Tallgrass Prairie Restoration in the United States

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Abstract

Over 95% of tallgrass prairies have been degraded or destroyed, representing a loss of one of the most important pieces of ecological heritage in the United States. This paper aims to provide some insight into whether tallgrass prairie restoration efforts at present are reflective of the goal of returning disturbed lands to their native state, and at what point these restored prairies begin to take on the characteristics of a native prairie. It begins with an outline of the characteristics of a tallgrass prairie, followed by an analysis of the ways human activities impact this ecosystem. This information is then used to provide an analysis of restoration goals and impacts. Finally, current restoration efforts in the United States are considered, particularly in terms of location and size, and are found to be improving, but still in need of more large-scale projects.

Introduction

Tallgrass prairies in North America represent one of the region's most important pieces of ecological heritage. However, they also represent an ecosystem that has been almost completely destroyed as a result of their fertile soils, ideal for cultivation. The conversion of tallgrass prairies into cornfields or cattle farms does not merely result in a reduction of grass in a vast sea of the stuff – instead, hundreds of species that rely on this ecosystem to survive are affected. Fortunately, it is possible with some effort to restore and maintain tallgrass prairies, benefiting not only these species, but also human populations. The value of tallgrass prairies is manifested in a number of ways; examples are increased biodiversity and the services provided by a healthy ecosystem, including carbon fixation by prairie plants.

Biodiversity is a term for the amount of genetic or species variation in a given area. Although it is inherently valuable in itself, it can also be valued for the benefits it has the potential to provide in the future. For example, it is possible that species that are as yet undiscovered or unstudied may hold compounds that are useful in medicine or industry. It is also possible that in the event of major environmental changes or crop diseases, genetic diversity will allow some members of an otherwise doomed species to survive and reproduce. This is particularly important for species grown for food. For these reasons, it is beneficial to preserve biodiversity. However, there is evidence that the planet is currently undergoing a mass extinction, based on species loss well above the natural background rate. This mass extinction is unique in that it seems to be mainly the result of human activities and overpopulation.[1]

Tallgrass prairies have been particularly affected by human habitat destruction, and as a result are at risk of having many casualties to the biodiversity crisis. The inherent value of species variation makes it necessary to attempt to restore this vastly destroyed habitat. The World Wildlife Fund has designated the ecoregions that make up the major base of North American tallgrass prairie as being "globally outstanding", emphasizing the need to save the area. This emphasized by the fact that as of 1994 55 grassland species in the United States were listed as threatened or endangered and 728 were candidates, including animal species that thrive in or rely on this ecosystem.[2] For example, many grassland bird species are in decline as a result of damage to their habitat. Eastern Meadowlarks have declined 72% in the last 40 years.[3] The network-like character of natural ecosystems, with countless interactions between species, has two major implications. The first is that it makes it likely for unforeseen difficulties with restoring these areas to arise. The second is that saving one ecosystem, such as tallgrass prairies, can have a much wider impact in terms of preservation of biodiversity.

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[1] Christopher J. Humphries, Paul H. Williams, and Richard I. Vane-Wright. "Measuring Biodiversity Value for Conservation." *Annual Review of Ecology and Systematics* 26 (1995): 93-111. http://www.jstor.org/stable/2097200 (accessed April 18, 2010).

[2] Fred Samson and Fritz Knopf, "Prairie Conservation in North America," *Bioscience* 44, no. (1994): 418-421. http://www.jstor.org/stable/pdfplus/1312365.pdf (Accessed April 18, 2010).

[3] Corina J. Rahmig, William E. Jensen, and Kimberly A. With, "Grassland Bird Responses to Land Management in the Largest Remaining Tallgrass Prairies," *Conservation Biology* 23, no. 2 (2008): 420-432. http://www.ksuwildcats.com/withlab/publications/Rahmig_etal_2009.pdf (accessed April 18, 2010).

Ecosystem services are another reason to value natural areas in the environment. This is something that the United States Department of Agriculture has already begun to appreciate, as demonstrated in their Conservation Reserve and Wetland Reserve Programs.[4] Some of the most crucial services provided by tallgrass prairie are prevention of soil erosion and fixation of nitrogen and other nutrients into fertile soil. Unfortunately, the ability of tallgrass prairies to create healthy and fertile soils is one of the first things that settlers in North America noticed about them, and it has been the cause of much of the destruction and degradation these areas have undergone. The Dust Bowl period serves as a stark reminder of the way that mistreated lands can lead to the loss of topsoil. However, even following that experience, current agricultural practices still result in topsoil being lost at least ten times faster than it can be replaced.[5] Restoration of tallgrass prairies is beneficial for damaged soils and may help reduce the loss of topsoil. Reduction of carbon in the atmosphere is another example of an ecosystem service provided by tallgrass prairies.[6] In general, grasslands are more efficient carbon sinks than similar areas populated by forests and are therefore better suited to reduce climate change.[7] As human consumption and population continue to increase at alarming rates, it is likely that carbon dioxide emissions will continue to be an environmental concern. Any way to reduce the amount of carbon in the atmosphere is a positive step for reducing the potentially drastic negative impacts of climate change.[8]

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[4] Patricia Engler, "Conservation Reserve Program," *Natural Resources Conservation Service*, 23 June 2009, http://www.nrcs.usda.gov/programs/CRP/.
[5] Tom Paulson, The Lowdown on Topsoil: It's Disappearing, *Seattle PI,* January 22, 2008, http://www.seattlepi.com/local/348200_dirt22.html.
[6] Ibid.
[7] Fred Samson and Fritz Knopf, "Prairie Conservation in North America," *Bioscience* 44, no. (1994): 418-421. http://www.jstor.org/stable/pdfplus/1312365.pdf (Accessed April 18, 2010).
[8] Friedman, Dana, "Kansas Patch Burning," *Natural Resources Conservation Service*, http://www.nrcs.usda.gov/news/thisweek/2005/010505/susag6.html.

Although these are good things, it is also significant to note that they do not necessarily coincide with the goal of recreating a true prairie; although it is relatively easy to plant an area with native seeds and watch these seeds take root, which will effectively prevent erosion and provide habitat for some species, to actually recreate a complete prairie is much more difficult. Careful maintenance through conducting burns, controlling invasive species, and monitoring the prairie's development can help the process, but in the end the most crucial function in this equation is time. It took millions of years for the tallgrass prairie to evolve to its status at the time that humans converted 9/10s of it into cropland within a generation.[9] To reverse damage to cultivated lands, such as nutrient-depleted soils, and recreate a true prairie may take long amounts of time.[10] As a result of this difficulty, there is a need for a system for determining what precisely defines a successfully restored prairie. The aim of this paper is to provide some insight into this area, and use the conclusions to inform an examination of what lands are best for tallgrass prairie restoration in the United States and to what extent this has been reflected in restoration efforts up to this time. The paper will begin with a review of the history of tallgrass prairies and follow with a discussion of the ways in which certain activities can impact the habitat. This information will then be used to define a successfully restored tallgrass prairie and to analyze the current status of restoration efforts in the United States.

History

Although tallgrass prairies occur in locations outside North America, the North American prairies are unique due to the dominance of big bluestem – a grass species that can grow above

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[9] *America's Lost Landscape: The Tallgrass Prairie*, DVD, David O'Shields. (2005; Minnesota: New Light Media, 2005.)

[10] Kelly Kindscher and Larry L. Tieszen, "Floristic and Soil Organic Matter Changes After Five and Thirty-Five Years of Native Tallgrass Prairie Restoration," *Society for Ecological Restoration* 6, no. 2 (1998): 181-196. http://www3.interscience.wiley.com/journal/119132782/abstract?CRETRY=1&SRETRY=0 (Accessed April 18, 2010).

10 feet and creates an inland sea of grass. Conditions that favor the growth of these environments are largely the result of the Rocky Mountains. The height of these mountains forces moist air from the Pacific to rise upward to altitudes where air is cooler, causing it to precipitate much of the water it is holding. As a result, rainfall is sparse east of the Rocky Mountains, leading to deserts and shortgrass prairies. Further east, moist air rises northward from the Gulf of Mexico and is absorbed by the warmer, descending air. This allowed for the formation of mixed grass prairies in central Kansas and Nebraska, and further east for the growth of tallgrass prairies, which receive twice as much rainfall as the shortgrass prairies. Still further east, deciduous forests grow and pose a risk to the eastern edge of what was once the tallgrass prairie ecosystem.[11]

Partially as a result of this variation in moisture levels based on geographic location, different species are more prominent in different regions of tallgrass prairie. For example, northern prairies tend to have a higher proportion of shorter, drier species.[12] However, overall tallgrass prairies have been dominated by big bluestem, Indian grass, and switchgrass through out North America. While these species are the most dominant, largely due to their visibility, they are not by any means the only species on the prairie. Fifty-two percent of vascular diversity in prairies are in perennial forbs, and in some cases, 73% of flora can be herbaceous perennials. Graminoids, in contrast, contribute only about a quarter of total species diversity.[13] Examples of other significant species include oak groves in drier areas, transitional species in mixed grass

[11] O.J. Reichman, *Konza Prairie* (Kansas: University Press of Kansas, 1994), 5.
[12] Taylor H. Ricketts, Eric Dinerstein, David M. Olson, Colby J. Loucks, William Eichbaum, Dominick DellaSalla, Kevin Kavanagh, Prashant Hedao, Patrick Hurley, Karen Carney, Robin Abell, and Steven Walters, *Terrestrial Ecoregions of North America: A Conservation Assessment (World Wildlife Fund Ecoregion Assessments)* (Washington, DC: Island Press, 1999).
[13] Douglas Ladd, "Vascular Plants of Midwestern Tallgrass Prairies," in *The Tallgrass Restoration Handbook for Prairies,* edited by Steven Packard and Cornelia F. Mutel (Washington, DC: Island Press, 1997) 351-399.

areas, and underground microbial communities.[14] Factors that can influence species diversity aside from geographic location include substrate material, terrain, and dynamic patches of microhabitat that result from disturbance, rainfall, or changes in temperature, light, or moisture.[15]

Variation in what may initially appear to be a static environment is a defining feature of natural ecosystems and leads to a problem in clearly defining ecoregion boundaries. Nature does not necessarily understand the human need to create clear lines to separate one area from another – ambiguous regions are common. In the case of tallgrass prairies, determining their actual historic location has been made still more difficult by the enormous extent to which they have been lost. Most agree that tallgrass prairie originally covered, "most of what is now Iowa, Illinois, southern Minnesota, northern Missouri, and the eastern edges of the Dakotas, Nebraska, Kansas and Oklahoma".[16] However, the exact outline of the region is still somewhat fuzzy. A major reason for this has to do with the way that one chooses to define the ecoregions. Two of the most widely-adopted systems for defining ecoregions are those of Robert Bailey and James Omernik. Bailey's hierarchical system defines ecoregions using macroclimate as the principle factor. This is logical because macroclimate has a strong impact on the distribution of life on Earth. Smaller ecological levels are further defined by smaller climate subzones. In contrast, Omernik's system, which is used by the U.S. Environmental Protection Agency, uses a number of environmental factors, such as potential natural vegetation, physiogeography, land use, and soils, to define ecoregions.[17] Different factors are given different weight. The contrast between these two systems is striking – Bailey defines 28 ecoregions, 21 of which are found in the United

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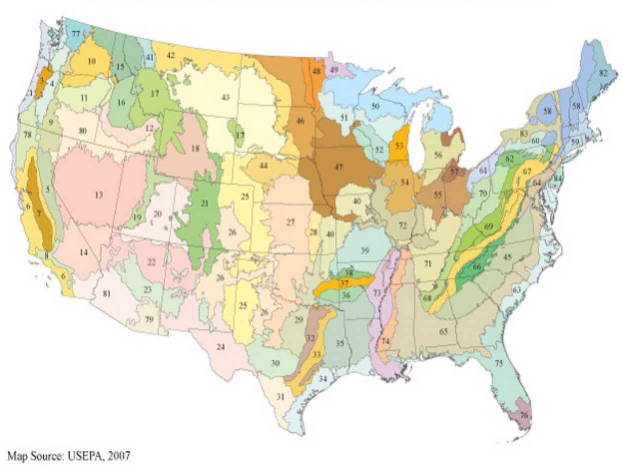
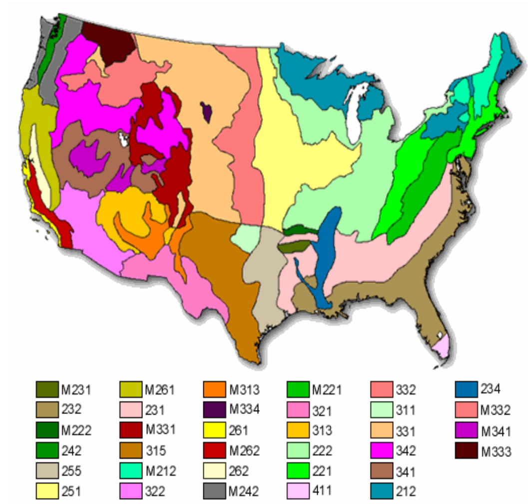
[14] Michael R. Miller, "Prairie Underground," in *The Tallgrass Restoration Handbook for Prairies,* edited by Steven Packard and Cornelia F. Mutel (Washington, DC: Island Press, 1997), 23-27.
[15] O.J. Reichman, *Konza Prairie* (Kansas: University Press of Kansas, 1994), 40.
[16] Ibid.
[17] Bruce A. Stein, Lynn S. Kutner, and Jonathon S. Adams, eds. *Precious Heritage: The Status of Biodiversity in the United States*. (New York: Oxford University Press, 2000), 208-209.

States, while Omernik identifies 76 ecoregions across the United States.[18] Their maps can be compared below:



Derived from Omernik
http://www.epa.gov/we
d/pages/ecoregions/lev



Bailey
http://el.erdc.usace.army.mil/emrr
p/emris/emrishelp2/provinces_bail

The World Wildlife Fund and the Nature Conservancy have also each developed different maps of ecoregions in the United States, largely based on the work of Bailey and Omernik.

While different ecoregion systems result in different definitions of the historical location of tallgrass prairie, it is important to note that there are far more similarities between the maps than differences. There are variations around the edges, but there is general agreement on the major areas. This is partially because most systems are based on a potential vegetative map of the United States created by August W. Küchler.[19] Additionally, it is also important to recognize that the lines drawn on these maps do not necessarily correlate specifically to areas on the ground – particularly when much of the habitat being recorded has since been destroyed, and it is effectively impossible to pinpoint exactly where one region ended and another began. For this

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[18] Ibid.

[19] Taylor H. Ricketts, Eric Dinerstein, David M. Olson, Colby J. Loucks, William Eichbaum, Dominick DellaSalla, Kevin Kavanagh, Prashant Hedao, Patrick Hurley, Karen Carney, Robin Abell, and Steven Walters, *Terrestrial Ecoregions of North America: A Conservation Assessment (World Wildlife Fund Ecoregion Assessments)* (Washington, DC: Island Press, 1999), 12.

reason, this paper interprets the "tallgrass prairie" region broadly, considering an area to be historically tallgrass prairie if it is categorized as such on any of the four maps being considered (those of Bailey, Omernik, the Nature Conservancy, and the World Wildlife Fund).

Today, the location of tallgrass prairies has changed drastically, as they have been largely degraded either for farming or cattle grazing. Presently, less than 5% of the original habitat remains, mainly in areas that were found unsuitable for cultivation (such as the Flint Hills, which were not possible to plow due to the underlying limestone). The impacts of this treatment will be examined below.

Impacts of Disturbance to Tallgrass Prairies

Essential Functions of a Healthy Prairie

In order to fully understand the impacts that can result from human intervention on virgin tallgrass prairie ecosystems, it is first necessary to understand how prairies function prior to human interference. For example, in a tallgrass prairie, disturbance is the norm. One of the most crucial functions is regular burns. Although at first glance these may seem extremely destructive, it has been revealed that they are actually necessary to maintain a tallgrass prairie. The accumulation of dead grasses and other detritus can be damaging by limiting the ability of water and sunlight to reach the soil. Not only do they directly interfere by acting as a barrier, but they also allow smaller organisms on top of grass litter to use rainwater and nitrogen first, preventing it from ever reaching the soil.[20] Detritus can limit the amount of useable energy reaching the soil from the sun by as much as 58%.[21] Temperature of new shoots of some plants (such as big bluestem, one of the most prominent species on the prairie) can also be increased by the presence of detritus, causing them to lose more water to evapotranspiration. At the same time,

[20] O.J. Reichman, *Konza Prairie* (Kansas: University Press of Kansas, 1994), 104-114.
[21] A.K. Knapp and T.R. Seastedt, "Detritus Accumulation Limits Productivity of Tallgrass Prairie," *BioScience*: 36, no. 10 (1986): 662-668. http://www.jstor.org/stable/1310387 (Accessed April 18, 2010).

temperatures at soil level are reduced, potentially delaying the start of the growing season. These factors, combined with the reduced access to nutrients, water, and sunlight, can combine to cause physiological and morphological changes in the grasses that lead to up to 32% lower rates of carbon dioxide fixation[22]. By removing this detrimental layer, fire is enormously beneficial to prairie health.

In addition to clearing out dead plant life, fire also provides a number of other services to the prairie. For example, by converting these dry plants into ash, it puts nitrogen and other nutrients into a form that is absorbed much more easily. Although some of the nutrients are lost in the burn, the efficiency of this process relative to slow breakdown by microorganisms more than makes up for this loss.[23] Burns also reduce competition by removing species that have not specifically evolved to handle this competition. This includes woody invaders, which are both destroyed by burns and are prevented from taking root by stronger root systems that are encouraged by burns.[24] At the same time, the productivity of the native prairie species is increased due to the aforementioned positive impacts of burns. In areas that are burned every other year, plant production can increase by more than 75% relative to areas that go unburned.[25]

Between the release of nutrients, improved temperature conditions, limitation of invasive species, and enhanced access to water, nutrients, and sunlight for photosynthesis, the benefits of fire to tallgrass prairies are clear. However, it is significant to note the damaging impacts of fires as well. For example, as mentioned earlier, some nutrients can be lost in the burn or blown away as ash following the burn. There are also some species that are native to prairies that are not necessarily adapted to regular burns and instead are damaged. Included in this category are some

[22] Ibid.
[23] O.J. Reichman, *Konza Prairie* (Kansas: University Press of Kansas, 1994), 104-114.
[24] Wayne R. Pauly, "Conducting Burns," in *The Tallgrass Restoration Handbook for Prairies,* edited by Steven Packard and Cornelia F. Mutel (Washington, DC: Island Press, 1997), 223-243.
[25] O.J. Reichman, *Konza Prairie* (Kansas: University Press of Kansas, 1994), 104-114.

forbs and cool-season grasses, which are not equipped to cope with burns in the same way as warm-season grasses.[26] As a result, burns later in the season may reduce the dominance of such cool-season grasses as porcupine grass and Canada wild rye. While forbs can be completely killed in a fire, cool-season grasses that are dormant during a spring burn are still able to recover. As a result, burns alter the proportion of species diversity on a prairie, but the overall benefits to the prairie more than outweigh these few shortcomings.[27]

Sources of disturbance aside from fire are also important in tallgrass prairies. The habitats within tallgrass prairies are characterized by the dynamic patches of microhabitats that result from disturbance. Historically, one of the most significant forces were prairie animals such as bison, although the mass slaughter of bison in the 1800s combined with great reduction in habitat have drastically reduced populations, making their interaction with the ecosystem difficult to study.[28] Similarly, populations of elk, coyote, and prairie wolves have also been greatly reduced. Other animals that impact microhabitats include rabbit, birds, white-tailed deer, and ground squirrels.[29] These animals impact the environment in many ways, such as by foraging for food, walking on the ground, and competing for and consuming resources. Actions such as these can aerate or compact the soil, influencing the growth of plants and their access to nutrients. These disturbances contribute to the biodiversity of prairies in that different microhabitats create opportunities for different species to take root.[30] For example, in foraging for insects, bird

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[26] Ibid.

[27] Wayne R. Pauly, "Conducting Burns," in *The Tallgrass Restoration Handbook for Prairies,* edited by Steven Packard and Cornelia F. Mutel (Washington, DC: Island Press, 1997), 223-243.

[28] Alan K. Knapp, John M. Blair, John M. Briggs, Scott L. Collins, David C. Hartnett, Loretta C. Johnson, and E. Gene Towne, "The Keystone Role of Bison in North American Tallgrass Prairie," *BioScience* 49, no. 1 (1999): 39-50. http://www.jstor.org/stable/1313492 (Accessed April 18, 2010).

[29] Taylor H. Ricketts, Eric Dinerstein, David M. Olson, Colby J. Loucks, William Eichbaum, Dominick DellaSalla, Kevin Kavanagh, Prashant Hedao, Patrick Hurley, Karen Carney, Robin Abell, and Steven Walters, *Terrestrial Ecoregions of North America: A Conservation Assessment (World Wildlife Fund Ecoregion Assessments)* (Washington, DC: Island Press, 1999).

[30] Ibid.

species may expose areas of soil in which new seeds can be successful. Without disturbance, a combination of detritus and thick roots would make this almost impossible.

The impact of grazing, particularly by bison, has been especially significant to tallgrass prairies. For example, shallows that bison once used for wallowing at times that they were full of mud can still be seen as depressions in some areas where bison have not been seen for 100 years.[31] These wallows increase diversity in the prairie by creating areas that fill with water during rains, creating temporary wetland microhabitats. It has also been shown that ungrazed prairie is more susceptible to incursive growth of shrubs than grazed prairie.[32] Another factor that contributes to increased diversity on prairies occupied by bison is selective grazing. Bison preferentially graze on grasses, giving a competitive edge to forbs that increases the overall diversity of the prairie. These actions also contribute to redistribution of nutrients through bison waste and by limiting the above-ground part of grass plants, reducing overall nutrient losses in fires. Similarly, the decomposition of bison carcasses also releases an enormous amount of nutrients into patches of the environment. [33] While cattle to a certain extent can fill this niche on restored prairies, there are important differences between the two species that will be addressed below.

Another important feature of tallgrass prairies is soil fungi. The activity that goes on beneath the surface is at least as important as the activity that goes on above it. This is true to the point that tallgrass prairies have been described as a root-driven ecosystem.[34] The highly active root-soil interface (rhizosphere) is the location of an enormous amount of biological activity

[31] O.J. Reichman, *Konza Prairie* (Kansas: University Press of Kansas, 1994), 48-52.
[32] Richard J. Hobbs, and Laura F. Huenneke, “Disturbance, Diversity, and Invasion: Implications for Conservation,” *Conservation Biology* 6, no. 3 (1992): 324-337. http://www.jstor.org/stable/2386033 (Accessed April 18, 2010).
[33] Alan K. Knapp, John M. Blair, John M. Briggs, Scott L. Collins, David C. Hartnett, Loretta C. Johnson, and E. Gene Towne, “The Keystone Role of Bison in North American Tallgrass Prairie,” *BioScience* 49, no. 1 (1999): 39-50. http://www.jstor.org/stable/1313492 (Accessed April 18, 2010).
[34] Michael R. Miller, “Prairie Underground,” in *The Tallgrass Restoration Handbook for Prairies,* edited by Steven Packard and Cornelia F. Mutel (Washington, DC: Island Press, 1997), 23-27.

involving the movement of nutrients between root systems, mycorrhizal fungi, and the soil. The symbiotic relationship between mycorrhizal fungi and the majority of prairie plants generally functions in one of two ways: either endophytic fungi act as an extension of the plant's own root system, bringing in nutrients from the soil back to the root system or a rhizobia-root nodule association exists. The former is critical for warm-season grasses and varies among cool-season grasses and forbs, while the latter is found in legumes.[35]

These interactions contribute to the health of tallgrass prairies in a number of ways. For example, they play a crucial role in the formation of soil aggregates. Stable aggregates of soil are the source of much of the productivity of these grasslands, in that they enable hydraulic conductivity of soils, as well as aeration and transmission of nutrients.[36] Additionally, they are a major factor in preventing erosion. The presence of mycorrhizal fungi has also been found to increase the health of host plants by increasing tolerance to heavy metals as well as disease resistance.[37] Activity of microbes in the soil also contribute to the growth of tallgrass prairie species by enabling access to nitrogen in the soil, which is generally in organic form and unavailable for uptake by plants.[38] The significance of the role of soil fungi is reflected in the way that it impacts interactions between species. For example, while in many ways necessary for a healthy tallgrass prairie, mycorrhizal fungi can also benefit invasive species that are in direct competition with native plants and are difficult to eradicate. For these reasons, it is possible to

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[35] Ibid.

[36] J.D. Jastrow, "Changes in Soil Aggregation Associated with Tallgrass Prairie Restoration," *American Journal of Botany* 74, no. 11 (1987): 1656-1664. http://www.jstor.org/stable/2444134 (Accessed April 18, 2010).

[37] Michael R. Miller, "Prairie Underground," in *The Tallgrass Restoration Handbook for Prairies,* edited by Steven Packard and Cornelia F. Mutel (Washington, DC: Island Press, 1997), 23-27.

[38] Dorota L. Porazinska, Richard D. Bardgett, Maria B. Blaauw, William H. Hunt, Andrew N. Parsons, Timothy R. Seastedt, and Diana H. Wall, "Relationships at the Aboveground-Belowground Interface: Plants, Soil Biota, and Soil Processes," *Ecological Monographs* 73, no. 3 (2008): 377-395. http://www.esajournals.org/ (Accessed April 18, 2010).

conclude that in restoring tallgrass prairies, it is necessary to be aware of changes happening below ground as well as above.

Human Impacts

Humans have interacted with prairies for hundreds of years, beginning with Native Americans who learned to use burns to influence the movement of bison herds. However, since European settlement and cultivation the nature of these interactions has changed, leading to widespread loss of species and habitat degradation. Conversion of an area of tallgrass prairie for cropland is potentially the most destructive thing that can happen to it. The ecosystem is completely wiped out, leaving no sign that it was there except for the presence of fertile soil from which to grow cash crops. The majority of damage is the result of plowing the soil and the application of fertilizers and other chemicals that can alter activity and productivity of the soil.

Plowing for cultivation obviously is destructive in that it removes all present vegetation in order to make room for crops. It is worth noting that the Flint Hills of eastern Kansas, which include some of the largest remaining areas of relatively undisturbed tallgrass prairie (including Konza Prairie), remain so because the presence of limestone beds made them unsuitable for plowing. Plowing can be a critical step in the restoration of tallgrass prairies, in that areas that have already been severely degraded may benefit from simply being plowed under and reseeded with native plants.[39] However, if there are any conservative or rare species remaining, this strategy is considered to be more damaging than beneficial, indicating that plowing can damage healthy tallgrass prairie.[40] Other impacts from plowing have been extensively studied. One major consequence that has been found is that it releases carbon sequestered in the soil. This has

[39] Stephen Packard and Laurel M. Ross, "Restoring Remnants," in *The Tallgrass Restoration Handbook for Prairies,* edited by Steven Packard and Cornelia F. Mutel (Washington, DC: Island Press, 1997), 63-88.
[40] Ibid.

implications both for global climate change and for soil health. Soil organic carbon plays a major role in what makes the soil of tallgrass prairies valuable, in terms of water retention, plant nutrition, soil aggregation, and erosion-prevention.[41] However, for the first 20 years following cultivation, this important nutrient is continually lost. According to one study, it can take 50-75 years following restoration for soil organic matter to return to levels prior to cultivation.[42] Soil aggregates are similarly altered by disturbance of the soil for purposes of cultivation.

Disturbance of soil in any way can also pave the way for invasive species. While it has already been shown that disturbance from animals, fires, and other natural factors play a crucial role in tallgrass prairie ecosystems, a moderate level of disturbance has been shown to be generally preferable. In contrast, plowing for the purposes of cultivation destroys previously extensive root systems as well as native species, which allows competitive species to both take root and thrive. Additionally, the act of disturbing soil may create a rougher surface for invasive seeds to attach to.[43]

The addition of soil nutrients in the form of fertilizers are another action associated with cultivation that can be very counterproductive to tallgrass prairie restoration. Species native to tallgrass prairies establish well on nutrient-poor soils and are able to return nutrients to the soil over time. However, fertilizers favor weeds that will compete with these native species.[44] The response of these lands to the addition of nitrogen and phosphorous has been compared to eutrophication in aquatic ecosystems – although the abundance of mycorrhizal fungi appears to

[41] Richard T. Conant, Keith Paustian, and Edward T. Elliot, "Grassland Management and Conversion into Grassland: Effects on Soil Carbon," *Ecological Applications* 11, no. 2 (2001): 343-355. http://www.jstor.org/stable/3060893 (Accessed April 18, 2010).
[42] Kendra K. McLauchlan, Sarah E. Hobbie, and Wilfried M. Post, "Conversion from Agriculture to Grassland builds Soil Organic Matter on Decadal Timescales," *Ecological Applications* 16, no. 1 (2006): 143-153. http://www.jstor.org/stable/40061787 (Accessed April 18, 2010).
[43] Richard J. Hobbs, and Laura F. Huenneke, "Disturbance, Diversity, and Invasion: Implications for Conservation," *Conservation Biology* 6, no. 3 (1992): 324-337. http://www.jstor.org/stable/2386033 (Accessed April 18, 2010).
[44] Virginia M. Kline, "Planning a Restoration," in *The Tallgrass Restoration Handbook for Prairies,* edited by Steven Packard and Cornelia F. Mutel (Washington, DC: Island Press, 1997), 31-46.

be increased, overall diversity is greatly reduced and the ecosystem becomes dominated by a few species.[45, 46]

Another form of cultivation that can impact tallgrass prairies is overgrazing. As discussed above, grazing itself can be beneficial by fulfilling the role played in the past by bison. In many cases of restoration, grazing (or mowing, as a substitute) is considered necessary to the growth of native species. However, the most effective amount of grazing seems to be moderate and related to the amount that the particular prairie would be grazed in nature.[47] Therefore, while damage is generally less intense than in the case of cultivation, due to the fact that grazing of cattle is still based on grass, and as a result does not require plowing, overgrazing of tallgrass prairies can still be extremely detrimental. By allowing too much of the top of a plant to be removed, the root systems are also weakened, limiting the uptake of water and nutrients. Over time, the system deteriorates, and species are lost. In extreme cases, desertification can occur.[48] Therefore, it is important to ensure that grazing is managed correctly.

One way that sustainable grazing is being practiced is through patch and burn grazing, which makes use of two important mechanisms of disturbance in prairies to raise animals for meat in the same spaces that prairies are being restored. However, while cattle and bison resemble each other behaviorally in many respects, there are still important differences between the two that should be acknowledged and will impact a tallgrass prairie. For example, cattle neither wallow nor are left to decompose after death. This removes one of the major ecological impacts of bison: the creation of microhabitats in wallows or high-nutrient areas from their

[45] Ahn-Heum Eom, David C. Hartnett, Gail W.T. Wilson, and Deborah A.H. Figge, "The Effect of Fire, Mowing, and Fertilizer Amendment on Arbuscular Mycorrhizas in Tallgrass Prairie," *The American Midland Naturalist Journal* 142 (1999): 55-70. http://www.jstor.org/stable/2426892 (Accessed April 18, 2010).
[46] Richard J. Hobbs, and Laura F. Huenneke, "Disturbance, Diversity, and Invasion: Implications for Conservation," *Conservation Biology* 6, no. 3 (1992): 324-337. http://www.jstor.org/stable/2386033 (Accessed April 18, 2010).
[47] Ibid.
[48] Michael Pollan, *The Omnivore's Dilemma* (New York: Penguin Books, 2006), 189-190.

decomposing carcasses. Additionally, bison graze more preferentially on grasses, leading to a lower proportion of annual forbs.[49] It is true that domestic cattle resemble bison in more respects than many other ungulates; however, these differences serve as a reminder that cattle cannot be called upon to fulfill every role of bison in a native prairie. This is another factor that should be considered in relation to overgrazing.

Fragmentation is another consequence of cultivation that can be damaging to tallgrass prairies. Both edge effects and adjacent lands can influence the species and traits of a prairie. Species that inhabit the edges of an ecosystem are different than those that inhabit the interior. As a result, very small patches of restored prairie may increase diversity, but without balancing the needs of all varieties of species. For example, one study found that many patches of tallgrass prairie, interspersed with heavily grazed patches, led to a much higher biodiversity than one large area of prairie. When species that are benefiting from fragmentation are aggressive or exotic species, it is important to create larger restoration areas. While whether this is the case remains unclear,[50] fragmentation will be problematic for certain species which cannot be supported by smaller areas, such as prairie chickens or bison. Similarly, species such as butterflies that are dependent on a large amount of one plant may benefit from very large areas, as this is more likely to result in a large amount of that plant.[51] Land adjacent to fragments can also have an impact on the health of a restored prairie. For example, as mentioned above, overall diversity was increased when patches of prairie were interspersed with heavily grazed patches. However, these same patches may not have fared as well if interspersed with cropland, where they were at

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[49] Alan K. Knapp, John M. Blair, John M. Briggs, Scott L. Collins, David C. Hartnett, Loretta C. Johnson, and E. Gene Towne, "The Keystone Role of Bison in North American Tallgrass Prairie," *BioScience* 49, no. 1 (1999): 39-50. http://www.jstor.org/stable/1313492 (Accessed April 18, 2010).

[50] Richard J. Hobbs, and Laura F. Huenneke, "Disturbance, Diversity, and Invasion: Implications for Conservation," *Conservation Biology* 6, no. 3 (1992): 324-337. http://www.jstor.org/stable/2386033 (Accessed April 18, 2010).

[51] Virginia M. Kline, "Planning a Restoration," in *The Tallgrass Restoration Handbook for Prairies,* edited by Steven Packard and Cornelia F. Mutel (Washington, DC: Island Press, 1997), 31-46.

risk for accidental exposure to pesticides, herbicides, or other chemicals used in agriculture. Proximity to woodlands is also detrimental, in that trees and shrubs have a tendency to reduce exposure to sun and wind. Increases in shade and decreased wind can limit the ability of some species to thrive in these areas. There is additionally the risk that these species will invade, spreading through the prairie and decreasing overall quality.[52] These are factors that must be considered in selecting areas for restoration, and specifically area size.

Defining a Successfully Restored Prairie

One of the first things to consider in selecting an area of prairie to be restored is whether it is part of what was historically a tallgrass prairie. There are a variety of possibilities in making this choice. For example, restoration can occur on lands that are merely degraded tallgrass prairies, or areas that were historically tallgrass prairies but are entirely degraded following cultivation and invasion by exotic species, or in areas that technically belong to other ecoregions. With this wide range of possibilities, it is necessary to determine at what point the value of the restored plot is reduced. In general, the value of restoring a prairie outside its historical range is greatly reduced. For example, historically woody areas that are capable of supporting tallgrass prairie but are likely to be degraded by invasion of nonnative species are not very beneficial to tallgrass prairie restoration. Alternatively, an area of the mixed-grass prairie ecoregion that lies adjacent to a tallgrass prairie ecosystem and is degraded to the point that it needs to be entirely reseeded may be more useful as a tallgrass prairie, being from a similar area and capable of supporting this ecosystem which is more rare than mixed-grass prairies. This relates back to the idea that ecoregions are not very clearly defined in nature, allowing for some flexibility. Additionally, patches of tallgrass prairie (particularly on the edges) may resemble mixed-grass prairie in terms of species composition. This is likely a result of the similar climate between the

[52] Ibid.

two adjacent areas. However, “restoring” a tallgrass prairie in an area with an entirely separate climate may not be effective. While it may be possible for some native species to take root, it is likely not possible to recreate the entire ecosystem, due to the fact that only hardier or season-specific plants would be able to thrive. As a result, these areas may be put to better use in restoring a native ecosystem that could be supported entirely, and as a result be more productive and efficient in terms of biodiversity. This is particularly true in that migrating birds or insects (e.g. butterflies) that benefit from the presence of restored patches as islands in which to rest during migration would likely not make use of these misplaced segments, depending on how far removed they are from the native ecosystem. This problem would reduce the overall advantages of establishing this tallgrass prairie. By avoiding restoring tallgrass prairies in increasingly unnatural places, it is possible to ensure the maximum environmental value is reaped from the amount of effort put into restoration. This would also prevent the spread of exotic species within these regions from the “restored” environment. As a result, it is determined that prairies that are not located within or very near to the established tallgrass prairie ecosystem cannot be considered restored prairies.

Another historical aspect of choosing areas for restoration relates to the past usage of these areas. For example, as mentioned earlier, areas being selected can range from moderately degraded remnants to entirely destroyed cropland that has been plowed and depleted of nutrients. The latter option is not ideal because of the damage to root systems as a result of plowing. The density of these roots takes a long time to be established. However, the vast majority of tallgrass prairie that has been destroyed has been for agriculture. This makes it necessary to restore tallgrass prairies even in these areas. The way that that soil and root systems are impacted by restoration is discussed in more depth below.

The size of a plot of land chosen for tallgrass prairie restoration also can impact how successful the restoration is. In general, a larger restoration can be considered more valuable for a number of reasons. For example, the heterogeneous quality of a large, natural prairie may increase biodiversity in that patches of microhabitats provide a greater variety of niches. A single large area can also provide habitat for native animals that require more space, thus increasing biodiversity. For example, a very large amount of land is necessary to support bison, which are a keystone species in tallgrass prairie and can greatly increase the quality. Similarly, larger areas contribute to increased reptile species-richness.[53] Such large areas would also limit damages to species richness in the event of ecosystem changes by facilitating movement of species, making it less likely for an entire population to be lost. This buffer against local extinction is extremely valuable to such a vastly degraded ecosystem. Smaller patches of restored prairie are also more susceptible to edge effects simply because the ratio of edge perimeter to area is high. While patches of grassland have been found to be more biodiverse than equivalent grasslands in one large area, it is possible that such an arrangement favors invasive or weedy species, rather than conservative species. [54] This is particularly true when adjacent lands are occupied by woody plants that are liable to invade the restored prairie and reduce diversity.[55]

While the value of a restored prairie is generally increased by greater size, there are still many benefits to smaller restorations. This is particularly true in that tallgrass prairie has become such a rare ecosystem in North America, making any amount of restoration valuable. Restored prairies as small as a quarter-acre have been found to provide a habitat for rare and conservative

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[53] Kenneth S. Mierzwa, "Amphibians and Reptiles," in *The Tallgrass Restoration Handbook for Prairies,* edited by Steven Packard and Cornelia F. Mutel (Washington, DC: Island Press, 1997), 319-337.
[54] Richard J. Hobbs, and Laura F. Huenneke, "Disturbance, Diversity, and Invasion: Implications for Conservation," *Conservation Biology* 6, no. 3 (1992): 324-337. http://www.jstor.org/stable/2386033 (Accessed April 18, 2010).
[55] Virginia M. Kline, "Planning a Restoration," in *The Tallgrass Restoration Handbook for Prairies,* edited by Steven Packard and Cornelia F. Mutel (Washington, DC: Island Press, 1997), 31-46.

native species.[56] In doing this, small patches of restored tallgrass prairie can serve as islands of respite for species that may otherwise have nowhere else to go. Small restored prairies are also important when the ways in which they are likely to be otherwise employed are considered. For example, on the privately owned front lawn of a house, a miniature tallgrass prairie is certainly healthier for the environment than exotic species that are watered and fertilized to encourage growth and treated with herbicides to prevent undesirable weeds. Similarly, the use of roadside columns as a way to provide a connection between disjointed patches of restored habitat has been advocated as a way to make productive environmental use out of otherwise unoccupied land. Although the strip design of these restored prairies is obviously in conflict with the desire to reduce edge effects, this again is counteracted by the benefit of increased tallgrass prairie to the environment. For example, butterflies have been found to benefit enormously from the establishment of roadside prairies.[57] These examples demonstrate that while large tracts of restored tallgrass prairie are preferable, the positive impacts of small-scale restoration should not be underestimated. For this reason, no amount can legitimately be categorized as too small.

The next questions in what defines a tallgrass prairie as successfully restored are more complex. These require consideration of what makes a tallgrass prairie a tallgrass prairie, as opposed to simply an uncultivated or unoccupied expanse of land. One of the primary factors of this definition obviously involves the presence of native vegetation characteristic of tallgrass prairies, such as big bluestem, Indian grass, and switchgrass. These plant species can often be reestablished within only a few growing seasons. However, it has also been established earlier in this paper that it takes many years of restoration for certain aspects of a prairie to be restored to the point that they resemble the environment that existed prior to human intervention. As a

[56] Virginia M. Kline, "Planning a Restoration," in *The Tallgrass Restoration Handbook for Prairies,* edited by Steven Packard and Cornelia F. Mutel (Washington, DC: Island Press, 1997), 31-46.
[57] Ibid.

result, any definition of a successfully restored tallgrass prairie must also include a quality aspect. There are a number of factors that can be used to define ecosystem quality – for example, the presence of a broad range of biodiversity, the ability to maintain itself without human intervention, the return of ecosystem services or the well-established presence of native species are all applicable. In recognition of the fact that many of these factors are integrated and indicators of each other, as well as in the interest of avoiding speculation by using information from previous studies, this paper will determine quality based on a few selected factors. These factors will be root depth and density of native grasses, soil characteristics (including size and diversity of microbial communities) and diversity and quality of native species.

The first of these characteristics, root depth and density, is significant in that it reflects the extent to which these grasses are established, particularly in a tallgrass prairie, where the root-soil interface is such an important and active area. Deep roots are necessary for transferring water and other nutrients deep into the soil, making them a significant contributor to ecosystem services, by assisting in recharging the water table and restoring the quality of soil. Additionally, in grasses like big bluestem, extensive underground root systems include horizontal stems called rhizomes, from which shoots are sent up during the growing season. By keeping these stems and as much as 60% of their biomass underground, these plants are able to recover from damage (such as from drought or grazing).[58] Therefore, the extensiveness of the root systems is a good indicator of the ability of the ecosystem to maintain itself. At the end of one growing season, it is possible for a new big bluestem plant to have roots extending two to four feet into the soil, but over several growing seasons they may reach depths of 12 feet or more.[59] One study found that during 12 years of grassland restoration, root biomass continued to increase linearly, which may

[58] O.J. Reichman, *Konza Prairie* (Kansas: University Press of Kansas, 1994), 62.
[59] O.J. Reichman, *Konza Prairie* (Kansas: University Press of Kansas, 1994), 67.

be indicative of a longer amount of time being needed to return root systems to the point at which they resemble native prairie patches.[60] However, this same study found that after 12 years, the restored prairie resembled native unburned prairie in terms of root biomass. Additionally, the fact that 70-80% of root biomass resides in the top 20-30 cm may be an indicator that when roots are well-established in this relatively shallow area, they may be able to fulfill many of the tasks of the root system without necessarily having equivalent biomass to a native prairie. Based on this reasoning, tallgrass prairie root systems are close to those of undisturbed prairies after approximately 10-15 years of well-managed restoration, assuming that at this point root depth extends 2 meters or more (as they are capable of doing after 2-3 growing seasons) and root biomass in the top 20 cm of soil approaches 838 to 1362 g/m^2, the approximate biomass in the top 20-30 cm of native unburned tallgrass prairie.[61]

Soil conditions and the size and biodiversity of soil microbial communities, though underground, are also representative of the aboveground quality of the prairie.[62] For example, it has been found that the return of soil carbon to previously cultivated soils is increased by the presence of perennial grasses, as opposed to simply letting them lie fallow.[63] However, it can still take 50-75 years for soil organic matter to return to native conditions.[64] This demonstrates the role that the act of restoration plays in returning the prairie soil qualities to its native state. The

[60] S.G. Baer, D.J. Kitchen, J.M. Blair, and C.W. Rice, "Changes in Ecosystem Structure and Function Along a Chronosequence of Restored Grasslands," *Ecological Applications* 12, no. 6 (2008): 1688-1701.
[61] Ibid.
[62] Michael R. Miller, "Prairie Underground," in *The Tallgrass Restoration Handbook for Prairies,* edited by Steven Packard and Cornelia F. Mutel (Washington, DC: Island Press, 1997), 23-27.
[63] S.G. Baer, D.J. Kitchen, J.M. Blair, and C.W. Rice, "Changes in Ecosystem Structure and Function Along a Chronosequence of Restored Grasslands," *Ecological Applications* 12, no. 6 (2008): 1688-1701.
[64] Kendra K. McLauchlan, Sarah E. Hobbie, and Wilfried M. Post, "Conversion from Agriculture to Grassland builds Soil Organic Matter on Decadal Timescales," *Ecological Applications* 16, no. 1 (2006): 143-153. http://www.jstor.org/stable/40061787 (Accessed April 18, 2010).

table below provides an outline of some other soil qualities and how they change over the course of a prairie restoration:[65]

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Table 1
Physical, chemical and biological properties of soils investigated from Manhattan, KS, USA.[a]

Property[b]	Cropland	Restored grassland			Native tallgrass prairie		
	CTC	RG_{00}	RG_{98}	RG_{78}	BNP	BNP_{150}	UNP_{150}
pH	6.0 (0.1)	7.5 (0.1)	5.7 (0.1)	6.8 (0.5)	6.3 (0.04)	6.2 (0.2)	6.1 (0.3)
% Sand	3.6 (0.6)	5.4 (1.2)	4.3 (0.5)	3.6 (1.1)	5.8 (1.2)	5.9 (0.3)	6.1 (0.8)
% Silt	68 (5)	57 (7)	69 (8)	66 (2)	70 (3)	64 (5)	64 (1)
% Clay	29 (6)	37 (7)	27 (4)	30 (2)	24 (2)	30 (6)	30 (1)
EC ($\mu S\ cm^{-1}$)	112 (11)	127 (19)	63 (7)	95 (32)	94 (13)	89 (8)	120 (22)
Total organic C ($g\ kg^{-1}$ soil)	18 (1)	28 (1)	17 (2)	27 (1)	38 (2)	39 (5)	34 (0.2)
Total N ($g\ kg^{-1}$ soil)	1.6 (0.0)	2.3 (0.1)	1.6 (0.1)	2.1 (0.1)	3.0 (0.2)	2.8 (0.2)	2.7 (0.1)
Inorganic N ($mg\ kg^{-1}$ soil)	19 (3)	13 (2)	10 (1)	12 (1)	13 (2)	15 (0)	16 (2)
POC ($g\ kg^{-1}$ soil)	1.1 (0.3)	4.4 (0.1)	2.8 (0.3)	4.3 (1.0)	6.1 (0.1)	8.1 (1.6)	5.7 (0.7)
PON ($g\ kg^{-1}$ soil)	0.07 (0.02)	0.20 (0.01)	0.09 (0.01)	0.16 (0.04)	0.27 (0.04)	0.29 (0.07)	0.28 (0.02)
C_3 ($mg\ kg^{-1}$ soil)	76 (6)	246 (20)	167 (10)	252 (14)	333 (22)	399 (20)	330 (18)
C_{MIN} ($mg\ CO_2$–C^{-1} kg soil $24\ d^{-1}$)	169 (17)	793 (49)	504 (12)	756 (23)	838 (66)	1056 (68)	778 (10)
N_{MIN} ($mg\ kg^{-1}$ soil $24\ d^{-1}$)	30 (3)	17 (2)	14 (2)	29 (6)	71 (6)	45 (13)	84 (18)
SMBC ($mg\ kg^{-1}$ soil)	373 (52)	1119 (29)	491 (61)	938 (87)	1097 (63)	1246 (61)	940 (52)
$PLFA_{SUM}$ ($nmol\ g^{-1}$ soil)[c]	39 (6)	82 (4)	61 (8)	92 (9)	94 (24)	106 (20)	107 (15)
$PLFA_{WIN}$ ($nmol\ g^{-1}$ soil)	45 (15)	86 (9)	53 (8)	84 (8)	145 (13)	131 (8)	123 (19)
$Fungal/Bacterial_{SUM}$ Ratio	0.17 (0.02)	0.30 (0.02)	0.26 (0.03)	0.32 (0.03)	0.21 (0.02)	0.24 (0.02)	0.20 (0.02)
$Fungal/Bacterial_{WIN}$ ratio	0.31 (0.10)	0.36 (0.09)	0.26 (0.02)	0.38 (0.07)	0.31 (0.02)	0.31 (0.05)	0.27 (0.03)

[a] Values are mean (standard deviation) of three soil samples collected in summer.
[b] EC = Electrical conductivity; POC = Particulate organic C; PON = Particulate organic N; C_3 = Flush of CO_2–C during the first 3 days following rewetting of dried soil; C_{MIN} = Mineralizable C; N_{MIN} = Mineralizable N; and SMBC = Soil microbial biomass C.
[c] Values for PLFA and fungal/bacterial ratio are from summer (SUM) and winter (WIN).

In this table, CTC refers to a conventionally tilled cropland that had grown soybeans for greater than 50 years. RG denotes "restored grassland", with the subscript indicating since what year the land has been restored. RG_{00} is presented as a point of interest, but is of a different soil type than the other prairies presented and should not be used for the basis of comparison. BNP indicates "burned native prairie", while "UNP is "unburned native prairie." For these, the subscript indicates the size of the prairie in square meters.

Overall, these results indicate that as time passes following the restoration of a prairie, the pH becomes more neutral, carbon content overall increases, ion content increases, and soil microbial biomass increases. If these trends are taken to apply to most prairie restorations, they indicate that over time following a restoration, changes occur in the soil that create an

[65] Kamlesh Jangid, Mark A. Williams, Alan J. Franzluebbers, John M. Blair, David C. Coleman, and William B. Whitman, "Development of Soil Microbial Communities During Tallgrass Prairie Restoration," *Soil Biology and Biochemistry* 42 (2010): 301-312. http://www.sciencedirect.com/ (Accessed April 18, 2010).

environment that is increasingly conducive to supporting life. In this sense, the soil becomes healthier and more reminiscent of native prairie. Additionally, populations of microorganisms are also able to increase as a result of these changes (as indicated by the figures in the table), which are crucial to the health of native plants. However, the table also shows that many soil conditions have still failed to stabilize even following 28 years of restoration. For example, the standard deviation of pH in the 1978 restored grassland is 0.5, in contrast to the 0.04 of the native, burned prairie. Other factors were also shown to have not stabilized in the restoration time frame studied.[66] This indicates that a time frame greater than 30 years may be necessary for soil quality to be fully restored. Similarly, soil aggregation has also been found to greatly increase upon restoration following cultivation, although between 50 and 60 growing seasons appeared to be necessary for aggregates to reach the maximum for the soil type. However, the particularly rapid growth within the first 5-10 growing seasons may still have significant impacts on the overall biology of the soil.[67] Therefore, it may take considerably less time than suggested by studies of soil quality for the microbial populations and prairie species that they support to begin to resemble native prairie.

It is unclear whether plant communities influence the composition of microbial communities or vice-versa. However, the direct relationship between the two is established and demonstrates the importance of examining soil microbes for the purpose of determining quality of a restored prairie.[68] For example, the study of Janglid, et. al referenced above found that over time, the microbial communities grew more similar to those of the native prairie, but that in

[66] Ibid.
[67] J.D. Jastrow, "Changes in Soil Aggregation Associated with Tallgrass Prairie Restoration," *American Journal of Botany* 74, no. 11 (1987): 1656-1664. http://www.jstor.org/stable/2444134 (Accessed April 18, 2010).
[68] Katarina Hedlund, "Soil Microbial Community Structure in Relation to Vegetation Management on Former Agricultural Land," *Soil Biology and Biochemistry* 34 (2002): 1299-1307. http://www.sciencedirect.com/ (Accessed April 18, 2010).

transition some populations were common that existed neither prior to restoration nor in the native prairie. These transitional microbes are indicative of the need for a considerable amount of time to pass before the microbial communities are developed. This conclusion is reinforced by the finding that even following 28 years of restoration, the prairie had still not returned to its native state.[69] This reinforces earlier conclusions that in terms of soil quality, a relatively long period of time is necessary for restoration.

Finally, the aboveground qualities of the prairie are also extremely important. For example, often even with continued addition of native seeds, it has been found that after a few years of steady increase following restoration, prairie diversity begins to decline. This represents an important difference between native prairie remnants and restored prairie.[70] It is even more significant with the knowledge that it takes longer than this time frame for other characteristics to reach desired restoration goals. Unfortunately, this problem is potentially the result of dominance of certain desirable grasses, such as big bluestem and Indian grass, which are characteristic of tallgrass prairies. For example, one study found that on average, prairie restorations grow significantly higher and denser than native prairies.[71] This is the consequence of particularly tall species (such as big bluestem) growing in greater quantities and preventing settlement of other species. However, whether this is the sole reason for the diversity problem in restored prairies is unclear. Other explanations that have been suggested are that succession occurs at a faster rate on restored prairies or that restoration conditions favor certain species. For

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[69] Kamlesh Jangid, Mark A. Williams, Alan J. Franzluebbers, John M. Blair, David C. Coleman, and William B. Whitman, "Development of Soil Microbial Communities During Tallgrass Prairie Restoration," *Soil Biology and Biochemistry* 42 (2010): 301-312. http://www.sciencedirect.com/ (Accessed April 18, 2010).

[70] Philip Camill, Mark J. McKone, Sean T. Sturges, William J. Severud, Erin Ellis, Shano Talukder, and Andrew Trout, "Community- and Ecosystem-Level Changes in a Species-Rich Tallgrass Prairie Restoration," *Ecological Applications* 14, no. 6 (2004): 1680-1694. http://www.esajournals.org/doi/pdf/10.1890/03-5273 (Accessed April 18, 2010).

[71] Rebecca L. Ammann, and Dennis W. Nyberg, "Vegetation Height and Quality of Original and Reconstructed Tallgrass Prairies," *American Midland Naturalist* 154, no. 1 (2005): 55-66. http://www.jstor.org/stable/3566615 (Accessed April 18, 2010).

example, it is possible that restored prairies are more likely to develop mycorrhizal symbioses favoring clonal species, such as big bluestem. Similarly, it has also been suggested that the absence of disturbance from selective grazing of native fauna, such as bison, disrupts the balance of the restored prairie.[72] This evidence suggests that a successfully restored tallgrass prairie is not one that is unusually dense, nor one that is unusually tall, but rather one that is balanced and diverse in the manner of a native prairie.

An effective way to determine if the biodiversity of a restored prairie is beneficial to the goals of ecosystem restoration and reminiscent of the variety in a native prairie is to consider the presence of conservative species. These species thrive best in a successionally advanced community; in a well-restored prairie, they should outcompete most aggressive and exotic species.[73] One way of assessing prairie quality quantitatively is to use a ranking system that gives native plants a coefficient of conservatism that ranges from 0 to 10. Value is assigned only to native species and based on the conservatism of a species, as defined above.[74] A mean value for conservatism can then be determined. This system is particularly useful in that conservatism values can be changed to reflect location, making it possible to compare the quality of prairies from different areas of North America, despite differences in what defines a conservative plant for these areas.[75] Additionally, one study found that although a regularly burned prairie demonstrated the same effect of reduced diversity after only a few years seen in other restored

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[72] Philip Camill, Mark J. McKone, Sean T. Sturges, William J. Severud, Erin Ellis, Shano Talukder, and Andrew Trout, "Community- and Ecosystem-Level Changes in a Species-Rich Tallgrass Prairie Restoration," *Ecological Applications* 14, no. 6 (2004): 1680-1694. http://www.esajournals.org/doi/pdf/10.1890/03-5273 (Accessed April 18, 2010).
[73] Stephen Packard, "Restoration Options," in *The Tallgrass Restoration Handbook for Prairies,* edited by Steven Packard and Cornelia F. Mutel (Washington, DC: Island Press, 1997), 47-62.
[74] Ibid.
[75] Linda A. Masters, "Monitoring Vegetation," in *The Tallgrass Restoration Handbook for Prairies,* edited by Steven Packard and Cornelia F. Mutel (Washington, DC: Island Press, 1997), 279-301.

prairies, conservatism continued to increase.[76] This suggests that using conservatism is a more accurate way to determine prairie quality over time. Extrapolating on the (admittedly limited) information in this study, it will take about 20 years for restoration efforts to lead to a steady level of conservatism. The subjectivity of this rating system and the value assigned to the studied prairie (3.5), combined with fact that less-conservative native species are in many cases also necessary to a balanced ecosystem, lead to the conclusion that a conservatism value of between 3.5 and 5 would suggest a well-restored tallgrass prairie, in terms of aboveground plant species.[77] This should also imply a prairie that is not disproportionately dense or so dominated with a few species of grasses that other species are unable to grow.

Finally, insects and animals of the restored prairie must be considered. The importance of prairie size to these species has already been discussed. For example, species such as bison, prairie chickens, butterflies, and reptiles are all dependent on a relatively large patch of restored prairie. Bison are particularly significant, in that they not only indicate prairie quality but also contribute to it. However, many restorations cannot be expected to support species such as bison or breeding pairs of prairie chickens due simply to size. Other animal species can also serve as indicators of prairie quality. For example, many bird species have very specific requirements. One study compared bird diversity on differently-managed patches of restored prairie, particularly the abundance of Dickcissels, Eastern Meadowlarks, and Grasshopper Sparrows. This study found that greater bird diversity existed on grazed pastures and native prairie hayfields than on fields that are part of the Conservation Reserve Program (CRP). The difference in CRP fields seems to be the result of differences in prairie structure due to the ways in which

[76] Ibid.
[77] Linda A. Masters, "Monitoring Vegetation," in *The Tallgrass Restoration Handbook for Prairies,* edited by Steven Packard and Cornelia F. Mutel (Washington, DC: Island Press, 1997), 279-301

these areas were restored.[78] This is a sign that a higher abundance of prairie birds is indicative of a well-restored prairie. Because grasslands naturally have a lower diversity of prairies than many other areas, finding between 7 and 10 species can be considered a well-restored prairie in terms of bird diversity.[79] By contrast, insect species seem to be a poor indicator of prairie quality. Of about 1000 insects identified in a study of prairie insect needs, only a little more than a quarter were found to be remnant-reliant, or requiring very high quality prairies in order to survive.[80] It is therefore possible for a very great diversity of insects to exist on a prairie that is only moderately well-restored.

Status of Tallgrass Prairie Restoration in the United States

Concern for the tallgrass prairie ecosystem has been on the rise in recent years. Efforts have ranged from individual private properties to large projects funded by the government or conservation organizations that are being used to determine successful management techniques. The table below reflects many restoration efforts currently being undertaken and their respective locations:[81]

State	Prairie Name	Acres	State	Prairie Name	Acres
AR	Baker Prairie	70		Bluestem Prairie	3258
	Cherokee Prairie Natural Area	565		Pembina Trail and Pankratz Memorial Prairie	2500
	Chesney Prairie Natural Area	60		Richard Mathilde Elliott Scientific and Natural Area	529
	Downs Prairie Natural Area	34		Staffanson Prairie	95
	H.E. Flanagan Prairie Natural Area	357	**MO**	Diamond Grove Preserve	570
	Konecny Prairie Natural Area	49		Niawathe Prairie	240
	Railroad Prairie Natural Area	244		Osage	1467

[78] Corina J. Rahmig, William E. Jensen, and Kimberly A. With, "Grassland Bird Responses to Land Management in the Largest Remaining Tallgrass Prairies," *Conservation Biology* 23, no. 2 (2008): 420-432. http://www.ksuwildcats.com/withlab/publications/Rahmig_etal_2009.pdf (accessed April 18, 2010).
[79] Ibid.
[80] Douglas J. Taron, "Insects," in *The Tallgrass Restoration Handbook for Prairies,* edited by Steven Packard and Cornelia F. Mutel (Washington, DC: Island Press, 1997), 305-318.
[81] Adapted from: "Prairie People and Places," *Grassland Heritage Foundation,* http://grasslandheritage.org/peoplePlaces.php?action=explore.

	Roth Prairie Natural Area	41		Paint Brush Prairie	234
	Searles Praire Natural Area	10		Prairie State Park	2982
	Terre Noire Natural Area	71		Shaw Nature Reserve	
IL	Goose Lake Prairie Nature Preserve	1000		Taberville Prairie	1680
	Liberty Prairie	2500		Tucker Prairie	146
	Fermilab Prairie[82]	700		Wah-Kon-Tah Prairie	1040
	Midewin National Tallgrass Prairie	19,000	**NE**	Homestead National Monument of America	100
IA	Cayler Prairie	160		Nine-mile prairie	260
	Five Ridge Prairie	789		Twin Lakes Wildlife Management Area	1370
	Freda Haffner Kettlehole	110	**ND**	Sheyenne National Grasslands	71,000
	Hayden Prairie	240	**OK**	Tallgrass Prairie Preserve	32000
	Kalsow Prairie	160	**SD**	Ordway, Clovis, Altamont, Crystal Springs, Aurora, Sioux, Makoce Washte, and Vermillion	10,000 (together)
	The Loess Hills (Broken Kettle Grasslands, Knapp Prairie, Sioux City Prairie, Folsum Point Preserve)	>7000	**WI**	Avoca Prairie Savanna	1885
	Neal Smith National Wildlife Refuge	8654		Kettle Moraine Fen and Low Prairie	250
	Rolling Thunder Prairie	123	**KS**	El Dorado State Park	8000
MN	Agassiz Dunes	674		Konza Prairie	8616
	Blazing Star Prairie	160		The Prairie Center	300
				Tallgrass Prairie National Preserve	

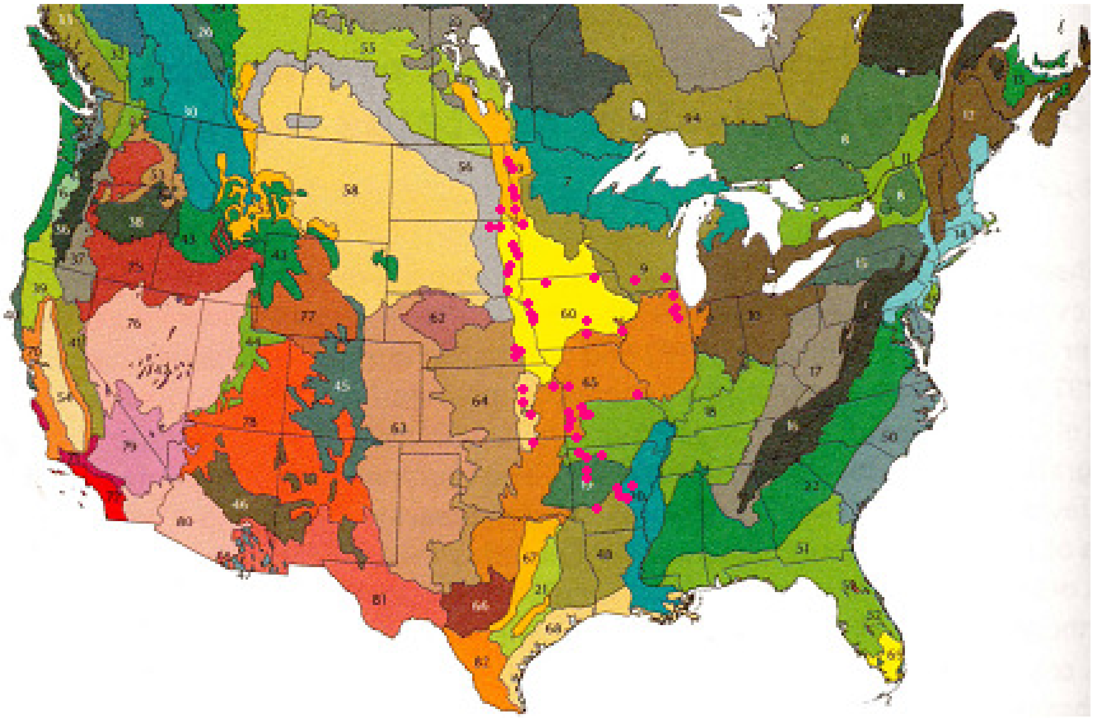
Many of these prairies are part of restoration projects that include not only tallgrass prairie, but also short- and mixed-grass prairie. This list should also not be taken as comprehensive. However, it does provide a good sense of where restoration efforts are being undertaken and what size these restorations are. Two other major projects being undertaken that are not reflected here are the Conservation Reserve Program, through which the U.S. government provides money to farmers to restore cropland for ecosystem services, and Iowa's integrated roadside vegetation management program, which is designed to use roadside lands to restore native vegetation (in

[82] Spencer Pasero, "Fermilab Restored Prairie," *Fermilab Prairie*, 2000, http://ed.fnal.gov/samplers/prairie/fnal_prairie.html.

contrast to their previous practice of maintaining a monoculture of exotic grasses).[83,84] These smaller-scale projects, combined with some of the large-scale restorations, such as Midewin National Tallgrass Prairie, Sheyenne National Grasslands, and Konza Prairie, demonstrate the ways in which public and private efforts have begun to move towards large-scale restoration projects. This is particularly true with Midewin, which is the first national tallgrass prairie in the country and was established in 1996.[85] It is important to recognize, however, that national grasslands have the goal of conservation, but for the explicit purpose of providing ecosystem services. Therefore, these lands are also somewhat at risk of exploitation despite their official status as restored grasslands. For example, one of the 4 states goals behind establishing Midewin National Tallgrass Prairie is, "To allow the continuation of existing agricultural uses of lands within Midewin National Tallgrass Prairie for the next 20 years, or for compatible resource management uses thereafter."[86]

Another important thing to consider is whether these restorations are being undertaken within the historical range of tallgrass prairie. The map below shoes the location of the restorations and remnants listed above in comparison to the World Wildlife Fund's map of ecoregions in the United States[87]:

[83] Patricia Engler, "Conservation Reserve Program," *Natural Resources Conservation Service*, 23 June 2009, http://www.nrcs.usda.gov/programs/CRP/.
[84] Leslie Ries, Diane M. Debinski, and Michelle L. Wieland, "Conservation Value of Roadside Prairie Restoration to Butterfly Communities," *Conservation Biology* 15, no. 2 (2001): 401-411. http://cefns.nau.edu/Academic/CSE/Lab/Documents/RiesDebinskiWieland.PDF (Accessed April 18, 2010).
[85] "About Midewin," *Midewin National Tallgrass Prairie*, 2002, http://www.fs.fed.us/mntp/about.htm.
[86] Ibid.
[87] Taylor H. Ricketts, Eric Dinerstein, David M. Olson, Colby J. Loucks, William Eichbaum, Dominick DellaSalla, Kevin Kavanagh, Prashant Hedao, Patrick Hurley, Karen Carney, Robin Abell, and Steven Walters, *Terrestrial Ecoregions of North America: A Conservation Assessment (World Wildlife Fund Ecoregion Assessments)* (Washington, DC: Island Press, 1999).



The major tallgrass prairie ecoregions in this map are 59, 60, and 61 (light orange, yellow, and beige), which form a strip down the middle of the map. Based on this, tallgrass prairie restoration appears to be taking place within a very loose interpretation of ecoregion guidelines. For example, it is clear that the vast majority of restorations that do exist are on the periphery of the historical area. However, many of these restorations also provide habitat for a wide variety of tallgrass prairie species. For example, Sheyenne National Grasslands is technically outside the historical range, but includes many native species, including prairie chickens, demonstrating that it still fulfills the goals of restoration.[88] It is interesting to note that although most of Iowa was at one time tallgrass prairie, there are only a few peripheral tallgrass prairies in this state. This is likely indicative of the prominence of agriculture in Iowa; it also shows an area where restoration could be expanded. Similarly, Missouri also shows room for improvement. While states like

[88] "Last Call for Tallgrass in North Dakota," *U.S. Geological Service: Northern Prairie Wildlife Research Center*, 3 August 2006, http://www.npwrc.usgs.gov/resource/plants/tallgras/lastcall.htm.

Wisconsin and South Dakota also have a very low area of tallgrass prairie restoration, these are also not states where tallgrass prairie was predominant in the past.

One problem that becomes apparent in looking at this list is that the majority of tallgrass prairie restorations are relatively small scale. The majority of restorations listed are less than 1000 acres, and this is not inclusive of the smallest restorations. While this paper has established that a restored prairie of any size can be valuable, larger sizes are less susceptible to damage and local extinction while also able to support species that require more space. For example, a single 1000 lb bison will consume, on average, about 30 air-dry pounds of forage per day (female bison range from 900 to 1200 lbs, while males range from 1500 to 2000 lbs). On a typical prairie, this means that 1000 acres can support about 91 bison.[89] The relatively small size of the majority of tallgrass prairie restorations (combined with the challenge of establishing a successful bison herd) is likely a main reason that only approximately 150,000 bison presently occupy the Great Plains.[90] This is extremely significant considering the keystone role of bison in tallgrass prairies. Similarly, other issues of quality and diversity relate back to the size of the prairie as well. However, the large-scale restoration projects that do exist, in combination with smaller-scale projects, are overall achieving the goal of increasing restored tallgrass prairie area. Hopefully restoration efforts will continue to move in this direction.

Conclusion

Tallgrass prairies are an important part of North American ecological heritage that have been largely lost to agriculture since European settlement. Human impacts on these prairies have led to loss of soil as well as soil nutrients, damage to root systems, and reduction of biodiversity

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[89] Allen A. Steuter, "Bison," in *The Tallgrass Restoration Handbook for Prairies,* edited by Steven Packard and Cornelia F. Mutel (Washington, DC: Island Press, 1997). 339-347.

[90] Alan K. Knapp, John M. Blair, John M. Briggs, Scott L. Collins, David C. Hartnett, Loretta C. Johnson, and E. Gene Towne, "The Keystone Role of Bison in North American Tallgrass Prairie," *BioScience* 49, no. 1 (1999): 39-50. http://www.jstor.org/stable/1313492 (Accessed April 18, 2010).

and available habitat for conservative species through direct destruction and prevention of natural processes (such as burns). Consequentially, restoration of these lands can provide many benefits to the environment, particularly in terms of biodiversity, while also providing ecosystem services such as carbon sequestration, erosion prevention, and improvement of soil quality. In restoring tallgrass prairies, it is important to attempt to maximize restoration size and increase both above- and belowground diversity, while limiting efforts to the ecosystem's historical range. In the United States, restoration efforts have reflected these goals to a certain extent, but there is considerable room for improvement. There is a need to create more large-scale, centrally located restoration efforts that can support a wider variety of native plant and animal species in areas where tallgrass prairies were found historically.

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