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Legacy Effects in Prairie Restoration: A 73-Year Spatial History

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ABSTRACT Black Earth Rettenmund Prairie State Natural Area, one of the highest quality prairie remnants in southern Wisconsin's Driftless Area, has been the target of extensive restoration efforts since it was acquired by The Nature Conservancy (TNC) in 1986. In the present work, I analyzed the spatial history of this prairie using a Geographical Information System (GIS) and an extended series of air photos, on-the-ground surveys, early maps, and land-use records. In 1937, when the first air photo was taken, the site was nearly devoid of trees and shrubs. In subsequent years, the site became progressively woody until at the time of purchase by TNC, it was over half covered by shrubs and trees. Maps and field notes made by TNC and the Wisconsin Department of Natural Resources (DNR) provided detailed information on the woody taxa at the time of acquisition. Quaking aspen (*Populus tremuloides*), eastern cottonwood (*P. deltoides*), and sumac (*Rhus glabra*) were the dominant woody species. Stewardship files during more than 25 years of restoration work provided data on the effort expended. Tree and shrub removal and frequent prescribed burns were used to restore the prairie. Although these efforts led to substantial success, a legacy of the woody vegetation remained, complicating restoration efforts. Sumac and gray dogwood (*Cornus racemosa*) are particularly troublesome, but brambles (*Rubus sp.)* and grape (*Vitis sp.*) also present problems. I used a Global Positioning System (GPS) to define boundaries of current woody areas and I found that they corresponded closely to the areas previously dominated by trees and shrubs.

KEY WORDS aspen, Black Earth Rettenmund Prairie, GIS, legacy effects, historical ecology, *Populus*, remnant prairie, *Rhus*, spatial history, tree/grass interactions

Prairie and woods are often in competition, especially within the region of North America called the "prairie-forest border." In his early work in Illinois, Gleason (1909) noted that "it is a matter of common knowledge that in this region the forest is everywhere pushing out upon the prairie." Later he noted "before the development of agriculture…succession between prairie and forest proceeded in both directions, even at the same time" (Gleason 1927). Gleason (1912) also noted that the survival of many forest herbs, even after the forest was gone, represented a legacy of former forest occupancy (see Briggs et al. 2005 for a recent review).

Legacy effects are of increasing interest in restoration ecology. Researchers now recognize that: "site history is embedded in the structure and function of all ecosystems, that environmental history is an integral part of ecological science, and that historical perspectives inform policy development and the management of systems…" (Foster et al. 2003). A variety of tools are available for research on environmental history (Egan and Howell 2001) , of which a Geographic Information System (GIS) is one of the most important.

My work represents a detailed study of the conflict between prairie and woody vegetation (trees and shrubs) on a high-quality prairie remnant that suffered major degradation before restoration work began. I made extensive use of historical aerial photography, GIS, detailed stewardship records, and on-the-ground analysis to investigate the competition between prairie and woods. The expansion of woody species into grasslands is generally attributed to a lack of fire or grazing, or climate change (Bragg and Hulbert 1976, Briggs et al. 2002, Tilman et al. 2000). Fire, the most important tool during short-term restoration work, has been used extensively at the present site.

STUDY AREA

My study developed as an offshoot of prairie restoration work done at Black Earth Rettenmund Prairie, a high-quality Wisconsin State Natural Area in the Driftless Region of southern Wisconsin (Fig. 1). This preserve, although only about 6 ha (16 acres), is an outstanding prairie and is widely noted for phenomenal floral displays throughout the growing season. According to The Nature Conservancy (TNC) guide to Wisconsin preserves,"Black Earth Rettenmund Prairie is considered one of the best remaining examples of dry-mesic prairie in Wisconsin….[It was]…once rated among the top ten natural areas in Dane County in private ownership" (Maher 1988).

This prairie has been studied by Wisconsin botanists for many years, even while still in private ownership. Plant ecologist J. T. Curtis used this site as an outdoor teaching classroom. It also was one of the prime dry-mesic prairies used by Curtis and his students in the seminal work *Vegetation of Wisconsin* (Curtis 1959). Research on Black Earth Prairie under Curtis' direction was carried out by Anderson (1954). In 1961, when Curtis died, the prairie was still predominantly free of woody plants.

The prairie grasses at this site are typical of southern Wisconsin remnant prairies and include big bluestem (*Andropogon gerardii*), Indian grass (*Sorghastrum nutans*), little bluestem (*Schizachyrium scoparium*), prairie dropseed (*Spo-*

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Figure 1. Air photograph of Black Earth Rettenmund Prairie State Natural Area taken in 2008, showing the surrounding area. The road on the north is Fesenfeld Road, and that on the east is Dane County Highway F. The site is about 0.6 km west of the Village of Black Earth in Dane County, Wisconsin. Except for a small woody area, the prairie is now surrounded entirely by plowed fields or pastures; total area is 6 ha.

robolus heterolepis), side oats grama (*Bouteloua curtipendula*), and needle grass (*Stipa spartea*). In addition, there are over 150 species of forbs. Showy forbs that are often responsible for spring and summer displays include butterfly milkweed (*Asclepias tuberosa*), lead plant (*Amorpha canescens*), purple prairie clover (*Dalea purpurea*), yellow star grass (*Hypoxis hirsuta*), rough blazing star (*Liatris aspera*), dwarf blazing star (*L. cylindracea*), wood lily (*Lilium philadelphicum*), hoary puccoon (*Lithospermum canescens*), wood betony (*Pedicularis Canadensis*), downy phlox (*Phlox pilosa*), blue-eyed grass (*Sisyrinchium campestre*), and spiderwort (*Tradescantia ohiensis*). The annual display of wood lily is especially noteworthy. Unusual and/or state-monitored species include Richardson's sedge (*Carex richardsonii*), cancer root (*Orobanche uniflora*), prairie turnip (*Pediomelum esculentum*), prairie goldenrod (*Solidago ptarmicoides*), and death camas (*Zigadenus elegans*).

In 1937, when the first air photo was taken by the U.S. Soil Conservation Service, the prairie was virtually devoid of trees (Fig. 1). As time progressed, the site became increasingly woody, until at the time of TNC acquisition in 1986, a large amount of the site was woody. Despite this degradation, Black Earth Rettenmund Prairie still had a reputation as a high-quality site.

Upon acquisition in 1986, this preserve became a major project of TNC and the Bureau of Endangered Resources of the Wisconsin Department of Natural Resources (DNR), and its restoration is well documented in TNC and DNR files and in the personal files of W. and S. Gaskill, who were the stewards from 1988 to 1995. The Prairie Enthusiasts (TPE) took over management of the site in 2001, and the land title was transferred to TPE in 2007.

METHODS

Air Photos

The 15 air photos I used to track vegetation changes on Black Earth Rettenmund Prairie span a 73-year period from 1937 through 2010. I obtained the early air photos (22.5 cm × 22.5 cm black-and-white prints) from the U.S. National Archives and Record Administration or from the Robinson Map Library at the University of Wisconsin-Madison. I scanned these photos at 600 dpi and saved them in TIFF format for subsequent use in GIS. I downloaded more recent National Agricultural Imagery Program photos, in ortho format, from the Wisconsinview.org website.

Analysis with GIS

I used ArcMap 10.0 (ESRI, Inc., Redlands, CA) to analyze the air photos and to prepare images. I consulted an ortho-based air photo of Dane County, Wisconsin from either 2008 or 2010 to obtain the coordinates used to georeference the other air photos.

I quantified woody areas on air photos by heads-up digitization. Before analysis, I used software tools provided by ArcMap to adjust the contrast and brightness of each air photo to obtain optimal view of the woody areas. I drew ellipses, circles, or polygons over the woody patches and larger individual trees. Depending on the year, the number of woody patches varied from as few as 4 to as many as 148. For each year, I converted the whole set of shapes to an ESRI shape file which then served as a layer which could be turned on or off, adjusted for line and fill, and analyzed quantitatively.

In 2010 and 2011 locations of existing woody patches and areas where prairie grasses were visually scarce were measured with a Global Positioning System (GPS) device (Garmin 76CSx; Garmin International Inc., Olathe, KS). I used sumac (*Rhus glabra*) as a surrogate for all woody shrubs because it was the most widespread shrub; it was located in early October when the leaves were intensely red. I quantified areas of impoverished prairie in mid-October by walking the boundaries between these areas and the adjacent high-quality prairie.

RESULTS

Quantitative Analysis of Woody Encroachment

The 15 aerial photographs provide a spatial history of the changes in woody area with time. Although I created maps for all dates, only maps for 1937, 1987, and 2010 are presented to give a spatial overview of the changes with time (Fig. 2a). Woody vegetation was at its peak in 1987, and by 2010, was greatly reduced due to the extensive restoration work.

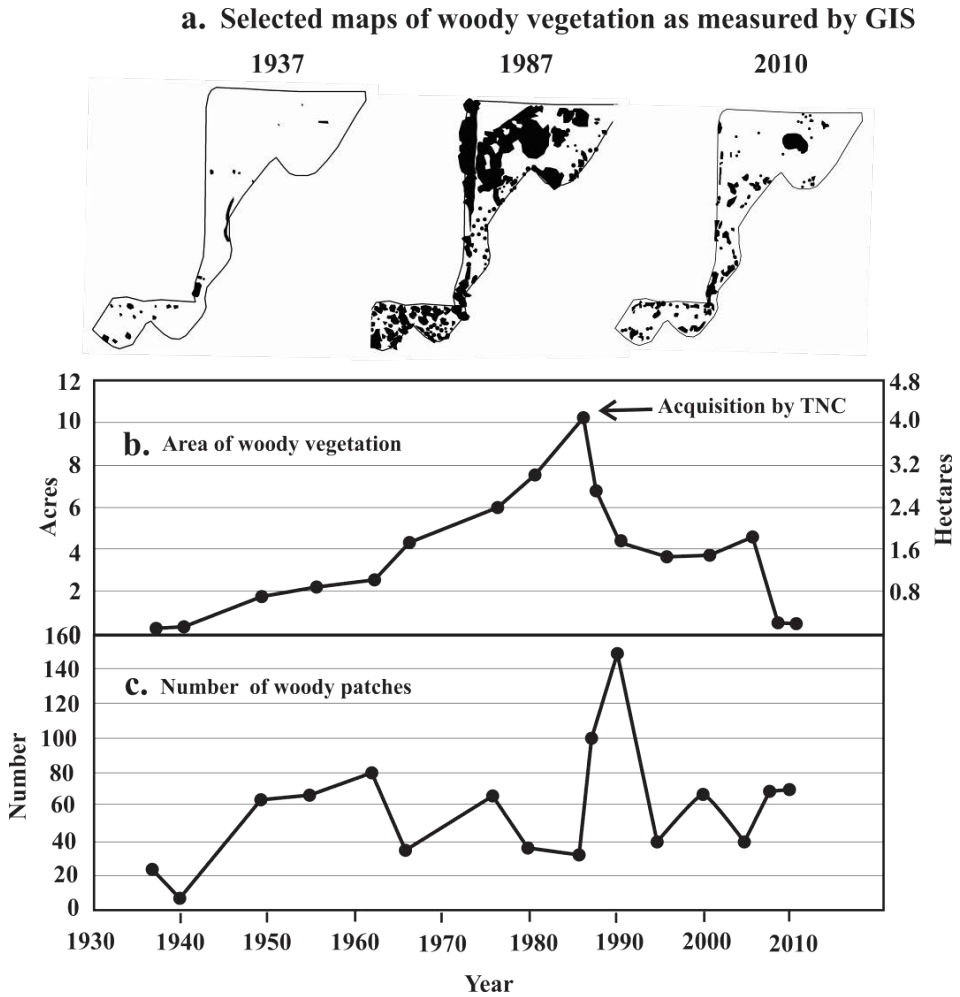

Figure 2. Woody vegetation for different years as measured on air photos by GIS. (a) Thumbnails for the key years of 1937, 1987, and 2010. (b) Change in woody areas with time over the 73-year period. (c) Change in number of woody patches with time.

Beginning in approximately 1949 there was a gradual increase in woody area, and the rate accelerated between 1980 and 1987 (Fig. 2b). Additionally, there was an extended lag phase in the early years, but beginning in the mid 1970s there seemed to be a "tipping point" after which the site "exploded" with woody vegetation; at the peak of the graph over half of the site was woody (Fig. 2b).

During the period 1976 to 1987 there was a marked *decrease* in the number of patches as invading shrubs and trees coalesced into continuous stands (Fig. 2c). In contrast, through the restoration period of 1986–1991 there was a marked *increase* in the number of patches as the major tree-dominated areas were removed (presumably leaving behind isolated trees or shrub thickets; Fig. 2c).

In the early years the woody areas were sparse. This period was at the end of a lengthy drought (the "Dust Bowl") in Midwestern North America that extended through most of the 1930s (Worster 1979) and ended in the early 1940s. The early shrub and tree development took place in the south part of the prairie adjacent to an undisturbed woodlot. By the time of the 1949 photo, woody patches had increased and some of the trees at the south part were quite large. A remaining stump of eastern cottonwood *(Populus deltoides)* in this area measures 50 cm in diameter.

Vegetation at the Time of Land Acquisition by The Nature Conservancy

In Wisconsin TNC archives is a hand-drawn sketch map providing considerable detail on the woody vegetation of "Black Earth Prairie". This map, dated 26 April 1984, was prepared by botanist C. K. Converse. At that time there were two substantial aspen clones, several sumac and gray dogwood (*Cornus racemosa*) clones, plus honeysuckle (*Lonicera sp*.), prickly ash (*Zanthoxylum americanum*), and other woody vegetation.

An "on-the-ground" 1986 color photo found in TNC files provides a distant view of the north unit. An aspen clone can be seen at the top of the hill; this clone measured 1.1 ha on the 1986 aerial photograph. Although this clone was removed in 1986–1987, its presence is reflected in the scattered woody vegetation still present at this site. The aspen in this clone were about 12–15 cm in diameter (R. Hoffman, Wisconsin Department of Natural Resources, personal communication). Another feature of the original color photo is the intense red color of a large sumac clone at the northeast corner of the property (also shown on the Converse map).

Restoration Work

The site was acquired by TNC in the late fall of 1986 and was dedicated as Black Earth Rettenmund Prairie State Natural Area a few months later. Initial management efforts were directed toward prescribed burns. Two burns had been done by the DNR in the 1970s when the site was still in private ownership, but in 1985 TNC initiated an extensive burn program, dividing the preserve into three burn units. Each year one or sometimes two units were burned, so that each unit was burned at least once in a three-year cycle. Prescribed burns played a major role in keeping brush from regaining control of the site.

Tree and brush removal and other restoration work at Black Earth Rettenmund Prairie was initially a joint effort of the Wisconsin DNR and TNC, but TNC assumed full responsibility after about three years. The aspen clones were removed (by girdling followed by cutting after the trees had died) in 1986–1989. Major trees along the west boundary also were removed in those early years of restoration.

Because of the high quality of the site, it was a top priority for restoration work. In the 1990s, many volunteer work parties under TNC leadership cleared brush and trees. Work party notes frequently mentioned honeysuckle, buckthorn (*Rhamnus cathartica*), and other invasive woody species. Beginning in 2002, TPE took over the restoration work, focusing on control of both herbaceous weeds (predominantly sweet clover) and invasive shrubs. Based on the DNR, TNC, and TPE stewardship records, over 4,000 hours of work was expended between 1986 and 2010 to bring the prairie to its current state. Although most of this was volunteer work, heavy labor in the early years was done by paid state employees or private contractors working under grants.

Legacy Effects

The maps and notes prepared by TNC at the time of acquisition provided a detailed spatial record of the tree and shrub areas of the site. I used GPS to relate the present locations of problem areas with the original woody sites. Although woody vegetation was largely eliminated about 25 years ago and thereafter with extensive use of prescribed fire, the legacy of woody vegetation persists. Because of its extensive distribution, ease of recognition, and difficulty of control, I used smooth sumac as a surrogate for the major woody species.

During fall 2010 and 2011 I located and subsequently recorded spatial positions (LAT/LONG coordinates) of all of the sumac clones that were still present. Additionally, I noted other remaining shrubs such as gray dogwood and hazelnut (*Corylus americana*). Waypoints corresponding to these locations were imported into GIS as a shape file. The existing shrub areas corresponded closely to the 1987 tree/shrub layers. Although trees and shrubs from 1987 were gone, their historical presence was reflected in the distribution of shrub-dominated areas. As a consequence of frequent prescribed fires, stem heights of 2010 and 2011 shrub areas also were notably shorter than those from 1987.

The distribution of prairie grasses also exhibits legacy effects. This was most clearly shown in one of the former aspen

areas. Twenty-five years after tree removal, Kentucky bluegrass dominated the aspen area where all significant woody vegetation was removed. This remained so despite repeated overseeding with native prairie species.

DISCUSSION

Black Earth Rettenmund Prairie was originally an undisturbed high-quality prairie remnant that became heavily degraded through woody plant encroachment, and through great effort, has been preserved as an outstanding prairie remnant. Today it has a reputation as one of the best quality remnants in southern Wisconsin, and is considered a "jewel" of the Wisconsin State Natural Areas system (T. Meyer, DNR, personal communication). Its floral displays (especially of *L. philadelphicum*) attract many visitors, and school and college groups frequently visit the site. Despite its reputation as a prairie, woody vegetation remains a problem and extensive restoration work continues throughout the year.

The spatial history provides a detailed picture of the interaction between prairie and woody vegetation. Availability of a large set of air photographs, and the detailed files of the DNR and TNC made this GIS-focused study possible. Frequent fire is generally considered to be the major factor slowing or preventing the conversion of grassland to shrubland (Briggs et al. 2002, 2005). However, despite extensive use of fire for over 25 years, woody vegetation continues to be a problem on Black Earth Rettenmund Prairie.

Because of the long narrow shape and small size of the site (6 ha), there are many edges along which encroaching woody plants can enter. The air photos from 1949 through 1955 showed that the trees and shrubs first arrived along the south edge, adjacent to a closed-canopy woodlot, and along the long fence line at the west end of the property. A large aspen clone colonized the knoll at the top of the north unit, probably from air-blown seed, since there are numerous aspen clones in nearby woodlots. Once established, this clone spread rapidly by root sprouting. The legacy of the two aspen clones can be seen to this day. In both former aspen sites, prairie grasses are mostly absent, and although prairie forbs thrive, shrubs continue to invade. Every few years, despite biennial burns, it is necessary to use herbicide to control small aspen seedlings or resprouts as well as other woody vegetation.

Geographical Information System software provided an incisive tool for the present study. The long time sequence of air photos offered the opportunity to quantify the rate of change in the woody areas. Using the analytical tools of ArcMap, it was possible to measure the area of each woody patch. The rate of spread of shrubs and trees approximately follows a typical growth curve, with a long lag phase preceding a nearly logarithmic increase. Left unchecked this prairie would have almost certainly become solid woods, as have so many other prairie remnants in southwestern Wisconsin.

An important conclusion from this study is that despite the fact that the tree and shrub vegetation have been largely eliminated, the legacy of this former vegetation remains. Thus, what is present today is a result of what was there in the past. The "land remembers." This conclusion has important implications for restoration ecology, and provides strong support for the discipline of historical ecology (Egan and Howell 2001).

Although there has been little direct experimental research on the effect of shrub and tree shading on prairie plants, research on the understory vegetation of oak savannas provides important clues (Bray 1958, 1960, Leach and Givnish 1999). Prairie (warm-season) grasses such as big and little bluestem and side oats grama are found in oak savannas only in the sunniest areas; these species are only able to compete where they grow under higher light intensities. Weaver (1968) noted that the principal warm-season grasses grow poorly or die at lower light intensities. In contrast, because of their growth habit, shrubs and trees are adapted to lower light intensities, are able to thrive under these conditions, and often are able to grow under their own shade. Clonal species such as aspen, sumac, and gray dogwood are able to spread because root sprouting permits them to colonize new ground. Once established, they can thrive indefinitely.

MANAGEMENT IMPLICATIONS

My findings at Black Earth Rettenmund Prairie suggest some principles of importance for restoration ecology.

- **In the prairie/forest border area, shrub and tree control are essential if the prairie habitat is to be maintained.** During the early stages, shrub establishment may seem benign, but this is obviously incorrect. In the early stages of colonization, shrubs and trees are easily removed. Once the explosive growth phase has set in, not only is removal of much more biomass necessary, but invasive populations grow at a vastly increased (quasi-exponential) rate. With exponential growth, it is the last doubling that turns a site from restorable to hopeless.
- **Frequent fire, although important, is not enough.** Fire is now a widely accepted component of integrated management systems of prairies and savannas (Briggs et al. 2005). However, we often assume that fire on a 3- to 4-yr cycle may be sufficient, but this may be a mistake on sites with a legacy of woody vegetation. At Black Earth Rettenmund Prairie, burns were conducted on the various units on the average of every third year for 25 years. Despite this frequency, shrub growth continues to remain a problem in formerly wooded areas. Sumac and gray dogwood in particular continue to thrive. It is a mistake to assume that because a restored prairie is in "good shape", it will stay that way with only an occasional burn. The remnant areas that "escaped" the woody invasion may not need such frequent burns but should still

be burned every 2–3 years to avoid the potential for new shrub invasion.

- **Seed collecting and overseeding are essential.** A site that has been woody for an extended period of time almost certainly has lost most or all of its warm season grasses, as well as some of the more light-demanding forbs. The seed bank for such a site is uncertain and probably highly variable. Without overseeding, restoration of such a site may take years, if ever. Even if there is a good seed source nearby, spontaneous overseeding would be unreliable and dependent on the quality of the seed. Even 25 years after the initial restoration work began, formerly woody areas at Black Earth Rettenmund Prairie remain floristically impoverished. Although each restoration project must be analyzed individually, if the site was woody it can safely be assumed that overseeding will be needed.
- **Control of native shrubs is important.** Most of the shrubs dealt with at Black Earth Rettenmund Prairie were native species, and because of this were not aggressively pursued during the early phases of restoration. However, many of these native shrubs must be controlled because they are highly invasive. Mowing helps but eradication of shrubs requires herbicide application either on cut stems or as a basal bark treatment.

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