An Analysis of Bluff Prairie Size in Great River Bluffs State Park from 1936 to 1996

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Abstract
Great River Bluffs State Park of Minnesota contains many bluff prairies, or goat prairies. These prairies are threatened by encroaching invasive species and provide an ideal habitat for the timber rattlesnake (*Crotalus horridus*). Management practices have been implemented in the park to preserve these natural communities. Aerial photography from nine years between 1936 and 1996 was used to determine bluff prairie boundaries for each year. The boundary sizes (in acres) were compared and combined with a database of management practices to perform analyses using Geographic Information Systems (GIS). The decrease in the size of the bluff prairies was to be expected with the passage of time. With the implementation of management practices, an increase was seen in the size of bluff prairies on a percentage basis between 1979 and 1996. Although the original bluff prairie sizes were not reached by 1996, areas of bluff prairies were reclaimed, increasing the threatened natural community and habitat for threatened species like the timber rattlesnake.

Introduction

Prairies found on the south and southwest facing sides of steep hills in Minnesota are known as bluff prairies or goat prairies. In these areas the sun shines more directly on the land, creating a microhabitat different from the climate of level land or land with a different aspect. The summer is warmer and drier than on the nearby flat lands (MN DNR, 1979).

In Minnesota, bluff prairies are found in the driftless area, or the southeastern part of the state that was not covered by ice during the last glaciations. The driftless area includes parts of Minnesota, Wisconsin, Iowa and Illinois. Although the glaciers did not cover the driftless area, glacial meltwaters did leave their mark on the landscape. The water cut its way through the sandstone and limestone creating a landscape of bluffs and valleys (Ojakangas, 1982).

A threatened habitat in Minnesota, dry prairies (bluff prairies) were identified as natural communities, or groups of "native plants and animals that interact with each other and their abiotic environment" in the Minnesota County Biological Survey (MCBS) conducted by the Minnesota Department of Natural Resources (MN DNR) in the 1980s (MN DNR, 1996). Because Great River Bluffs State Park of Minnesota (formerly O.L. Kipp State Park) contains several types of natural communities including bluff prairies, the park was classified as an area of high biodiversity. At the time of the survey, the park contained thirty bluff prairies.

Prior to the establishment of Great River Bluffs State Park, much of the land

that later become the park was farmed. Erosion was a problem for the farmers, however, because of the soil type and slope of the upland. Therefore, in the early 1960s the Forestry Division of the MN DNR purchased much of the land that the park includes today. Plantations of red and white pine, green ash, and walnut were started. Later in 1976, The Parks Division of the MN DNR purchased the land for protection and restoration of natural resources. Today the park has 2,835 acres (MN DNR, 1979).

One of the most important ecological aspects of bluff prairies as natural communities is that they provide an ideal habitat for the timber rattlesnake (*Crotalus horridus*). Due to human persecution, and loss or degradation of habitat, the timber rattlesnake population has declined in Minnesota. The rarity of recent records prompted a change in state status from rare to threatened. The presence of optimal habitat for rattlesnakes in Great River Bluffs State Park makes the park "one of the most important areas in the region where this species can exist in a relatively protected state" (MN DNR, 1996). The rock outcrops of both King's Bluff and Queen's Bluff Scientific and Natural Areas (SNAs) in the park serve as dens in the winter and basking surfaces during the summer for the rattlesnakes.

Bluff prairies are threatened by encroaching woody vegetation and invasive exotic plant species including crown vetch (*Corinalla varia*) and leafy spurge (*Euphorbia esula*) near hiking paths. In the absence of natural fire and grazing, woody plants and invasive exotic plants invade the prairies (MN DNR, 1996). Many of the bluff prairies were surrounded by deciduous forest, increasing the chances for invasive woody species such as sumac (*Rhus* sp.) and buckthorn (*Rhamnus cathartica)* to invade the bluff prairies.

To offset the effects of invasive species and to try to preserve the bluff prairies, natural resource management practices were implemented in the park. The most frequently used management strategy was a combination of burning, and cutting and pulling invasive species. The burns kill the species that are not native to the bluff prairies. After removing the invasive species, prairie grasses and flowers such as little bluestem (*Andropogon scoparius*), sideoats grama (*Bouteloua curtipendula*), prairie blazing star (*Liatris pycnostachya*) and flowering spurge (*Euphorbia corollata*) are able to flourish (Wendt, 1984). In between burn events, pulling and cutting invasive species allows the native prairie grasses and flowers to dominate the area. Beginning in the 1980s, management practices were entered into a database.

As a result of the importance of bluff prairies in southeastern Minnesota, this project was created to look at the change in size and the effect of management practices on bluff prairies over time. In 1999 a new management plan is being written for the park. Seeing the size changes and the long term effects of management practices on bluff prairies in the park may help resource managers better understand the relationships of bluff prairie size and management over time and help them better manage these natural communities.

Methods

Methods included the acquisition of data, manipulation of data, the creation of new data and analysis of the data (Figure 1).

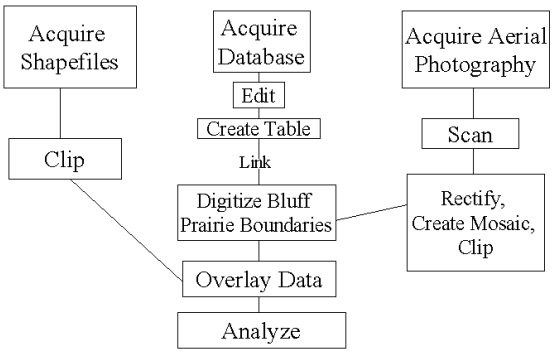

Figure 1. Flow chart of steps for data acquisition, manipulation, shapefile creation and analysis for bluff prairies in Great River Bluffs State Park of Minnesota.

Acquisition and Manipulation of Shapefiles

Shapefiles used in the project were provided by the MN DNR. Databases of information for Region V of the MN DNR were obtained. The databases contained more information than was needed for the project, so to decrease the storage space needed and to look at only the data for the park, the data were clipped. Using the clip tool in the DNR Arcview Utility Tools Extension v1.2 the data that pertained to the park were selected and the extra data were not used. The shapefiles used included the park boundary, park roads, Minnesota County Biological Survey (MCBS) natural communities and rare species data, and SNAs.

Database Acquisition and Manipulation

A database of management practices, in dBase format, was obtained from the MN DNR Parks Department Region V Resource Manager and was edited in Corel Paradox. Codes were added to signify the management practices used on the bluff prairies (prescribed burns =1, cut invasive species = 2 and pulled invasive species = 3). A table containing the data of the management practices performed in the park between 1980 and 1995 was created.

Acquisition and Manipulation of Aerial Photography

Aerial photography was gathered from the University of Minnesota Map Library, the MN DNR Engineering Department, and the United States Geological Survey (USGS). Photography from 1936, 1940, 1947, 1954, 1962, 1968, 1979 and 1996 were the years available at the time of the project.

A 1991 Digital Orthoquad (DOQ), or a computer generated image of the earth's surface with a scale of 1:24,000, that was digitally scanned and processed to remove distortion, was clipped with the DNR DOQ/DRG Extension to the area of the park. A digital raster graphic (DRG) is a scanned color image of a USGS standard series topographic map. The aerial photos were scanned at 300 dpi and the DOQ was used as a georeference to rectify the photos.

Image rectification is a process whereby images are geographically referenced to real-world locations. Using the DNR EPPL7 Extension v2.01b in Arcview 3.1, points of known geographic location were identified on the DOQ. These points were matched with points on the aerial photography and the image was manipulated ("rubber-sheeted") to match the known points.

Some photos had many features that could be matched with the DOQ, while others had very few. In the photos with fewer matching points, more manipulation was done to match the real world coordinates. The measurement of

how close the points are to the real world coordinates and therefore how much manipulation was performed to match the points is called the Root Mean Square (RMS) error. The RMS error was calculated for each rectified aerial photograph. The average RMS error was 12.0. This error was lower than a large RMS error (20) as defined by the MN DNR (MN DNR, 1999). After rectification, the images were merged with the mosaic tool and clipped with the park boundary using the DNR EPPL7 Extension v2.10b.

Creating Bluff Prairie Boundaries

Looking at the rectified images on the computer screen, the boundaries of the bluff prairies were traced (heads up digitized) for each year of photography. By digitizing the boundaries, bluff prairie polygons were created. The minimum mapping unit, or the smallest polygon that could positively be identified as a bluff prairie was 0.2 acres. These polygons were attributed with a bluff prairie identification number (Figure 2). Using the calculate tool in the DNR Arcview Utility Tools Extension v1.2, the area (acres and square meters) and perimeter (feet and meters) were calculated.

The percentage change in acres and change in acreage between each year and between 1936 and 1996 were calculated using Quattro Pro and Excel. These numbers were added to the tables of the bluff prairie polygon shapefiles. Proximity data, management data, and natural community and rare occurrence data were also added to the tables.

Analysis

Using the acreage data from the bluff prairie polygons and the management data for the bluff prairies, analyses were performed to look at the relationships between bluff prairie size over time and management practices. Analyses were used to look for trends in the size of the bluff prairies and the effects of management on the bluff prairies over time.

Figure 2. All of the bluff prairies found in Great River Bluffs State Park between 1936 and 1996. The gray represents all of the bluff prairies seen on aerial photography. The bluff prairies are numbered with their assigned identification number.

The percent change in total acreage of the bluff prairies, for which acreage data for all nine years of photography were available, was plotted against each year of photography. The percent change in acreage for the bluff prairies that received no management were plotted against each year to show the change in bluff prairie size from 1936 to 1996. The percent change in managed bluff prairies was also plotted against each year to show the effects of management practices on the bluff prairies.

To look at the correlation between the percent change of acreage in the bluff prairies and management, the bivariate one-tailed Pearson Correlation was performed with the Statistical Package for the Social Sciences (SPSS). Values greater than zero represent a positive correlation where both variables increase. When one of the variables decreases and the other increases a negative correlation occurs, and no correlation occurs when the value equals zero.

The database of the bluff prairie polygons that contains the management data for each bluff prairie was queried to find the management practices used on each bluff prairie. These management data were compared with the acreage data to see which management practice or practices resulted in the most acreage increase.

Results

Bluff Prairie Size Change

All of the bluff prairies that were visible on the 1936 photography were greater than 0.9 acres (Table 1). Thirteen of the seventeen bluff prairies showed their greatest acreage in 1936. All seventeen bluff prairies found on the 1936 photography decreased in size between 1936 and 1940 and many of them continued to do so with the passage of time. At various points between 1936 and 1996, the size of some bluff prairies increased. Twenty-three of the thirty-nine bluff prairies increased in size between 1947 and 1954, varying from the general trend of decrease in acreage per year (Table 2). As a result of the increase in the size of several bluff prairies between 1947 and 1954, the greatest acreage of bluff prairies was in 1954. After the 1954 increase in bluff prairie size the trend of size decrease over time continued (Figure 3). Overall, between 1936 and 1996, all of the bluff prairies decreased in size. A correlation coefficient of -0.7 was calculated for the comparison of total acreage with time for the bluff prairies. As time passed, the total acreage of bluff prairies decreased.

Size and Management Practices

Increase in acreage for some but not all of the bluff prairies was seen between 1979 and 1996. Bluff prairies number 3 and 4 increased in size between 1979 and 1991 and numbers 2, 4, 5 and 18 increased in size between 1991 and 1996. Management practices were implemented during this time period. Queen's Bluff increased between 1979 and 1991, but decreased again from 1991 to 1996.

Management was implemented at different times and in different combinations on the bluff prairies. Some bluff prairies did not receive management between 1979 and 1996 and some did not receive enough management to prevent the invasion of exotic species. However, with the addition of management to the prairies, a percentage increase was seen in the managed bluff prairies with nine years of data.

The smaller bluff prairies decreased faster than the larger bluff prairies (Table 3). Bluff prairies number 27, 37, 38 and 39 decreased 100% between 1936 and 1996. All of these prairies were less than three acres in 1936. On the other hand, bluff prairies number 2 and 3 (King's Bluff and Queen's Bluff) decreased only 40.8% and 46.8%,

Table 1. The size in acres of bluff prairies in Great River Bluffs State Park of Minnesota from 1936 to 1996. Bluff prairie boundaries were digitized using nine years of rectified aerial photography, and acreage was calculated for each polygon. Numbers are rounded to the nearest tenth[1]. The " -" indicates no aerial photography available for that area for that year.

Bluff Prairie	1936	1940	1947	1954	1962	1968	1979	1991	1996
1	5.2	6.2	4.7	5.9	5.0	4.7	3.1	3.1	4.0
2	15.2	13.0	11.4	14.0	12.4	11.5	9.0	8.2	9.0
3	27.9	23.5	23.0	21.1	18.5	17.8	14.3	15.4	14.9
4	6.9	6.2	5.0	4.9	4.2	3.7	2.6	2.8	3.8
5	8.9	4.7	3.1	5.6	2.6	3.8	1.2	1.2	1.3
6	12.2	10.6	4.9	10.1	8.3	7.5	4.9	3.0	2.1
8	7.3	5.4	3.4	3.4	3.1	2.4	1.7	2.0	1.4
9	-	3.5	4.0	3.6	2.5	1.5	2.2	0.9	0.5
11	-	7.0	8.2	5.6	4.3	3.3	3.7	0.5	0.0
12	5.0	3.2	3.3	3.2	3.0	2.1	2.3	1.0	1.0
13	-	<0.2	<0.2	3.5	3.0	0.7	0.6	0.3	0.0
15	-	<0.2	<0.2	0.4	0.5	0.2	0.0	0.0	0.0
16	4.0	3.1	2.9	3.2	2.2	1.8	1.4	1.1	1.1
17	-	-	2.3	3.5	2.1	2.2	1.9	1.3	1.6
18	8.2	5.9	5.8	6.3	7.0	4.1	4.2	3.2	5.1
19	-	2.6	1.0	2.7	5.1	2.9	3.2	2.1	2.2
20	-	<0.2	<0.2	0.8	0.8	0.6	0.6	0.3	0.0
21	-	1.6	<0.2	6.7	5.6	3.9	3.6	3.3	1.6
22	-	2.1	3.8	5.5	5.2	2.9	3.7	3.5	2.3
24	-	<0.2	<0.2	7.8	7.7	6.9	4.7	1.4	0.0
26	-	2.9	3.5	3.8	3.4	3.9	3.6	2.4	2.0
27	1.5	<0.2	<0.2	2.6	1.5	0.7	1.1	0.4	0.0
28	2.8	<0.2	<0.2	5.4	3.4	3.8	2.9	2.4	1.2
30	7.9	2.8	<0.2	7.2	3.4	4.3	3.1	1.4	0.0
35	5.5	8.2	<0.2	5.8	5.0	3.5	2.3	0.0	0.0
36	-	<0.2	3.4	12.0	12.4	8.4	8.5	7.4	4.3
37	2.1	1.4	<0.2	1.2	<0.2	0.6	1.6	0.0	0.0
38	2.7	2.2	1.3	2.3	1.9	1.1	1.3	0.0	0.0
39	0.9	0.5	<0.2	0.7	0.9	0.4	0.4	0.0	0.0
total[2]	124.2	115.6	95.2	158.9	135.2	111.2	93.8	72.2	59.3

[1]In the instances where no bluff prairie was seen on the aerial photography in a given year but was seen on the following year of photography, a value of <0.2 acres was entered into the table. In these cases, because no known management took place it was not likely that a bluff prairie disappeared and then reappeared in the following years. A value of 0.0 acres was entered into the table when a bluff prairie was not seen on the following year of aerial photography. Here the bluff prairie could have decreased to nothing.

[2]The totals were calculated by adding only the acreages of the bluff prairies greater than the minimum mapping unit.

Table 2. The size change in acres of bluff prairies in Great River Bluffs State Park of Minnesota from 1936 to 1996. Bluff prairie boundaries were digitized using nine years of rectified aerial photography, and the acreage change between each year of photography and between 1936 and 1996 was calculated. Numbers are rounded to the nearest tenth. The " -" indicates no aerial photography available for that area for that year.

Bluff Prairie	1936 to 1940	1940 to 1947	1947 to 1954	1954 to 1962	1962 to 1968	1968 to 1979	1979 to 1991	1991 to 1996	1936 to 1996
1	1.0	-1.5	1.2	-0.9	-0.3	-1.6	-0.1	1.0	-1.2
2	-2.2	-1.6	2.6	-1.6	-0.9	-2.5	-0.7	0.8	-6.2
3	-4.4	-0.5	-1.9	-2.7	-0.7	-3.5	1.1	-0.5	-13.0
4	-0.7	-1.2	-0.1	-0.8	-0.5	-1.1	0.2	1.0	-3.1
5	-4.2	-1.6	2.5	-3.0	1.3	-2.7	0.1	0.1	-7.6
6	-1.6	-5.7	5.1	-1.8	-0.8	-2.5	-1.9	-0.9	-10.1
8	-1.9	-2.0	0.0	-0.3	-0.7	-0.7	0.3	-0.6	-5.9
9	-	0.5	-0.4	-1.1	-1.0	0.7	-1.3	-0.5	-
11	-	1.3	-2.6	-1.3	-1.0	0.4	-3.2	-0.5	-
12	-1.8	0.1	-0.2	-0.2	-0.9	0.2	-1.3	0.0	-4.0
13	-	-0.2 to 0.2	3.3 to 3.5	-0.5	-2.3	-0.1	-0.3	-0.3	-
15	-	-0.2 to 0.2	0.2 to 0.4	0.0	-0.3	-0.2	0.0	0.0	-
16	-0.9	-0.2	0.2	-1.0	-0.4	-0.4	-0.3	0.0	-2.9
17	-	-	1.2	-1.3	0.1	-0.3	-0.5	0.2	-
18	-2.3	-0.1	0.5	0.7	-2.9	0.1	-1.0	1.9	-3.1
19	-	-1.7	1.8	2.4	-2.2	0.3	-1.2	0.2	-
20	-	-0.2 to 0.2	0.6 to 0.8	0.0	-0.2	0.0	-0.3	-0.3	-
21	-	-1.4 to -1.6	6.7	-1.0	-1.7	-0.3	-0.3	-1.7	-
22	-	1.8	1.6	-0.3	-2.3	0.8	-0.2	-1.2	-
24	-	-0.2 to 0.2	7.6 to 7.8	-0.1	-0.8	-2.2	-3.4	-1.4	-
26	-	0.6	0.4	-0.5	-0.5	-0.3	-1.3	-0.4	-
27	-1.5	-0.2 to 0.2	2.4 to 2.6	-1.1	-0.7	0.4	-0.7	-0.4	-1.5
28	-2.8	-0.2 to 0.2	5.2 to 5.4	-2.1	0.4	-0.9	-0.5	-1.1	-1.5
30	-5.1	-2.8	7.2	-3.7	0.8	-1.2	-1.7	-1.4	-7.9
35	2.7	-8.2	5.8	-0.8	-1.5	-1.2	-2.3	0.0	-5.5
36	-	3.2 to 3.4	8.6	0.5	-4.1	0.1	-1.1	-3.1	-
37	-0.7	-1.4	1.0 to 1.2	-1.2	0.4 to 0.6	1.0	-1.6	0.0	-2.1
38	-0.6	-0.9	1.0	-0.4	-0.8	0.2	-1.3	0.0	-2.7
39	-0.3	-0.3 to -0.5	0.5 to 0.7	-0.2	-0.5	0.0	-0.4	0.0	-0.9
total[1]	-27.3	-24.9	34.6	-23.7	-24.0	-17.2	-21.1	-5.1	-79.2

[1]The totals were calculated by adding the acreages of the bluff prairies greater than the minimum mapping unit only. The entries that included a range of data were not included in the total for each column.

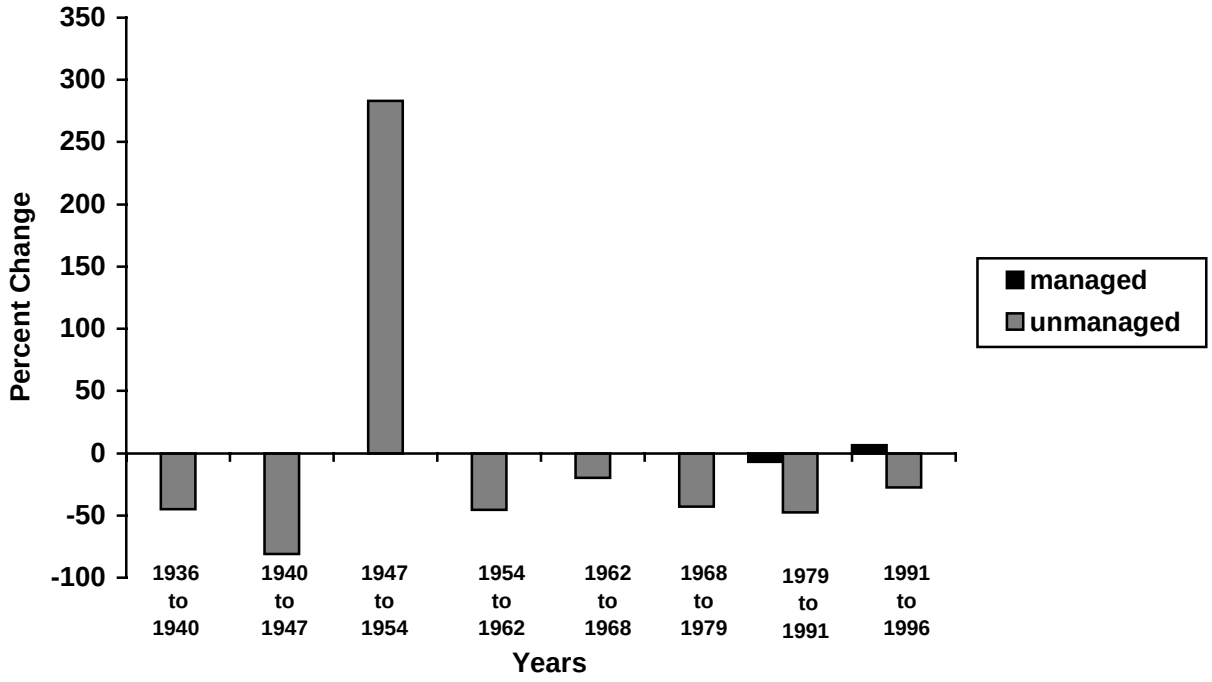

Figure 3. Percent change in total acreage of managed and unmanaged bluff prairies in Great River Bluffs State Park between each year of photography from 1936 to 1996. Management did not begin on bluff prairies in the park until 1980. The bluff prairies with data available in all nine years of photography were used.

respectively. In 1936 King's Bluff was 15.2 acres and Queen's Bluff was 27.9 acres. King's and Queen's Bluffs were the largest of the bluff prairies in 1936.

The bluff prairies with acreages greater than 3 acres and smaller than 15.2 acres varied in the decrease on percentage basis between 1936 and 1996. Bluff prairies 30 and 35 also decreased 100% between 1936 and 1996. These bluff prairies were 7.9 and 5.5 acres in 1936, respectively. Bluff prairies 1, 4, and 18 decreased 22.7%, 38.2% and 38.2%, respectively. These bluff prairies were between 5.2 and 8.2 acres in 1936. A decrease ranging from 71.5% to 85.2% was seen in bluff prairies 5, 6, 8, 12 and 16. These bluff prairies ranged from 4.0 to 12.2 acres in 1936.

Most of the management on bluff prairies was a combination of burning, cutting and pulling invasive species. Ten of the 12 managed prairies used all three management practices and prescribed burning was used on 11 out of the 12 managed bluff prairies in the park.

Discussion

The decrease in the size of the bluff prairies was to be expected with the passage of time. From the perspective of landscape ecology, bluff prairies are patches, or wide, relatively homogeneous areas that differ from their surrounding areas

Table 3. The percent change in size of bluff prairies in Great River Bluffs State Park of Minnesota from 1936 to 1996. Bluff prairie boundaries were digitized using nine years of rectified aerial photography, and the percent change between each year of photography and between 1936 and 1996 was calculated. Numbers are rounded to the nearest tenth[1]. The " -" indicates no aerial photography available for that area for that year.

Bluff Prairie	1936 to 1940	1940 to 1947	1947 to 1954	1954 to 1962	1962 to 1968	1968 to 1979	1979 to 1991	1991 to 1996	1936 to 1996
1	18.2	-24.0	25.0	-15.1	-5.2	-33.8	-2.4	32.4	-22.7
2	-14.8	-12.3	22.8	-11.1	-7.6	-22.0	-8.1	9.3	-40.8
3	-15.8	-2.0	-8.2	-12.6	-3.7	-19.7	7.7	-3.4	-46.8
4	-9.7	-19.0	-1.7	-15.3	-12.0	-29.7	9.2	33.9	-44.9
5	-47.6	-33.2	81.2	-54.0	48.2	-69.7	7.3	5.3	-85.2
6	-12.9	-53.4	103.8	-17.5	-10.0	-34.0	-39.0	-29.9	-82.7
8	-25.5	-37.5	0.6	-9.5	-22.8	-30.0	19.2	-29.1	-80.6
9	-	13.8	-10.4	-30.4	-39.0	44.8	-58.1	-51.4	-
11	-	18.4	-31.5	-23.1	-23.0	10.8	-85.9	-100.0	-
12	-36.1	4.0	-4.6	-5.0	-31.0	11.9	-56.8	-1.9	-80.3
13	-	*	*	-14.0	-77.6	-16.0	-42.8	-100.0	-
15	-	*	*	9.1	-67.6	-100.0	*	*	-
16	-21.9	-7.0	8.1	-31.6	-18.4	-17.6	-23.8	3.8	-71.5
17	-	*	53.7	-38.1	4.5	-16.1	-29.0	16.4	-
18	-28.1	-1.2	8.4	11.8	-41.6	1.3	-23.3	58.2	-38.2
19	-	-63.1	181.4	87.0	-43.3	11.0	-35.9	7.3	-
20	-	*	*	4.0	-30.1	-5.4	-48.5	-100.0	-
21	-	-100	*	-15.8	-30.9	-8.2	-7.7	-52.8	-
22	-	86.4	42.2	-5.1	-43.7	26.2	-4.8	-35.1	-
24	-	*	*	-0.7	-10.3	-31.8	-71.4	-100.0	-
26	-	19.1	11.0	-11.8	14.1	-6.6	-34.8	-16.8	-
27	-100.0	*	*	-43.8	-49.9	55.1	-65.2	-100.0	-100.0
28	-100.0	*	*	-38.2	11.8	-21.7	-18.6	-47.9	-54.8
30	-64.6	-100.0	*	-52.2	24.4	-27.1	-54.1	-100.0	-100.0
35	48.2	-100.0	*	-13.1	-30.0	-39.9	-100.0	*	-100.0
36	-	*	248.4	3.9	-32.7	1.3	-12.4	-41.7	-
37	-33.9	-100.0	*	-100.0	*	156.0	-100.0	*	-100.0
38	-20.4	-39.8	78.5	-18.6	-40.3	18.5	-100.0	*	-100.0
39	-38.2	-100.0	*	27.2	-58.4	10.8	-100.0	*	-100.0
total[2]	-6.1	-18.3	66.9	-14.9	-17.7	-15.6	-26.8	-26.8	-52.2

[1]The * represents bluff prairies with a percentage range. Because a value of <0.2 acres was used in Table 1, one number could not be figured for the percent change.

[2]The totals were calculated by using the totals in Table 1 to find the percent change between each year of photography and from 1936 to 1996.

(Forman 43). The edge of the patch is an area of transition between the patch and the surrounding landscape. In the edge area, transition species exist. As time progresses, if no forces stop the progression of edge species into the patch, the patch will decrease in size.

A decrease in the acreage of the bluff prairies was found between 1936 and 1996 even though management practices were implemented after the park was established. The correlation between the passage of time and the decrease in overall acreage of bluff prairies in the park showed the effects of succession. As time passed, the invasive species of the surrounding deciduous lands began to take over the

prairies. Increases in the sizes of the bluff prairies at various points between 1936 and 1996 may have been a result of natural fires, and precipitation and temperature fluctuations.

A possible explanation for the increase in the size of the prairies between 1947 and 1954 is less precipitation than normal. Between 1931 and 1955 the average precipitation per year was 29.23 inches (United States Environmental Data Service, 1975). This average was lower than the 32.57 inches/year average of 1961 to 1990 (National Weather Service, 1999). These drier conditions might have been too dry for deciduous invasive species to spread to the prairies.

In the case of bluff prairies, fires and grazing naturally decrease the invasion of other species into the bluff prairies. Natural fires are not found on the bluff prairies in the park anymore because they are suppressed due to residential areas surrounding the park. Therefore, management by humans is the only way bluff prairies will remain.

A positive percent change in total acreage occurred on the bluff prairies between 1979 and 1996. The increase in the size of bluff prairies between 1979 and 1991 was seen in bluff prairies number 3 and 4. Increases also occurred in the sizes of bluff prairies 2, 4, 5 and 18 between 1991 and 1996. These increases in bluff prairie size were expected with the implementation of management practices. Burning prairies, and pulling and cutting invasive exotic species reclaims the area of the bluff prairie and therefore increases the number of acres.

Bluff prairies number 2 and 18 decreased between 1979 and 1991, but increased between 1991 and 1996 during the period when the most management practices were recorded. A combination of burning, and cutting and pulling invasive species produced the most increase in acreage.

Reclamation of area for bluff prairies does not always work though, when the rate of invasion is greater than the rate of reclamation through management. For the rest of the managed bluff prairies (6, 9, 11, 13, 15, 16, and 22) all but bluff prairie 15 decreased from 1979 to 1996. Bluff prairie 15 was 0.0 acres in 1968 and remained that way until 1996 according to the methods used. In these cases the area of the bluff prairies did not increase from 1979 to 1996. If the rate of invasion is greater than the rate of management, the area decreases. Factors such as the size and steepness of the bluff prairie, the types of management practices used on the bluff prairie, the frequency of management on the bluff prairie and the type of invasive species effect the overall increase or decrease in bluff prairie size.

Using the method of drawing bluff prairie polygons by using aerial photography, anything less than the minimum mapping unit (0.2 acres) was entered as a value of 0.0 acres in the database. However, in some cases, bluff prairies had values greater than 0.2 acres in the years prior to and following a year with a value of 0.0 acres. For example, in 1940 bluff prairie 30 was 2.8 acres using this method. In 1947, the value entered was less than the minimum mapping unit, and in 1954 the value was 7.2 acres.

The odds of a bluff prairie decreasing from 2.8 acres to 0.0 acres and then increasing to 7.2 acres in 1954 without management is very unlikely. Succession, the replacement of one kind

of community by another kind, (Krebs, 1988) usually does not reverse without the aide of humans or natural disturbance. Therefore, in the absence of any known natural disturbance it is not likely that the bluff prairie decreased to 0.0 acres and then increased again. Hence, where the data went from an acreage of at least 0.2 acres to 0.0 acres and then back to 0.2 acres or greater, <0.2 acres was entered into the table. Representing the size of the bluff prairies as <0.2 acres showed that it was not likely that the bluff prairie was 0.0 acres in that year.

The bluff prairies with entries of <0.2 acres in Table 1 were not absolute values, therefore the acreage change between years could not be recorded as an absolute value in Table 2. In these cases, a range of values was used representing the lowest and highest possible changes in acreage. The percent change was also affected. The total columns of the tables are the total of the values greater than the minimum mapping unit.

In cases where the acreage did not increase to at least the minimum mapping unit in the following year of photography, the entry of 0.0 acres was left in the table. In these cases, the bluff prairie could have decreased to nothing.

The smaller bluff prairies decreased more on a percentage basis than the larger bluff prairies. The four smallest prairies on the 1936 photography decreased 100% between 1936 and 1996. Bluff prairies number two and three (King's and Queen's Bluffs), the largest two bluff prairies in 1936, decreased 40.8% and 46.8%, respectively. The higher percentage of decrease in smaller bluff prairies was expected because a smaller area takes less time to decrease than a larger area. A bluff prairie with an area less than three acres would take less time to be overtaken by invasive species than a bluff prairie with an area of 27.9 acres.

Queen's Bluff increased in size between 1979 and 1991 but decreased again between 1991 and 1996. Prescribed burns and the cutting of sumac were performed between 1983 and 1991. The size of the prairie increased during the time when most of the management was recorded. Although Queen's Bluff decreased in size between 1991 and 1996, it still remained the largest bluff prairie in the park. In 1996, the size of Queen's Bluff was 14.9 acres.

Even though Queen's Bluff decreased in size with the passage of time, it still exists. Several bluff prairies in the park were not visible on aerial photography in 1996. Five of these bluff prairies were less than five acres in 1936 and were not managed. More vigorous management on the smaller bluff prairies is needed to preserve them over time. If the small bluff prairies are left unmanaged, they disappear faster than the larger bluff prairies such as Queen's Bluff and King's Bluff.

Conclusion

This project was intended to look at the change in size of bluff prairies over time using GIS. Combining aerial photography, shapefiles, a database of management and natural and rare species information, it was seen that bluff prairies in Great River Bluffs State Park have decreased in size over time. Management practices implemented in the park were effective in increasing the acreage of some of the bluff prairies

between 1979 and 1996.

The bluff prairies did not increase to their original sizes, but reclamation of part of the area that was formerly bluff prairie increased the threatened natural community and habitat for threatened species like the timber rattlesnake. Further analysis could look at more photography, especially recent photography to develop more relationships between data. The effects of precipitation, slope, aspect, soil and temperature could also be explored.

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