Land-Use History in Ecosystem Restoration: A 40-Year Study in the Prairie-Forest Ecotone

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Abstract

Land-use history, recent management, and landscape position influence vegetation at the Rockefeller Experimental Tract (RET), a 40-year-old restoration experiment in northeast Kansas. RET is representative of the prairie-forest ecotone, containing native tallgrass prairie and oak-hickory forest, but unique in having tracts of replanted prairie, seeded in 1957, that have undergone long-term restoration treatments: burned, grazed, mowed, or untreated. A land-use history database for RET was compiled using a geographic information system to integrate historic and contemporary sources of information. Restoration management on the reseeded prairie has had a profound effect on forest development: mowing or burning precluded forest establishment (<3% forest cover), whereas portions of untreated or grazed areas became heavily forested (>97% forest cover). Forest colonization depends upon biotic and edaphic conditions at the time restoration was initiated: for areas replanted to prairie and managed by grazing, forestation was 6% on land in cultivation prior to replanting, 20% on former pastureland, and 98% on land deforested just before replanting. Patterns of forest colonization were also significantly associated with three landscape positions: near existing forest, along water courses, and along ridge tops. Additionally, land-use history analyses showed that the presence of various prairie and forest species resulted from persistence and not from colonization following restoration. Because of the lasting imprint of historic land use on the landscape, our results indicate that it is essential that restoration studies be evaluated within a site-specific historical context.

Key words: ecosystem restoration, prairie restoration, disturbance history, land-use history, historical ecology.

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Introduction

Ecosystem restoration within the prairie-forest ecotone and the conservation of extant highly fragmented native communities are receiving much attention (e.g., Mlot 1990; Thompson 1992; Packard 1994; Packard & Mutel 1997). The prairie biome, which once covered a vast expanse in the American Midwest, is now greatly diminished (Küchler 1964; Whitney 1994). Under aboriginal conditions, local habitats within the ecotonal region were interdigitating areas of forest and prairie, determined largely by interaction of fire, topography, moisture, soil type, and native grazers (Wells 1970; Küchler 1974; Anderson 1990). Following settlement by people of European origin, forest communities were heavily influenced by logging and grazing of domestic livestock (Whitney 1994). Concurrently, prairie was altered directly through farming (e.g., plowing and grazing) or indirectly through suppression of wildfires, allowing expansion of woody vegetation (Anderson 1990). In the prairie-forest ecotonal region, woody species invade grasslands that are not burned or mowed (e.g., Fitch 1965; Knight et al. 1994; Holt et al. 1995); this is a serious concern for restoration and conservation (Packard & Mutel 1997).

Historic effects of land use commonly persist within diverse ecosystems, including prairie and forest, and are known to influence old-field succession (e.g., Fitch 1965; Hamburg & Sanford 1986; Christensen 1989; Glitzenstein et al. 1990; Foster 1992; Foster et al. 1992; Myster & Pickett 1994; Whitney 1994). An understanding of disturbance history and vegetation change provides a context for ecological studies (Christensen 1989; Pickett 1989; Tilman 1989), a basis for natural resource management and planning (Foster 1992; Motzkin et al. 1996; White & Walker 1997; Black et al. 1998; Cissel et al. 1999; Moore et al. 1999; Swetnam et al. 1999; Egan & Howell in press), and is essential in environmental modeling (e.g., Burke et al. 1991; Parton et al. 1994; Aronson & Le Floc'h 1996; Aber et al. 1997). Research focused on restoration or preservation of ecosystems in the prairie-forest ecotone must consider the historical context under which communities developed and the subsequent changes brought about by European settlement. Unfortunately, because of the scarcity of older restoration sites, few studies have been able to consider long-term effects of historic land use on ecosystem dynamics.

We investigated how land use history has influenced the vegetation on a 40-year-old restoration site in northeast Kansas. The study area is representative of the prairie-forest ecotone in that, before 1956, it was farmed for 85–90 years. What is unusual is that different management treatments have been applied for 40 years on native and replanted prairie, thereby providing a unique opportunity to examine the interaction of historic (pre-1956) land use, long-term (post-1956) management practices, and landscape position on ecosystem restoration. Our study had two goals: to assess the impact of land-use history on ecological restoration and to demonstrate a methodology for considering historic land use that is applicable to other conservation and restoration sites in the prairie-forest ecotone of the Midwest.

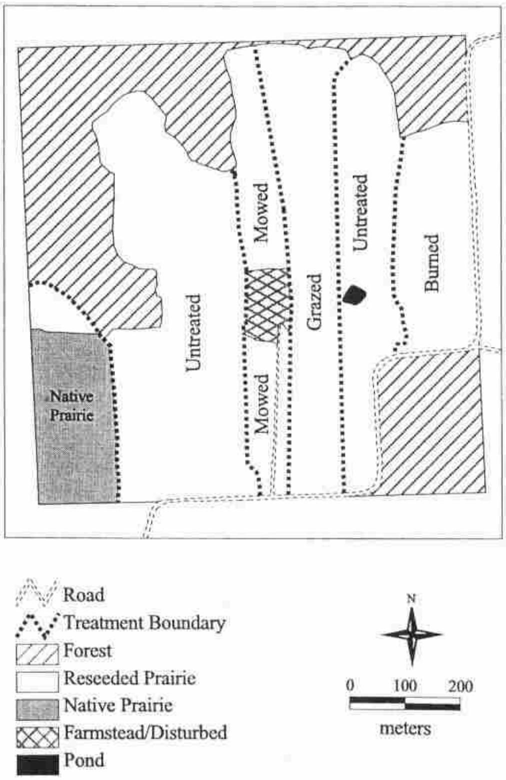

Figure 1. Experimental design of Rockefeller Experimental Tract showing boundaries of experimental treatments (applied to reseeded prairie from 1962–present), areas not reseeded to prairie in 1957 (forest, native prairie and farmstead), and major cultural features.

Study Site

This study was conducted at the 65-ha Rockefeller Experimental Tract (RET), located in southeastern Jefferson County, Kansas. RET was established as a prairie restoration experiment by the University of Kansas in 1956 (Fitch & Hall 1978). RET has three general landscape components: upland areas replanted to prairie in 1957, and subjected to different management practices; native habitats, including unplowed native prairie and oak-hickory forest, which serve as baselines for comparison with restored areas (see White & Walker 1997); and successional woods and disturbed sites.

The restoration study at RET began in the spring of 1957 when the formerly pastured and cultivated parts of upland were disked and sown with a mixture of four species of prairie grasses: *Andropogon gerardii* (big bluestem), *Andropogon scoparius* (little bluestem), *Sorghastrum nutans* (Indian grass), and *Panicum virgatum* (switch grass). Note that although we refer to these areas as "reseeded" or "replanted" prairie, other prairie species were not planted. In 1962, 5 years after the original sowing of prairie grasses, one of four general management regimes was applied to tracts of reseeded prairie (Fitch & Hall 1978; H. S. Fitch 1995, personal communication) (Fig. 1): burning—springtime burns at 1- to 4-year intervals; grazing—cattle pastured annually during the growing season; mowing—mowed or hayed annually; and untreated—no management treatment.

Native habitats on RET include a 4-ha native prairie (Fig. 1), the Rockefeller Native Prairie, which has a rich vascular flora of 165 native species (Kindscher 1994). From the 1870s until 1956, the native prairie was maintained primarily as a hay meadow (Fitch & Hall 1978). Since 1957, it has been managed by spring burns at 1- to 3-year intervals, with some mowing to control woody vegetation. The other native habitat of RET consists of native oak-hickory forest. Although this forested area has had no management since 1956, it was grazed and logged following Euro-American settlement. Thus both the prairie and forest we refer to as "native" have had some disturbance.

Materials and Methods

We developed a land-use history for RET using historical sources (public land surveys, ownership records, agricultural censuses, interviews, unpublished data, and aerial photographs) and contemporary surveys of vegetation. We then used a geographic information system (GIS) to assess the impact of historic land use, restoration management, and landscape position on forest expansion in the restoration areas.

Land-Use History

General Land Office (GLO) survey records (field notes from 1856 and 1860 and accompanying plat maps) were examined to assess distribution of historic vegetation (prairie and forest) and cultural features at RET. Ownership records were used to examine ownership patterns and to verify information in agricultural censuses. Historic farm management at RET was assessed by reviewing agriculture schedules from the Kansas State census. We report agricultural data only for years when the owner of record was also the occupant of the farm: 1875, 1885, 1915, and 1925. We grouped raw data on crop acreages from the agricultural schedules into four derived categories: tilled acreage (combined acreages for corn, winter wheat, oats, kafir, flax, millet, and Irish potatoes); hay/forage acreage (combined acreages for alfalfa, timothy, and bluegrass); orchard acreage; and prairie acreage. We looked at changes in acreages in the various categories to evaluate farm management. Additional information on historic conditions of RET was determined by reviewing published papers and unpublished data, conducting interviews, and examining landscape photographs and slides, atlases, and miscellaneous correspondence.

Aerial photography from the last 60 years was used to evaluate historic land use (1937–1956) and to delineate experimental treatments (after 1957). Boundaries of historic land-use units (see Fig. 2) came largely from aerial photographs (black and white, 1:20,000 scale) taken in 1937, 1941, 1954, and 1959. We identified historic land-use units (i.e., agricultural fields or groupings of fields) with consistent boundaries (1937–1959) by coregistering photographs based on common features over the period: fences, wooded fence lines, sharp transitions of biotic communities, and roads. Miscellaneous photographs and ground measurements were used to complete interpretations.

Tree composition and abundance were sampled to determine successional character of selected land-use units (units J, M, N, and O, Fig. 2). Within circular plots (38.5 m^2/plot), we recorded species and size (diameter at breast height [dbh], to nearest 1 cm) of trees >5 cm dbh (10 plots/unit). We tallied the number of later-successional species (*Quercus* spp. [oaks] and *Carya ovata* [shagbark hickory]) and earlier-successional species (*Ulmus* spp. [elms], *Fraxinus americana* [white ash], and *Juniperus virginiana* [eastern red-cedar]) based on knowledge of successional stage in this region (Fitch & McGregor 1956; Fitch & Hall 1978). Other species were included in sampling, but not grouped into successional stage. Species lists of vascular plants in all units were based on field work from 1989–1990 (K. Kindscher unpublished data), with additional surveys in areas of interest.

GIS Database and Analysis of Forest Cover

We used ARC/INFO and ARC GRID (v.7.x, Environmental Systems Research Institute, Redlands, CA) software for GIS database creation, maintenance, and analysis. Forest cover was digitized from four aerial photographs: three black and white photographs (1954, 1966, and 1974) and a color infrared photograph (1994); all photographs were taken in summer with leaf-on conditions. Each photograph was scanned to create a grey-scale image with a threshold used to distinguish forest and nonforest. Manual interpretation was then used to verify and correct classification. Other coverages were hand digitized.

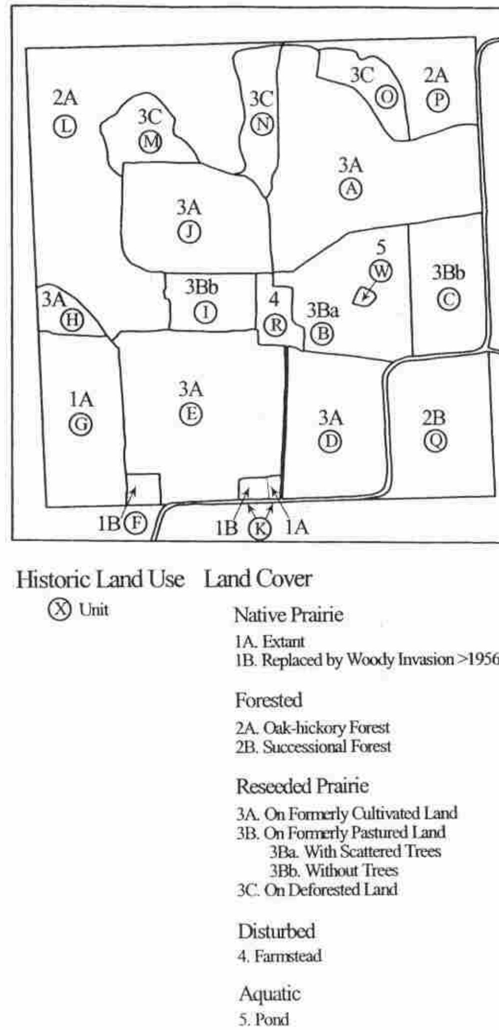

Figure 2. Map of historic land-use units at Rockefeller Experimental Tract (units designated by encircled upper case letters) and land cover (alphanumeric codes). Land cover based on current (1998) land cover and historic (1956) land use/land cover. Refer to Fig. 1 for orientation, scale, and cultural features.

GIS analysis was used to quantify changes in forest cover for each initial (1957) condition identified within each treatment. A 5-m buffer was delineated along historic land use (Fig. 2) and treatment boundaries (Fig. 1) to minimize the effect of forest cover associated with these edges. GIS was also used to assess successional change in forest cover in relation to three characteristics of landscape position: proximity to pre-existing forest; proximity to water courses; and proximity to ridge top (where soil erosion is less). This was accomplished using the 1966 and 1974 aerial photographs (representing conditions shortly after initiation of treatments and after 8 additional years of forest colonization, respectively). To avoid confounding effects of active restoration treatment (i.e., burning, grazing, or mowing), analyses were performed for a relatively large untreated area at RET; the area was predominantly (93%) a former cultivated field (unit E, Fig. 2), but also contained a small amount of former native prairie (units F and K, Fig. 2). Change in forest cover between the two dates was examined based on distance from the existing (1966) forest. Similarly, we assessed change in forest cover in relation to distance from water courses, as defined by gully bottoms that extended up to the edge of the 1966 forest. Finally, we assessed forest change in relation to ridge top, as defined by flow on a reverse digital elevation model; for the ridge analysis we excluded forest that was within 40 m of existing forest (80% of the forest cover excluded). Forest cover was based on a cell size of 1 m, and pre-existing forest was defined as areas of forest cover >25 m^2. Distance effects from the three landscape features (pre-existing forest, water courses, and ridge) were assessed using a one-sample Kolmogrov-Smirnov test by comparing the ratio of forest colonization (fraction of forest within a 1-m interval:fraction of area within the same 1-m interval) against a theoretically uniform distribution.

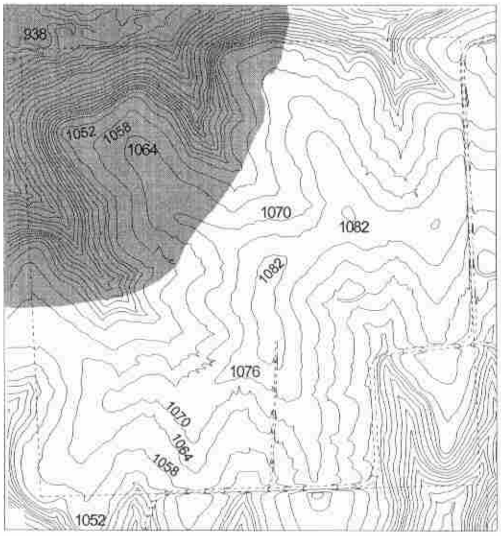

Figure 3. Topographic map of Rockefeller Experimental Tract showing elevations (6-foot contour intervals) and distribution of presettlement forest (shaded area, as determined from General Land Office plat map of 1860). Refer to Fig. 1 for orientation, scale, and cultural features.

Results

Land Use History

Presettlement (ca 1860). GLO maps show RET as 75% prairie and 25% forest (Fig. 3) with the northwest corner of RET including about 17 ha of a 136-ha grove of forest. Given the methods used to construct the original GLO maps, the absolute area of forest must be considered as approximate, e.g., see Hutchison (1988) and Delcourt & Delcourt (1996). GLO field notes (1860) describing the western side of RET reported witness trees as hickory, mulberry, and black oak and described the forest as, "Timber Oak and Hickory of an inferior quality, with undergrowth Hazel, Plum, and Briars."

Postsettlement (1868–1956). The RET tract was granted from the United States Government to the Union Pacific Railway in 1868; the land then had 11 different owners between 1869–1956. Agricultural (census) statistics indicate that the prairie was rapidly plowed and converted to agriculture, with 62 acres tilled by 1885. Tilled acreage (primarily corn and oats) increased little between 1885 and 1925, but it appears that native prairie was partially replaced by introduced grasses (timothy and bluegrass) and alfalfa during this time. Only 35 (reported) acres of prairie remained by 1885, and this was reduced to 10 acres by 1915; this is presumably the extant Rockefeller Native Prairie. Two acres of orchard were reported in 1875, livestock grazing (1885–1925) consisted of 3–5 horses and mules and 6–8 head of cattle. For years prior to 1956, the cultivated parts of RET had been used for growing milo, oats, wheat, barley, and alfalfa (Fitch 1958). There was an 18-acre block of pasture in the central part of the original farm (Fitch 1958), and the Rockefeller Native Prairie was maintained as a hay meadow (R. L. McGregor 1995, personal communication). *Poa* spp. (bluegrasses, primarily *P. pratensis*) were present in the western part of the former pasture in 1956 (unit B, Fig. 2) and was a dominant species in the same area in 1962, presumably not killed by disking prior to reseeding of prairie species in 1957 (H. S. Fitch, unpublished data).

Conditions at the Time of Replanting (1956). Two broad community types were present on RET when the restoration study began (1956): forested areas and nonforested (open) habitat consisting of native prairie or land that was to be replanted to prairie. We describe here the characteristics of these habitats, because they are important in interpreting vegetation change and restoration, and use these data to construct our map of land use and land cover (Fig. 2).

In general, forested areas on RET in 1956 represented two different woody habitats: oak-hickory forest and successional forest. Oak-hickory forest was identified in units L and P (Fig. 2). This category included closed-canopy oak-hickory forest (*sensu* Küchler 1974), as well as adjacent areas that were probably more savanna-like in presettlement times. Within these areas, vegetation surveys (K. Kindscher unpublished data) confirmed presence of woody species (e.g., *C. ovata*, *Quercus borealis* [northern red oak], *Aesculus glabra* [Ohio buckeye], *Asimina triloba* [common pawpaw], *Juglans nigra* [black walnut], *Ostrya virginiana* [ironwood], *Prunus serotina* [black cherry], *Staphylea trifolia* [American bladdernut], and *Tilia americana* [American basswood]) and herbaceous species (e.g., *Cypripedium calceolus* [yellow lady's slipper], *Podophyllum peltatum* [May-apple] and *Solidago missouriensis* [Missouri goldenrod]) commonly occurring in oak-hickory forest, with other species indicative of open woods and savanna (e.g., *Elymus virginicus* [wild rye], *Erythronium mesochoreum* [prairie fawn-lily], and *Amphicarpaea bracteata* [American hog-peanut]).

Historically, humans have undoubtedly impacted this forested area. Although topoedaphic character (thin soils, rocky outcrops, and steep slopes) and wooded nature precluded tilling or mowing, the area was probably useful for grazing and harvesting firewood and logs. For example, numerous trees have multiple stems, a condition indicating historic cutting or grazing, and old sawn stumps from logging were reported (Birdsell & Hamrick 1978). A portion of these woods, particularly the western portion, was presettlement forest that was disturbed (after 1870), but the impact was not severe enough to eliminate characteristic species. Adjacent woods within this topographically diverse area were probably more savanna-like, or even prairie, at presettlement times, but progressed into forest with suppression of fire.

Successional forest was found primarily in the southeast corner of RET (unit Q, Fig. 2). Evidence that this is a successional forest, which developed on what was originally prairie (1850s), is based primarily on GLO data describing prairie habitat, and by the dominance of early successional trees and relative absence of characteristic oak-hickory species (most noticeably absent are *C. ovata* and *Q. borealis*). As for land use, extant rock (limestone) fences indicate the area was fenced for grazing early in the history of the original farm. Old maps (e.g., Everts 1887) show this area was separated from the rest of the farm at an early stage, apparently because of the need to build a public roadway (1872 road easement) that avoided the head of a steep ravine in the southeast corner of RET (Fig. 3).

Open areas consisted of the Rockefeller Native Prairie proper (unit G, Fig. 2), which has long been recognized as a native prairie (e.g., Fitch & Hall 1978), and land reseeded to prairie. Within the area described as formerly cultivated or pastured and reseeded to prairie (Fig. 1), vegetation was determined to consist of four general conditions in 1956: recently deforested area, former pasture with scattered trees and *Poa*, former cropland and pasture generally free of woody vegetation, and native prairie.

Aerial photography revealed that three forested sites (units M, N, and O, Fig. 2) near the forested ravine were cleared between 1954–1956. Historic data (H. S. Fitch, unpublished data) support the idea that oaks and hickories established quickly in these areas following reseeding with prairie grasses in 1957. Our surveys showed that these areas largely composed of later-successional trees, rather than the characteristic earlier-successional species. Of trees >5 cm dbh, *C. ovata* and *Quercus* spp. comprised 83 ± 7% of stems in unit M, 68 ± 7% of stems in unit O, and 59 ± 9% of stems in the northern part of unit N. By comparison, the southern part of unit N contained a smaller percentage of later-successional species (only 6 ± 4% *C. ovata* and *Quercus* spp. versus 85 ± 5% early-successional species) indicating a different, but unknown, disturbance history, while a ridge area of unit J that was cultivated prior to 1957 consisted of 1 ± 1% later-successional species versus 95 ± 3% early-successional species, the trend normally expected in this region. This greater relative composition of later-successional trees in deforested areas was statistically significant (units M, O, and N-north differed from units J and N-south; Dunn's test, $p < 0.05$, following a significant Kruskal-Wallis, $H = 35.674$, df $= 4$, $p < 0.001$). These same trends in distribution of early- versus late-successional species were supported by basal area measurements.

Although units B and C (Fig. 2) comprised a pasture prior to 1956 (Fitch 1958), unit B had more woody species and *Poa*, indicating residual effects of previous land use (H. S. Fitch personal communication). Aerial photographs showed unit B with scattered trees prior to 1956, and unit C more open and perhaps even tilled in 1937 (Figs. 4 & 5). We observed that cool-season grasses still dominate the western part of unit B (that part subjected to grazing treatment), with abundant *Festuca arundinacea*, and lesser amounts of *Bromus inermis* and *P. pratensis*.

Cultivated and pastured areas reseeded to prairie grasses comprised the majority of formerly open areas, with the greater area having been under cultivation in 1956. Aerial photographs showed these areas were generally free of woody vegetation in 1954.

We identified two areas that were likely native prairie in 1956 (units F and K, Fig. 2). Interviews confirmed that unit F, which is now a closed-canopy woodland, was prairie before 1956 (R. L. McGregor personal communication), but apparently contained some trees (see 1954 coverage, Figs. 4 & 5). Even though historic field

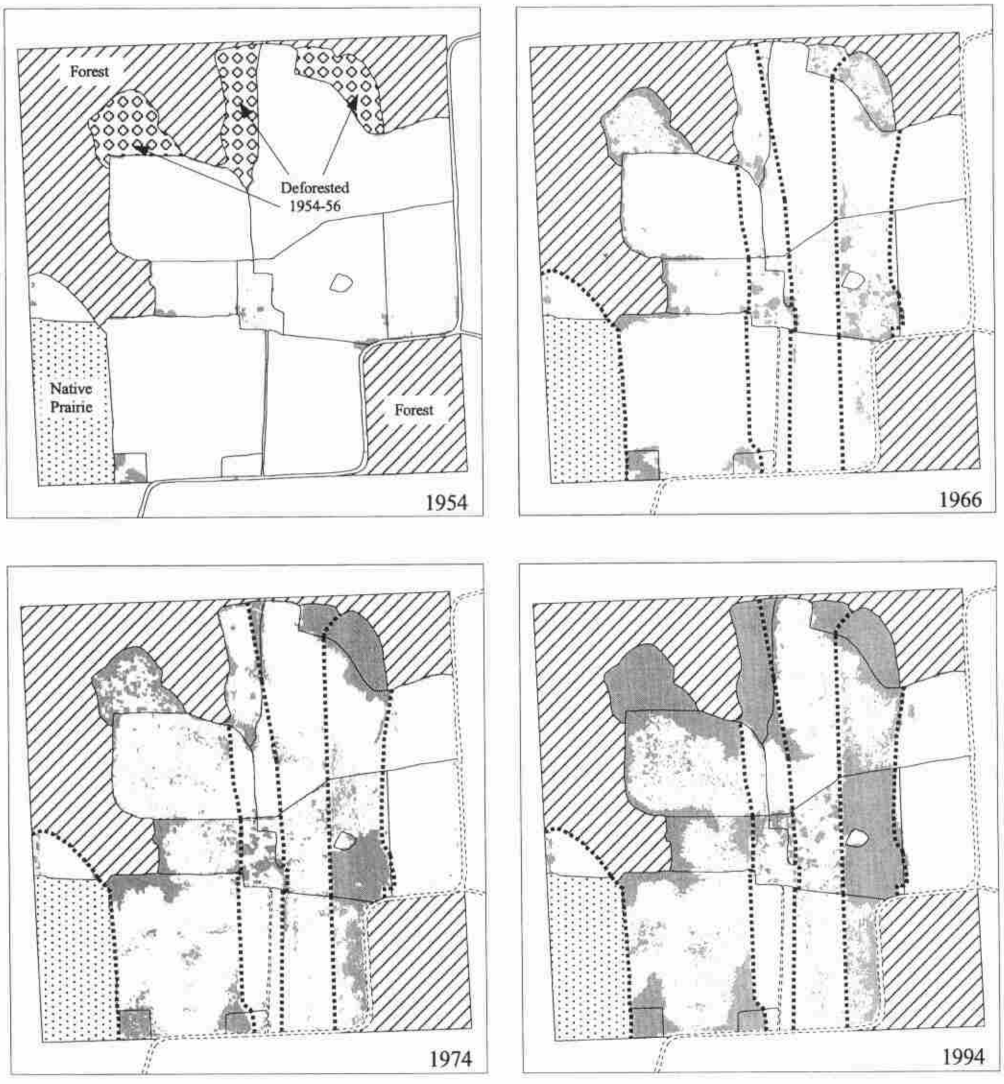

Figure 4. GIS representation of changing forest cover (woody canopy) on areas reseeded to prairie grasses in 1957 at the Rockefeller Experimental Tract as determined from aerial photographs of 1954, 1966, 1974, and 1994. Within the areas reseeded to prairie in 1957, forest cover is represented as gray shading with nonforested area as white. Refer to Fig. 1 for orientation, scale, cultural features, and boundaries of restoration treatments. Refer to Fig. 2 for historic land-use units.

notes mention several prairie species in both units (Fitch & Lawlor unpublished data), we did not find these species in the now-wooded portions of these two small units (i.e., prairie herbs were out-competed by woody vegetation). However, several prairie species, including *Amorpha canescens* (lead plant) and *Ceanothus herbaceous* (New Jersey tea), were found in the area of unit K that had been mowed since 1957.

Forest Cover

Forest cover varied with management treatment (post-1957) and with initial (1956) biotic and edaphic conditions (Table 1). Greater forest cover was found on areas that were not burned or mowed, and on areas that initially contained some woody vegetation or were recently deforested (Table 1).

Landscape position also influenced the probability of forest colonization (Figs. 6 & 7A–7C). We found significantly greater increases in forest near existing forest (Kolmogrov–Smirnov, $Z = 6.9909$, $p < 0.0001$, $n = 133$) (Fig. 7A), and along water courses ($Z = 6.8810$, $p < 0.0001$, $n = 158$) (Fig. 7B). For example, being within 20 m of the 1966 forest area comprised 18% of the untreated area (dotted line, Fig. 7A), but 63% of the total new forest (solid line, Fig. 7A). For that portion of forest (residual 20%) that was not in close association with forest sources or water courses (>40 m from forest edge or stream courses), probability of forest expansion was significantly less as distance away from ridges increased ($Z = 6.1079$, $p < 0.0001$, $n = 97$) (Fig. 7C). For example, being within 10 m of the ridge comprised 52% of the residual forest, but only 18% of the area (Fig. 7C).

Discussion

Historical Context and Environmental Setting

Knowledge of the environmental setting and historical context of a site is essential for undertaking ecosystem

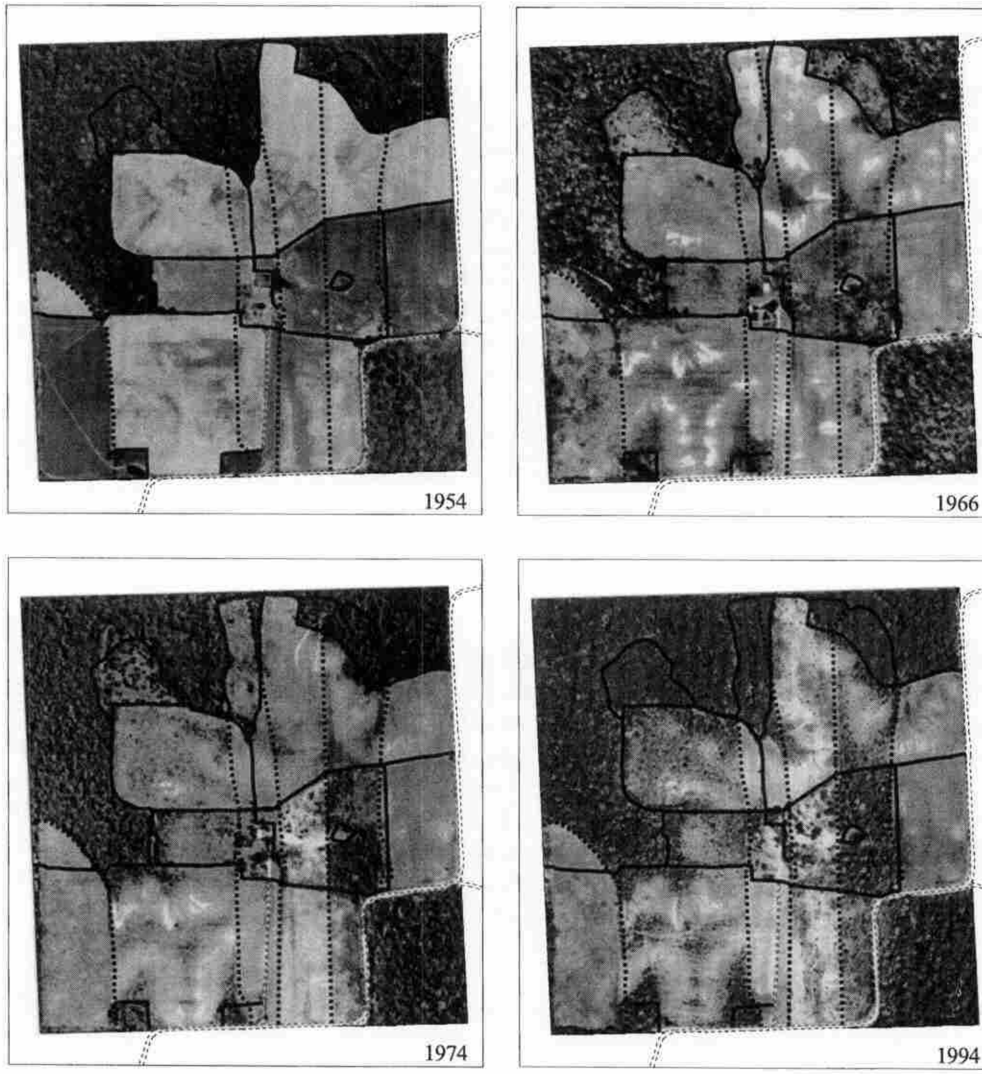

Figure 5. Sequence of four aerial photographs at Rockefeller Experimental Tract (1954, 1966, 1974, and 1994) showing orientation of restoration treatments (see Fig. 1) and historic land use units (see Fig. 2). Forested areas appear dark on photographs and areas of active soil erosion appear as light, shiny areas (especially apparent on 1966 photograph). Refer to Fig. 1 for orientation, scale, and cultural features.

restoration (White & Walker 1997). Immediately prior to Euro-American settlement, RET was predominantly an ecosystem mosaic of tallgrass prairie, oak-hickory forest, and savanna. As such, RET is potentially similar in setting to many restoration sites along the prairie-forest ecotone. However, because the cultural practices of early indigenous people are known to have altered ecosystems in a major way (e.g., Anderson 1996; McCann 1999), individual sites along the prairie-forest ecotone may differ in characteristics depending on timing and intensity of historic use. Although we do not think the Kansa Indians, who controlled a large area surrounding RET for some time prior to 1800 (Fitch 1965; Unrau 1991), had an impact on RET that was different from their regional influence, we do not know how RET may have been used by earlier peoples. Blankslee (1996) has reported that the sites of prehistoric cultures in Kansas correspond to the locations of presettlement groves of hardwood forest described in the GLO surveys, so sites like RET may have been used intensively. Thus, it is reasonable to expect that sites along the ecotone, while similar in ecological setting, will differ in their history of human influence before Euro-American settlement.

Major alteration of the prairie-forest ecotone occurred with settlement of the region by people of European origin. RET likely typifies the historic disturbance regime in the region; shortly after it was purchased as a farm the prairie was plowed, crops and orchards planted, livestock pastured, and a homestead maintained. We found nothing to indicate that historic (1868–1956) uses of RET were anything other than those for a typical farm of the region. However, given the range of activities on a typical, early-Midwestern farm there are numerous possibilities for disturbance effects of varying size, intensity and scope (e.g., Whitney 1994). Thus, historic land use is an important variable when analyzing restoration within a single site, as shown in this study, or when making comparisons among different sites along the prairie-forest ecotone.

Vegetation Change on Reseeded Areas

Environment and history are recognized as prominent factors controlling the distribution of plant communities across the landscape (Glitzenstein et al. 1990). These factors are not independent because the site character largely determines the use, and vice versa (e.g., Foster 1992). For example, thin rocky soils were less likely to be tilled than deeper soils at a given site and, within a tilled area, erosion may be more severe in areas with greater slope. Conceptually, we considered that plant communities on reseeded prairie tracts at RET resulted from integration of environment and history over three broadly varying, and interacting, factors: restoration management practices during the last 40 years, conditions at the time of replanting (1956), and landscape position. In truth, the plant community has resulted from complex interaction of these and other factors, such as animals (Howe 1999), and external factors (Pickett 1989) that have operated on the ecosystem.

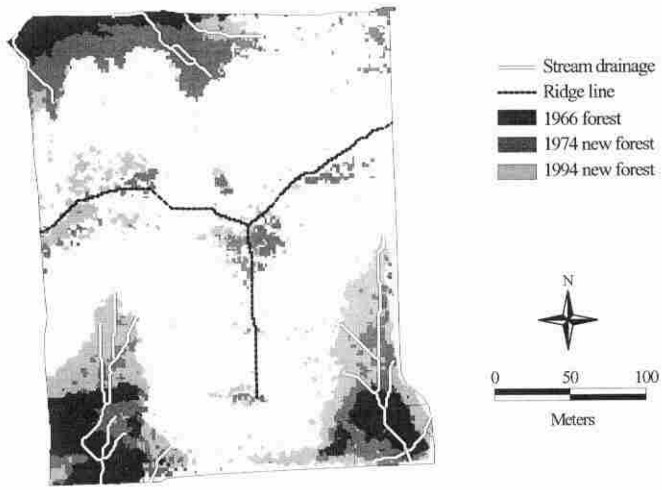

Figure 6. Forest cover changes in an untreated area (units E, F, and K, Fig. 2) of the Rockefeller Experimental Tract. Change in forest cover (1966 baseline) shown as new forest in 1974 and 1994.

Restoration Management Practices. Management practices had strong effects on woody plants; little forest development occurred in burned or mowed treatments, in contrast to portions of grazed or untreated areas that were heavily colonized (Table 1). These results agree with earlier observations at RET (Fitch & Hall 1978). Thus, at RET restoration management practices provide an over-riding effect on forest invasion (i.e., effects of historic land use and landscape position on forest invasion can only be observed where management does not preclude the forest community). Although it was beyond the scope of this study to examine the direct effects of management on herbaceous plants, it is clear that management regimes that permit woody invasion will alter herbaceous communities, because woody plants often out compete herbaceous species.

Table 1. Woody canopy within management units (Fig. 1) at Rockefeller Experimental Tract at three dates, separated by conditions just prior to reseeding to prairie grasses in 1957 (Fig. 2). Data given as aerial extent of woody canopy (m^2) and as a percentage of the unit or subunit covered by woody canopy. Data on woody canopy are based on aerial photographs and GIS analyses (see Fig. 4). Note that in 1956, woody canopy on these tracts was less than 3% (based on 1954 aerial photograph and deforestation of three sites previously discussed).

			% Canopy Coverage		
Management	*Initial Conditions*	*Area (m^2)*	*1966*	*1974*	*1994*
Burned		566,200			
	cultivated	220,400	0.0	0.5	1.9
	pasture	345,800	0.4	0.5	0.8
Untreated		754,100			
	cultivated	400,800	5.9	26.9	39.3
	pasture w/*Poa*	253,600	21.7	58.4	97.8
	deforested	99,700	42.6	100	100
Grazed		862,200			
	cultivated	657,600	0.3	4.2	6.3
	pasture w/*Poa*	169,100	1.9	8.8	20.4
	deforested	35,500	18.3	94.3	97.6
Mowed		315,900			
	cultivated	315,900	0.8	3.1	3.0

Initial Conditions. Initial conditions of the plant community are known to have persistent effects that may be observable in the character of the plant community at any given time in the future (Keever 1983; Myster & Pickett 1990, 1994). Therefore, knowledge of initial conditions of ecosystems is critical in evaluating ecological studies (Pickett 1989; Tilman 1989), including vegetation change in restoration. We identified two forest types and four habitat conditions within nonforested areas that occurred in 1956; these altered the subsequent development of the plant community. We found significant effects on the woody plant community, mediated through initial starting conditions, in grazed or untreated areas: canopy development was fastest in the recently deforested areas, intermediate on former pasture with scattered trees, and slower in the former cultivated areas (Table 1). This was likely due to the presence of woody vegetation with live roots and shoots, not killed by preparation of the seedbed in 1957, that quickly sprouted and recolonized. We also found differences in composition of tree species correlated with disturbance history, with greater abundance of later-successional species in areas that were deforested just prior to reseeding. Failure to account for differences in initial conditions could lead to spurious interpretation of management effects on invasion of woody vegetation.

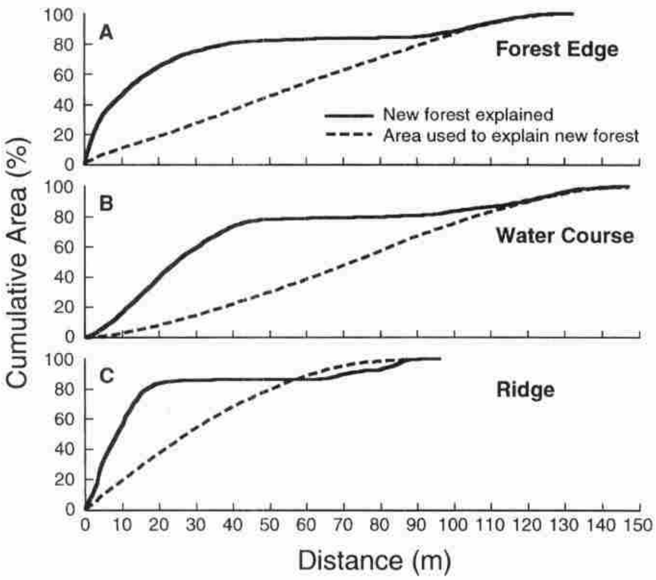

Figure 7. Forest cover changes between 1966 (baseline) and 1974 on an untreated area of the Rockefeller Experimental Tract (see Fig. 6): (A) cumulative percent area as a function of distance from edge and showing both observed new forest and percentage of total area used to predict the new forest; (B) cumulative percent area as a function of distance from water course; and (C) cumulative percent area as a function of distance from ridge for residual forest not explained in (A) and (B).

Within the prairie plant community, we found initial (1956) conditions reflected as persistence of species after 40 years of management. For example, within a small area of the mowed treatment we found *A. canescens* and *C. herbaceous*—these are "conservative" native species indicating an area that has not been heavily disturbed through farming or grazing (Sperry 1994). Failure to detect such former prairie areas, with remnant populations of conservative species, could lead to erroneous assumptions about the speed of restoration. Likewise, occurrence of non-native *Poa* in a former pasture area probably did not result from invasion, but rather an artifact of land-use history. Although reseeded areas at RET are reported to have low species richness compared with the native prairie (Fitch & Hall 1978; Schott & Hamburg 1997; Kindscher & Tieszen 1998; K. Kindscher unpublished data), it is imperative that these assessments, and similar assessments at other restoration sites, are evaluated within the context of initial starting conditions.

Landscape Position. Even within areas of similar land-use history, factors such as landscape position can produce heterogeneity within restoration units. For example, we found greater forest cover associated with three characteristics of landscape position: proximity to pre-existing forest edge, proximity to water courses, and proximity to ridge lines. This same pattern, though not analyzed quantitatively, was generally observable across RET, especially in untreated and grazed areas. We did not collect data to identify the mechanisms causing these distributions; however, previous studies provide insight. In general, for woody plants to colonize a site they must first disperse to the site and then germinate and survive (McDonnell 1986, 1988). In part, the landscape features describing forest invasion at RET may be related to soil erosion and its effect on the germination and survival of woody species. Soil texture on ridges at RET is coarser than on adjacent side slopes (S. Hamburg 2000, personal communication). Areas where soils have less erosion (e.g., ridges) or greater deposition (e.g., stream courses) are invaded faster by woody species. Greater forest cover on ridges likely resulted from the interaction of landscape position with previous land use (cultivation), whereby soils on slopes were inherently more erodible than those on adjacent ridges and, after cultivation, were in a degraded state relative to soils on ridge settings and, therefore, less likely to be colonized by woody species. Expansion of forest along water courses (up gradient) seems related to better conditions for plant establishment and survival in the depositional soils along gullies; these sites would likely have soil texture, moisture and nutrient conditions, and microclimate more favorable to forest development. Greater abundance of woody propagules, seeds, and vegetative sprouts (as suggested by Fitch & Hall 1978), along with favorable conditions for tree establishment, in areas near existing forest seems a likely explanation of greater forest increase in proximity to existing forest. Thus while soil condition is likely a key variable determining forest invasion at RET, interactions with other variables, such as distance to existing forest, determines the actual rate and extent of forestation for any specific site.

Restoration Assessment

Our study highlights the importance of analyzing vegetation change at restoration sites not only in terms of the treatments applied, but also in consideration of the heterogeneity resulting from interaction of land-use history with environmental factors. For example, assessment of long-term restoration effects at RET, within the original experimental design, demonstrated coarse changes in vegetation (e.g., woody species largely precluded from burned or mowed areas). However, within restoration treatments at RET, there were differences in both forest and prairie communities, associated with land-use history (pre-1957) and landscape position, that persisted despite 40 years of restoration treatment. Such heterogeneity necessitates a sampling design that is stratified with respect to landscape history to fully consider restoration. On a broader level, the influence of land-use history within landscapes has been widely documented (e.g., Pickett 1989; Tilman 1989; Myster & Pickett 1990; Foster 1992). Although the importance of site history in restoration ecology is logically inferred from such studies, the role of site history has seldom been studied explicitly within the context of long-term restoration.

Central to our success in determining the site history at RET was the combining of historical data with contemporary plant surveys—this approach will be useful whether working at established sites or in planning restorations. Ideally, site history should be incorporated into the experimental design of new restoration sites so that subsequent research will be more definitive and broadly applicable. Unfortunately, restoration sites that lack detailed land-use histories will have to work retroactively to develop databases, as we did at RET, and this is generally more difficult than doing the work before implementing restoration. Although we believe our framework of historic land use on RET is accurate, given the range of land use over the years, there are likely some areas where we have overlooked, oversimplified, or misinterpreted land-use history. However, we look upon our study as providing a basic framework for considering restoration at RET and demonstration of a methodological approach that is applicable to other sites in the region.

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