extremes of temperature and moisture. Also, having aspects exposed to the full drying effect of the sun as well the full brunt of prevailing winds combine to enhance evapotranspiration compared to adjacent ecological sites. Bluff prairie plants are both pyrogenic (fire adapted) and heliophytic (sun-loving).

Prior to European settlement, open prairies persisted on these sites since the Holocene Thermal Maximum, 9000-5000 BP (i.e., the hypsithermal; Anderson, 1954). Fire, drought, and native grazers were the primary natural disturbances on pre-settlement bluff prairies. It is likely that these sites burned at least three to five times per decade (Jones and Bowles, 2013). These periodic fires removed litter (dead plant material) and stimulated the growth and flowering of grasses and forbs. They also limited the occurrence of trees, especially eastern redcedar, which is extremely fire intolerant. In landscapes with predominant south- to west-facing valley sides, there was a complex pattern of open bluff prairie, savanna, and open oak woodlands (Figure 4). Fire-tolerant bur, white, and black oaks occupied the edges of bluff prairie landforms. Only during long, fire-free intervals in times of higher than average precipitation, would tree and shrub species increase on bluff prairies. In comparison, in landscapes with predominately north- to east-facing valley sides, ravines favored development of true forests, due primarily to the change in aspect.

Bluff prairies greatly increase the diversity of plants and animals in the landscape (see Table 6, later in document). Prairie grasses and prairie forbs not usually found on other landform settings in the region occur on bluff prairies. Common native prairie grasses that are present include little bluestem, prairie dropseed, sideoats grama, big bluestem, Indian grass, switchgrass, prairie Junegrass (*Koeleria macrantha*), and porcupinegrass (*Hesperostipa spartea*). The mid height grasses, little bluestem and prairie dropseed, dominate the site. Likewise, a significant presence of prairie forbs like compassplant, candle anemone (*Anemone cylindrica*), fewleaf sunflower, stiff goldenrod (*Oligoneuron rigidum*), and white prairie clover (*Dalea candida*) are indicators of DCBP.

Some forb species found on bluff prairies are the sole host to certain insect species. There are many invertebrate species, including some 29 species of land snails that are found only on prairies and savannas (Theler, 1997). Several vertebrate species also rely heavily on bluff prairie habitat. These include the six-lined racerunner (*Cnemidophorus sexlineatus*), prairie ringneck snake (*Diadophis punctatus*), and the timber rattlesnake (*Crotalus horridus*). For example, it is the warm, open bluff prairie habitat that allows timber rattlesnakes to successfully reproduce at the northern limit of their range. Also, golden eagles (*Aquila chrysaetos*) wintering in the region often are seen hunting on bluff prairies. It is possible that the recent expansion of this species into the MLRA is due in part to restoration of DCBP, and related ecological sites (Craig Maier, Ecologist with the Tallgrass Prairie and Oak Savanna Fire Science Consortium, personal communication).

Figure 4. Painting depicts a scene from 1847 showing expansive open bluff prairie, grading to oak savanna and woodland; looking up the Mississippi River to Trempealeau Mountain, Trempealeau County, WI. Painting by Henry Lewis, Plate 3, Indian Deputation, The Valley of the Mississippi Illustrated, Printed by the Minnesota Historical Society, 1967.



105XY001 Dolomite Colluvium Bluff Prairie	
Code	**Process**
T1A	Fire-free >20 years, eastern redcedar invasion
T1B	Fire-free >20 years, deciduous tree/shrub invasion
T2A	Released shrubbery increase following eastern redcedar cutting and removal
T2B, T3B	Non-native species dominance
1.1A	less than 3 fires per decade
1.2A	3 to 5 fires per decade
2.1A	Longer since fire and/or less than ideal physical setting
2.2A	More recent fire &/or ideal physical setting
3.1A	Longer since fire &/or less than ideal physical setting
3.2A	More recent fire &/or ideal physical setting
R2A, R3A	Woody removal, prescribed burning, herbicide treatment of deciduous trees/shrubs, seeding to increase diversity
R4A	Difficult restoration, many long term treatments

Figure 5. State-and-transition model for Dolomite Colluvium Bluff Prairie.

The last 300 years can be divided into three disturbance eras that relate to bluff prairies: 1) before 1860, prior to European settlement; 2) from 1860 to 1960, post settlement; and 3) 1960 to present. The first period ended with European settlement, no later than 1860. In this pre-settlement time period, DCBPs were in the Reference State (State 1; Figure 5), fluctuating between the High Diversity Prairie community (Phase 1.1) and the Reduced Diversity Prairie community (Phase 1.2) depending on the frequency of fire. Prior to European settlement, indigenous cultures used fire liberally for a multitude of purposes over thousands of years (Abrams and Nowacki, 2008). During this time, drought-enhanced landscape fires were common, as many as five per decade, and were not suppressed (Jones and Bowles, 2013). Native species on bluff prairies were in a dynamic equilibrium related to the frequency of landscape scale fires. Native grazers like elk (*Cervus canadensis*), bison (*Bison bison*), and white-tailed deer (*Odocoileus virginianus*) were present, and undoubtedly had an effect on bluff prairie dynamics. However, it is generally unclear to what level native grazers may have affected disturbance dynamics of bluff prairies (Thomson, 1940).

The second period started immediately post-European settlement, roughly between 1860 and 1960 (Thomson, 1940). Many, if not most DCBP sites were completely transitioning from the Phase 1.1 to Phase 1.2 at this time. However, fire continued to be commonplace. Tree ring data at Fults Hill Prairie Nature Preserve in Illinois indicate that fires occurred three to five times per decade from the late 1800s all the way through the middle 1900s (Jones and Bowles, 2013). This confirms many of the observations of local residents, land managers and conservation professionals – in that land owners (mostly farmers) commonly burned bluff prairie sites up until about 1960. These fires were set for various reasons. In parts of the Root River Valley in Minnesota, for example, neighbors would gather and set fires to pastured areas in and around bluff prairies (Valiree Green, MN DNR Forester, personal communication). Also, people in Lansing, Iowa recall seeing fires burning on bluff prairies across the Mississippi River that were set by Wisconsin citizens, in an attempt to control timber rattlesnake populations (Armund Bartz, WI DNR Ecologist, personal communication). During this time period, bluff prairies were used intermittently for grazing purposes (Thomson, 1940). Specifically, a mix of grazers would forage on these sites, including cattle, sheep, and goats (Jaime Edwards, MN DNR Nongame Biologist, personal communication). Livestock numbers increased from the early 1900s through the middle 1900s. Grazing on bluff prairies became intensive during the severe drought years of the 1930s, when farmers were desperate for forage (Dr. Stanley Trimble, UCLA Professor, personal communication). Many bluff

prairies were overgrazed and became degraded by soil erosion. However, in some cases this varied and diverse mix of grazing systems limited significant encroachment of trees and shrubs, which undoubtedly helped maintain bluff prairies in the Reference State, albeit likely in a degraded condition.

Also during this second time period, non-native plants were first introduced. The impact of non-native, invasive species gradually increased over time and is continuing to increase today. In addition, some native species, such as common pricklyash (*Zanthoxylum americanum*), smooth sumac, and gray dogwood (*Cornus racemosa*) gradually became invasive; historically, their abundance was controlled by fire. Most bluff prairies were not transitioning to the Eastern Redcedar/Prairie State (State 2) and probably not to the Scrub Deciduous Tree and Shrub/Prairie State (State 3) in the second time period, as is evidenced by aerial photos from the 1930s thru 1950s, showing little significant change in tree and shrub cover. Thomson (1940) found that the dominant trees and shrubs invading certain bluff prairie sites along the Mississippi River in Wisconsin in the 1930s were smooth sumac, paper birch, American hazelnut, bur oak, black oak, and shagbark hickory. It is important to note that Thomson (1940) made no mention of eastern redcedar.

The third period started in 1960 and continues to present day, when fire intervals on bluff prairies generally decreased to less than two per decade, with fire-free intervals of ten to twenty years or more (Jones and Bowles, 2013). Historically, there was a direct relationship between fire frequency and climate, in that fire occurrence was more likely during times of drought (Stambaugh and Guyette, 2006; Jones and Bowles, 2012). With the advent of fire suppression, which was used as a mechanism for public safety, the relationship between fire and climate became negated. This fire suppression coincided with an increase in non-farm rural population, along with fragmentation of land ownership, both of which contributed to the reduction in fire frequency. Old, cultural ways of land management through burning were abandoned, which contributed to the reduction in landscape wide fires. This period of local fire suppression is embedded within a larger geographical area spanning much of the eastern United States, whereby fire has been ubiquitously suppressed, leading to forest encroachment and “mesophication” (Nowacki and Abrams, 2008). There was also a dramatic change in farming practices in this third time period. The diversity of grazing animals found on farms decreased, and grazing on bluff prairies ceased altogether in many

areas. Most of the remaining Reference State DCBPs transitioned to Phase 1.2, the Reduced Diversity Prairie, as fire return intervals decreased. It was during this most recent time period that many DCBPs transitioned to States 2 and 3. The introduction and spread of non-native, invasive plants continued in this time period. Specifically, the introduction of common buckthorn (*Rhamnus cathartica*) has degraded many native habitats, including bluff prairies, and is the hallmark invasive species of the Non-Native Invaded State (State 4).

In general, xeric site conditions contribute to extended persistence of these ecosystems, due in large part to the fact that few species can tolerate such extreme sites (Evers, 1955). Still, fire is an essential process, needed to maintain even the most xeric prairies (Jones and Bowles, 2013; Robertson, et al. 1995; Thomson, 1940; Greg Nowacki, USFS Ecologist, personal communication). The exact frequency of fire that is required to maintain the DCBP Reference State, or restore alternative states depends on physical setting and the unique history of a given bluff prairie site. The fire intervals stated in the state-and-transition model (Figure 5) are not based on empirical data. Rather, they are based on data published from similar ecosystems, and most importantly, input from numerous land managers and local conservation experts. Today, many bluff prairies exist as small, fragmented relics, surrounded by encroaching woody species. Restoration requires a combination of management techniques, including mechanical removal of invading trees and shrubs, herbicide application to tree and shrub species with propensity to stump sprout, and prescribed fire. Management should always start in areas near the highest quality prairie openings of a site (i.e., the steepest, most convex slopes, with south to southwest aspect). These areas are most likely to respond to restoration treatments. Once at least some herbaceous cover is restored (after one or more growing seasons), prescribed fire can be introduced and repeated up to every other year, if possible (Jones and Bowles, 2013). Prescribed fires will further stimulate dormant prairie seed. In subsequent years, gradual expansion of management to the entirety of the site can be considered. In cases of resulting in low species diversity, supplemental seed or plugs are sometimes introduced, ideally from local sources and similar ecological sites. The initial stages of bluff prairie restoration could be impacted if sites are located near common buckthorn seed sources. When any bluff prairie restoration project is considered, an evaluation of potential common buckthorn seed sources should be completed. Adjacent woodlands with common buckthorn will be a likely seed source.

The presence of restricted plants and animals presents a challenge when using prescribed burning as a management tool. Fires may impose greater stress on certain plant and animal populations in contemporary, confined landscapes that lack connectivity (Nelson et al., 2013). Although fire is essential for restoring and maintaining bluff prairies, burns should be designed so they do not have unintended impacts. Burning only a portion of a bluff prairie unit in any given year may reduce the likelihood of these impacts.

Some variability in DCBP sites can be described, often depending on differences in physical landform features, disturbance and management history, and type of adjacent plant communities. The driest, most xeric locations of any given DCBP site is on shoulder slopes, or upper most backslopes of large, doubly convex nose slopes. These south and southwest facing slopes are the most exposed to climatic extremes, and are the most likely locations to persist in the absence of fire. In contrast, locations on a bluff prairie landform that are even slightly concave can provide comparatively better growing conditions for plants; in some cases allowing trees to persist, even in the presence of fire.

Small areas of rock outcrops do occur on this ecological site. Rock outcrops and cliffs are a distinct ecological site with their own unique plant community. Lichens and bryophytes are a component of this rock outcrop plant community. Shoulder slopes or narrow ridges are the most likely position for rock outcrops. Plant communities are drier and less productive adjacent to rock outcrops, where soils are shallow to bedrock. Other areas of rock outcrop include small ledges and cliffs, which often have a higher density of shrubs and trees immediately adjacent to them. Cliffs and ledges provide protection from fire, as well as cooler, shaded microsites where woody species can become established (Foote, 1966). This complexity adds to the diversity of a site by providing unique habitat for plants like purple-stemmed cliff brake (*Pallaea atropurpurea*) and smooth cliffbrake (*Pallaea glabella*), that are not found on the DCBP ecological site. Even large boulders can produce similar dynamics. In fact, historically these cliff areas were the historic refugia for eastern redcedar, ultimately becoming the primary seed source fueling the invasion of this species onto DCBP sites during the third time period.

STATE 1 – REFERENCE STATE

DCBP Reference States can be found in scattered locations throughout MLRA 105, particularly in Wisconsin and Minnesota. Prior to European settlement, 70,000 acres of the Reference State once existed, mostly in Community Phase 1.1 (Tables 6 through 9). River valleys trending east-west, with south-facing valley sides had bluff prairies on almost all suitable physical settings (Figure 6; Scottston and Atherton, 2013). During this period, drought-driven fires were unimpeded, often set by indigenous peoples. As many as five fires per decade burned large, landscape scale areas (Jones and Bowles, 2013). Evidence for what this phase looked like comes from realistic landscape painters, such as one by Henry Lewis in 1947 (Figure 4). Other artists, like George F. Fuller (1853), Edwin Whitefield (1858) and Alfred Sederberg (1867) depicted similar landscapes of the Mississippi River valley that included reference to bluff prairies (Coen, 1976). There are also historical accounts of bluff prairies. For example, in 1781, Jonathan Carver described a prairie on a steep hillside along the lower Wisconsin River: “For miles nothing was to be seen but lesser mountains, which appeared at a distance like haycocks, they being free from trees…and only a few groves of hickory and stunted oaks covered some of the vallies,” (Curtis, 1959).

Reference states of DCBP on a given site can range in size from large, open prairie covering entire landforms, to small openings surrounded by forest and limited to the most exposed, steepest, and convex areas. Breaks in the slope, either from changes in the underlying bedrock, bedrock outcrops, or drainageways, may have a higher concentration of shrub and tree species, but do not detract from overall prairie condition. Periodic disturbances from fire maintained the dominance of drought and fire adapted native grasses and forbs by limiting the growth and dominance of trees and shrubs, especially eastern redcedar. Disturbance-free periods initially favor grass dominance and eventually allow encroachment of shrubs, then trees. Two community phases are recognized in this state. Shifts between these phases are based primarily on fire frequency, and secondarily on grazing. With decreasing fire frequency, a shift from Community Phase 1.1 to 1.2 will occur, and exhibit an increase in shrub densities and overall decrease in species diversity, especially the loss of annuals and species of shorter stature (Kraszenski and Waller, 2008).

Figure 6. A bluff prairie landscape immediately following European settlement; facing east down Winnebago Creek Valley, Houston County, MN. Photo taken in 1899. University of Minnesota Archives.

Mesic tall grass prairies, which occur on soils with higher available water capacity, have been reported to develop into closed canopy forest in as little as 35 years without fire (Hoch and Briggs, 1999; Thomson, 1940). In comparison, the persistence of bluff prairies in the absence of fire would likely be longer. The transition to State 2 (Eastern Redcedar/Prairie) versus State 3 (Scrub Deciduous Tree and Shrub/Prairie) remains a question. It depends, at least partially, upon which plant communities are surrounding the site. Aspect may also be a factor. Bluff landforms that have a larger proportion of south or southwest aspects compared to west to west-southwest, and/or south-southeast may be more likely to transition to State 2. Soil type may be another factor. Sites that transition to State 2 may have lower available water capacity soils than State 3. These higher available water capacity soils could result from a thin loess cap. Further study is needed on this topic.

Table 6. Reference State, Community Phase 1.1 composition, with approximate annual production and cover estimates.
(Species listed are based on dozens field sites, as well as MN DNR 2005, Cochrane and Iltis 2000, and Henderson 1995)

Layer	Common Name	Scientific Name	USDA Symbol	Annual Production (lbs/ac)	Cover (%)
Shrubs/ Woody Vines	LEADPLANT	*Amorpha canescens*	AMCA6	15-150	1-15
	SMOOTH SUMAC	*Rhus glabra*	RHGL	15-150	1-15
	COMMON NINEBARK	*Physocarpus opulifolius*	PHOP	0-25	0-15
	GRAY DOGWOOD	*Cornus racemosa*	CORA6	0-25	0-15
	ROSE	*Rosa* spp.	ROSA5	0-5	0-15
Grasses/ Grass-like	LITTLE BLUESTEM	*Schizachyrium scoparium*	SCSC	50-500	25-75
	PRAIRIE DROPSEED	*Sporabolus heterolepis*	SPHE	50-500	5-50
	BIG BLUESTEM	*Andropogon gerardii*	ANGE	10-100	5-25
	SIDEOATS GRAMA	*Bouteloua curtipendula*	BOCU	25-100	5-25
	INDIANGRASS	*Sorghastrum nutans*	SONU2	0-150	0-25
	SWITCHGRASS	*Panicum virgatum*	PAVI2	0-150	0-25
	PENNSYLVANIA SEDGE	*Carex pensylvanica*	CAPE6	1-50	1-15
	LONG-STALKED PANIC GRASS	*Dichanthelium perlongum*	DILI2	1-50	1-15
	MUHLENBERG'S SEDGE	*Carex muehlenbergii*	CAMU4	0-25	0-5
	PORCUPINEGRASS	*Heterostipa spartea*	HESP11	0-25	0-5
	PLAINS MUHLY	*Muhlenbergia cuspidata*	MUCU3	0-25	0-5
	HAIRY GRAMA	*Bouteloua hirsuta*	BOHI2	0-5	0-1
	FEW SEEDED PANIC GRASS	*Dichanthelium oligosanthes*	DIOLO	0-5	0-1
	PRAIRIE JUNEGRASS	*Koeleria macrantha*	KOMA	0-5	0-1
Forbs	STIFF TICKSEED	*Coreopsis palmata*	COPA10	15-150	5-25
	FLOWERING SPURGE	*Euphorbia corollata*	EUCO10	15-150	5-25
	COMPASSPLANT	*Silphium laciniatum*	SILAL2	0-150	0-15
	STIFF GOLDENROD	*Oligoneuron rigidum*	OLRIR	10-100	1-15
	SKYBLUE ASTER	*Symphyotrichum oolentangiense*	SYOOO	0-100	0-15
	AROMATIC ASTER	*Symphyotrichum oblongifolium*	SYOB	0-100	0-15
	FEWLEAF SUNFLOWER	*Helianthus occidentalis*	HEOCO	0-100	0-15
	WESTERN SILVER ASTER	*Symphyotrichum sericeum*	SYSE2	0-50	0-15
	WHITE HEATH ASTER	*Symphyotrichum ericoides*	SYERE	0-50	0-15
	PURPLE PRAIRIE CLOVER	*Dalea purpurea*	DAPU5	0-25	0-15
	GRAY GOLDENROD	*Solidago nemoralis*	SONE	0-25	0-15
	STIFF SUNFLOWER	*Helianthus pauciflorus*	HEPA19	0-25	0-15
	WHORLED MILKWEED	*Asclepias verticillata*	ASVE	0-15	0-10

Species list continued

Layer	Common Name	Scientific Name	USDA Symbol	Annual Production (lbs/ac)	Cover (%)
	PRAIRIE BLUE-EYED	*Sisyrinchium campestre*	SICA9	0-5	0-5
	DOWNY PHLOX	*Phlox pilosa*	PHPI	0-5	0-5
	CANDLE ANEMONE	*Anemone cylindrica*	ANCY	0-5	0-5
	BASTARD TOADFLAX	*Comandra umbellata*	COUM	0-5	0-5
	DOWNY PAINTED CUP	*Castilleja sessiliflora*	CASE5	0-5	0-5
	TALL BLAZING STAR	*Liatris aspera*	LIAS	0-5	0-5
	PRAIRIE FLEABANE	*Erigeron strigosus*	ERST3	0-5	0-5
	FALSE BONESET	*Brickellia eupatorioides*	BREU	0-5	0-5
	BUTTERFLY WEED	*Asclepias tuberosa*	ASTU	0-5	0-5
	COMMON SPIDERWORT	*Tradescantia ohiensis*	TROH	0-5	0-5
	PRAIRIE GOLDENROD	*Oligoneuron album*	OLAL2	0-5	0-5
	GROOVED FLAX	*Linum sulcatum*	LISU4	0-5	0-5
	CANADIAN LOUSEWORT	*Pedicularis canadensis*	PECA	0-5	0-5
	JEWEL SHOOTINGSTAR	*Dodecatheon amethystinum*	DOAM	0-5	0-5
	CYLINDRICAL BLAZING	*Liatris cylindracea*	LICY	0-5	0-5
	INDIAN PAINTBRUSH	*Castilleja coccinea*	CACO17	0-5	0-5
	HOARY PUCCOON	*Lithospermum canescens*	LICA12	0-5	0-5
	PRAIRIE GROUNDSEL	*Packera plattensis*	PAPL12	0-1	0-1
	LEONARD'S SKULLCAP	*Scutellaria parvula*	SCPAM	0-1	0-1
	BIRDFOOT VIOLET	*Viola pedata*	VIPE	0-1	0-1
	PASQUE FLOWER	*Pulsatilla patens*	PUPAM	0-1	0-1
	WOMAN'S TOBACCO	*Antennaria plantaginifolia*	ANPL	0-1	0-1
	STIFF GENTIAN	*Gentianella quinquefolia*	GEQUO	0-1	0-1
	VIOLET WOODSORREL	*Oxalis violacea*	OXVI	0-1	0-1
	WOOD LILY	*Lilium philadelphicum*	LIPHP	0-1	0-1

Community Phase 1.1- High Diversity Prairie Community Phase 1.1 represents the central concept of the DCBP ecological site (Figure 7). During pre-settlement, and immediate post settlement time periods, DCBP sites were maintained in Phase 1.1 as long as there were three to five fires per decade (Jones and Bowles, 2013). On bluffs where fire didn't occur at this frequency, communities transitioned to Phase 1.2, and diversity of prairie species declined. Early grazing systems which included a diversity of grazers (e.g., cattle, sheep, goats, etc.) may have helped maintain bluff prairies in Phases 1.1 and 1.2. A good example of what this complex of Reference State communities may have looked like is portrayed in a photo from the Winnebago Creek Valley, Minnesota (Figure 6). Bluff prairies extended from the lower backslope to the summit on most bluffs and valley sides that are in the range of bluff prairie physical setting parameters.

Community Phase 1.1 is the only data supported community phase of this ecological site description. High intensity vegetation data were collected at three type location sites in Minnesota and Wisconsin, and are representative of 1.1.

Pathway 1.1A - Fire frequency less than three fires per decade. A possible decrease in grazing intensity, especially by a diversity of grazers may also be a factor.

Table 7. Reference State, Community Phase 1.1
Annual Production.
(Data presented are based on three type locations.)

	Lbs./acre		
Growth Form	Low	Normal	High
Grass/Grasslike	343	515	572
Forb	699	1,048	1,165
Shrub/Vine	91	136	151
Total Annual Production	1,173	1,760	1,955

Table 8. Reference State, Community Phase 1.1 vertical structure. (Data presented are based on three type locations.)

	Percent Cover			
Height Above Ground (ft.)	Grass/ Grasslike	Forb	Shrub/ Vine	Tree
0.5’	5-17	0-4	1-2	-
0.5-1’	11-44	0-11	1-5	-
1-2’	17-52	3-9	1-8	-
2-4.5’	0-2	0-7	0-3	-
4.5-13’	-	-	-	-

Table 9. Reference State, Community Phase 1.1 ground surface cover. (Data presented are based on ground cover transects at three NRCS type locations.)

Type	**Minimum (%)**	**Maximum (%)**
Grass/Grasslike	2	9
Forb	0	1
Shrub/Vine	0	1
Tree	-	-
Non-Vascular Plants	-	-
Biological Crust	0	3
Litter	29	69
Surface Fragments (.25-3”)	8	21
Surface Fragments (>3”)	6	23
Bedrock	-	-
Water	-	-
Bare Ground	3	42

Figure 7. Photo of Reference State (community phase 1.1 High Diversity Prairie) for Dolomite Colluvium Bluff Prairie; Brodale soils. Photo by Kyle Steele at Spring Green Preserve State Natural Area, Sauk County, Wisconsin in August of 2014.

Community Phase 1.2 - Reduced Diversity Prairie A small decrease in fire frequency from Phase 1.1 results in increasing grass and shrub dominance, along with a decrease in forbs (Figure 8). Little bluestem and prairie dropseed thatch builds up, thus not allowing some forbs to proliferate. Annuals and shorter prairie species are the first to decline (Kraszewski and Waller, 2008). Smooth sumac, gray dogwood, and common ninebark are the primary increasing shrubs. Less than ideal landform settings (like small drainageways) transition first, and develop outward from there. In this Phase, Reference State bluff prairies risk fragmentation, isolation, and possible decline in species diversity.

In contemporary restoration settings, there is a tendency for prescribed fires to be set in the late winter to early spring. During this time, surrounding forested ecological sites often are still covered in snow, which provides a natural fire break, helping with containment of prescribed fires. Historically, Reference State fires would have also occurred during the growing season and into fall, and were likely more intense. Implementing fall and late spring fires will provide a greater impact on setting back shrub and tree species, and likely produce more immediate restoration results (Jon Cole, MN DNR Area Manager, personal communication.) However, vertebrate species like the timber rattlesnake and also many invertebrate species may be impacted with this strategy (Armund Bartz, WI DNR Ecologist, personal communication and Jaime Edwards, MN DNR Nongame Biologist, personal communication).

Figure 8. Photo of Reference State (Community Phase 1.2 Reduced Diversity Prairie) for Dolomite Colluvium Bluff Prairie ecological site; Brodale soils. Photo by Peter Hartman at Vinegar Ridge Recreation Area, Houston County, Minnesota in November of 2013.

Pathway 1.2A - Increase fire frequency to at least three to five fires per decade. Supplemental controlled grazing and herbicide treatment of shrubs near cliffs, ledges, and large boulders will speed up restoration to Phase 1.1.

Transition 1A - A gradual transition to a tree and shrub dominated condition (primarily eastern redcedar), occurring over 20 years of fire suppression. A lack of grazing by a diversity of grazers may also accelerate this transition.

Transition 1B - A gradual transition to a tree and shrub dominated condition (primarily deciduous trees and shrubs), occurring over 20 years of fire suppression. A lack of grazing by a diversity of grazers may also accelerate this transition.

STATE 2 – Eastern Redcedar/Prairie State

This state is dominated by eastern redcedar, which can be relatively even-aged, but there often are a few scattered older trees, especially near cliffs and ledges, or on very steep slope breaks. Eastern redcedar is a fire sensitive species, especially in early growth stages. Their presence is an indication that fire has been absent for a prolonged period (>20 years). Determining the age of dominant trees could give an idea of when fire was excluded. Historically, eastern redcedar is thought to colonize from cliff habitat during periods of fire exclusion (Jones and Bowles, 2013). Other shrubs common to bluff prairies and scattered deciduous trees are also present at an increased density. Densities can range from 40 to nearly 100 percent. Interconnected patches of prairie are common when densities closer to 40 percent. However, the decline in diversity of prairie species (in particular the loss of annuals and those of shorter stature) may have already taken place (Kraszewski and Waller, 2008). When densities reach nearly 100 percent, a few prairie species persist with diminutive stature, and it is likely that the soil contains a seed bank of prairie species.

Figure 9. Photo of Eastern Redcedar/Prairie State (Community Phase 2.1, Eastern Redcedar with Prairie Openings) for Dolomite Colluvium Bluff Prairie ecological site; Brodale soils. Photo by Peter Hartman at a bluff near Elba, Winona County, Minnesota in November of 2013.

Community Phase 2.1- Eastern Redcedar with Prairie Openings This phase consists of 40 to 80 percent cover of eastern redcedar, with small, patchy prairie openings (Figure 9). The prairie openings are not completely shaded by adjacent trees. Native deciduous shrubs and trees are also encroaching, but not dominant. Invading trees gain initial footing on the less than ideal landform settings. They begin to invade slightly concave areas that collect runoff, and around boulders, cliffs, and ledges. South to southwest aspects on, the steepest and most convex areas, tend to persist as prairie openings. West to west-southwest aspects and south-southeast aspects are more prone to tree encroachment. Upper backslopes and shoulder slopes tend to persist as prairie opening while lower backslopes tend to be invaded by woody species. Because of fragmentation and isolation of the prairie openings, the diversity of prairie species, and in particular the loss of

shorter prairie species may have already taken place (Kraszewski and Waller, 2008). Taller and more mesic prairie species, like wild bergamot (*Monarda fistulosa*) and narrowleaf mountainmint (*Pycnanthemum tenuifolium*) may become established in the prairie openings (Armund Bartz, WI DNR Ecologist, personal communication).

This community phase has the most potential for restoration to the Reference State, with minimal investment of resources resulting in comparatively rapid response of native flora.

Pathway 2.1A - Continued absence of fire, with a gradual increase in eastern redcedar density (>80 percent cover) and height.

Community Phase 2.2 - Eastern Redcedar Dominant This phase consist of greater than 80 percent eastern redcedar cover (Figure 10). Between dense thickets of eastern redcedar, formerly persistent prairie openings are subject to shading. Some native deciduous shrubs and trees exist, but eastern redcedar is the dominant canopy tree. Under this dense cover, some stunted prairie species remain. At this stage, there has been a significant loss in species diversity. However, it is likely that a seedbank of prairie species persists in the soil. Species particularly capable of persisting in the seedbank include: leadplant (frequent), little bluestem, prairie dropseed (fairly frequent), panic grasses (*Dichanthelium* spp.), stiff tickseed, flowering spurge, bluebell bellflower (*Campanula rotundifolia*), field pussytoes (*Antennaria negelecta*), and candle anemone (Jaime Edwards, MN DNR Nongame Biologist, personal communication).

Prescribed burns may not carry if there is not enough fuel beneath dense eastern redcedar thickets. Mechanical removal, herbicide treatment, and spot burning can be used to create openings as intermediate steps toward natural community restoration. Various bird species use eastern redcedar thickets and carry in seeds from offsite. As a result, when eastern redcedar is removed, shrub species like smooth sumac, gray dogwood, blackberry species (*Rubus* spp.), and pricklyash may rapidly become released. Herbicide treatment of these shrubs is often critical for their control. Proceed with caution if common buckthorn, or other invasive species are, or may be present.

Figure 10. Photo of Eastern Redcedar/Prairie State (Community Phase 2.2 Eastern Redcedar Dominant) for Dolomite Colluvium Bluff Prairie ecological site; Brodale soils. Photo by Peter Hartman at a bluff near Houston, Houston County, Minnesota November of 2013.

Pathway 2.2A - Reduction of eastern redcedar and other tree and shrub species to 40 to 80 percent cover.

Transition 2A - Increased shade, providing potential for more shade tolerant deciduous trees and shrubs to become established. Sudden removal of eastern redcedar in State 2 can release seeds of shrubs brought in by birds, such as: smooth sumac, gray dogwood, blackberry species, and pricklyash.

Transition 2B - Common buckthorn becomes an established, co-dominant shrub, and is reproducing onsite.

Restoration Pathway 2A - Complete removal of eastern redcedar and restoration of fire regime, leading to restoration of prairie flora characteristic of the Reference State.

STATE 3 – Scrub Deciduous Tree and Shrub/Prairie State

This state is dominated by native deciduous shrubs and small, immature trees, mixed with a small amount of eastern redcedar. This gradual transition results from prolonged periods of fire suppression, generally over 20 years. Deciduous shrub species that are normally found on this ecological site increase in density and height. Pioneer deciduous tree species invade from local sources. Prairie grasses and forbs still exist in the understory, but woodland forbs, grasses, and sedges may be appearing. Shrubs are tall and relatively dense. The most common species include: smooth sumac, gray dogwood, common ninebark, blackberry species, and common pricklyash. Sapling trees are scattered, and often of poor form. Common species may include: pin cherry (*Prunus pensylvanica*), bur oak, black oak, quaking aspen (*Populus tremuloides*), paper birch (*Betula papyrifera*), black cherry (*Prunus serotina*), green ash (*Fraxinus pennsylvanica*), and black walnut (*Juglans nigra*). Overall tree and shrub densities can range from 40 percent to nearly 100 percent. Interconnected patches of prairie are common when densities closer to 40 percent. However, a decline in the diversity of prairie species (in particular the loss of annuals and those of shorter stature) may have already taken place (Kraszewski and Waller, 2008). When densities reach nearly 100 percent, a few prairie species persist with diminutive stature, and it is likely that the soil contains a reservoir of prairie species in the seed bank.

Community Phase 3.1 - Small Deciduous Trees and Shrubs with Prairie Openings This phase consists of 40 to 80 percent cover of deciduous shrubs (Figure 10), many of which are native to the site, but occur at a much higher density than before. Eastern redcedar can be present, but it is not dominant. The prairie openings are not completely shaded by adjacent trees. Invading shrubs gain initial footing on the less than ideal landform settings. They begin to invade slightly concave areas that collect runoff, and around boulders, cliffs, and ledges. South to southwest aspects on, the steepest and most convex areas, tend to persist as prairie openings. West to west-southwest aspects and south-southeast aspects are more prone to tree encroachment. Upper backslopes and shoulders tend to persist as prairie opening while lower backslopes tend to be invaded by woody species. Because of fragmentation and isolation of the prairie openings, the diversity of

prairie species, and in particular the loss of shorter prairie species may have already taken place (Kraszewski and Waller, 2008). Taller and more mesic prairie species, like wild bergamot (Monarda fistulosa) and narrowleaf mountainmint (Pycnanthemum tenuifolium) may become established in the prairie openings (Armund Bartz, WI DNR Ecologist, personal communication).

This community phase has potential for restoration to the Reference State, but will probably require use of herbicide to control deciduous trees and shrubs.

Pathway 3.1A - Continued absence of fire, with a gradual increase in height and density of shrubs and young deciduous trees.

Figure 11. Photo of Scrub Deciduous Tree and Shrub /Prairie State (Community Phase 3.1 Small Deciduous Trees and Shrubs with Prairie Openings) for Dolomite Colluvium Bluff Prairie ecological site; Brodale soils. Photo by Peter Hartman at Five-Mile Bluff State Natural Area, Pepin County, Wisconsin in April of 2014.

Community Phase 3.2 - Small Deciduous Trees and Shrubs Dominant This phase consists of greater than 80 percent cover of deciduous trees and shrubs. Trees are tall enough to form a discontinuous canopy over parts of the shrub layer. Shrubs can form a discontinuous canopy under the trees. Trees are typically immature and of poor form. The understory is shaded by a combination of both the tree and shrub layers. Prairie grasses and forbs are present, but their diversity is significantly reduced and most species are completely absent. Savanna and open woodland species are beginning to appear, such as: feverwort (*Triosteum perfoliatum*), white rattlesnakeroot (*Prenanthes alba*), Canada lettuce (*Lactuca canadensis*), Virginia wildrye (*Elymus virginicus*), hairy wildrye (*Elymus villosus*) (Jaime Edwards, MN DNR Nongame Biologist, personal communication).

Sites in this phase require considerable effort to restore, and may be considered essentially not restorable because of the investment required to control trees and shrubs. Prescribed burns may not carry if there is not enough fuel beneath the dense canopy. Mechanical removal, herbicide treatment, and spot burning can be used to create openings as intermediate steps toward natural community restoration. Herbicide treatment of shrubs and trees is probably critical for their control. Proceed with caution if common buckthorn, or other invasive species are, or may be present.

Pathway 3.2A - Reduction of deciduous trees and shrubs to 40 to 80 percent cover.

Transition 3B - Common buckthorn becomes an established, co-dominant shrub, and is reproducing onsite.

Restoration Pathway 3A - Nearly complete removal of deciduous trees and shrubs and restoration of fire regime, leading to restoration of prairie flora characteristic of the Reference State.

Figure 12. Photo of Scrub Deciduous Tree and Shrub/Prairie State (Community Phase 3.2 Small Deciduous Trees and Shrubs Dominant) for Dolomite Colluvium Bluff Prairie ecological site; Brodale soils. Photo by Peter Hartman at Five-Mile Bluff State Natural Area, Pepin County, Wisconsin, in April of 2014.

STATE 4 – Non-Native Invaded State

This state occurs when non-native, invasive shrubs become well established and produce novel, monotypic plant communities. Common buckthorn is the primary species of concern, but the non-native honeysuckles *(Lonicera tartarica, L. morrowii*) may be present as well. Sites near urban areas are more likely to be in this state. These species produce abundant seed and can rapidly spread by other by coppice regeneration, especially when they are cut without herbicide treatment. Birds are a primary dispersal agent of common buckthorn, often importing seed to DCBP sites that are in States 2 or 3. In some cases, when common buckthorn is present in the understory, but is not noticeable, attempts for restoration can release it, ultimately transitioning the site to State 4. In

addition, thickets of common buckthorn can sometimes be found on the edges of sites in Community Phase 2.2. If eastern redcedar is removed there can be an onslaught of common buckthorn invading the site.

The initial stages of bluff prairie restoration could be impacted if sites are located near common buckthorn seed sources. When any bluff prairie restoration project is considered, an evaluation of potential common buckthorn seed sources should be completed.

Figure 13. Photo of Non-Native Invaded State (Community Phase 4.1 Common Buckthorn Established) for Dolomite Colluvium Bluff Prairie ecological site; Brodale soils. Photo by Peter Hartman at a bluff in Jefferson Township, Houston County, Minnesota in April of 2014.

Community Phase 4.1 - Common Buckthorn Established In this phase, common buckthorn is mature, produces abundant seed, and has spread throughout the site (Figure 13). Other non-native woody species may also be present, including non-native honeysuckles. Non-native forbs may also be increasing, such as sweetclover (*Melilotus officinalis*), which is a primary non-native forb invading bluff prairies. Native woody species are also present (as in States 2 and 3) and can have a high percent canopy cover. Prairie grasses and forbs still persist under the tree and shrub canopies, but their diversity is reduced, with many or most species being absent.

Sites in this phase require considerable effort to restore, and may be considered essentially not restorable because of the investment required to control trees and shrubs. Prescribed burns may not carry if there is not enough fuel beneath the dense canopy. Mechanical removal, herbicide treatment, and spot burning can be used to create openings as intermediate steps toward natural community restoration. Herbicide treatment of common buckthorn is critical for its control.

Restoration Pathway 4A - Removal of common buckthorn, and other native and non-native shrubs and trees, with restoration of fire regime. This will likely require consecutive years of multiple types of management treatments.

Supporting Information

Relationship to Other Established Classifications

Wisconsin's Natural Communities (WI DNR, 2014); the reference community of this ecological site is most similar to:

Primary: Dry-Mesic Prairie and Dry Prairie

(Noteworthy differences – Dry Prairie includes both dolomite and sandstone, and is listed as having bedrock near the surface; Dry-Mesic Prairie does not include bluff landform settings)

MN DNR Native Plant Community Classification (MN DNR, 2005); the reference community of this ecological site is most similar to:

Primary: UPs13c Dry Bedrock Bluff Prairie (Southern)

(Noteworthy differences – includes both dolomite and sandstone, and is listed as having thin soils over bedrock)

Vegetation Associations (National Vegetation Classification System, NatureServe, 2014); the reference community of this ecological site is most similar to:

Primary: Little Bluestem Bedrock Bluff Prairie

(Noteworthy differences – is listed as having thin soils over bedrock)

Biophysical Setting (Landfire, 2009); the reference community of this ecological site is most similar to:

Primary: North-Central Interior Sand and Gravel Tallgrass Prairie

(Noteworthy differences – generally a broader concept; describes soils less than four inches over bedrock)

Secondary: Paleozoic Plateau Bluff and Talus

(Noteworthy differences – describes soils with loess cap that are shallow and moderately deep to bedrock)

Associated Ecological Sites

This ecological site often co-occurs with Sandstone Colluvium Bluff Prairie (SCBP, 105XY002). They are commonly found together on the same landform when the bedrock stratigraphy is Oneota dolomite over Jordan sandstone over St. Lawrence dolomite. DCBP generally makes up 60 to 99 percent of the landform, while SCBP makes up one to 40 percent. If SCBP is of low percent on a bluff, the most likely place to find it is below any sandstone cliff or ledge. Often, the loamy-skeletal dolomite colluvium from DCBP covers the sandy soils of SCBP, masking the effect of the underlying sandstone geology. Sites that have more than 12 inches of loamy-skeletal colluvium

covering sandier textures are considered within the range of DCBP. This is particularly common on bluffs where there is no outcropping of the Jordan sandstone.

Also, embedded within this ecological site are cliff and shallow to bedrock ecological sites. There are many surrounding ecological sites which include a number of reference plant community types, including oak savanna, dry-mesic oak woodland, and mesic hardwood forest. Ecological Site Descriptions have not been completed on any of these soils and plant communities.

Similar Ecological Sites

Sandstone Colluvium Bluff Prairie (SCBP, 105XY002) is both *associated* and *similar* to DCBP (see above). SCBP has a similar disturbance regime and shares many of the same species. However there is a distinct difference in productivity and height form. DCBP produces almost double (192%) the total annual production (lbs/ac) of the associated sandstone ecological site. DCBP includes a complex dry-mesic and dry prairie, whereas SCBP is exclusively dry prairie. The short-mid-tall grass ratio of grass cover differs to a great extent (20-60-20 for DCBP versus 47-47-6 for SCBP). Species like sideoats grama are common on DCBP but make up a small fraction of the total annual production, as compared to the SCBP. Some species, like hairy grama, are virtually exclusive to the associated SCBP. These differences are noticeable when traversing a bluff that has both DCBP and SCBP. The vegetation on SCBP is thinner and shorter, has more bio-crusts, and a significant amount of soil surface exposure. In comparison, DCBP vegetation is thicker and taller with little soil surface exposure.

Cliff and shallow to bedrock ecological sites are also both *associated* and *similar*. They are much less productive plant communities and include a component of bedrock outcrop. When associated to DCBP, these are located on summits of narrow ridges, above major cliff edges, and on shoulder slopes or benches near bedrock outcrops. It is currently believed that the shallow to bedrock ecological site becomes the predominant bluff prairie type in the part of the MLRA where the Galena Formation is prominent. More work is needed to confirm this observation.

Published literature on “hill prairies” in Illinois was used to guide development of fire intervals for DCBP (Evers, 1955 and Jones and Bowles, 2013). In comparison to these Midwestern hill prairies that were derived from deep loess, DCBP has lower available water capacity. Regardless, these

two ecosystems are very similar and it is believe they would have had similar disturbance dynamics.

Inventory Data References

A total of 36 integrated plots, ranging from Tier 2 to Tier 3 intensity, were used as a basis for this ecological site. Three of these were Type Locations representing the data-supported Community Phase 1.1 in the state-and-transition model, and included all necessary data elements for a Tier 3 dataset (Table 10). No other community phases were supported with quantitative data analysis. All 36 plots had soil pedon and site data collected by a professional soil scientist using a form equivalent to SF-232. All pits were hand-dug using sharpshooters and/or bucket augers. All pits used a rock probe to a depth of at least 60 inches, to confirm depth of soils. Of the 36 plots, 13 of the sites were in Minnesota and 23 were in Wisconsin. Of the sites in Minnesota, nine had an associated MN DNR relevè and/or element occurrence data. Associated relevès included: 0963, 0964, 0974, and 0977.

Table 10. Location of Tier 3 data used for Type Locations. All sites are state natural areas and are considered sensitive.

State	County	Ownership	Legal Description	Latitude	Longitude
Minnesota	Houston	Mound Prairie SNA, Richard Dorer State Forest, MN DNR	T104N R5W S34	43.76553241	-91.43125575
Wisconsin	Sauk	Spring Green Preserve, The Nature Conservancy	T8N R4E S6	43.20466667	-90.05627808
Wisconsin	Crawford	Rush Creek SNA, WI DNR	T10N R6W S6	43.36583662	-91.13173898

Other References

Anderson, O. 1954. The Phytosociology of Dry Lime Prairies of Wisconsin. PhD. Thesis, University of Wisconsin. Madison, WI.

Cochrane, T.S. and H.H. Iltis. 2000. Atlas of Wisconsin Prairie and Savanna Flora. Technical bulletin No. 191. Wisconsin Department of Natural Resources. Madison, WI.

Coen, R.N. 1976. Painting and Sculpture in Minnesota - 1820-1914. University of Minnesota Press. Minneapolis, MN.

Curtis, J. T. 1959. The Vegetation of Wisconsin - An Ordination of Plant Communities. The University of Wisconsin Press. Madison, WI.

Evers, R. 1955. Hill Prairies of Illinois. Bulletin of the Illinois Natural History Survey. 26:5, 367-446.

Foote, K. G. 1966. The Vegetation of Lichens and Bryophytes on Limestone Outcrops in the Driftless Area of Wisconsin. Bryologist 69:265-292.

Henderson, Richard A. 1995. Plant Species Composition of Wisconsin Prairies. Technical bulletin No. 188. Wisconsin Department of Natural Resources. Madison, WI.

Hoch, G. A. and J.M. Briggs. 1999. Expansion of Eastern Red Cedar (*Juniperus virginiana*) in the Northern Flint Hills, Kansas. In:, p. 9–15. In: Proceedings of the 16th North American Prairie Conference. J. T. Springer (ed.). University of Nebraska, Kearney, NE.

Jones, M. and M. Bowles. 2013. Tree Ring Analysis of Eastern Red Cedar Reveals Fire History of Fults Hill Prairie Nature Preserve, and its Relationship to Climate and Loss of Prairie Vegetation. The Morton Arboretum. Lisle, IL.

Kraszewski, S.E. and D.M. Waller. 2008. Fifty-five Year Changes in Species Composition on Dry Prairie Remnants in South-central Wisconsin. Torrey Botanical Society 135:2, 236-244. 2008.

Landfire. 2009. Landfire National Vegetation Dynamics Models. USDA For. Serv. and U.S. Department of Interior. Washington, DC.

Minnesota Department of Natural Resources. 2005. Field Guide to the Native Plant Communities of Minnesota: the Laurentian Mixed Forest Province. Ecological Land Classification Program, Minnesota County Biological Survey, and Natural Heritage and Nongame Research Program. St. Paul, Minnesota.

NatureServe. 2014. NatureServe Explorer: An online encyclopedia of life [web application]. Version 7.1. NatureServe, Arlington, Virginia. Available at http://explorer.natureserve.org; last accessed September 25, 2014.

Nelson, P. W., J. A. Fitzgerald, K. Larson, R. McCoy, A. Schotz, J. Taft, T. Witsell, and B. Yahn. 2013. Central Hardwoods Joint Venture Glade Conservation Assessment for the Interior Highlands and Interior Low Plateaus of the Central Hardwoods Region. Central Hardwoods Joint Venture. Available online at http://www.chjv.org/projects.html; last accessed October 21, 2014.

Nowacki, G. J. and M.D. Abrams. 2008. The Demise of Fire and “Mesophication” of Forests in the Eastern United States. BioScience 58:123-138.

Robertson, K. R., M.W. Schwartz, J.W. Olson, J. W., B.K. Dunphy, and H.D. Clarke. 1995. 50 Years of Change in Illinois Hill Prairies. Erigenia 14:41-52.

Shea, M. E., L.A. Schulte, and B.J. Palik. 2014. Reconstructing Vegetation Past: Pre-Euro-American Vegetation for the Midwest Driftless Area, USA. Ecological Restoration 32:417-433.

Scottston, B. and T. Atherton. 2013. A Creek Runs Through Me, A History of the Winnebago Creek Valley in Southeast Minnesota. North Star Press. St. Cloud, MN.

Stambaugh, M.C. and R.P. Guyette. 2006. Fire Regime of an Ozark Wilderness Area - Arkansas. American Midland Naturalist 165, 237-251.

Theler, J. 1997. The Modern Terrestrial Gastropod (Land Snail) Fauna of Western Wisconsin's Hill Prairies. Nautilus 110.4, 111-121.

Thomson, J.W., Jr. 1940. Relic Prairie Areas in Central Wisconsin. Ecological Monographs. 10:4, 685-717.

Weaver, J. E. 1968. Prairie Plants and Their Environment - A Fifty-year Study in the Midwest. University of Nebraska Press. Lincoln, NE.

WI DNR 2014. Wisconsin's Natural Communities. Available online at http://dnr.wi.gov/topic/EndangeredResources/communities.asp; last accessed October 21, 2014.

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Table 11. List of primary contributors and reviewers.

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