

Expansion of gallery forest on Konza Prairie Research Natural Area, Kansas, USA

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Abstract

To determine the dynamics of the spatial extent of gallery forest on Konza Prairie Research Natural Area (KPRNA), aerial photographs taken over a 46 year time frame were digitized into an ARC-INFO Geographic Information System (GIS). A Global Positioning System (GPS) was used to collect ground control points to co-register the photographs for each year. Gallery forest areas for the three major drainage boundaries (Kings Creek, Shane Creek, and White Pasture) were analyzed to assess the uniformity of change in the landscape system. Results indicated that the total gallery forest area on KPRNA has increased in area from 157 ha in 1939 to over 241 ha in 1985. During this time, there was an increase in the total number of patches and a decrease in the mean size of forest patches. However, the rate of increase was not consistent over this time period, nor was it uniform from one drainage basin or stream order to another. Detailed spatial analysis of the forested area with a geomorphology and digital elevation model of Konza Prairie showed that in 1985, 58% of the forest was on alluvial/colluvial soil, yet only 15% of that soil type was forested. In addition, over 70% of the forest was on the 0–15% slope interval, but only 15–20% of that slope interval was forested. These results may be attributed to a variety of factors such as changing management practices (*i.e.*, frequency of fires and herbicide spraying) and the temporal constraints on extent to which the gallery forest can expand across the landscape.

Introduction

The characteristics and distribution of forested areas within the Great Plains of America have intrigued investigators since the discovery and settlement of this area by Europeans. Coronado, in 1541, noted that 'there is not any kind of wood in all these plains, away from the gullies and rivers, which are very few.' (Bragg and Hulbert 1976). Alternately, Gleason (1913) concluded that the plains of the midwest may have been forested to a much larger extent at one time but, with Indian set-

tlement came fire which slowly destroyed most of the forested land, turning it into the prairie it is today. Gleason made no account of fires which started naturally. From recent studies, we now know that fire is, and always has been, a vital component of the tallgrass prairie ecosystem, whether it be human or lightning induced (Gleason 1913; Sauer 1950; Penfound 1962; Bragg and Hulbert 1976; Pyne 1983; Hulbert 1985; Abrams 1986).

Research on Konza Prairie Research Natural Area (KPRNA) has focused primarily on the effects of fire on tallgrass prairie. Without recurrent fire,

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litter accumulates, grass production usually declines, plant composition changes, and woody species invade (Abrams *et al.* 1986; Briggs *et al.* 1989; Briggs and Gibson 1992; Collins and Gibson 1990; Gibson, 1988; Knapp and Seastedt 1986; Seastedt *et al.* 1991). With the re-introduction of bison (*Bos bison*) on KPRNA in 1987, the role of native grazers is also being examined (Nellis *et al.* 1992; Vinton *et al.* 1993). Studies have suggested that forest expansion into the tallgrass prairie has occurred within the last 100 years (Abrams 1986; Abrams 1992; Bragg and Hulbert 1976). However, little quantitative work on the dynamics of the gallery forest (narrow bands of forest along stream drainages) within the tallgrass prairie ecosystem has been conducted.

The purpose of this study was to examine the dynamics of the spatial extent of gallery forests on KPRNA from 1939 to 1985. In particular, our goal was to rigorously quantify the forest expansion during this time interval and the variation in forest expansion across different geomorphic types and drainage patterns within the tallgrass prairie landscape.

Study area

Konza Prairie Research Natural Area (KPRNA) is a tallgrass prairie reserve located in the Flint Hills region about 10 km south of Manhattan, KS. Konza Prairie is representative of the Flint Hills, a dissected upland with chert-bearing limestone layers. The steep-sided hills are characterized by exposed Permian limestone and shale strata that prevented cultivation. The ridges are usually flat with shallow, rocky soils, whereas the larger and wider valleys have deep permeable soils. Most watersheds contain broad, nearly level upland (Florence cherty clay loam soils; Typic Natrustolls) and lowland (Tully silty clay loam soils; Pachic Argiustolls) soils (Jantz *et al.* 1975). Elevation on KPRNA ranges from 320 meters to 444 meters, with most of the land in the range of 366 to 427 meters. The climate is temperate mid-continental and 75% of the annual precipitation (35-year mean = 835 mm) occurs during the growing season (April to September).

This 3487 ha area is largely native grassland dominated by big bluestem (*Andropogon gerardii*), little bluestem (*A. scoparius*), Indian grass (*Sorghastrum nutans*), and switch grass (*Panicum virgatum*) (Freeman and Hulbert 1985). Dominant tree species within the gallery forest on KPRNA include bur oak (*Quercus macrocarpa*), chinquapin oak (*Q. muehlenbergii*), hackberry (*Celtis occidentalis*) and American elm (*Ulmus americana*).

Under an experimental plan initiated in 1971, different watersheds (catchment basins) were placed under a variety of prescribed burning (mid-April) regimes ranging from annual, 2-, 4-, 10-, and 20-year (long term unburned) intervals (Hulbert 1985). Prior to the purchase of KPRNA by the Nature Conservancy in 1972 most of the area was grazed by cattle and it is estimated that the area was burned at intervals of 1–3 years (Hulbert 1985).

Methods

Black and white aerial photographs from 1939, 1950, 1969, and 1985 were used to determine forest extent and expansion in this study. A Global Positioning System (GPS) (Pathfinder, manufactured by Quantity Navigation), was used to collect the ground control points for trees, road intersections, and settlement foundations that could be detected in each of the photographs and were still present on the landscape when ground survey was conducted in 1991. A total of 43 points were collected at an accuracy of approximately 5–10 meters.

The spatial extent of the gallery forest was then hand digitized from the aerial photographs into a Geographical Information System (GIS) (Arc/Info) for each year. The 1939, 1950, 1969 and 1985 photographs, which were taken in sections, were then combined into one GIS coverage per year for further analysis. The ground control points were evenly distributed throughout KPRNA so that distortion was minimal when transforming to UTM coordinates. Forested areas were then divided by drainage basin for area calculations to assess differences in forest dynamics in different drainages. Three drainage areas contained over 90% of the gallery forest on KPRNA: Kings Creek, Shane Creek, and White

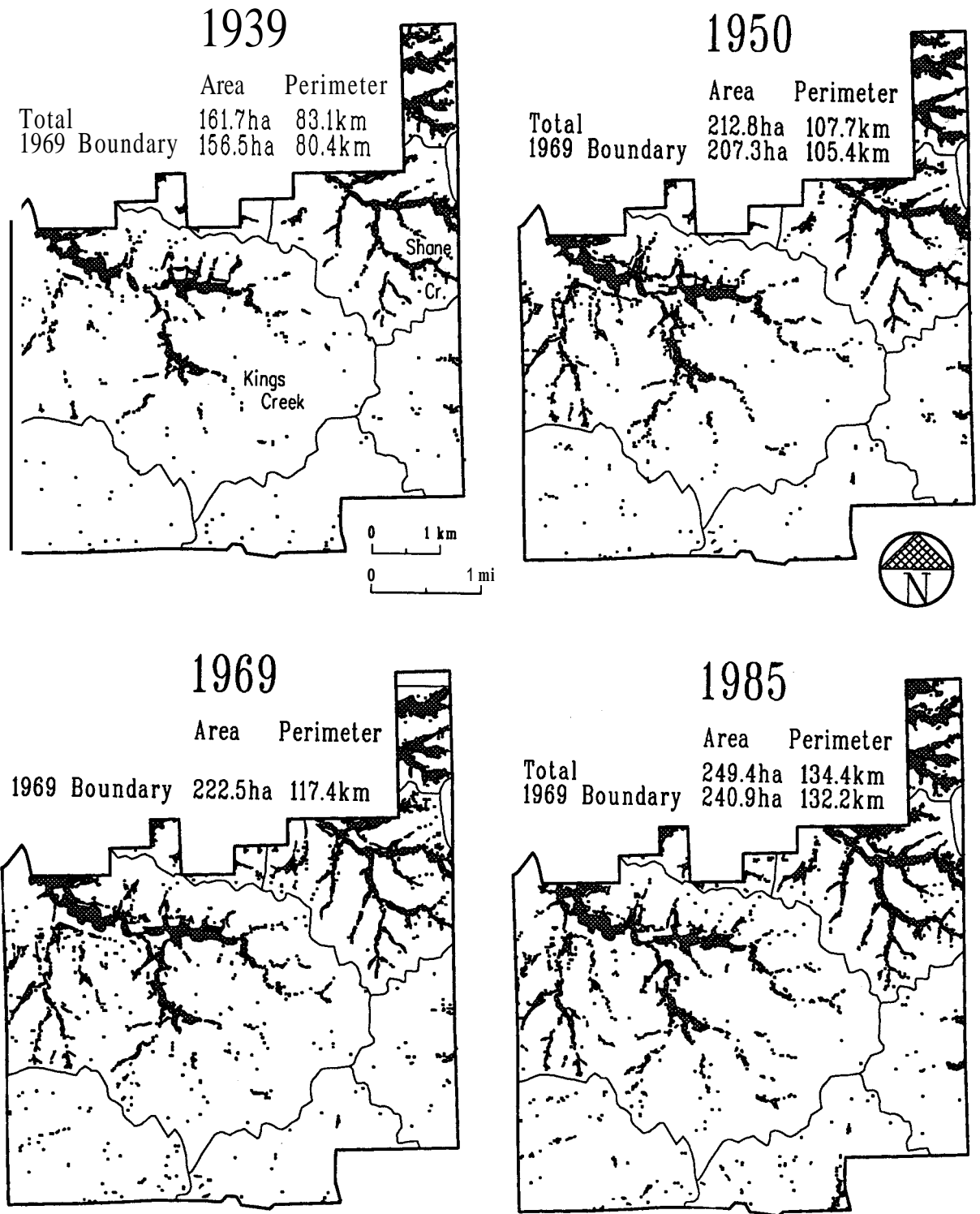


Fig. 1. Gis Representation of gallery forest expansion digitized from aerial photographs from 1939, 1950, 1969 and 1985. The two main drainage units (Shane Creek and Kings Creek) of Konza Prairie Research Natural Area are indicated on the 1939 coverage.

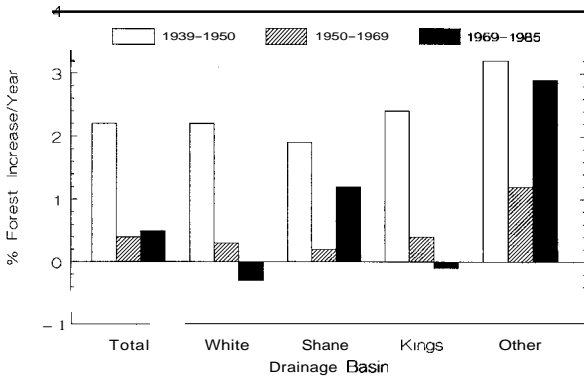


Fig. 2. Gallery forest expansion rates per year for three intervals; 1939-1950, 1950-1969 and 1969-1985.

Pasture, with Kings and Shane Creek being the main drainage units on KPRNA.

All years were then analyzed using the GIS by overlaying a detailed geomorphology coverage (Smith 1991) and a digital elevation model which also contained slope calculations to determine the relationships among gallery forest expansion and landscape characteristics (*i.e.*, soil types, topography, etc.). The percent of the forested area on geomorphic classifications and the percent of the geomorphic classification forested were calculated by overlaying the two separate GIS coverages with the forested area. This same technique was used for the slope intervals. The area of cropland was not used for any of the calculations from the alluvial/colluvial Quarternary deposits and the 0-5% slope interval because it was assumed to be land which could have been forested if it were not for the yearly plowing of the soil. The cropland was determined by using a combination of historical landuse accounts, historical aerial photographs, satellite imagery, and the locations of present agricultural fields on KPRNA (less than 4% of the total area). Management practices since European settlement were also examined to determine the historical human impact on the gallery forest on KPRNA.

Results and discussion

The spatial extent of the gallery forest area within KPRNA increased from 156 ha in 1939 to 241 ha in 1985 (a 54% increase) (Fig. 1). However, the rates

of increase were not uniform over time or from one drainage basin to another, especially after 1950 (Fig. 2). The total forest area did increase through 1985, but it did so at a slower rate.

A testable hypothesis concerning the decrease in the rate of forest expansion (after 1950, Figs. 1 and 2) is that only a limited amount of suitable land is available for forest establishment, thus, a decrease in expansion rates (after 1950; Fig. 2) has resulted from a decrease in suitable land available. This hypothesis was tested by extensive analysis of the size, extent, shape and location within the landscape (with respect to slope and geomorphology) of forest patches from 1939 to 1985.

Patch analysis

The size, extent and shape of the patches were analyzed three ways. 1) Comparing the size and number of forest patches across the four time periods. If the forest is expanding simply due to increased area of existing patches, the number of patches will remain constant over time, while the size of the patches will increase. 2) An analysis was done along primary (first, main branch of the stream), secondary (second branch of the main stream), and tertiary (branch of the secondary stream) branches of the streams to test if expansion occurred at different rates on different size streams or between the two main drainage units (Kings Creek and Shane Creek; Figs. 1 and 2) using ANOVA. Scheffe's multiple range test was used to elucidate differences between years or stream types at $p < 0.05$. This analysis was conducted as a way to determine if the forest patches are dispersing along the riparian corridors. 3) The fractal dimension of the forest patches was measured. The fractal dimension (D), is proportionate to the slope of the regression line when the logarithm of the perimeter is regressed on the logarithm of the area (Mandelbrot 1983). An increase in the fractal dimension of forest patches over time would suggest that the patches are increasing their perimeter to area ratio (a measure of the sinuosity of the forest patches). As suggested by Milne (1991), small patch areas were not used in the analysis to reduce bias.

Table 1. Number of forest patches, total area of forest patches and mean size of forest patches on the two main drainages unit of KPRNA from 1939 to 1985. Kings = Kings Creek Drainage Unit; Shane = Shane Creek Drainage Unit. Primary Stream = first, main branch of the stream; Secondary stream = second branch of the main stream; Tertiary str. = branch of the second stream. Units are in meters. (Number in parenthesis represents year).

	Number of forested patches	Total area of forested patches	Mean patch size
Primary stream			
Kings (1939)	15	569363.6	37957.6
Kings (1950)	24	688380.5	28682.5
Kings (1969)	21	725641.5	34554.4
Kings (1985)	20	653941.4	32697.1
Shane (1939)	3	91164.4	30388.1
Shane (1950)	2	104849.9	52425.0
Shane (1969)	7	126685.3	18098.0
Shane (1985)	5	150732.9	37683.2
Secondary stream			
Kings (1939)	31	414149.7	13359.7
Kings (1950)	57	604679.2	10608.4
Kings (1969)	59	650623.2	11027.5
Kings (1985)	68	623629.5	9171.0
Shane (1939)	15	243364.1	16224.3
Shane (1950)	9	328465.2	36496.1
Shane (1969)	23	372241.4	16184.4
Shane (1985)	22	461691.0	209865.0
Tertiary stream			
Kings (1939)	26	137898.3	5303.8
Kings (1950)	41	212704.0	5187.0
Kings (1969)	48	245682.6	5118.4
Kings (1985)	51	281764.7	4943.2
Shane (1939)	17	289967.1	17056.9
Shane (1950)	15	340349.2	22689.9
Shane (1969)	17	309513.4	18206.7
Shane (1985)	32	397643.5	12426.4

From 1939 to 1985 the general trend across the prairie landscape was an increase in the number of patches and a decrease in the mean size of patches (Table 1). This would indicate that the existing forest patches (in 1939) did not simply grow in size but rather new forest patches were established on the landscape.

The Kings Creek drainage had significantly more forested area than the Shane Creek drainage ($T = 4.87$; $p < 0.001$), thus the two drainage units were analyzed separately. ANOVA of Kings Creek drainage by year found that the forest area in 1939 was significantly lower than the other three time periods ($F = 11.83$; $p = 0.006$). However, the mean patch size across the four years were not sig-

nificantly different ($F = 2.18$; $p = 0.19$). The area and size of forest patches along different stream types did significantly differ across the time periods with primary streams $>$ secondary streams $>$ tertiary streams (Area, $F = 151.69$, $p = 0.0001$; Mean, $F = 207.93$, $p = 0.0001$).

The Shane Creek drainage behaved differently than the Kings Creek drainage. The 1939 time period had the lowest forested area but contrary to the Kings Creek drainage unit, only the 1985 time period was significantly higher than the 1939 time period ($F = 6.11$, $p = 0.03$). Comparing the mean forested area had only the 1950 time period significantly higher than the other time periods ($F = 4.66$, $p = 0.05$). The forest patches along the different

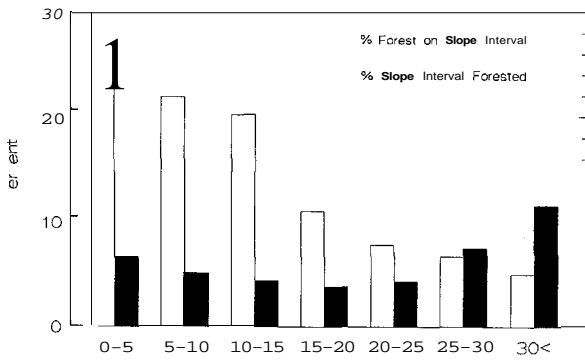


Fig. 3. Percent of gallery forest on each slope interval vs. the percent of the slope interval forested (mean percentage from 1939, 1950, 1969 and 1985).

stream types followed the same pattern as on the Kings Creek drainage with primary streams > secondary streams > tertiary streams (Area F = 49.07, $p = 0.002$; Mean, F = 6.49, $p = 0.032$).

No significant differences between the fractal dimension were found between any of the time periods from 1939 to 1985 ($F = 0.89$, $p > 0.75$). This would suggest that the patches are maintaining a relative constant perimeter to area ratio and that the overall shape and complexity of the forest patches are similar over the 46 year time period.

Slope and geomorphology analysis

As the percent slope interval increases, the amount of forest contained on each interval decreases (Fig. 3). This is misleading, however, because the total area of each slope interval also decreases. Therefore, the percent of each slope interval forested was calculated (excluding cropland). The % area forested on each interval decreases to an interval of about 15–20 percent and the percent of each slope interval forested then starts to increase again. Thus, the percent of the slope interval forested actually increases with an increase in percent slope above 20%. One explanation for this trend is that fire intensity and duration are less on the drier and rockier slopes than on deeper soil sites (Gibson *et al.* 1990). This, coupled with an absence of litter (especially grasses), may decrease fire intensity, allowing some seedlings to become established on some of the

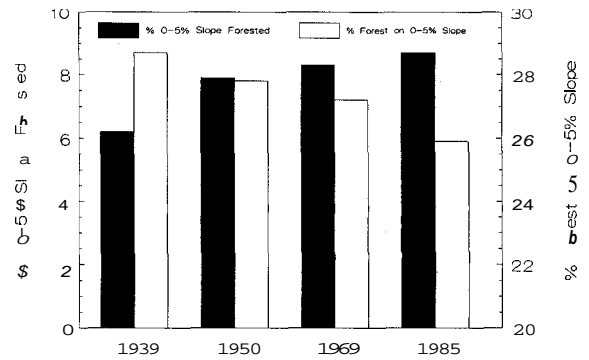


Fig. 4. Change over time for the 0–5% slope interval; percent of the slope interval forested vs. percent of forest on the slope interval.

steeper slopes (pers. comm. Alan Knapp, Division of Biology, Kansas State University, 1993).

The amount of forested area increased over time on the 0–5% slope interval, while the percent of the total forest area on that slope interval decreased (Fig. 4). This indicates an overall shift over time of forest from this slope (0–5%) to steeper slopes. Results also show that about 70% of the forest lies on the 0–15% slope interval, but only about 15–20% of that slope interval is forested (Fig. 3). This indicates a surplus of land which has a suitable percent slope for forest cover expansion as dictated by the preferences of the dominant gallery forest species. However, the 0–15% slope interval also represents hill tops, where other conditions do not favor gallery forest expansion.

The geomorphology study provides a better estimate as to how much forest-prone land is not forested since all alluvial/colluvial deposits are along stream channels which are favorable to tree establishment and growth. About 60% of the gallery forest is found on alluvial/colluvial Quaternary deposits, yet only 10–15% of that geomorphic type is forested (Fig. 5). This indicates a surplus of land which is suitable for forest establishment. The results from the slope and the geomorphology analysis lead us to conclude that the landscape of KPRNA is not preventing the continuation of forest expansion and that some other variable, such as landuse practices (*i.e.*, fire or grazing), is limiting forest invasion.

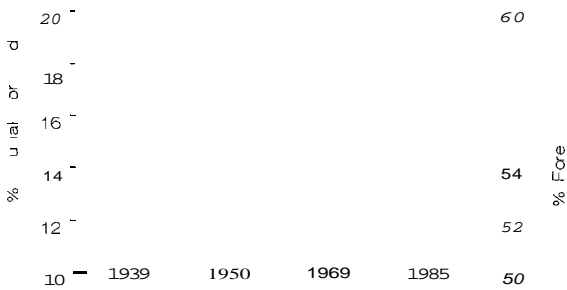


Fig. 5. Change over time for the alluvial/colluvial quaternary deposits; percent alluvial forested vs. percent of forest on alluvial.

Management

Increased amounts of settlement meant an increase in the amount of human impact on the KPRNA environment which could have led to the slowing and varying rates of forest expansion since 1950. Many cultural variables have been proven to have an important impact on the relationship between forest and tallgrass prairie.

Originally, it was the suppression of prairie fires which brought the most change to the tallgrass prairie ecosystem, namely forest expansion. The official suppression of prairie fires was practiced until the 1950's. Now it is known that burning of the tallgrass prairie greatly improves grass productivity, as well as reducing forest expansion on valuable grazing land.

Grazing is a vital part of the tallgrass prairie and has had two major effects on the establishment and growth of woody plants. First, grazing prevented the normal reproduction and growth of the trees by the packing of soil, browsing and breakage of seedlings, and the consumption of seeds (Abrams 1986, 1992). Detailed information on historical (1890–1961) cattle grazing practices on KPRNA are not well known, but it is generally assumed that all portions of KPRNA were grazed by cattle throughout this time period (Hulbert 1985). Current management practices include bison on certain parts of KPRNA to examine the natural role of grazing by these ungulates on the tallgrass prairie

ecosystem and to compare areas grazed by bison with those grazed by cattle.

Secondly, modern grazing management practices in the Flint Hills have also controlled forest expansion into rangeland by herbicide spraying, mowing, and prescribed spring burning. Herbicide spraying, over two consecutive years, was included in the management policy for most of the gallery forest in the early 1960's when KPRNA was a privately owned working cattle ranch (pers. comm. Ted Barkley, Director of KPRNA, 1993). The effects of herbicide spraying probably affect the 1969–1985 rate of expansion rather than the rate between 1950 and 1969, because the dead trees were not removed from the landscape immediately after spraying and dead trees could not be detected in this analysis (Fig. 2). Herbicide spraying could account for the variability in the 1969–1985 rate of expansion among drainage areas as certain areas were undoubtedly sprayed more heavily depending on the value of the rangeland. It is difficult to determine exactly how much of the forest was killed by the herbicides.

Due to the steep and rocky slopes, most of KPRNA has not been cultivated. However, from the aerial photographs, there is evidence that some trees were removed from the prairie. Why these trees were removed and exactly how much is difficult to determine. However, it is believed that the total area of gallery forest removed is small as there has been very limited commercial forestry practiced in the Flint Hills.

The effects of the current management plan of prescribed burning for KPRNA, which started for most of the area in 1977, probably didn't effect the 1969–1985 results but may have a greater impact in the future. However, fire as an agent for increasing rangeland production has been used in parts of the Flint Hills since the late 1800's.

Conclusions

There is no question that the absolute amount of forested areas has increased in the Flint Hills within the last 100 years. Abrams (1986) reported a dramatic increase in gallery forest area between 1859

and 1939 from studying the Original Land Office Surveys for KPRNA. In 1859, only two areas of about 5 ha of continuous forest were noted. However, these surveys were conducted along section lines only (N-S and E-W) and the extent of gallery forest away from these section lines was not noted. Thus, forested area in 1859 was probably underestimated. However, in general, the Flint Hills region was described as rolling prairie completely devoid of any woody vegetation (Abrams 1986). In contrast, in 1939, over 159 ha of forest was detected on KPRNA, a 97% increase since 1859. Our detailed analysis indicated that this trend of dramatic forest expansion within the tallgrass prairie continued between 1939 and 1950 with a 24.5% increase in gallery forest area over eleven years. In addition, we have demonstrated that the expansion of the gallery forest is not being limited by the landscape of KPRNA and that in effect, only 10–15% of the alluvial-colluvial deposits along the stream channels is forested. Other factors such as land-use practices (*i.e.*, fire) are limiting the expansion of the gallery forest.

It is estimated that prairie fires occurred approximately every 2–3 years since European settlement (Abrams 1985). The gallery forest probably burned less frequently (9–10 years) as estimated from tree core analysis (1985). The difference between the fire frequencies of 2–3 years for the prairie ecosystem and 9–10 years for the forest ecosystem is not significant when the two are in balance with respect to each other because the ecosystems operate at different time scales. The grasses are adapted to fires and reach maturity in one growing season, whereas woody species mature after several growing seasons. A tree which is five years old will be heavily damaged by frequent fires which occur within the forests or on the fringes of the forests. Well established trees will not be killed by these fires which tend to wipe out the younger generation. On the other hand, without frequent fires forbs, and eventually woody species, invade the tallgrass prairie ecosystem (Briggs and Gibson 1992). Therefore, to maintain the equilibrium existence between the two ecosystems fires must not occur as often in the gallery forest as in the adjacent tallgrass prairie.

Reduction in the frequency and/or intensity of fires on the prairie also leads to a reduction in the fire frequency and intensity in the forests and this fosters forest expansion because more tree seedlings are able to grow past a point at which the fires no longer kill them or inhibit their maturity. This reduction in fire frequency and intensity occurred with European settlement due not only to suppression of fires, but also because man-made features such as roads and fences kept the fires from spreading as they would have otherwise (Abrams 1986). Therefore, the absence of fires on the prairie ecosystem had a vital effect on increasing woody species invasion. The spatial extent of the gallery forest on KPRNA has been expanding and this is due to European settlement of the area, which led to a reduction in fire frequency. It is more difficult to explain why the rates of expansion changed when they did, and why they are not uniform among the drainage boundaries on KPRNA.

There are many factors which influence the dynamics of the spatial extent of the gallery forest on KPRNA. One important aspect is the time it takes for trees to become established and also the time it takes for them to be removed from the landscape once dead. Therefore, the aerial photographs, which do not indicate the stages of succession or age of trees, can only give a general understanding of the spatial extent of the gallery forest.

Certain questions about the natural environment of KPRNA cannot be answered because European settlement has altered the prairie ecosystem. Determining the effects of one variable of gallery forest dynamics from another is difficult because there are so many variables which affect this complex system. The importance of fire in limiting forest expansion into the prairie does appear clear, however. Without fire, 'the forest is naturally dominant, and tends to spread over wider areas at the expense of the prairie.' (Gleason 1913).

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