AN ABSTRACT OF THE THESIS OF

Chad V. Gatlin for the Master of Science

in Biology presented on July 14, 1998

Title: Beaver in the Great Plains: Habitat Suitability Index and Flooding

Abstract approved: Elmer J. Finck

In 1991, Kansas Department of Wildlife and Parks (KDWP) and Kansas State University (KSU) censused beaver (Castor canadensis) colonies and collected habitat information on riverine systems throughout Kansas. The resulting publication showed that the United States Fish and Wildlife Service's habitat suitability index model (HSI) does not work well in Kansas. In 1995 and 1996, portions of 9 of the rivers censused in 1991 by KDWP and KSU were recensused for beaver colonies. Several habitat characteristics were recorded in an attempt to fine tune the HSI for use in the Great Plains. River depth, river width, and river bed substrate were not shown to have statistically significant effects on beaver locations. Therefore, these variables were not considered to be valuable enough to add to the HSI for use in the Great Plains. Water fluctuation, which is used in the current HSI, was not shown to have a strong relationship with beaver colony density. Therefore, in the Great Plains, water fluctuation should be dropped from the current HSI. Two variables, slope of the river bank and river bank substrate, were shown to have statistically significant effects on beaver locations ($\underline{P} < 0.0001$, $\underline{P} = 0.0001$, respectively) . Therefore, when calculating a beaver HSI in the Great Plains, these variables should be added. Using Geographic Information Systems (GIS), I calculated land use and

related it to beaver use and non-use of sites. Beaver showed no preference for locating colonies adjacent to any particular land use. However, a comparison of combined agricultural and woodland to grassland ($\underline{P}$ = 0.071) suggests that different methods for evaluating land use with GIS should be investigated. Large quantities of field time could be saved if food requisites are quantified with GIS instead of in the field.

In 1993 and 1995, major flooding occurred in the Midwest and eastern Great Plains. The effect of these floods on riverine beaver colonies was investigated by using the beaver census data collected by KDWP and Kansas State University in 1991 as a baseline. The censuses conducted in 1995 and 1996 showed no relationship between beaver colony densities and number of flood days on each respective river ($\underline{P}$ = 0.1446). Newborn beaver kits are the members of a beaver colony that are most susceptible to floods. Since young beaver do not disperse until 2 to 3 years of age, noticeable decreases in colony density may not have been detected at the time of the study.

BEAVER IN THE GREAT PLAINS:

HABITAT SUITABILITY INDEX AND FLOODING

A Thesis

Submitted to the

Division of Biological Sciences

Emporia State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

Chad Vincent Gatlin

August 1998

Thesis
1998
G

Elmer J. Finck
Approved by Major Advisor

Approved by Committee Member

Lloyd B. Fox
Approved by Committee Member

Approved by Committee Member

David Edds
Approved by Committee Member

Approved for Major Department

Timothy M. Downs
Approved for Graduate Council

ACKNOWLEDGMENTS

I thank my advisor, Dr. Elmer J. Finck, for his support, suggestions, critiques, and encouragement throughout my study. I feel that I have grown an incredible amount as a biologist under his tutelage. Thanks goes to committee member, Dr. Lloyd Fox, for supplying me with the 1991 beaver census data, as well as for countless hours spent discussing wildlife biology in general and my project in particular. I also thank the rest of my committee members, Drs. James Aber, David Edds, and Dwight Moore, each of whom taught me a great deal about their particular expertise in science. I also thank Dr. Larry Scott for help with statistical analysis, Roger Ferguson for help with equipment, and Roger Applegate for help with computer programs. This project would not have been possible without my field assistants, many of whom were volunteers, and I thank them. They were: Paul Bixel, Matt Combes, Darrel Edson, David Ganey, Bob Kopecky, Katie McGrath, Doug Robinson, Christiane Roy, and Chris Williams.

Very special thanks goes to my family. To my two boys, Levi and Logan, for bringing joy to my life. To my wife, Beth, for surviving graduate school with me. Of course, none of this would have been possible without her support and understanding. I would also like to thank my parents, Ted and Linda, who have always supported me in everything I have done.

Equipment and/or financial support were provided by the Emporia State University Faculty Research and Creativity Committee, ESU Division of Biological Sciences, Ross Natural History Fund, Kansas Department of Wildlife and Parks, and Pittman-Robertson Funds.

PREFACE

My thesis has two chapters, which will be submitted to two different scientific journals. Each chapter has been written in the style appropriate to its respective journal.

Chapter 1 deals with modifications of an HSI model for use in the Great Plains and will be submitted to the Journal of Wildlife Management. The running head is RH: Beaver HSI Modification • Gatlin. Key words: beaver, Castor canadensis, GIS, GPS, Great Plains, habitat, HSI, Kansas, river, suitability.

Chapter 2 deals with the effects of the floods of 1993 and 1995 on beaver populations and will be submitted to the Wildlife Society Bulletin. The running head is RH: Beaver and Floods • Gatlin. Key words: beaver, Castor canadensis, flood, Flood of 1993, Great Plains, Kansas.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

TABLE OF CONTENTS (CONTINUED)

Page

LIST OF TABLES

Table Page

LIST OF FIGURES

LIST OF FIGURES (CONTINUED)

LIST OF FIGURES (CONTINUED)

LIST OF APPENDICES

CHAPTER 1

Habitat Suitability Index Modifications for Beaver in the Great Plains

Abstract: During 1995, and 1996, beaver (Castor canadensis) colony densities were assessed along riverine systems in the southeastern quarter of Kansas and compared to data collected at the same sites in 1991. A Global Positioning System (GPS) and Geographic Information Systems (GIS) were used to determine the location of colonies along the rivers. GIS was also used to determine land use along the rivers. Additionally, during 1995 and 1996, several habitat characteristics were evaluated at random sites and beaver activity sites. By relating beaver colony densities to habitat characteristics, modifications were made to locally adapt a beaver Habitat Suitability Index (HSI) model for use in the Great Plains. Beaver preferred sites of steeply sloped bank ($\bar{x}$ = 78°) into which to dig their burrows (P < 0.0001). Beaver also preferred sites with a silt bank, as opposed to finer substrates, such as clay, or coarser substrates, such as gravel or rock (P = 0.0001). I recommend that the slope of the bank and bank substrate be added as variables when calculating HSI for beaver in the Great Plains. Water fluctuation is an important habitat characteristic in the current HSI. I did not find a strong relationship between beaver colony density and water fluctuation, and recommend that water fluctuation be dropped from the HSI model when used in the Great Plains. Current HSI models do not evaluate the proximity of agricultural fields, a potentially important source of food for beaver in the Great Plains. Using GIS, I evaluated the availability of agricultural land and woodland to beaver colonies. I did not show that beaver have greater access to

agricultural land or woodland along their colonies than that available along the entire river ($\underline{P}$ = 0.071). However, this habitat characteristic probably deserves further investigation.

INTRODUCTION

The North American beaver (Castor canadensis) is capable of dramatically changing its habitat by building dams and canals and cutting down trees (Naiman et al.1986, Naiman et al. 1988, Smith et al. 1991). In some cases new wetlands are created by the activity of beaver. In other cases valuable riparian habitat is lost due to the clearing of trees from riversides. In still other cases, a sustainable population of beaver is desired for fur trapping purposes. Therefore, management goals for beaver may vary drastically depending on the overall management goals for an area.

In order to successfully manage beaver populations, one should understand which environmental characteristics beaver select when finding a place to live. Several habitat suitability index (HSI) models have been written for beaver (Retzer et al. 1956, Slough and Sadleir 1977, Allen 1983, Howard and Larson 1985, Beier and Barrett 1987). All of these HSI models use measurements of habitat characteristics to attempt to evaluate how suitable an area is for beaver. However, there is no complete agreement on exactly which habitat characteristics are the most relevant. Allen (1983) took extensive measurements of available woody vegetation plus three physical attributes of the environment: stream gradient, water fluctuation, and shoreline development factor. Slough and Sadleir (1977) reported that available food is the most important habitat variable in streams. Beier and Barrett (1987) reported that "...beaver habitat use depends mainly on physical variables and not on food abundance variables..."

One reason for the disagreement on which habitat characteristics are important could be that the range of the beaver covers most of North America and therefore consists of many different habitat types at the landscape level. Many researchers warn that either local evaluations should be done to determine local vegetation conditions or that the HSI only be used in habitats similar to that in which it was created (Howard and Larson 1985, Beier and Barrett 1987, Barnes and Mallik 1997).

One of the most common HSI models used today is the U. S. Fish and Wildlife Service's HSI model for beaver by Allen (1983). Although a favorite of government conservation and wildlife agencies, this HSI was produced by using data primarily from montane landscapes (Robel et al. 1993). Use of the HSI in non-montane landscapes can result in poor predictability of beaver habitat. Robel et al. (1993) found only 17% of the variation in beaver colony density along riverine systems in Kansas explained by Allen's HSI (1983). In riverine systems, Allen's HSI (1983) uses extensive vegetation measurements and one physical habitat variable, water fluctuation. Robel et al. (1993) suggested modifying the water fluctuation requisite in Allen's HSI (1983) as well as adding other variables to attempt to improve the HSI for use in the Great Plains. Among the suggested variables were stream or river substrate and proximity to row crop agriculture.

My objective was to modify Allen's HSI (1983) for use in the Great Plains in general, and specifically in Kansas. I investigated several habitat characteristics, most of which are not used in the current HSI.

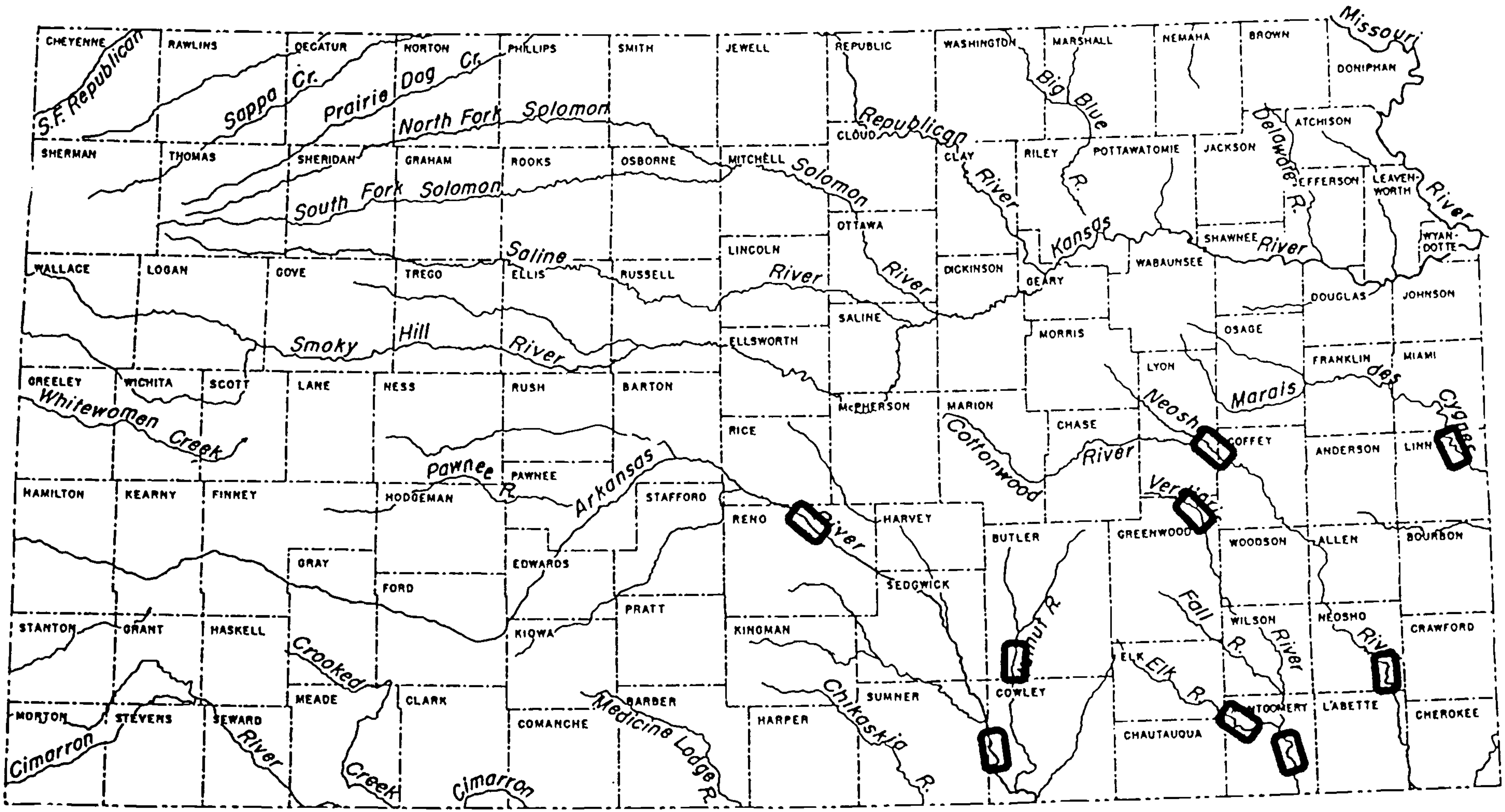
STUDY AREA

My study was conducted in the southeastern quarter of Kansas, which lies in the eastern Great Plains of the United States. All rivers sampled are contained within an area bounded by 38^0 23' N, 98^0 12' W, 37^0 10' N, and 94^0 46' W and are part of the Arkansas and Osage river watersheds. Rivers in Kansas are generally slow flowing with gradients less than 6% (Robel et al. 1993). Many of the rivers have been impounded, often causing sudden fluctuations in water level as reservoirs begin or cease releasing water. The riparian forest along the rivers can vary from being over 100 m wide to nonexistent. Woody vegetation consists mainly of cottonwood (Populus deltoides), hackberry (Celtis occcidentalis), and willow (Salix sp,) with sycamore (Platanus occidentalis), American elm (Ulmus americana), and black walnut (Juglans nigra) being locally abundant.

Nine stretches of river were selected to be sampled once during 1995 and once during 1996 (Fig. 1). Each river section was 10 km long and was not impounded along the portion being sampled. The nine study sites were subjectively chosen as a subset from a 1991 study (Robel et al. 1993) done by Kansas State University and the Kansas Department of Wildlife and Parks (KDWP). I thank Dr. Fox of KDWP for supplying access to the data from the 1991 study. In the 1991 study, 21 different 25-km sections of river were sampled across the entire state.

Fig. 1. Location of study sites in southeastern Kansas. Each study site is 10 km long.

Base map is an uncopyrighted map of the entire state of Kansas.



CHEYENNE
RAWLINS
DECATUR
NORTON
PHILLIPS
SMITH
JEWELL
REPUBLIC
WASHINGTON
MARSHALL
NEMAHA
BROWN
DONIPHAN
SHERMAN
THOMAS
SHERIDAN
GRAHAM
ROOKS
OSBORNE
MITCHELL
CLOUD
CLAY
RILEY
POTTAWATOMIE
JACKSON
ATCHISON
JEFFERSON
LEAVEN-WORTH
WYAN-DOTTE
WALLACE
LOGAN
GOVE
TREGO
ELLIS
RUSSELL
LINCOLN
OTTAWA
DICKINSON
GEARY
WABAUNSEE
SHAWNEE
DOUGLAS
JOHNSON
SALINE
ELLSWORTH
MORRIS
OSAGE
LYON
FRANKLIN
MIAMI
GREELEY
WICHITA
SCOTT
LANE
NESS
RUSH
BARTON
RICE
McPHERSON
MARION
CHASE
COFFEY
ANDERSON
LINN
HAMILTON
KEARNY
FINNEY
HODGEMAN
PAWNEE
STAFFORD
RENO
HARVEY
BUTLER
GREENWOOD
WOODSON
ALLEN
BOURBON
GRAY
FORD
EDWARDS
SEDGWICK
STANTON
GRANT
HASKELL
KIOWA
PRATT
KINGMAN
WILSON
NEOSHO
CRAWFORD
MEADE
CLARK
COMANCHE
BARBER
HARPER
SUMNER
COWLEY
ELK
MONTGOMERY
LABETTE
CHEROKEE
MORTON
STEVENS
SEWARD
CHAUTAUQUA
S.F. Republican
Sappa Cr.
Prairie Dog Cr.
North Fork Solomon
South Fork Solomon
Solomon
Republican
Big Blue R.
River
Missouri River
Delaware R.
Kansas River
Saline River
Smoky Hill River
Whitewomen Creek
Pawnee R.
Arkansas River
Cottonwood River
Neosho River
Marais des Cygnes
Verdigris
Walnut R.
Fall R.
Elk R.
Wilson River
Crooked Creek
Cimarron
Medicine Lodge R.
Chikaskia R.

METHODS

Each 10-km long study site was chosen from within the 25-km section that had been sampled in 1991 (KDWP unpubl. data, Robel et al. 1993). Most study sites were selected by finding an easy road access to the river on a 7.5 minute topographic map, and by measuring upstream for 10 km along the river. Random sites were designated every 500 m and marked on the map, resulting in 20 random sampling points per river.

Field Techniques

Using an aluminum canoe with a gasoline motor, I censused each study site. Censuses were conducted between July and November in 1995 and in May and June in 1996. At least two researchers were always present. Both researchers scanned the banks for signs of beaver activity. Beaver activity included tracks in the bank, fresh tree cuttings, bank dens, slides, scent mounds, canals, cut corn, food caches, feed beds, or lodges. When beaver sign was sighted, the canoe was stopped and the following variables of river characteristics were recorded: type of beaver sign, WIDTH, DEPTH, SLOPE, HEIGHT, SUBbed, and SUBbank (Table 1). WIDTH was estimated at the water's edge in 5-m increments to 50 m and in 10-m increments from 50 m to 100 m. Anything over 100 m wide was recorded as 110 m. Using a weighted rope marked with knots, I measured DEPTH (Table 1) to the nearest 0.5 m. DEPTH was measured in the river channel when possible. If a deeper channel was not obvious, then DEPTH was measured at the middle of the river. SLOPE was measured by holding a canoe paddle parallel with the slope of the

Table 1. The abbreviations and descriptions of the variables.

Abbreviation	Description
WIDTH	Width of the river (5 m increments)
DEPTH	Depth of river (0.5 m increments)
SLOPE	Slope of river bank (degrees)
HEIGHT	Height of river bank (1 m increments)
SUBbed	River bed substrate
SUBbank	River bank substrate
FLUX annual	Water fluctuation (m/year)
WD100	Percentage of woodland within 100 m of colonies
WD100total	Percentage of woodland within 100 m of entire study site
CRP100	Percentage of crop within 100 m of colonies
CRP100total	Percentage of crop within 100 m of entire study site
WDCRP100	Percentage of crop and woodland within 100 m of colonies
WDCRP100total	Percentage of crop and woodland within 100 m of entire study site
WD30	Total number of woodland pixels touching river within colonies
WD30total	Total number of woodland pixels touching river within study site

Table 1. - continued

Abbreviation	Description
CRP30	Total number of crop pixels touching river within colonies
CRP30total	Total number of crop pixels touching river within entire study site
WDCRP30	Total number of crop and woodland pixels touching river within colonies
WDCRP30total	Total number of crop and woodland pixels touching river within entire study site
CROSS	WIDTH * DEPTH to give cross sectional area of river (m^2)

river bank. A clinometer was then laid along the paddle so that the slope could be read in degrees. HEIGHT was estimated in 0.25-m increments for heights < 1 m and in 1-m increments for heights > 1 m. Both HEIGHT and SLOPE were measured only on the side which contained sign at beaver activity sites, and on both sides of the river at random sites. SUBbed and SUBbank were qualitatively ranked from smallest to largest particle size (Table 2) based on the predominant substrate type present. SUBbed was sampled by using a Ponar dredge. SUBbank was determined visually.

Global Positioning System

During part of the 1995 and all of the 1996 field season, Global Positioning System coordinates (GPS) were recorded. Using a Magellan ProMark X, GPS coordinates were recorded to the nearest hundredth of a minute. Post processing of the location data was not possible since the locations were recorded to hard copy data sheets instead of stored in the GPS unit itself. Therefore, Selective Availability (SA) could affect the data. SA is an error put into the data received by the GPS unit from the satellites. Its intention is to keep other countries from using the United State's satellites to guide weapons. This error can be up to 100 m, but usually hovers closer to 20 m. In addition to having GPS locations, the navigator in the front of the canoe would mark the location of the sign on a 7.5 minute topographic map, which had been photocopied onto waterproof paper (field map). As the river was traveled, the navigator would also watch for the predesignated random sites. When a random site was reached the same variables were recorded as at beaver activity sites. If

Table 2. Ranks of predominant SUBbed and SUBbank substrate types.

Ranking	Description of substrate*
1	Clay
2	Clay/silt
3	Clay/gravel
4	Clay/rock
5	Silt
6	Silt/sand
7	Silt/gravel
8	Silt/rock
9	Sand
10	Sand/gravel
11	Sand/rock
12	Gravel
13	Gravel/rock
14	Rock
15	Bedrock/silt
16	Bedrock/gravel
17	Bedrock/rock
18	Bedrock

* All classifications were based on layman's definitions. Gravel was classified as substrate roughly < 5 cm across. Substrate > 5 cm was classified as rock.

beaver sign were observed at a random site then that site became a beaver activity site. No attempt was made to replace random sites lost in this way, so all rivers ended up with fewer than 20 random sites. There was an average of 12 random sites per study site.

Population Density

Population density estimates for beaver are often done by determining the number of colonies in an area and then multiplying by the average number of beaver/colony for the area (Busher et al. 1983, Robel et al. 1993). Swenson et al. (1983) warn that colony counts do not always give an accurate estimate of population size because colony size can change. Beaver colonies are family units generally consisting of one breeding pair of adults and their offspring. The offspring usually disperse around 2 years of age. These family units are normally territorial and occupy an exclusive stretch of river (Jenkins and Busher 1979).

I quantified beaver densities along rivers as the number of active colonies/km of river. Using colony density instead of a population estimate gives a relative measure of beaver use of an area without the problems of fluctuating colony size. Colony counts also buffer against the effects of local trapping, which can cause the beaver population to fluctuate independent of the habitat characteristics available. Fur trappers seldom trap out an entire colony, thus leaving some beaver so that the trapper may return to the same location again the following year.

In order to identify colony locations, the GPS coordinates were computer plotted onto a base map. Kansas Cartographic Database (KCD) hydrology files, which were used as the base map, were downloaded from the State of Kansas Geographic Information Systems Core Database, which can be found in the Data Access and Support Center (DASC) section of the Kansas Geological Survey's homepage on the Internet. An Idrisi (V. 3.0a) Geographic Information System (GIS) was used to plot coordinates obtained by the GPS. The KCD files were converted to Idrisi format by using the ArcIdrisi import module found in Idrisi. As each location was found with the GIS, it was marked onto a hard copy 7.5 minute topographic map. These locations were then compared to the locations on the field maps. Locations marked on the field map were almost always within 100 m of the GPS corrected locations and were usually within 20 m. Field map locations in 1996 were drastically wrong on the upper Arkansas River. The GPS was not used on this site in 1995 and both years the researchers were lost for most of the census at this site. Therefore, data from the Upper Arkansas River site were excluded from any analysis involving location or number of beaver colonies. Other rivers sampled without the GPS were considered to have accurate locations for both years based on the agreement between the field maps and the GPS corrected maps in the 1996 census.

Colonies were located by importing the KCD hydrology coverages into ArcView (V. 2.00.04), a computer program, which allows the viewing and minor manipulation of ArcInfo files. Distances between sign were measured in ArcView to determine where colonies were located. These colonies were then outlined with coded boxes representing the year the census was conducted (Appendix A). Colonies were determined for both field seasons. Census maps were obtained from the KDWP 1991 census (KDWP unpubl. data, Robel et al. 1993) and colonies were determined for that year as well.

Criteria for the amount of area a colony uses differ among researchers. Robel et al. (1993) designated areas of clumped beaver activity > 300 m to be a colony. Minimum size for beaver colony territories is reported being as little as 0.5 km long to as much as 2.5 km and distance between colonies ranges from 0.15 km to 1.59 km; maximum densities of colonies range from 0.83 colonies/km to 1.83 colonies/km (Bergerud and Miller 1977, Slough and Sadleir 1977, Busher et al. 1983, Swenson et al. 1983, Howard and Larson 1985, Beier and Barrett 1987, Broschart et al. 1989). I designated colonies as areas of > 300 m of clumped beaver activity. A break of > 300 m of no activity must occur to separate colonies. Some sites had continuous sign for > 1 km. In such cases there was considered to be 1 colony/km of river. Any left over segment > 500 m was considered to be an additional colony. Therefore, a 3.4-km segment of continuous sign would have 3 colonies while a 3.5-km segment would have 4 colonies. Many sites censused had beaver activity signs that were either isolated or < 300 m in length. These sites are probably being used by dispersing or transient beaver and do not represent a colony, although they do represent sites usable by beaver. These sites were not included in the estimate of the number of colonies along the river.

The previous study conducted at these sites (Robel et al. 1993) designated continuous sign as 1 colony/2.5 km resulting in a density of 0.4 colonies/km for sites with continuous sign. This is well below other published reports of colony density and is therefore a conservative estimate. My criteria result in a density of 1 colony/km of river in sites with continuous sign, which is still well within the range of previously reported densities. I am not including sites used by transient beaver and my criteria fall within previous researchers' findings. Thus, I am using a valid estimate of colony density.

Water Fluctuation

FLUX (Table 1) was obtained from gaging station records obtained from the U. S. Geological Survey. Each river has several gaging stations on it. Gaging station records show the depth of the river recorded on a daily basis in feet, which I converted to meters. The gaging station closest to the study site was always selected. No impoundments occurred between the gaging stations and the respective study sites. To quantify FLUX, the difference between the minimum and maximum depth for each month was calculated. This gave the maximum fluctuation of the river for the month. This monthly change in water level was then summed across the 12 months prior to the census date for each river. By summing across months, this method of quantifying water fluctuation takes into account both magnitude and frequency of the water fluctuation. However, FLUX does not differentiate between magnitude and frequency since increases in either the magnitude or frequency of the water fluctuations will cause FLUX to increase. I used one month as my unit of time for calculating

FLUX. By increasing or decreasing this amount of time, the variable can become more or less sensitive to water fluctuations. If the difference was measured on a weekly scale, the variable would become more sensitive. If measured every two months, the variable would become less sensitive. A filter coarseness of 1 month was chosen because it was thought that this would show how often fluctuations occur, but still be easy enough to calculate to be reasonably usable as an environmental variable.

Forage

Food requisite requirements for my model are represented by WD100, CRP100, WDCRP100, WD30, CRP30, and WDCRP30 (Table 1). The values for these variables were obtained by importing 1988 LANDCOVER files from the State of Kansas, Geographic Information Systems Core Database, which is available through the DASC section of the Kansas Geological Survey's homepage on the Internet. LANDCOVER files use thematic mapper Landsat images to produce land cover maps with a pixel size of 30 m x 30 m. Accuracy of the LANDCOVER data varies county by county, but all counties are considered to be at least 85% accurate. Land cover types are sorted into 10 categories: (1) urban water, (2) water, (3) urban woodland, (4) woodland, (5) residential, (6) commercial/industrial, (7) urban grassland, (8) grassland, (9) agricultural, and (10) other. All urban designations were combined with the corresponding non-urban designations, reducing the number of categories to 7. These LANDCOVER files were imported into ArcView and overlaid with the KCD hydrology files, which contained colony locations.

The amount of forage available along the rivers was quantified by printing a hard copy map of the LANDCOVER file for each study site. Sites with and without beaver colonies were then designated on each map. In order to determine available forage within 100 m of the river, a 100-m scale line was produced on each map prior to printing. A pencil compass was then set to scale by using the 100-m line and used to draw a parallel line 100 m from the river's edge (Appendix B). Using a clear sheet of plastic with a pixel drawn on it, I quantified and classified, according to its coding, all land area within 100 m of the river's edge. The percentage of land within each coding was calculated along the entire study site (WD100total, CRP100total, and WDCRP100total). The same calculation was then performed by using only sections of the river which had contained beaver colonies in any of the years sampled (WD100, CRP100, and WDCRP100).

Many previous investigators suggested that primary beaver foraging occurs within 50 m from the water (Jenkins 1980, Belovsky 1984, Fryxell and Doucet 1991). In order to quantify land use < 50 m from the river, I also counted the number of pixels of each land use type that actually touched the river. Since pixels are 30 m wide, this effectively quantified land use within 30 m of the river. The percentage of pixels of each code was calculated (WD30total, CRP30total, and WDCRP30total). The same calculation was then performed by using only sections of the river, which contained beaver colonies (WD30, CRP30, and WDCRP30).

Analysis

SPSS versions 6.1 and 7.5 were used for statistical analysis. Analyses were not nested, except where indicated, because I was testing overall characteristics of rivers for beaver habitat and not trying to find differences nested within one river system as compared to another.

One-way ANOVAs were performed on the habitat characteristics WIDTH, DEPTH, HEIGHT, SLOPE, SUBbed, SUBbank, and CROSS. The factor was type of sign, which was classified as either random site or beaver activity site. The sequential Bonferroni method was used to reduce the probability of experiment-wide error when performing multiple one-way ANOVAs (Rice 1989).

Beaver activity sites were divided into foraging sites (tracks and slides) and den sites. A step-wise discriminant function analysis was used to detect differences among den sites, foraging sites, and random sites with respect to the variables HEIGHT and SLOPE. Discriminant analysis is a statistical method, which allows for comparisons among multiple dependent variables.

Paired t-test were used to determine differences between the following pairs of variables: (1)WD100 and WD100total, (2) CRP100 and CRP100total, (3) WDCRP100 and WDCRP100total, (4) WD30 and WD30total, (5) CRP30 and CRP30total, and (6) WDCRP30 and WDCRP30total.

Since water fluctuation did not vary from place to place within a study site, FLUX was the only variable that could not be categorized by the presence or absence of beaver. Therefore, a simple linear regression was performed by pooling all years of data and by regressing the colony density by the corresponding FLUX. In an attempt to control for background variation within rivers, a second simple regression was performed in which the largest colony density for each river was paired with the corresponding year's FLUX.

A principal components regression was performed to control for other variables, which may influence the number of beaver colonies in conjunction with water fluctuation. Habitat variables with a significance of $\underline{P} < 0.10$ (see RESULTS), were modified to represent the entire river. These variables were: (1) SUBbank, (2) SLOPE, and (3) WDCRP30. The variables SUBbank and SLOPE were modified by only using measurements recorded at the preselected random sites, regardless of sign of beaver activity. WDCRP30 was quantified along each study site, regardless of sign of beaver colonies. Howard and Larson (1985) recommend using principal components regression to show relationships between a dependent variable and several possibly correlated independent variables (such as explanatory habitat variables). The factor analysis portion of the principal components regression creates one or more components from the correlated variables. The component values are then regressed against the dependent variable.

RESULTS

River Width and Depth

Beaver activity was found at sites where river width ranged from 5 m to over 100 m wide. WIDTH (Table 1) was not statistically significant (Table 3) between beaver activity sites and random sites. Furthermore, the mean WIDTH at beaver activity sites and random sites differed by only 2.7 m, which is much smaller than the 5 m increments at which WIDTH was measured. Therefore, the difference is much smaller than the scale at which the variable was measured.

DEPTH (Table 1) at beaver colonies ranged from 0.25 m to 6 m. DEPTH was not significantly different between beaver activity sites and random sites (Table 3). I found mean DEPTH between beaver activity sites and random sites to differ by only 17 cm (Table 3). DEPTH was measured in 0.5 m increments so this difference is again less than the scale at which the variable was measured.

Some researchers have combined depth of river and width of river to give cross-sectional area of the river as a measure of quantity of water available (McComb et al. 1990, Barnes and Mallik 1997). Combining width and depth into a cross-sectional area measurement for my data resulted in higher $\underline{P}$-values than either depth or width showed independently (Table 3).

Table 3. ANOVA results for comparisons between beaver activity sites and random sites.

Variable	N	Range	Mean	SD	df	F ratio	P-value	*Bonferroni
WIDTH					1, 747	2.74	0.0981	0.0125
Active	544	5-110 (m)	30.52 (m)	18.16				
Random	205	5-110 (m)	33.22 (m)	23.89				
DEPTH					1, 773	3.24	0.0720	0.0100
Active	558	0.25-6 (m)	1.70 (m)	1.11				
Random	217	0.25-8 (m)	1.53 (m)	1.21				
CROSS					1, 746	1.89	0.1690	0.0167
Active	543	3.75-195 (m^2)	49.89 (m^2)	37.42				
Random	205	1.25-300 (m^2)	45.58 (m^2)	40.12				
HEIGHT					1, 764	1.53	0.2157	0.0250
Active	550	0.25-6 (m)	2.37 (m)	1.10				
Random	216	0.38-6.5 (m)	2.45 (m)	1.13				

Table 3. -continued

Variable	N	Range	Mean	SD	df	F ratio	P-value	*Bonferroni
SLOPE					1, 766	29.28	<0.0001**	0.0071
Active	551	8°-overhang	62.36°	19.29				
Random	217	10°-overhang	54.21°	17.01				
SUBbank					1, 760	16.46	0.0001**	0.0083
Active	545	1-15	5.46	2.02				
Random	217	1-14	6.18	2.59				
SUBbed					1, 772	0.78	0.3745	0.0500
Active	558	1-18	9.70	4.56				
Random	216	1-18	9.37	4.57				

*Sequential Bonferroni corrected significance level value

** Designates statistical significance

Height and Slope of the River Bank

The height of the bank ranged from 0.25 m to 6 m at beaver activity sites and the slope of the bank ranged from a very gradual incline (8°) to overhanging banks. Beaver activity was found throughout this range, although dens tended to be associated with steeper banks. The one-way ANOVA did not show a statistically significant difference between beaver activity sites and random sites for HEIGHT (Table 3). However, SLOPE was statistically significantly different between beaver activity sites and random sites (Table 3). The mean HEIGHT at random sites was lower than the mean HEIGHT at den sites, but higher than the mean HEIGHT at foraging sites (Table 4). As with HEIGHT, the mean SLOPE at the random sites was higher than the mean SLOPE at foraging sites and lower than the mean SLOPE at den sites (Table 4).

The step-wise discriminant function analysis, which separated beaver activity sites into den sites and foraging sites, did show a statistically significant difference among den, foraging, and random sites for inclusion in the discriminant function for both SLOPE ($\underline{N}$ = 768, X^2 = 176.332, df = 2, $\underline{P}$ < 0.0001) and HEIGHT ($\underline{N}$ = 766, X^2 = 188.853, df = 4, $\underline{P}$ < 0.0001). The canonical correlation showed that SLOPE explained 45.37% of the variation among den, foraging, and random sites. Even though HEIGHT was statistically significant, it only increased the canonical correlation to 46.21%.

River Bed and Bank Substrate

I ranked substrate types on a continuous scale from 1 - 18 (Table 2). This classification assumes that the difference between each successive

Table 4. Mean SLOPE and HEIGHT among beaver den sites, beaver foraging sites, and random sites.

Variable	Den sites		Foraging sites		Random sites	
	Mean	SD	Mean	SD	Mean	SD
SLOPE	77.85°	19.96°	56.90°	15.77°	54.15°	17.07°
HEIGHT (m)	2.54	1.15	2.27	1.07	2.45	1.13

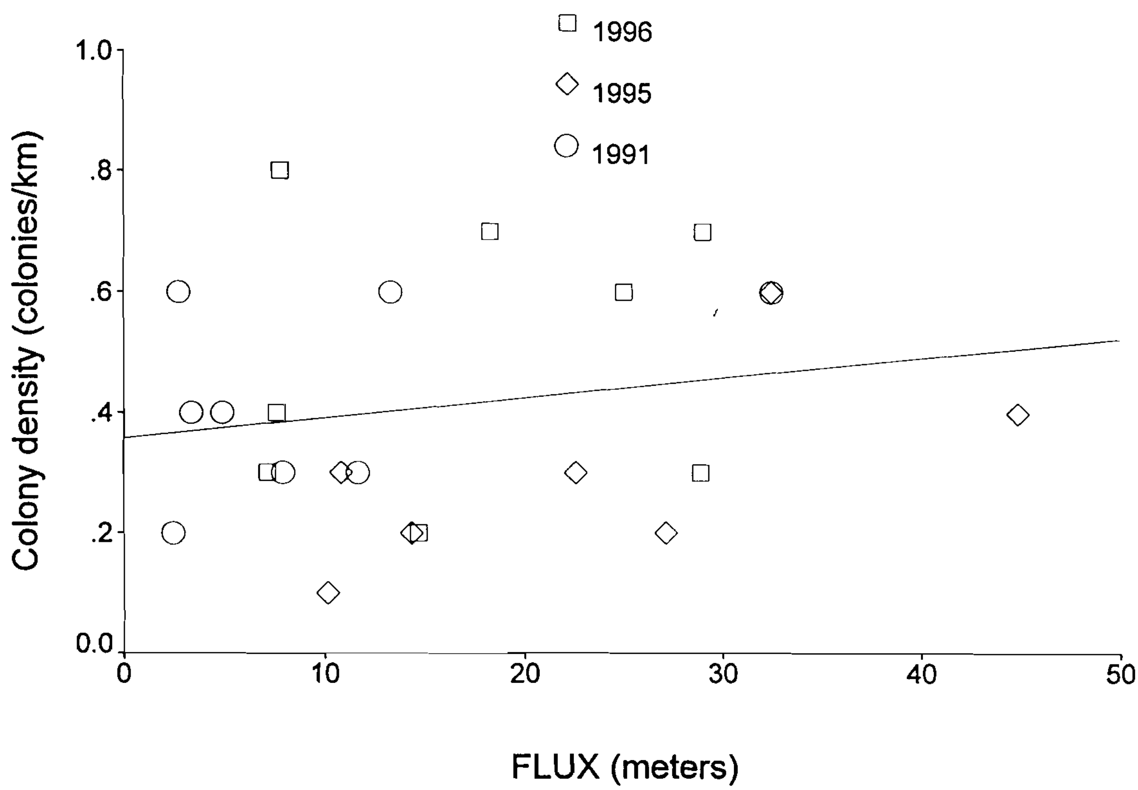
rank is equivalent. SUBbed (Table 1) did not have a statistically significant difference between beaver activity sites and random sites, and was, in fact, very nearly identical between beaver activity sites and random sites (Table 3). Although SUBbed differed among different rivers, it tended to stay very consistent within each individual river. This gave beaver living on a particular river very little choice about the river bed substrate type.

SUBbank (Table 1), on the other hand, did differ within individual rivers. I found a statistically significant difference between beaver activity sites and random sites (Table 3). Substrate types from clay through bedrock/silt were found at beaver activity sites, although den sites seldom ranked above silt/sand. Random sites ranged from clay through rock. The beaver activity site mean ($\bar{x}$ = 5.46) corresponded to a silt substrate and the random site mean ($\bar{x}$ = 6.18) corresponded to a silt/sand substrate.

Water Fluctuation

The variable FLUX (Table 1) is an objective measurement of water fluctuation, which takes into consideration both quantity of water fluctuation and frequency of fluctuation. A negative relationship between FLUX and colony density is expected since high water fluctuation should negatively affect beaver. In a simple regression combining all years of data (1991 data supplied by KDWP unpubl. data, Robel et al. 1993), FLUX explained only 3.6% of the variability in number of colonies/study site, and actually had a positive relationship with colony density (Fig. 2).

Fig 2. Colony density per study site as a function of the annual water fluctuation index (FLUX). Data from 1991 (KDWP unpubl. data, Robel et al. 1993), 1995, and 1996 are included as independent data points (N = 24, R^2 = 0.0391, SE = 1.93, F = 0.82, 1,6 df, P = 0.3747).


1996
1995
1991
1.0
.8
.6
.4
.2
0.0
0
10
20
30
40
50
Colony density (colonies/km)
FLUX (meters)

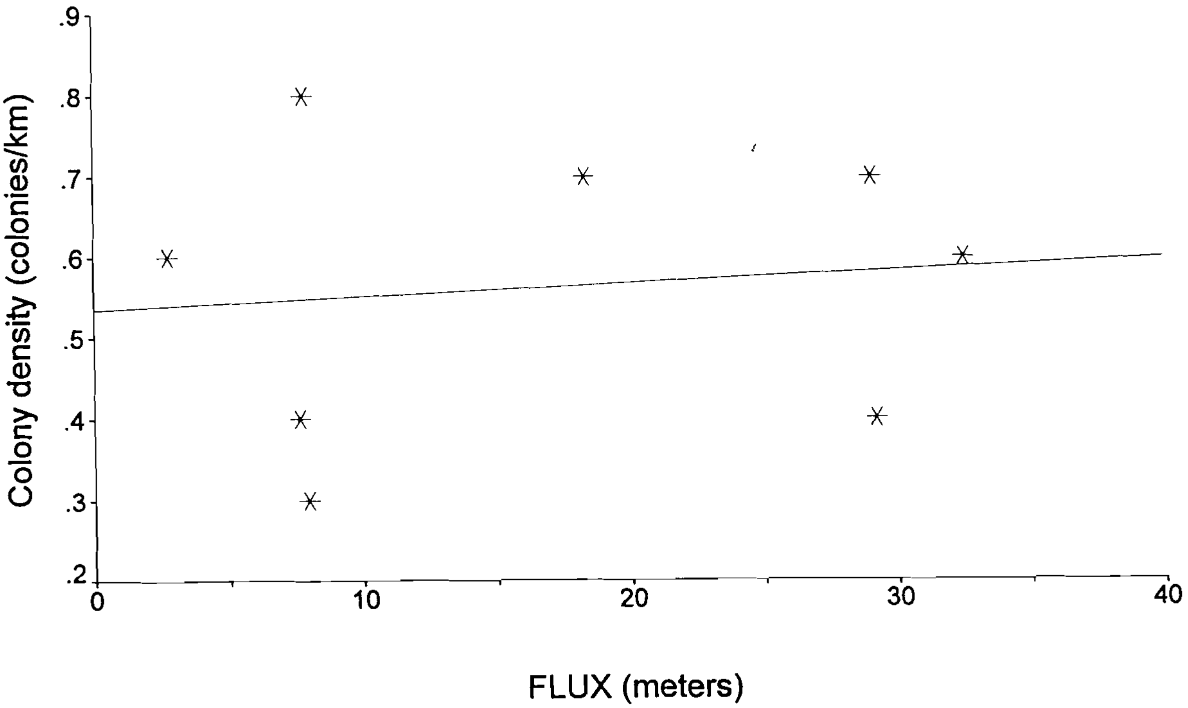
In an attempt to control for background variation within rivers, the largest colony density for each river (1991 data supplied by KDWP unpubl. data, Robel et al. 1993) was paired with the corresponding year's FLUX. A positive relationship was still shown, but FLUX explained even less of the variability in colony density (Fig. 3).

A principal components regression was run so that other possibly important variables could be included without adding the effects of collinearity. In the principal components regression FLUX and WDCRP30 from each river as well as the average SLOPE and SUBbank from each river were combined into a single factor. The resulting factor explained < 1% of the variation in number of colonies/study site (1991 data supplied by KDWP unpubl. data, Robel et al. 1993; $N = 8$, df = 6, $F = 0.05622$, $P = 0.8205$). These results combined with previous findings (Robel et al. 1993) indicate that water fluctuation is not an important indicator of beaver habitat in the Great Plains. However, if mean colony density/year is plotted with mean FLUX/year, an inverse relationship can be seen (Fig. 4). In a simple regression, mean FLUX/year explained 32.23% of the variability in the mean number of colonies/year (Fig. 5).

Land Use and Available Forage

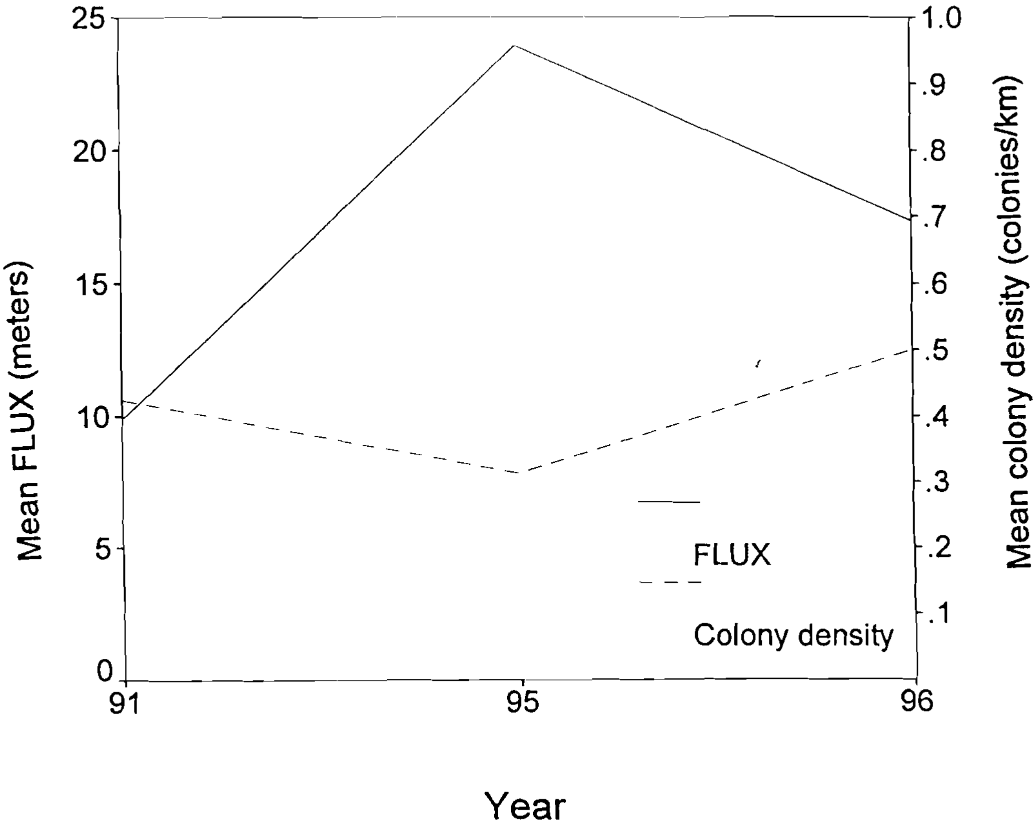
Land use along the rivers always fell into 1 of 3 classes: (1) grassland, (2) woodland, and (3) cropland. Land use within 100 m of the river was recorded in the variables WD100, WD100total, CRP100, CRP100total, WDCRP100, and WDCRP100total (Table 1). These variables were recorded to be consistent with Allen's HSI (1983) measurements of food requisites, which he measured within

Fig. 3. Colony density per study site as a function of the water fluctuation index (FLUX). Each study site is represented by the data from the year of the highest colony density on that study site (1991 data from KDWP unpubl. data, Robel et al. 1993; $N = 8$, $R^2 = 0.0121$, SE = 0.19, $F = 0.07$, 1,6 df, $P = 0.7955$).



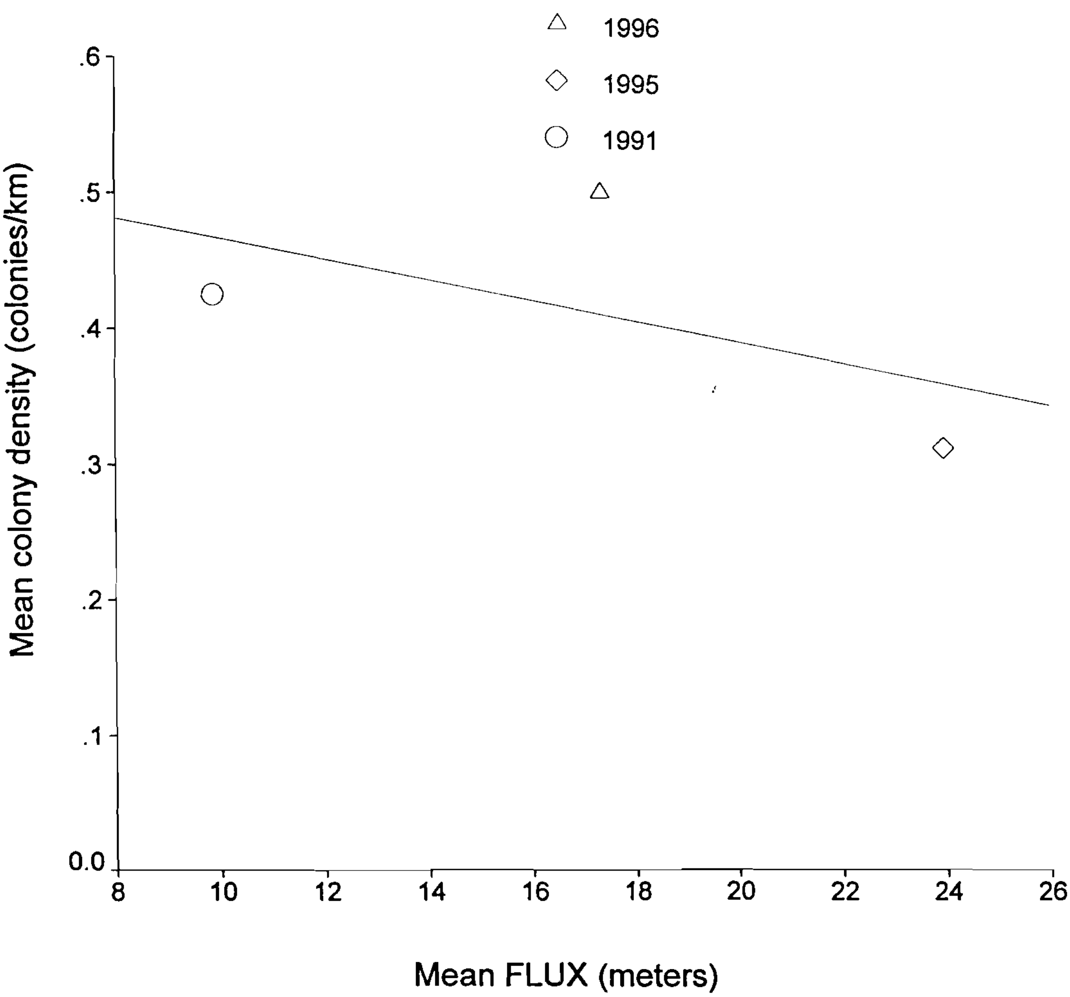
Colony density (colonies/km)
.9
.8
.7
.6
.5
.4
.3
.2
0
10
20
30
40
FLUX (meters)

Fig. 4. Mean water fluctuation index and mean number of colonies per study site for each year of data (1991 data from KDWP unpubl. data, Robel et al. 1993). Note that the x-axis is not a time scale, but simply identifies the year of the data.



25
20
15
10
5
0
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
Mean FLUX (meters)
Mean colony density (colonies/km)
FLUX
Colony density
91
95
96
Year

Fig. 5. Mean number of colonies per study site shown as a function of the mean FLUX ($N = 3$, $R^2 = 0.3223$, SE = 0.11, $F = 0.48$, 1,1 df, $P = 0.6157$). 1991 data from KDWP (unpubl. data) and Robel et al. (1993).


1996
1995
1991
Mean colony density (colonies/km)
.6
.5
.4
.3
.2
.1
0.0
8
10
12
14
16
18
20
22
24
26
Mean FLUX (meters)

100 m of the river. Paired t-tests showed no statistically significant difference between the amount of crop and woodland available to beaver colonies (1991 data supplied by KDWP unpubl. data, Robel et al. 1993) and that available along the entire study site (Table 5).

Other investigators have suggested that beaver primarily forage 40 m or less from the river (Hall 1970, McComb et al. 1990). I recorded land use within approximately 30 m of the river in the variables WD30, WD30total, CRP30, CRP30total, WDCRP30, and WDCRP30total (Table 1). Paired t-tests still showed no statistically significant difference between colony sites (1991 data supplied by KDWP unpubl. data, Robel et al. 1993) and the entire study site (Table 5).

Table 5. Results of paired t-tests comparing percentage of woodland and/or cropland adjacent to colonies to the percentage of woodland and/or cropland adjacent to the entire study site.

Variable	Mean	SD	df	t-value	2-tail sig	*Bonferroni
WD100	30.58%	12.61%				
WD100total	29.98%	12.92%				
Paired differences	0.60%	1.69%	7	1.01	0.348	0.0166
CRP100	42.39%	19.41%				
CRP100total	42.34%	19.18%				
Paired differences	0.05%	0.87%	7	0.16	0.875	0.0250
WDCRP100	72.96%	9.53%				
WDCRP100total	72.31%	10.30%				
Paired differences	0.65%	1.51%	7	1.21	0.264	0.0125
WD30	53.08%	18.90%				
WD30total	49.93%	15.32%				
Paired differences	3.15%	6.19%	7	1.44	0.193	0.0100

Table 5. -continued

Variable	Mean	SD	df	t-value	2-tail sig	*Bonferroni
CRP30	28.56%	21.33%				
CRP30total	28.70%	19.82%				
Paired differences	-0.14%	3.87%	7	- 0.10	0.923	0.0500
WDCRP30	81.64%	5.84%				
WDCRP30total	78.63%	8.44				
Paired differences	3.01%	4.00%	7	2.13	0.071	0.0080

*Sequential Bonferroni corrected significance level value

DISCUSSION

River Width and Depth

Slough and Sadleir (1977) found the width of the river could affect beaver's use of habitat in British Columbia. They found that increases in width, when considered with stream gradient, could restrict the beaver's ability to build dams and therefore increase water level instability. Howard and Larson (1985) and Beier and Barrett (1987) found that beaver preferred wider streams in Massachusetts and California, respectively. Beaver in the Great Plains will build dams on streams, but generally do not dam rivers with year round water flow. No beaver dams were encountered on any of my study sites and all of my sites had year round water flow. Since damming ability is not a consideration on rivers with year round flow, wide rivers probably do not affect beaver in the Great Plains. Furthermore, beaver activity was found at sites where rivers were as narrow as 5 m. Given these two considerations, any trends suggesting beaver prefer wider rivers is probably a misleading interpretation of the data. The width of rivers with year round water flow most likely has no effect on beaver colonization in the Great Plains and would not make a valuable indicator of beaver habitat.

Deeper rivers give beaver more room to dive and maneuver underwater, possibly providing more protection from their predators, and allowing them more water in which to float large foraged branches. Beier and Barrett (1987) found that depth of the stream was positively correlated to higher beaver densities in California and listed it as one of the three most important factors in determining habitat suitability for beaver. In Oregon, McComb et al. (1990) found depth statistically significant, but stated that it is probably not important as a habitat suitability indicator. I did not find a statistically significant difference for river depth in Kansas. In fact, the mean depth between beaver activity sites and random sites differed by less than half of the scale at which the depth was measured (Table 3). Therefore, depth of the river would probably not be a valuable indicator of beaver habitat in the Great Plains.

Height and Slope of the River Bank

Beaver in the Great Plains tend to not build lodges on flowing rivers. Instead they construct bank dens, which often have an entrance below the water line. An upward sloping tunnel leads to a large bed chamber above the water line. A river needs to have a bank sufficiently high enough above the average water line that beaver can construct the bed chamber. Even though HEIGHT showed a statistically significant difference in the step-wise discriminant function analysis, it only added a very small increase to the canonical correlation. Furthermore, the mean HEIGHT was extremely close among den sites, foraging sites, and random sites. This would indicate that bank height is probably not a limiting factor for beaver colonization of rivers in the Great Plains, and it would not be a valuable habitat indicator in a beaver HSI.

McComb et al. (1990) evaluated dam-site selection in Oregon and found that beaver prefer sites with a shallow slope. Alternately, Urich et al. (1984) found a high habitat suitability value associated with steep banks in Missouri. The Missouri HSI of Urich et al. (1984) is geographically closer to the Kansas than any other beaver HSI. Consistent with their HSI, I found SLOPE to be statistically significantly steeper at beaver activity sites than at random sites (Table 3).

Furthermore, I found river banks to be steeper at den sites than at random sites, and shallower at foraging sites than at random sites (Table 4). Bank denning beaver would be expected to prefer steeper banks. The steeper slope allows for easier horizontal digging of the burrow. Steep slopes also allow the beaver to angle the burrow upwards toward the bed chamber more quickly than a shallow slope would allow.

Shallow slopes at foraging sites would allow beaver to minimize energy output while leaving the river. Even though the mean SLOPE was greater at foraging sites than at random sites, the difference was very small (Table 4). Steep slopes are probably important to beaver as den sites, but it is doubtful that shallow slopes are critical enough for foraging to affect suitability of a site.

The slope variable was ultimately dropped from the Missouri HSI (Urich et al. 1984) because, in practical field use, it was found never to be a limiting factor (D. Urich, Mo. Dep. Conserv., pers. commun.). The variable, SLOPE, has strong potential as a beaver habitat indicator in the Great Plains. However, future testing of my modified HSI may show that SLOPE is not a limiting factor in the Great Plains.

River Bed and Bank Substrate

River bed substrate could affect a beaver's ability to anchor its food cache to the bottom of the river, and therefore could be important as a habitat suitability indicator. In my study sites, SUBbed ranged from clay to bedrock (Table 3), but was usually very consistent within a river system. Beaver living on a particular river had very little choice about the river bed substrate type. SUBbed was not statistically significant (Table 3) and would probably not make a good predictor of beaver habitat in the Great Plains.

Bank substrate is usually not included in beaver HSI's. McComb et al. (1990) tested bank substrate in Oregon, found that it was not statistically significant, and did not include it in their multivariate analysis. They classified bank type into three categories: (1) predominantly dirt or small cobble < 20 cm diameter, (2) cobble > 21 cm diameter, and (3) solid rock.

I found a statistically significant difference in SUBbank between beaver activity sites and random sites (Table 3). However, the difference in the means between beaver activity sites and random sites was less than one standard deviation apart (Table 3). Beaver activity sites' mean corresponded to a silt substrate. This does not mean that beaver always choose a silt substrate. However, it does indicate that beaver actively choose a finer substrate (toward the silt and clay end of the scale) over coarser substrates (toward the sand and rock end of the scale).

Bank substrate would be expected to have a significant effect on beaver use of a site. Silt would be the easiest substrate to dig into when building a bank den. Silt would also hold together adequately enough to keep the den from collapsing on itself. Clay would also work for den substrate. However, clay is more difficult to dig into than silt and therefore it would require considerably more energy to construct a den in a clay bank. Sandy substrates would not be difficult to dig into, but would most likely increase the odds of the den caving-in. As the substrate becomes increasingly rocky, the rocks would act as barriers, and make it increasingly difficult to dig a den. Given these arguments, SUBbank could be a valuable variable for evaluating beaver habitat.

Water Fluctuation and Flow

All of my study sites have a gradient of < 6% (Robel et al. 1993), which gives them a score of 1.0 for that category in Allen's HSI (1983). Water fluctuation is not quantified in Allen's HSI (1983), but is ranked by using a subjective ranking system where small water fluctuations that have no effect on burrow entrance receive a 1.0, moderate fluctuations that affect burrow entrances receive a 0.5, and extreme fluctuations receive a 0.0. All of my study sites would have been ranked at moderate or extreme water fluctuation, making the maximum HSI score for any site 0.5. A HSI score does not predict beaver density, only the likelihood of finding beaver at a site. However, as beaver habitat improves, beaver densities should go up (Robel et al. 1993). I found very high beaver colony densities (up to 0.8 colonies/km) on my study sites, which agrees with the suggestion of Robel et al. (1993) that Allen's method (1983) of evaluating water fluctuation does not work in the Great Plains.

I was unable to show a relationship between beaver populations and water fluctuation by using my method of quantifying water fluctuation (Figs. 2 and 3). However, the 1995 census had the overall lowest density of beaver colonies of any year censused (Figs. 4 and 5). This was the same year as the highest overall water fluctuation of any census year and only 2 years after the floods of 1993. However, figures 4 and 5 are both based on only 3 data points and caution should be used in putting too much weight into these results. It is possible that water fluctuation is important, but simply has not yet been properly measured. My method of measuring water fluctuation uses the bottom of the river as the reference point. Since bank height can vary from place to place, my method may not show how dens are affected by the water fluctuation. A method should be explored to measure water fluctuation with respect to the top of the bank instead of the bottom of the river. This may show how water fluctuation is actually affecting bank dens.

Land Use and Available Forage

Allen's HSI (1983) includes a food requisite section, which determines if enough food is available at a site to support a beaver population. Many studies of beaver as central place foragers show that beaver become more selective about food choices the farther they get from the water (Jenkins 1980, Belovsky 1984, McGinley and Whitham 1985, Basey et al. 1988, Fryxell and Doucet 1991). Beaver will forage up to 200 m from the water (Allen 1983), however, they primarily forage < 50 m from the water (Jenkins 1980, Belovsky 1984, Fryxell and Doucet 1991). McComb et al. (1990) only sampled to within 40 m of the water based on Hall's (1970) study that beaver do 90% of their foraging within 30 m of the stream edge.

Allen's HSI (1983) quantifies the food requisite within 100 m of the river. I quantified my food requisite at 100 m to stay consistent with Allen (1983). I also quantified my food requisite at 30 m since this probably more accurately reflects where beaver are doing the majority of their foraging.

Allen's HSI (1983) can require a great amount of field time to quantify the food requisite. Several physical attributes of the vegetation must be measured in the field. I used GIS to attempt to quantify the food requisite for beaver, thus reducing the amount of time spent on intense field sampling. Allen's HSI (1983) also has no method for considering row crops as a food source for beaver. Robel et al. (1993) suggested that row crops may be an important source of food for beaver in the Great Plains.

When woodland and agricultural land were tested independently, beaver did not show a preference for either land use (Table 5). However, if woodland and agricultural land are considered to be of equal importance to beaver, then the two variables can be lumped together (WDCRP). I still failed to statistically support that beaver were actively choosing cropland/woodland for colony locations. There are several possible reasons for this.

The resolution of the land cover maps is 900 m^2 (1 pixel is 30 m/side). A pixel on the land cover map shows the land use, which is predominant within that pixel. Therefore, a pixel showing crop coverage is mostly crop but may also contain grasslands, woodlands, or any of the other possible land uses. A finer resolution may be needed to show habitat selection by beaver.

A second possible explanation could be that the data set is not current enough. Data maps were chosen on a basis of being easily accessible for use in conducting HSI's. The data set chosen was LANDCOVER, because it is available free over the Internet. LANDCOVER was created from satellite images from 1988. While major changes in land use would not be expected in just 8 years, vegetation changes may be of a large enough magnitude to make it more difficult to accurately identify beaver habitat.

A third possible explanation is that forage is not a limiting factor in the Great Plains. Beaver colonies tend to move up and down the river from year to year (Appendix A). A 5 to 10 year continuous data set of colony locations may show that all areas of the rivers supply ample forage are eventually used as colony sites.

A fourth possible explanation is that the LANDCOVER data set's accuracy varies county by county. The accuracy is considered to be at least 85% accurate for all counties. This means that 1 out of every 5-6 pixels could be misclassified. Higher accuracy in the data set could lead to better means of identifying beaver habitat.

Given the low, though not significant, $\underline{P}$ value obtained for WDCRP30, GIS analysis of satellite data may become a very powerful tool for studying beaver HSI's. The use of GIS could most likely do an efficient and accurate job of identifying possible beaver habitat. A large portion of field time could be saved by doing simple pixel counts along rivers as opposed to the intense field sampling currently being used. However, before GIS applications become practical tools for beaver HSI's, newer data sets of satellite imagery and/or finer pixel size will have to become readily available. The low P value of WDCRP30 also indicates that proximity of row crop to the river as an indicator of beaver habitat may need further investigation.

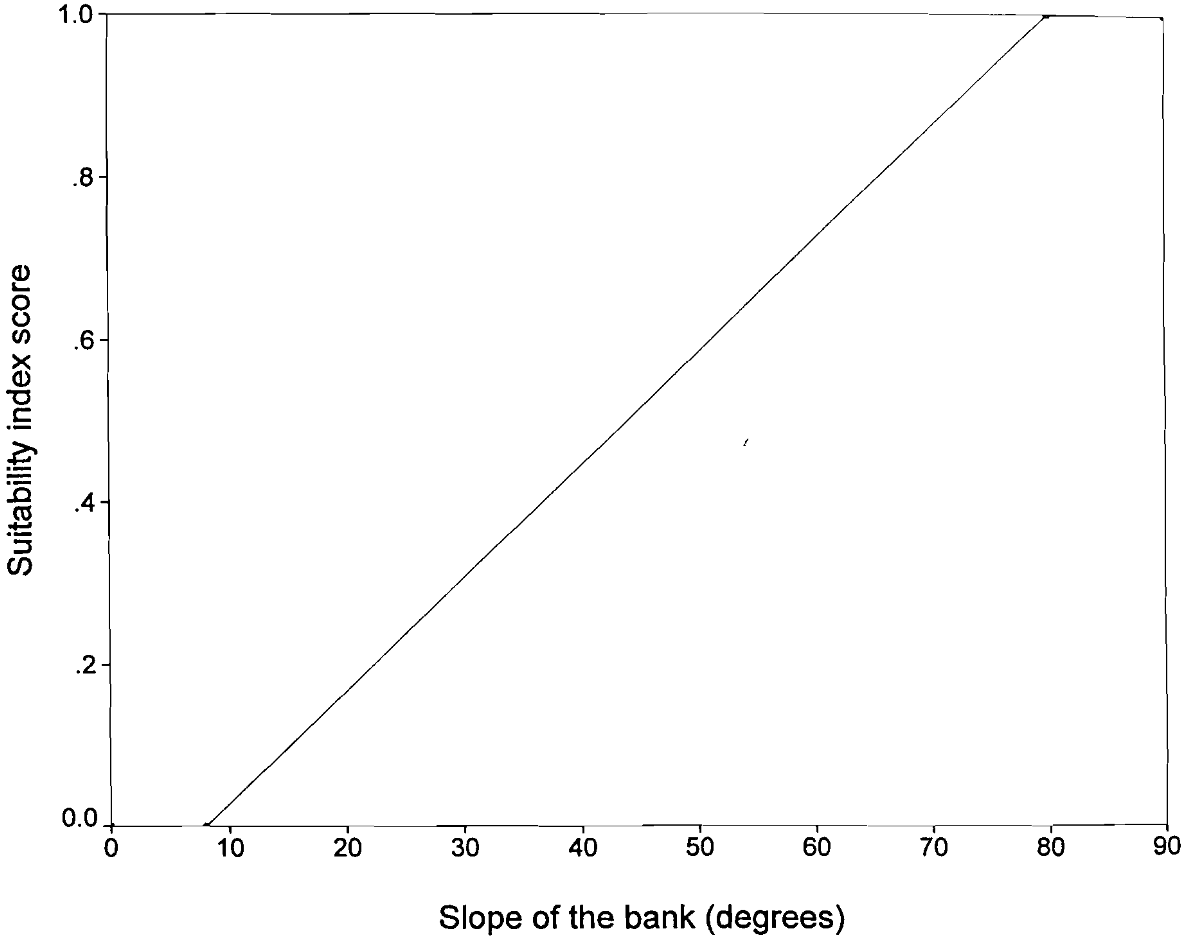
Calculating a HSI for Beaver in the Great Plains

Allen's HSI (1983) scores the suitability of habitat for beaver on a 0.0 - 1.0 scale with 0.0 being totally unsuitable for beaver and 1.0 being optimum habitat. The scores are derived from data collected in the habitat being evaluated. The collected data are used to calculate the food and water requisite. The HSI then works on a limiting factor basis; whichever of the requisites has the lowest score is the habitat's suitability score.

Suggested Changes to Allen's (1983) HSI

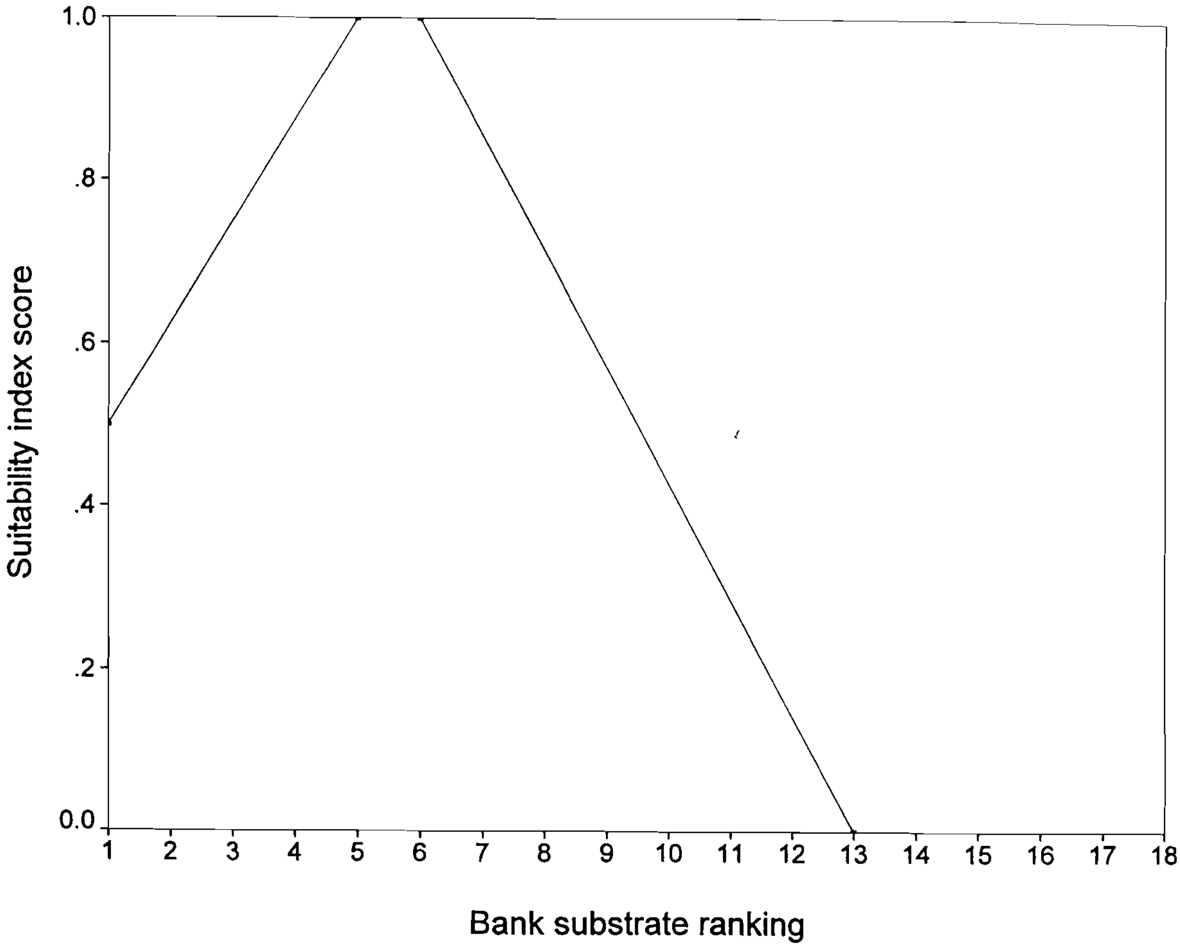
Two new requisites should be added to Allen's HSI (1983) for use in the Great Plains: slope of bank and bank substrate. Areas that are being evaluated for beaver habitat suitability should have sites of adequately sloped bank. By measuring the steepest sloped bank occurring at the site being evaluated and applying it to the curve in the suitability index graph (Fig. 6), the suitability index for slope of bank may be obtained. Since beaver colonies in the Great Plains occupy a minimum of 300 m of river, and colonies, which occupy more than 300 m of river generally have more than 1 den, it is recommended that the slope be evaluated every 300 m when large stretches of river are being evaluated.

Fig. 6. New suitability index related to the slope of the bank. The slope of the bank, measured in degrees, can be used to find the appropriate suitability index. Slopes < 8° have a suitability index of 0 while slopes > 80° have a suitability index of 1.0.


1.0
.8
.6
.4
.2
0.0
Suitability index score
0
10
20
30
40
50
60
70
80
90
Slope of the bank (degrees)

Bank substrate is also important for bank denning beaver. To obtain the suitability index for bank substrate, the river bank substrate should be ranked (Table 2). The suitability index can then be found by applying the bank substrate rank to the curve in the suitability index graph (Fig. 7). The highest suitability score found at a site should be used as the site's overall suitability index. As with the slope of the bank, river bank substrate should be evaluated every 300 m when large stretches of river are being evaluated.

Fig. 7. New suitability index related to bank substrate. The bank substrate should be ranked by using Table 2. The ranking can then be used to find the appropriate suitability index. Rankings from 5 to 6 have a suitability index of 1.0. Rankings $\geq$ 13 have a suitability index of 0.



1.0
.8
.6
.4
.2
0.0
Suitability index score
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Bank substrate ranking

Water fluctuation may be important to beaver habitat. However, neither Allen's method (1983) nor the method outlined in my study are suitable for evaluating water fluctuation. The "average water fluctuation on an annual basis" variable should be dropped from the HSI when being used in the Great Plains.

Eventually the food requisite portion of Allen's HSI (1983) can probably be done using by GIS applications. However, for now the field techniques described in Allen's HSI (1983) are superior and should be followed.

MANAGEMENT IMPLICATIONS

These modifications of Allen's HSI (1983) for beaver were made based on data collected in southeastern Kansas. Given the similarity of rivers and the lack of beaver HSI information from the Great Plains, extrapolation throughout the Great Plains may give satisfactory results. Beaver HSI's in general seem to work best locally, and extrapolation of these modifications beyond the Great Plains is not advised. As with any newly modified model, this model should be field tested for accuracy before basing management decisions on it.

LITERATURE CITED

Allen, A. W. 1983. Habitat suitability index models: beaver. U. S. Fish Wildl. Serv. FWS/OBS-82/10.30 Revised. 20 pp.

Barnes, D. M., and A. U. Mallik. 1997. Habitat factors influencing beaver dam establishment in a northern Ontario watershed. J. Wildl. Manage. 61:1371-1377.

Basey, J. M., S. H. Jenkins, and P. E. Busher. 1988. Optimal central-place foraging by beavers: tree-size selection in relation to defensive chemicals of quaking aspen. Oecologia 76:278-282.

Beier, P., and R. H. Barrett. 1987. Beaver habitat use and impact in Truckee River Basin, California. J. Wildl. Manage. 51:794-799.

Belovsky, G. E. 1984. Summer diet optimization by beaver. Am. Midl. Nat. 111:209-222.

Bergerud, A. T., and D. R. Miller. 1977. Population dynamics of Newfoundland beaver. Can. J. Zool. 55:1480-1492.

Broschart, M. R., C. A. Johnston, and R. J. Naiman. 1989. Predicting beaver colony density in boreal landscapes. J. Wildl. Manage. 53:929-934.

Busher, P. E., R. J. Warner, and S. H. Jenkins. 1983. Population density, colony compostition, and local movements in two Sierra Nevadan beaver populations. J. Mammal. 64:314-318.

Fryxell, J. M., and C. M. Doucet. 1991. Provisioning time and central-place foraging in beavers. Can. J. Zool. 69:1308-1313.

Hall, J. G. 1970. Willow and aspen in the ecology of beaver in Sagehen Creek, California. Ecology 41:484-494.

Howard, R. J., and J. S. Larson. 1985. A stream habitat classification system for beaver. J. Wildl. Manage. 49:19-25.

Jenkins, S. H. 1980. A size-distance relationship in food selection by beavers. Ecology 61:740-846.

Jenkins, S. H., and P. E. Busher. 1979. Castor canadensis. Mamm. Species 120:1-8.

McComb, W. C., J. R. Sedell, and T. D. Buchholz. 1990. Dam-site selection by beavers in an eastern Oregon basin. Great Basin Nat. 50:273-281.

McGinley, M. A., and T. G. Whitham. 1985. Central place foraging by beavers (Castor canadensis): a test of foraging predictions and the impact of selective feeding on the growth form of cottonwoods (Populus fremontii). Oecologia 66:558-562.

Naiman, R. J., C. A. Johnston, and J. C. Kelley. 1988. Alteration of North American streams by beaver. BioSci. 38:753-760.

Naiman, R. J., J. M. Melillo, and J. E. Hobbie. 1986. Ecosystem alteration of boreal forest streams by beaver (Castor canadensis). Ecology 67:1254-1269.

Retzer, J. L., H. M. Swope, J. D. Remington, and W. H. Rutherford. 1956. Suitability of physical factors for beaver management in the Rocky Mountains of Colorado. Colo. Dep. Game and Fish. Tech. Bull. 2. 33 pp.

Rice, W. R. 1989. Analyzing tables of statistical tests. Evolution 43:223-225.

Robel, R. J., L. B. Fox, and K. E. Kemp. 1993. Relationship between habitat suitability index values and ground counts of beaver colonies in Kansas. Wildl. Soc. Bull. 21:415-421.

Slough, B. G., and R. M. F. S. Sadleir. 1977. A land capability classification system for beaver (Castor canadensis Kuhl). Can. J. Zool. 55:1324-1335.

Smith, M. E., C. T. Driscoll, B. J. Wyskowski, C. M. Brooks, and C. C. Cosentini. 1991. Modification of stream ecosystem structure and function by beaver (Castor canadensis) in the Adirondack Mountains, New York. Can. J. Zool. 69:55-61.

Swenson, J. E., S. J. Knapp, P. R. Martin, and T. C. Hinz. 1983. Reliability of aerial cache surveys to monitor beaver population trends on prairie rivers in Montana. J. Wildl. Manage. 47:697-703.

Urich, D. L., J. P. Graham, and E. A. Gaskins. 1984. Habitat appraisal of private lands in Missouri. Wildl. Soc. Bull. 12:350-356.

CHAPTER 2

Effects of Floods on Beaver in Kansas

ABSTRACT

The floods of 1993 and 1995 ravaged the Midwest and eastern Great Plains regions of the United States. Beaver colonies, based on bank dens, in rivers in these regions would be expected to decline after catastrophic floods due to loss of shelter and drowning of kits. On 8 riverine study sites in Kansas, I compared 1991 beaver colony densities to densities after the floods (1995 and 1996). I found no evidence that the floods affected beaver colony densities ($\underline{P}$ = 0.094).

INTRODUCTION

In 1993, major flooding hit the Midwest and eastern Great Plains regions of the United States. Two years later the less severe, though still major floods of 1995 again ravaged the Midwest and eastern Great Plains. The floods changed the landscape in many areas in many ways. In some cases new wetlands were created, in others habitat was destroyed and fertile river valley cropland was buried under meters of sand and silt. The potential effects to wildlife were enormous and a suite of studies were conducted throughout the Midwest and eastern Great Plains to evaluate both the positive and negative effects on wildlife. The scope of these studies was large enough to earn a "Flood of 1993" special topics session at the 58th Annual Midwest Fish and Wildlife Conference in Omaha, Nebraska in 1996.

The North American beaver (Castor canadensis) has long been associated with floods. A literature search for beaver and floods brings up a long list of publications. However, most of these publications deal with flooding caused by beaver and their dam building activities. This is not surprising since beaver created ponds greatly change habitats and cause long reaching effects not only with the wetland itself, but with changed vegetation structure and succession long after the beaver have left and the pond has filled with silt and become a meadow. Therefore, scientists, from waterfowl biologists to water chemists, have studied beaver caused floods, but very few researchers have investigated the effects of non-beaver caused floods on beaver.

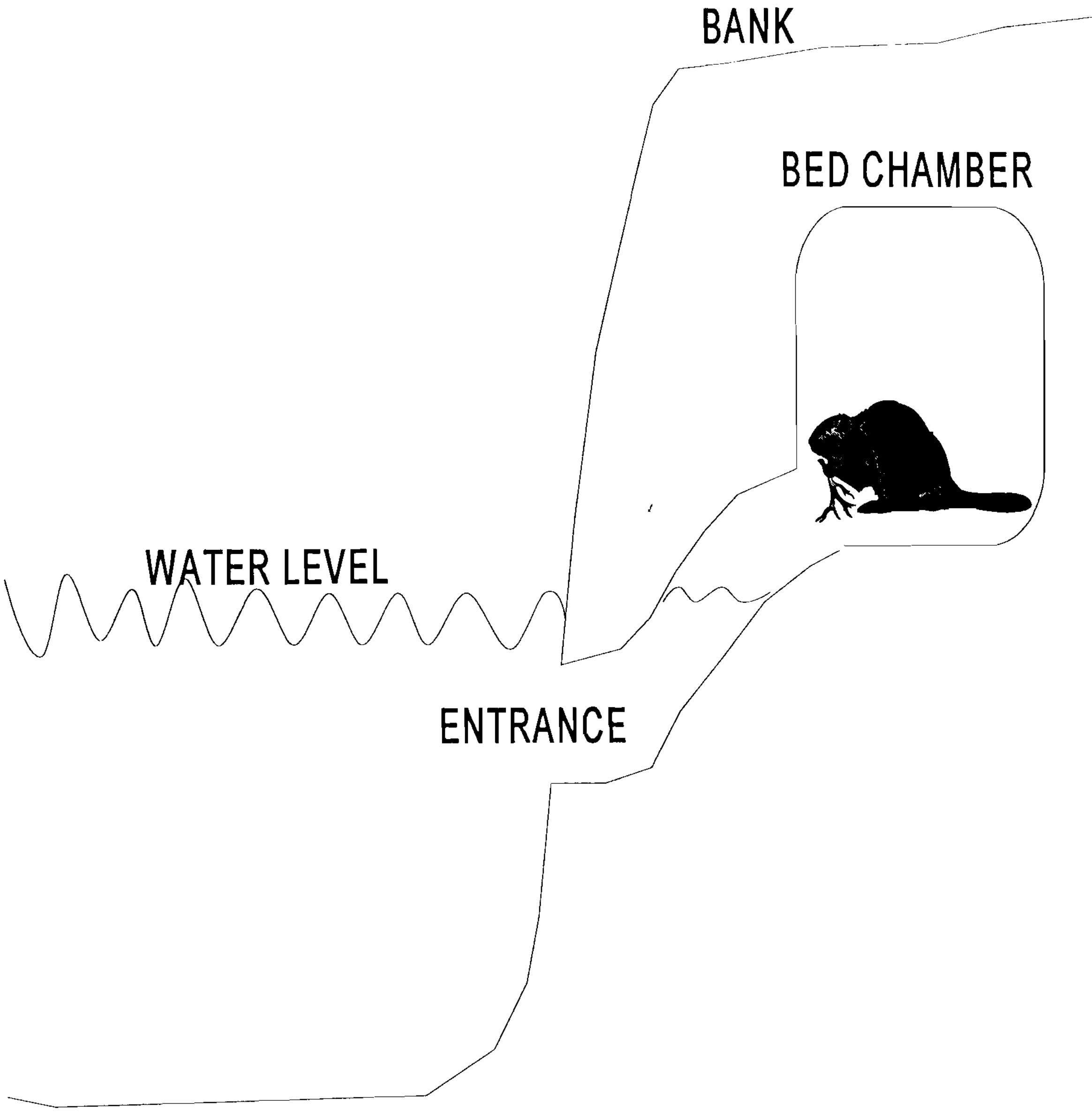
Floods may have several detrimental effects on beaver. Beaver live in family units called colonies. The colonies are made up of an adult breeding pair and several generations of their offspring. Offspring generally disperse between 2 and 4 years of age. Colonies are usually territorial and are associated with a series of bank dens along a particular stretch of river. Scent mounds, called castor mounds, are used to mark the colony's territory. Stretches of no beaver activity often separate beaver colonies. Major flooding would likely wash away scent mounds and landmarks used by the beaver to recognize their territories, possibly causing confusion and disorientation after the flood waters have receded.

Beaver living on large rivers in the Midwest and eastern Great Plains do not build dams. The rivers have year-round water flow and the beaver build bank dens, which usually have a below water entrance for protection from predators. The below water burrow angles up and opens into a bed chamber above the water line (Fig. 1). During the day, the nocturnal beaver rests in the bed chamber.

During floods, bank dens are totally unusable because the bed chambers are underwater. River otters (Lontra canadensis), which also use bank dens along rivers, abandon their dens during spring floods (Anderson and Woolf 1987). During the duration of the flood, the beaver would be forced to abandon the den and spend the day exposed.

Another possible detrimental effect of floods on beaver is the mortality of newborn kits before they are able to leave the dens. Kinler and Kinler (1990)

Fig. 1. Cut-a-way view of a beaver's bank den. The water level inside the den is the same as the water level of the river. If the river floods then the den is also flooded.


BANK
BED CHAMBER
WATER LEVEL
ENTRANCE

showed that both number of litters and number of young per litter were negatively associated with the frequency of nest chamber flooding in muskrats (Ondatra zibethicus). Rosell et al. (1996) stated that during floods the drowning of newborn beaver kits was an important mortality factor.

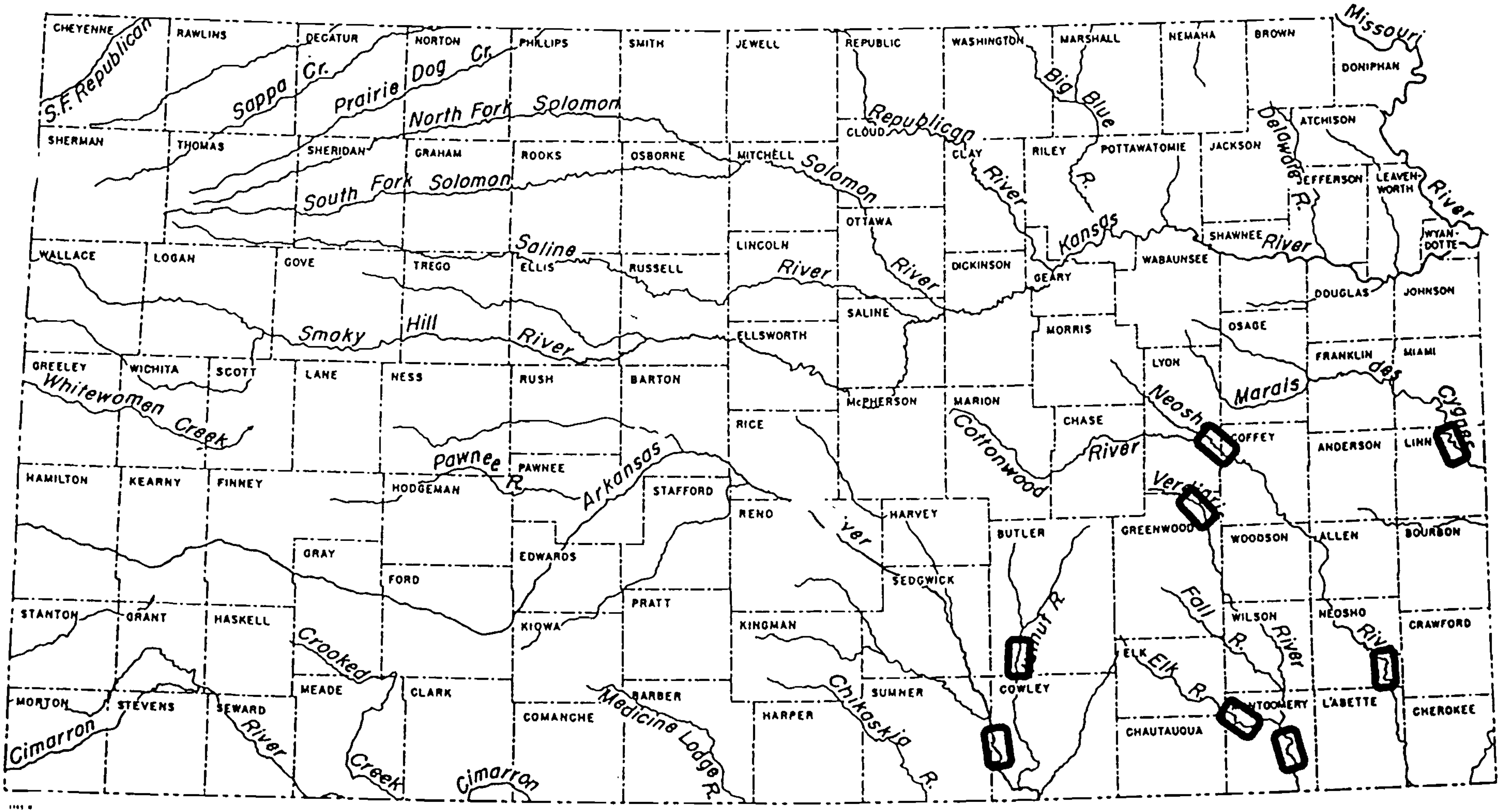
Because of the possible effects to adult beaver, juvenile beaver, and colony unity, large scale floods should have a negative effect on beaver colony densities. My objective is to investigate the effects of the floods of 1993 and 1995 on beaver colony densities in Kansas. Post-flood censuses conducted in 1995 and 1996 were compared to pre-flood censuses conducted in 1991 (Kansas Department of Wildlife and Parks (KDWP) unpubl. data, Robel et al. 1993). Corresponding water fluctuation records for riverine systems in Kansas, were used to evaluate the prediction that beaver colony densities should have been significantly lower on rivers in 1995 than in 1991 because of the 2 years of flooding that occurred between the censuses. After a year of normal water fluctuations, beaver colony densities should have begun to rebound in 1996.

STUDY AREA

My study was conducted on 8 stretches of river located in the southeastern quarter of Kansas (Fig. 2). All rivers are part of the Arkansas and Osage river watersheds and are generally slow flowing with occasional impoundments (Chapter 1). Sudden fluctuations in river water levels can occur when upriver reservoirs change outlet flow.

During the 1995 census, the upper stretch of the Neosho River was only partially censused and so upper Neosho River data from that year alone were not used. Data from 1991 (KDWP unpubl. data, Robel et al. 1993) and 1996 for the upper stretch of the Neosho River were used. Data from all other study sites were used for all 3 years (1991 data from KDWP unpubl. data, Robel et al. 1993).

Fig. 2. Location of the 8 study sites in southeastern Kansas. Each study site was 10 km long. Base map is an uncopyrighted map of the entire state of Kansas.


CHEYENNE
RAWLINS
DECATUR
NORTON
PHILLIPS
SMITH
JEWELL
REPUBLIC
WASHINGTON
MARSHALL
NEMAHA
BROWN
DONIPHAN
Missouri
S.F. Republican
Sappa Cr.
Prairie Dog Cr.
North Fork Solomon
Republican
Big Blue
Delaware R.
ATCHISON
SHERMAN
THOMAS
SHERIDAN
GRAHAM
ROOKS
OSBORNE
MITCHELL
Solomon
CLOUD
CLAY
River
RILEY
R.
POTTAWATOMIE
JACKSON
JEFFERSON
LEAVENWORTH
River
South Fork Solomon
OTTAWA
Kansas
SHAWNEE
River
WYANDOTTE
WALLACE
LOGAN
GOVE
TREGO
Saline
ELLIS
RUSSELL
LINCOLN
River
River
DICKINSON
GEARY
WABAUNSEE
DOUGLAS
JOHNSON
SALINE
Smoky Hill
River
ELLSWORTH
MORRIS
OSAGE
GREELEY
WICHITA
SCOTT
LANE
NESS
RUSH
BARTON
LYON
FRANKLIN
MIAMI
Whitewoman Creek
McPHERSON
MARION
Neosho
Marais des Cygnes
RICE
Cottonwood
CHASE
River
COFFEY
ANDERSON
LINN
Pawnee R.
PAWNEE
Arkansas
HAMILTON
KEARNY
FINNEY
HODGEMAN
STAFFORD
RENO
River
HARVEY
Verdigris
BUTLER
GREENWOOD
WOODSON
ALLEN
BOURBON
GRAY
EDWARDS
FORD
SEDGWICK
Walnut R.
Fall R.
STANTON
GRANT
HASKELL
PRATT
KIOWA
KINGMAN
WILSON
River
NEOSHO
River
CRAWFORD
Crooked
MEADE
CLARK
BARBER
Medicine Lodge R.
SUMNER
COWLEY
ELK
Elk R.
MONTGOMERY
LABETTE
CHEROKEE
MORTON
STEVENS
SEWARD
River
COMANCHE
HARPER
Chikaskia R.
CHAUTAUQUA
Cimarron
Creek
Cimarron

METHODS

Using a canoe, I conducted beaver censuses between July and November in 1995, and in May and June in 1996 (Chapter 1). My data were compared to data from a 1991 beaver census (KDWP unpubl. data, Robel et al. 1993). Each study site was censused once in 1995 and once in 1996. During censuses, signs of beaver activity were recorded on 7.5 minute topographic maps. Field positions were often verified by use of a Global Positioning System (Chapter 1). After censusing was complete, ArcView was used to plot locations of beaver activity onto maps generated from the Kansas Cartographic Database files (Chapter 1). Beaver densities were measured as number of beaver colonies/km within each study site. Colonies were considered to exist at sites with > 300 m of clumped beaver activity. Breaks between colonies required > 300 m of no activity. Occasionally, sites > 1 km were encountered with continuous beaver activity. In such cases, separate colonies were considered to occur every km. Any leftover segment > 500 m was also considered to be a separate colony (Chapter 1).

All statistics were performed by using SPSS version 6.1. The number of days each study site was flooded per year was determined by using data from the closest U. S. Geological Service's gaging station. Gaging stations give daily readings of the river water level in feet, which I converted to meters (Chapter 1). Flood stage is defined as water levels reaching the point to which significant loss of property or threat to life occurs (S. Predmore, National Weather Service, pers. commun.). Flood stage is always at least bank full, and sometimes out of the river banks. The number of flood days to have occurred on each river was determined for one year prior to the date of each census on each river.

The data collected represents 3 repeated measurements on the same 8 study sites. A repeated measures ANOVA was used to determine if the colony density changed within study sites among the 3 years sampled.

Since some of the rivers have a higher occurrence of flooding, even during non-flood years, a second analysis was performed to relate colony density to flooding regardless of year. In order to control for difference among rivers with regard to environmental factors other than water fluctuation, the data from 1991 (KDWP unpubl. data, Robel et al. 1993) was used as a baseline. Colony density data from 1995 and 1996 were transformed as an increase or decrease from the 1991 values for each river. Therefore, if a study site had 4 colonies in 1991, 2 in 1995, and 5 in 1996, the transformed score for that study site would be -2 for 1995 and 1 for 1996. Simple linear regression was used to test for a relationship between the transformed scores and the number of flood days during the previous 12 months for each respective study site.

Beaver colony densities could be affected in an overall positive or negative manner by floods. The non-parametric Friedman's test checks for statistical differences in increases or decreases within populations among years without taking into account the magnitude of those changes (Zar 1984). A Friedman's test was run to check for overall positive or negative population changes.

RESULTS AND DISCUSSION

I expected colony densities to drop between 1991 and 1995 and to rise between 1995 and 1996. Beaver colony densities did drop on 4 study sites in 1995, but colony densities remained constant at 2 sites and actually increased at 1 site. In 1996, colony densities increased at 5 sites, remained constant at 2 sites, and actually decreased at 1 site (Fig. 3). Friedman's test showed that the overall number of increases and decreases for each year was not statistically significant (N = 7, X^2 = 2.88, df = 2, P = 0.2369). Furthermore, the overall mean beaver colony density dropped in 1995 and rose in 1996, but the repeated measures ANOVA showed the difference not to be statistically significant (N = 7, F = 2.90, df = 2,12, P = 0.094). These results are somewhat difficult to interpret. No significant difference was shown, however significance was approached in the repeated measures ANOVA. The temptation exists to say that there is a trend and more data are needed to show a significant difference. However, one study site actually increased in beaver colony density immediately after two major floods and another site decreased in beaver colony density after a year of relatively low water fluctuation. The possibility exists that different intensities of flooding on different rivers had different effects on fluctuations in beaver colony densities. Some rivers flooded more days during 1996 than other rivers did during the floods of 1995. The simple linear regression run on the transformed density scores showed that only 16% of the variation in colony scores was explained by the number of flood days (Fig. 4).

Fig. 3. Beaver colony density of each study site for 1991(KDWP unpubl. data, Robel et al. 1993), 1995, and 1996. MDC = Marais des Cygnes River, VERD = Verdigris River, and ARK = Arkansas River. "U" and "L" after river name indicates upper and lower study sites, respectively, when more than one study site was located on the same river.

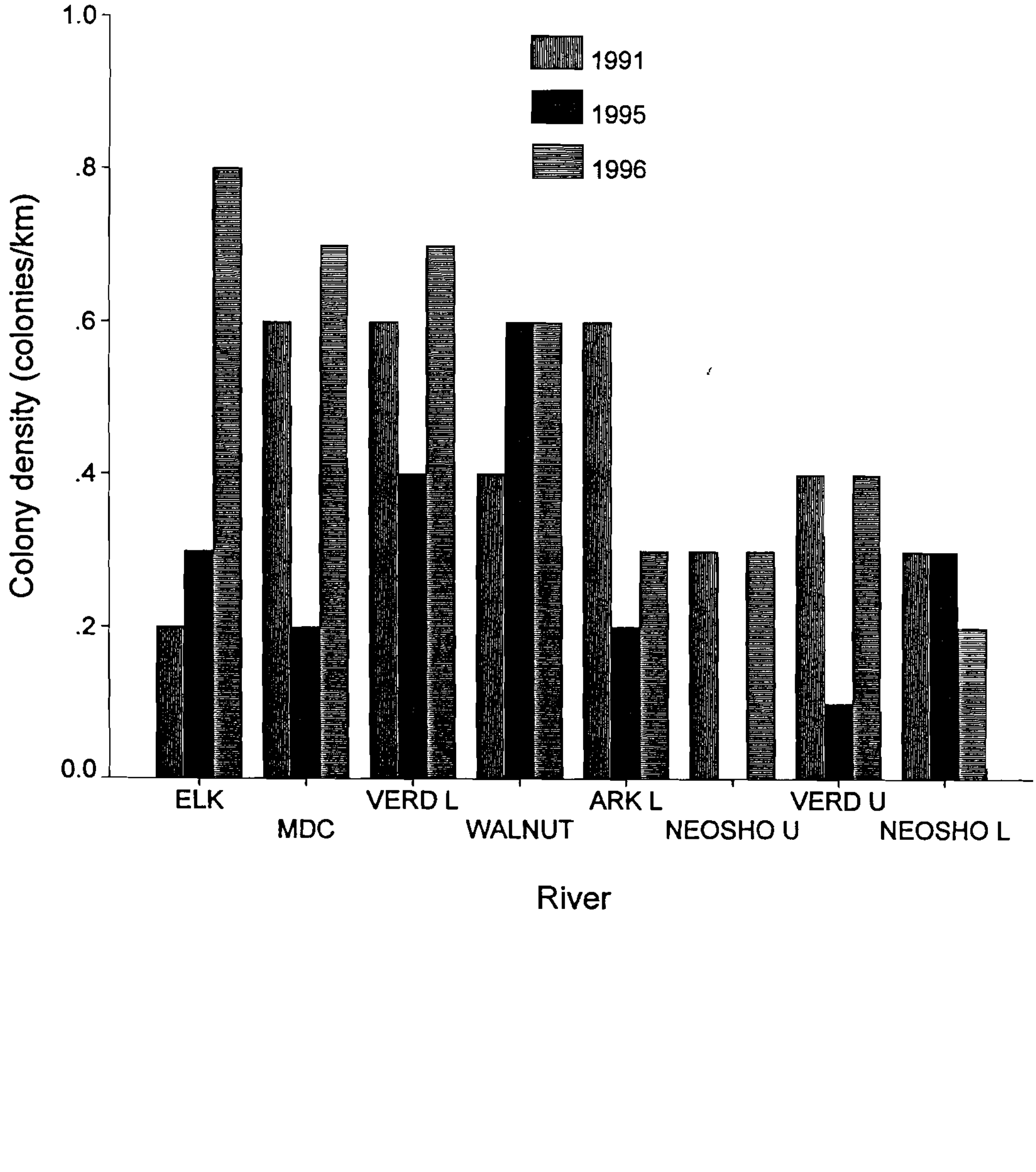
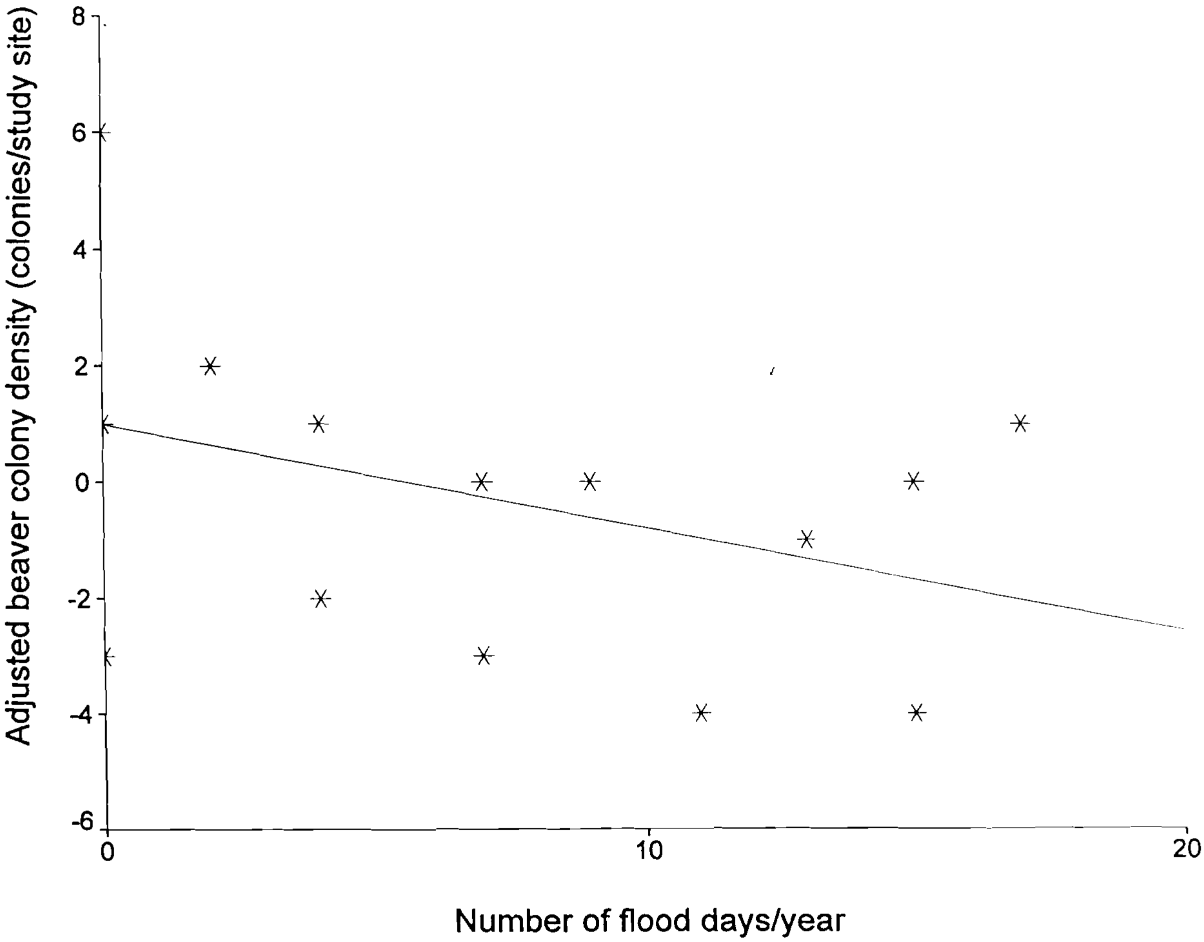

1.0
.8
.6
.4
.2
0.0
Colony density (colonies/km)
1991
1995
1996
ELK
MDC
VERD L
WALNUT
ARK L
NEOSHO U
VERD U
NEOSHO L
River

Fig. 4. Transformed beaver colony density scores regressed against number of flood days during the year prior to each census date (N =15, R^2 = 0.15635, SE = 2.56, F = 2.41, 1,13 df, P = 0.1446). Transformed colony density scores are the difference between colony density of a study site and the baseline colony density for that study area. The 1991 census (KDWP unpubl. data, Robel et al. 1993) was used as the baseline data.



Adjusted beaver colony density (colonies/study site)
8
6
4
2
0
-2
-4
-6
0
10
20
Number of flood days/year

The poor explanation of the variation in beaver colony densities by flood days and the nonsignificant difference in beaver colony densities among years before and after floods suggests that the floods of 1993 and 1995 had no real effect on beaver colony densities. Since these floods had no effect on beaver colony densities, the question of what beaver do during the floods needs to be addressed.

During floods, beaver may use the river like normal and simply have no dens to use as shelter. Another possibility is that they leave the river and go up smaller tributaries to wait out the flood. However, I began census work for beaver in 1995 less than 1 month after the flood waters had receded. Even this soon after the floods, I found beaver colony densities not significantly different from 1991 (KDWP unpubl. data, Robel et al. 1993). This suggests that beaver may not be leaving the rivers during the floods, or that they are at least returning to the rivers very quickly after the flood waters recede. Another piece of evidence, which suggests that beaver are using the rivers during the floods, is a tree I found which had a limb sticking out over the middle of the river. The tree limb was at least 3 m above the bank of the river and growing at an angle that would have prohibited the beaver from climbing it, yet it had been chewed on by a beaver. The only possible way for a beaver to have reached the branch was to have swum to it in the middle of the river when the river was at least 3 m above flood stage. Given these 2 bits of evidence, it is possible that beaver are using the rivers even during the floods. If this is the case, then the beaver must be living without dens and finding temporary shelter for the duration of the floods.

Young, dispersing beaver will use small, brushy trees as shelter during the day (pers. observ.). Erome (1984) states that European beaver (C. fiber) used bramble bushes as temporary resting places during floods.

The floods of 1993 and 1995 may have longer term adverse effects on beaver recruitment. If a majority of the kits are lost due to flooding, the beaver colony density estimates would not immediately change. Young beaver disperse at 2 to 3 years of age and 2 or more years may pass before a dispersing beaver's new colony is well established. Therefore, drops in colony density may not be detectable for 4 to 6 years after the floods. Furthermore, beaver can live 10 to 15 years in the wild in Kansas (Bee et al. 1981). The loss of the young from 1 or 2 years may be absorbed by the population and never be detectable without conducting age class censuses. Colony censuses need to be conducted to see if beaver colony densities do indeed drop as a long term effect of the floods.

LITERATURE CITED

Anderson, E. A., and A. Woolf. 1987. River otter habitat use in northwestern Illinois. Trans. of the Illinois Acad. of Sci. 80:107-114.

Bee, J. W., G. E. Glass, R. S. Hoffmann, and R. R. Patterson. 1981. Mammals in Kansas. University of Kansas, Lawrence. 300pp.

Erome, G. 1984. The different types of shelters built by the European beaver, Castor-fiber, in the Middle Rhone Valley, France. Revue d'Ecologie la Terre et la Vie 39:55-76.

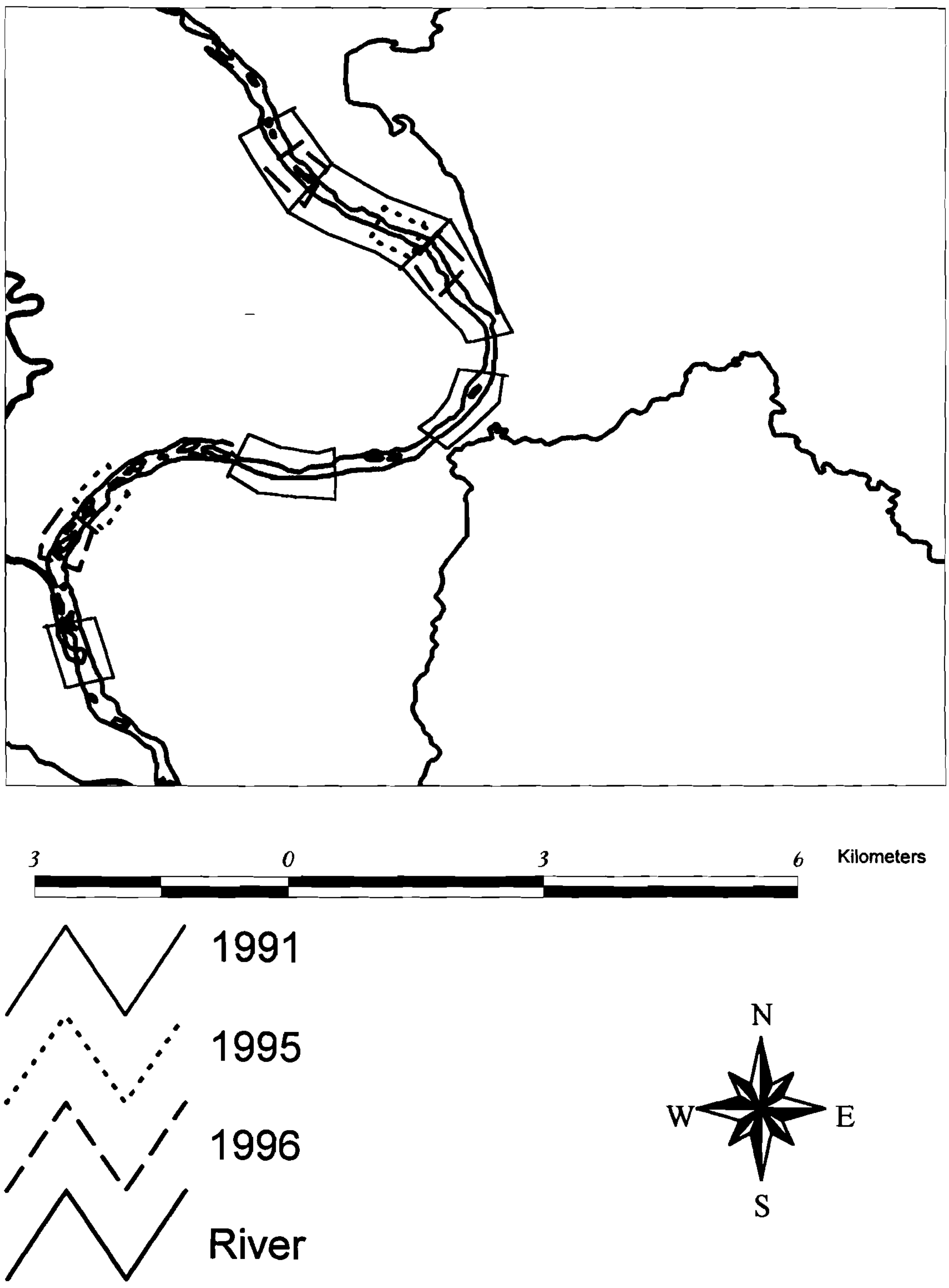
Kinler, Q. J., and N. W. Kinler. 1990. Effect of tidal flooding on mortality of juvenile muskrats. Estuaries 18:337-340.

Robel, R. J., L. B. Fox, and K. E. Kemp. 1993. Relationship between habitat suitability index values and ground counts of beaver colonies in Kansas. Wildl. Soc. Bull. 21:415-421.

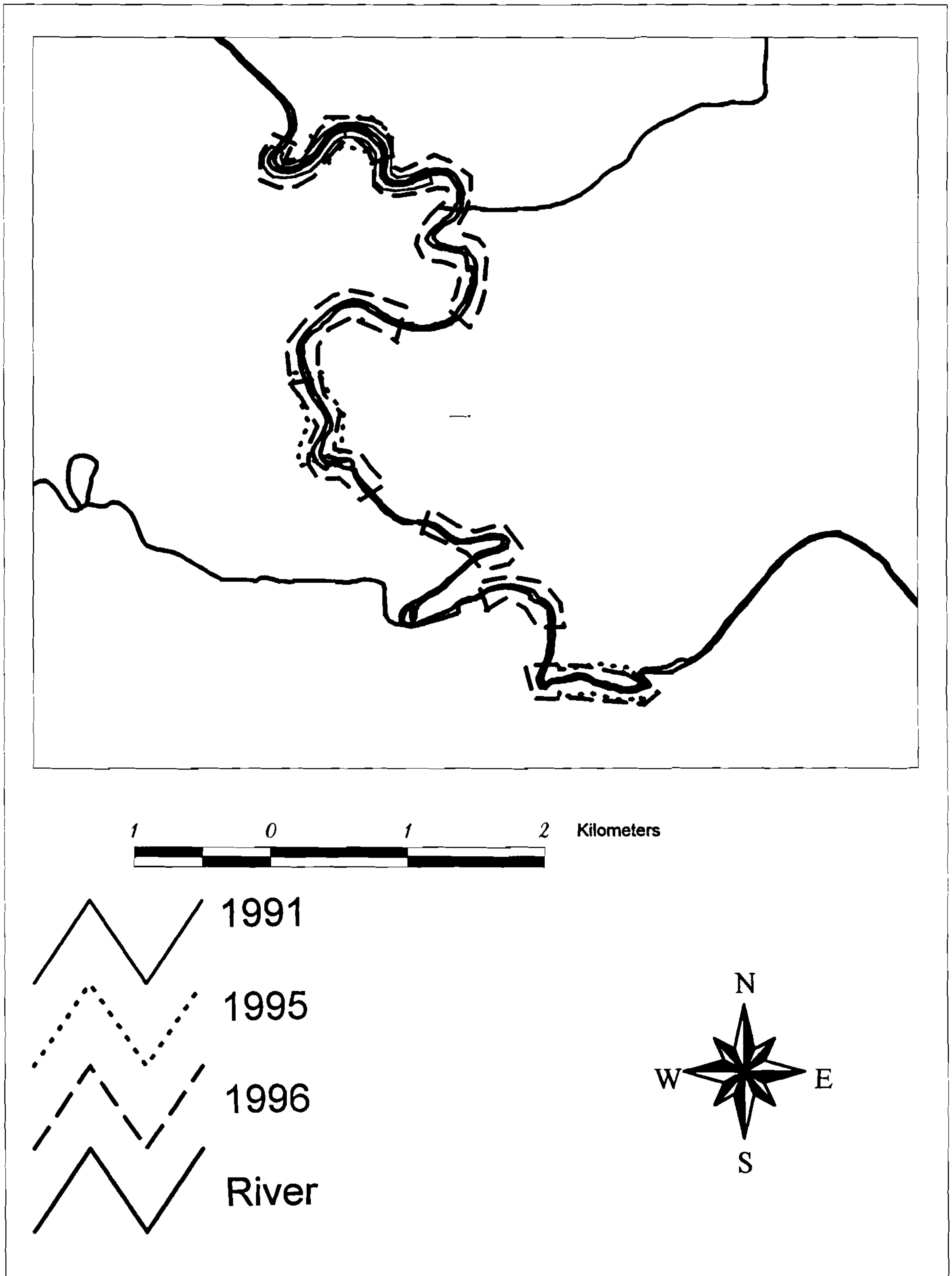
Rosell, F., H. Parker, and N. B. Kile. 1996. Causes of mortality in beaver (Castor fiber and canadensis). Fauna (Oslo) 49:34-46.

Zar, J. H. 1984. Biostatistical Analysis. Second ed. Prentice-Hall, Inc., Englewood Cliffs, N.J. 718pp.

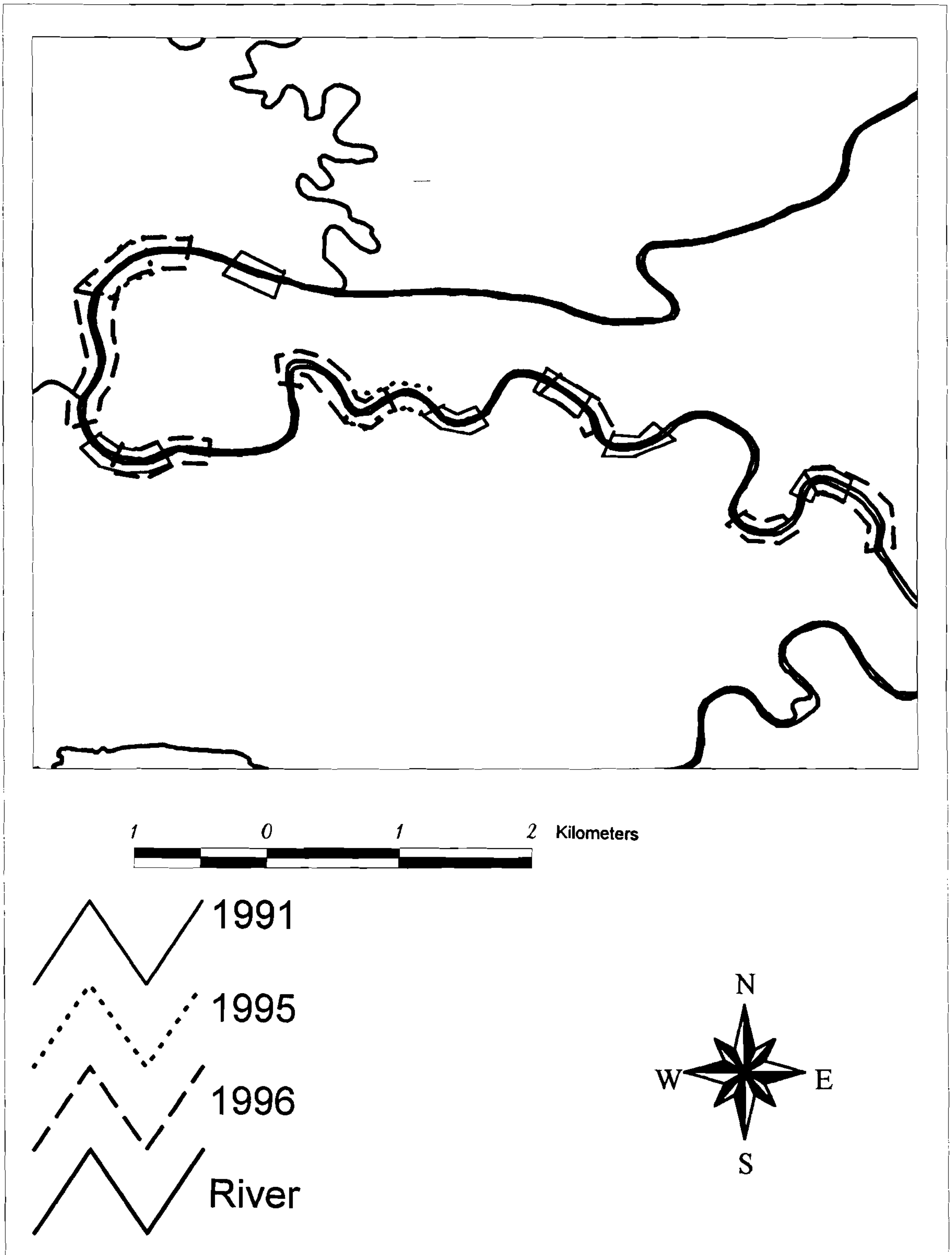
Appendix A. Locations of beaver colonies on 8 of the 9 study sites. Data from the upper stretch of the Arkansas River were excluded due to lack in confidence of the data. Data for 1991 are from KDWP (unpubl. data) and Robel et al. (1993).



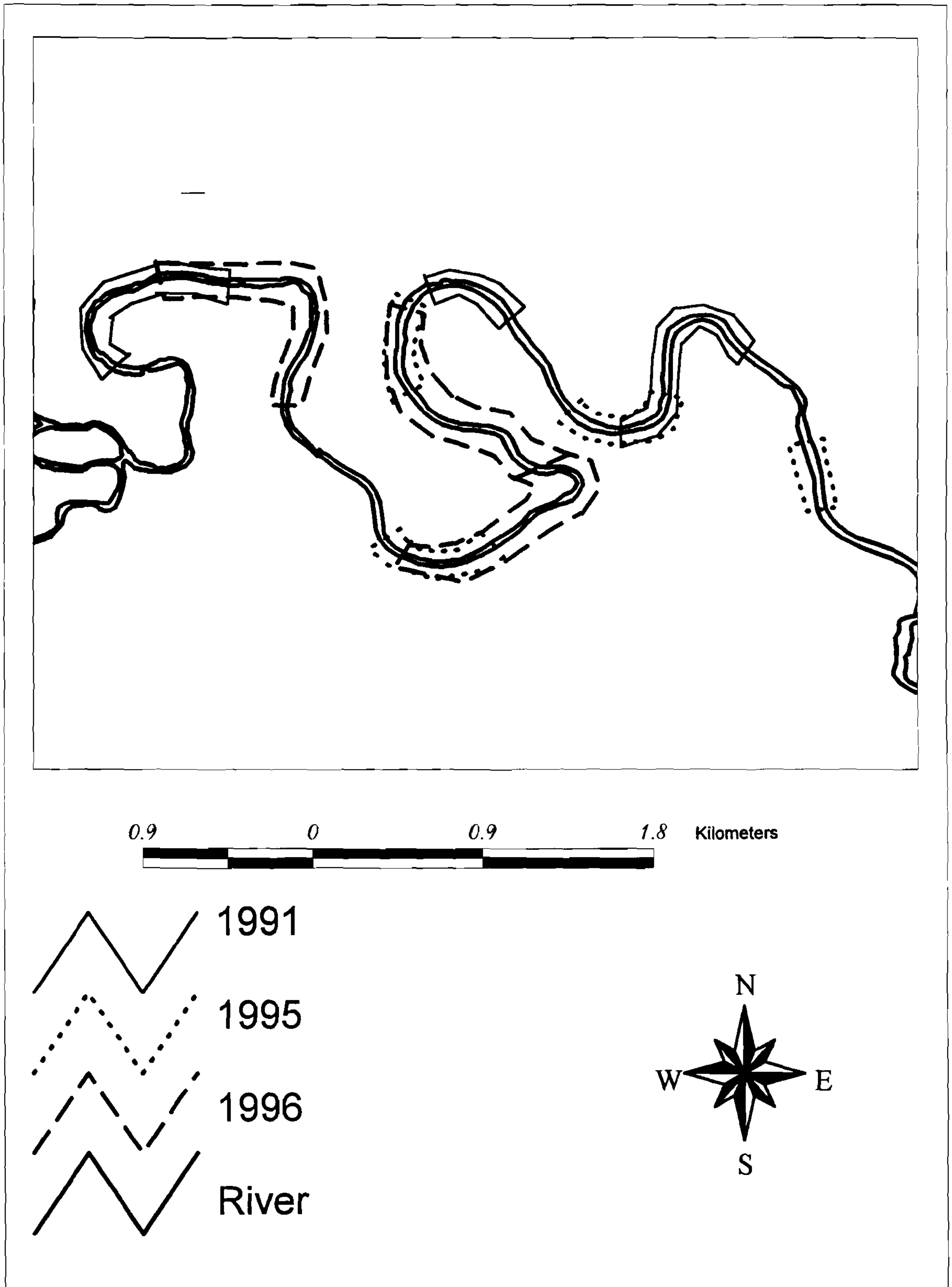
Lower stretch of the Arkansas River



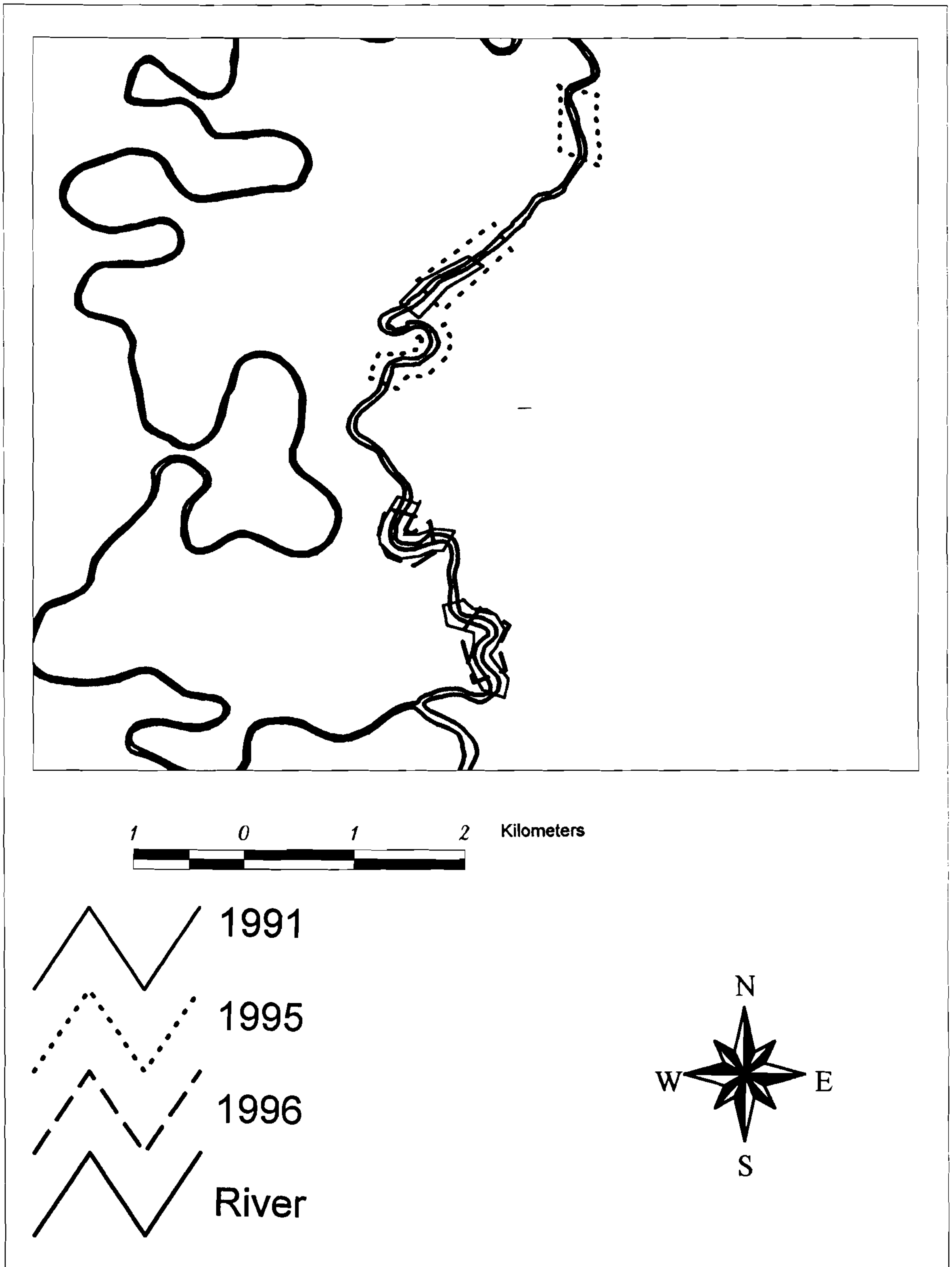
Elk River



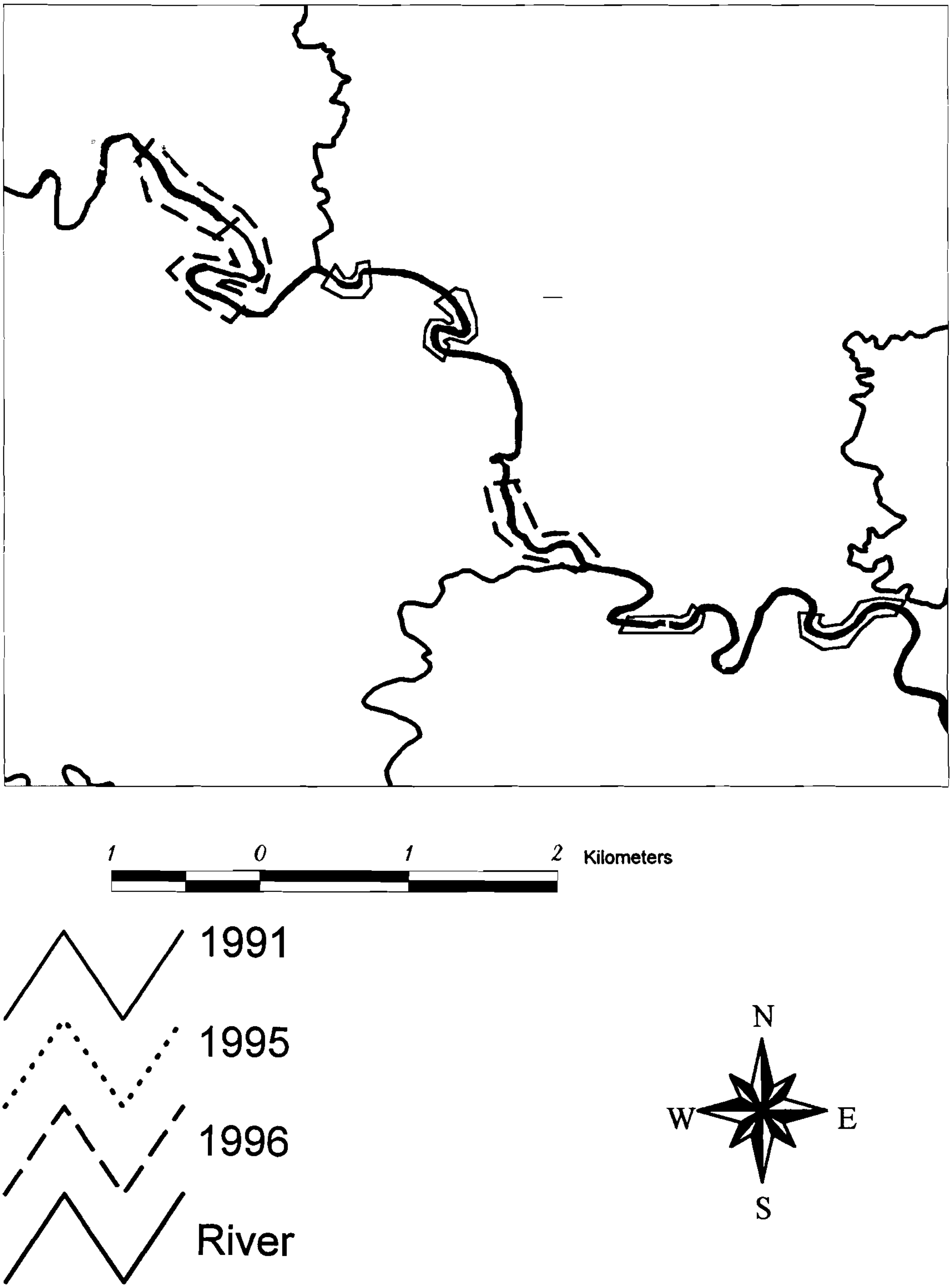
Marais des Cygnes River



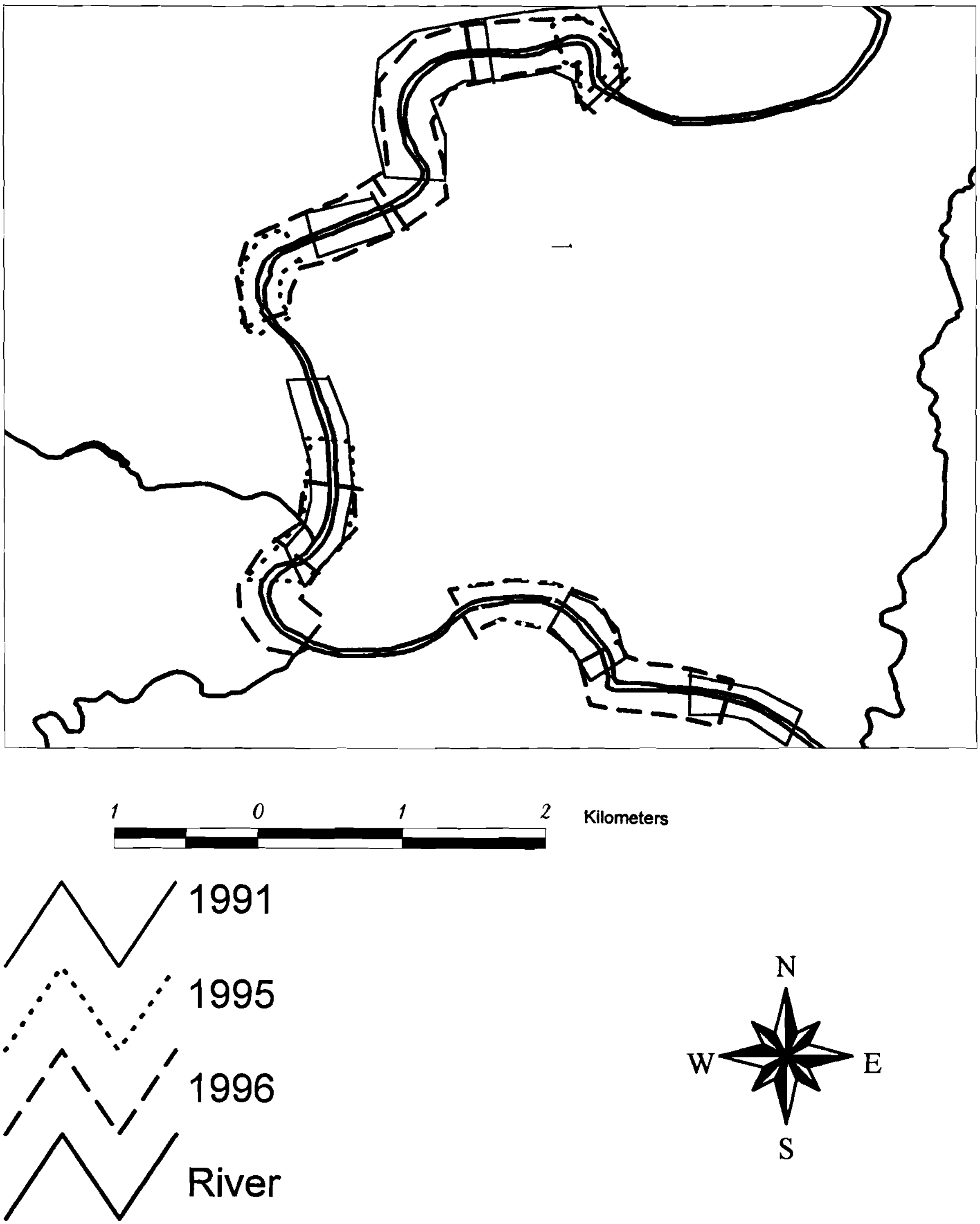
Upper stretch of the Neosho River



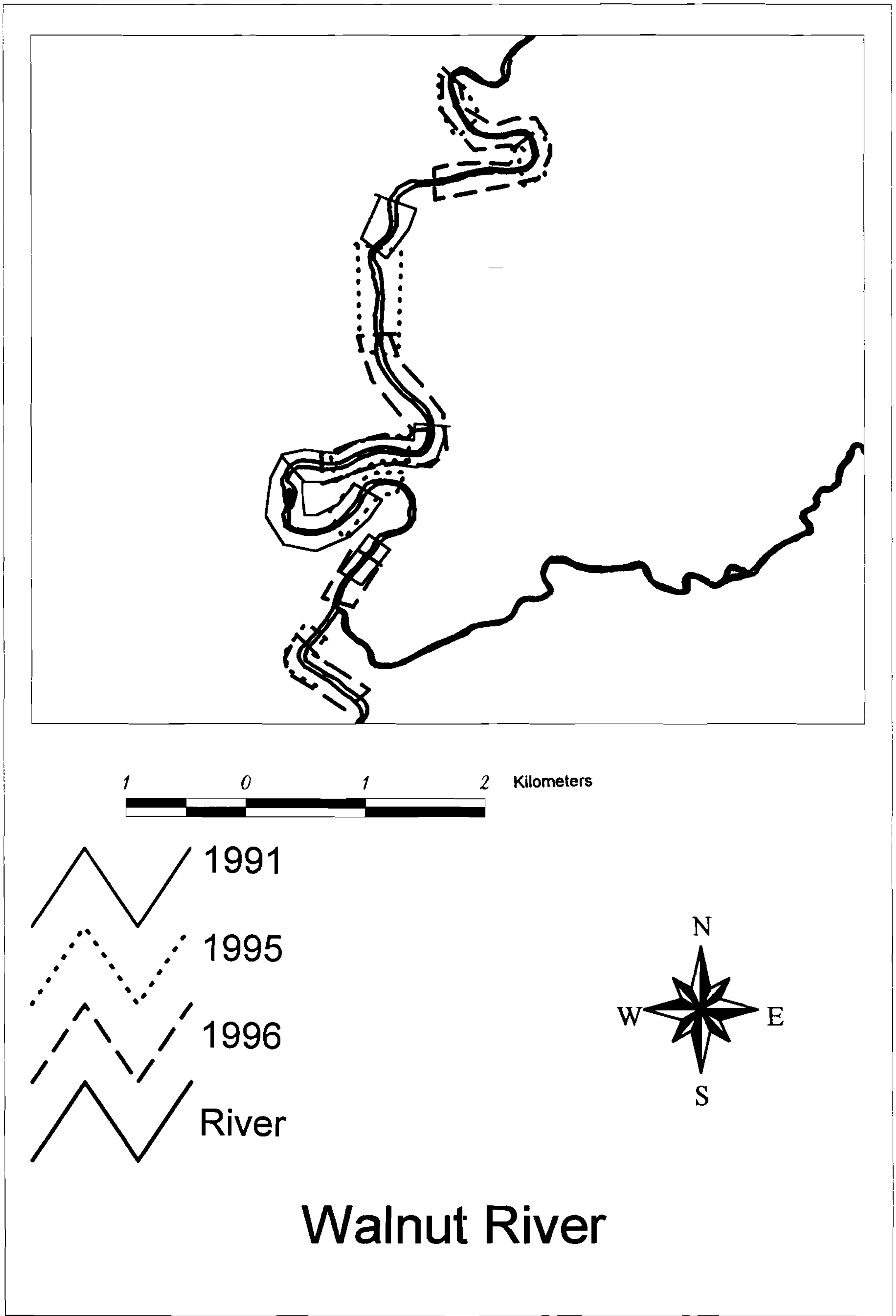
Lower stretch of the Neosho River



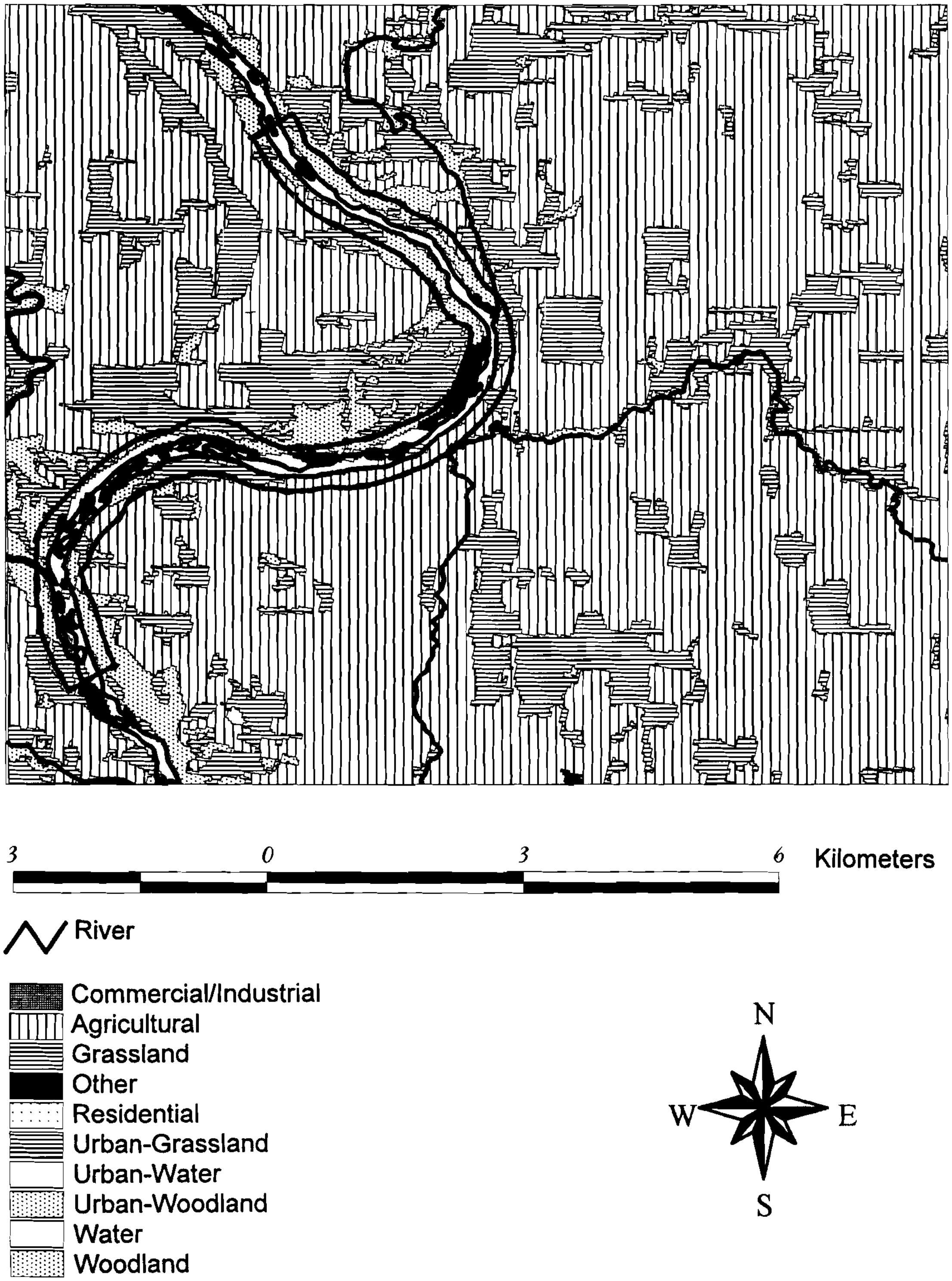
Upper stretch of the Verdigris River



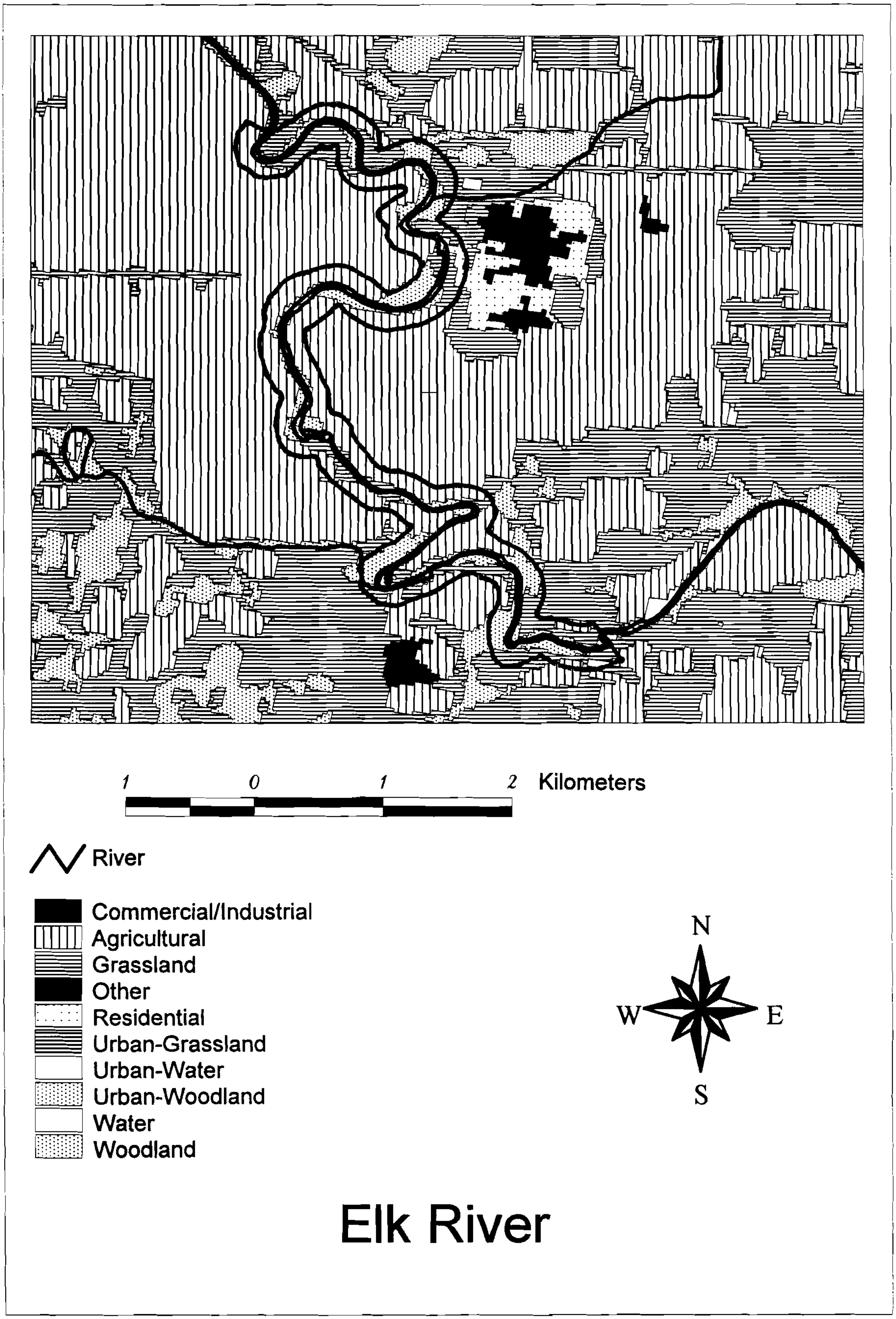
Lower stretch of the Verdigris River

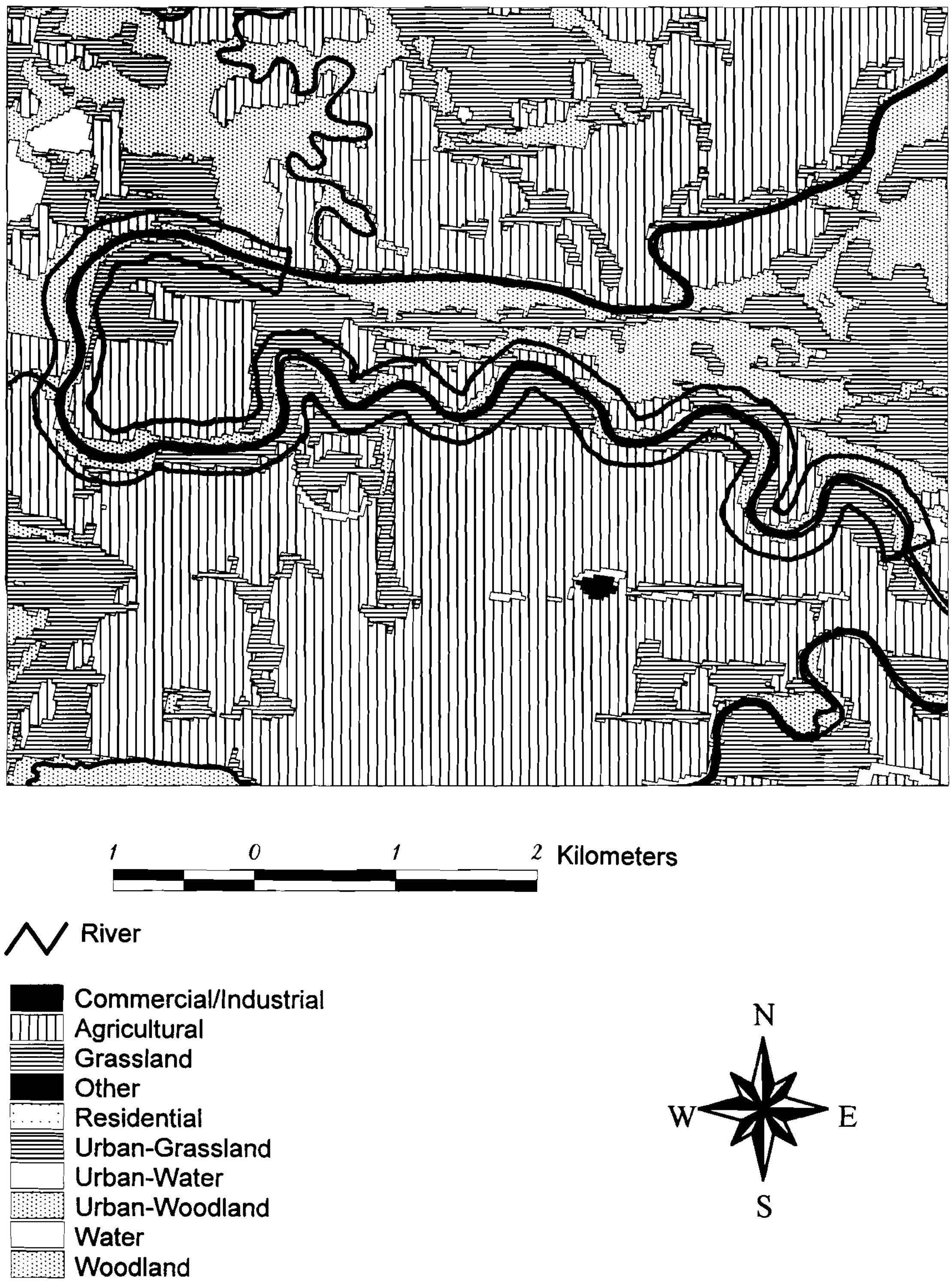

1 0 1 2 Kilometers
1991
1995
1996
River
N
W
E
S
Walnut River

Appendix B. Landcover maps of the 8 study sites as printed by using ArcView. The line parallel to the river represents the 100 m buffer zone in which WD100, CDP100, and WDCRP100 were quantified. Data from the upper stretch of the Arkansas River were excluded because of lack of colony site information.

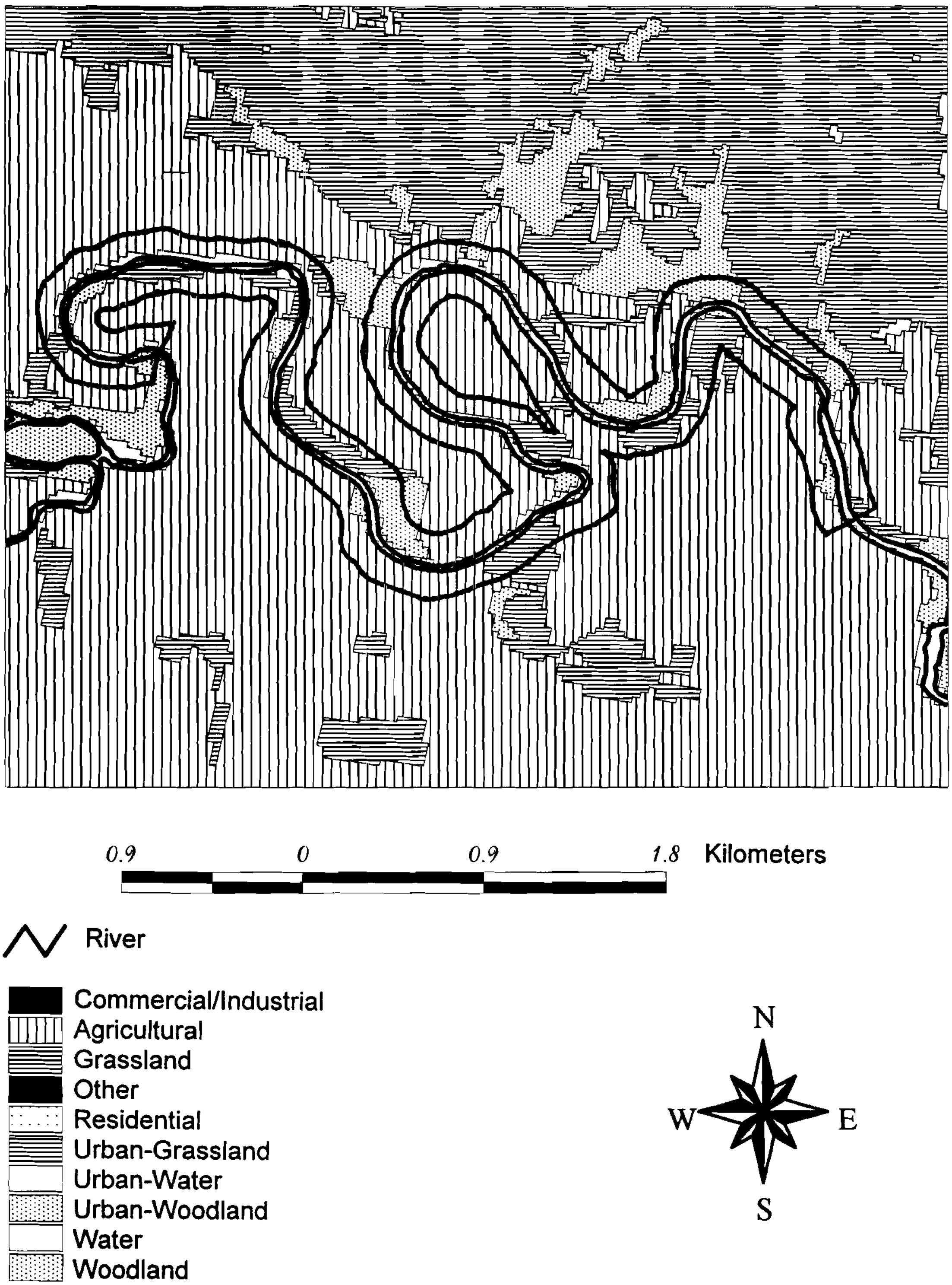


Lower stretch of the Arkansas River

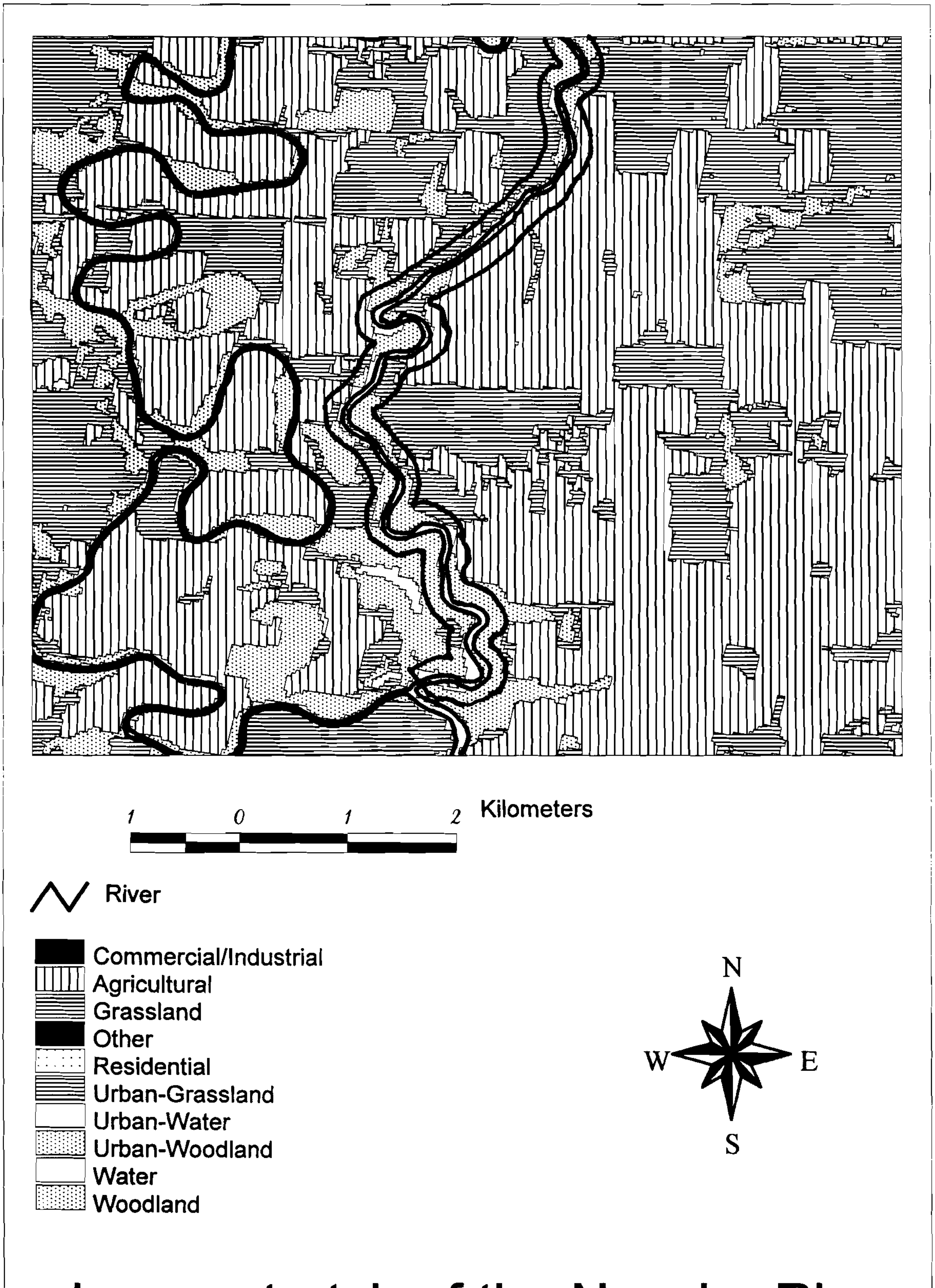

1 0 1 2 Kilometers
River
Commercial/Industrial
Agricultural
Grassland
Other
Residential
Urban-Grassland
Urban-Water
Urban-Woodland
Water
Woodland
N
W
E
S
Elk River



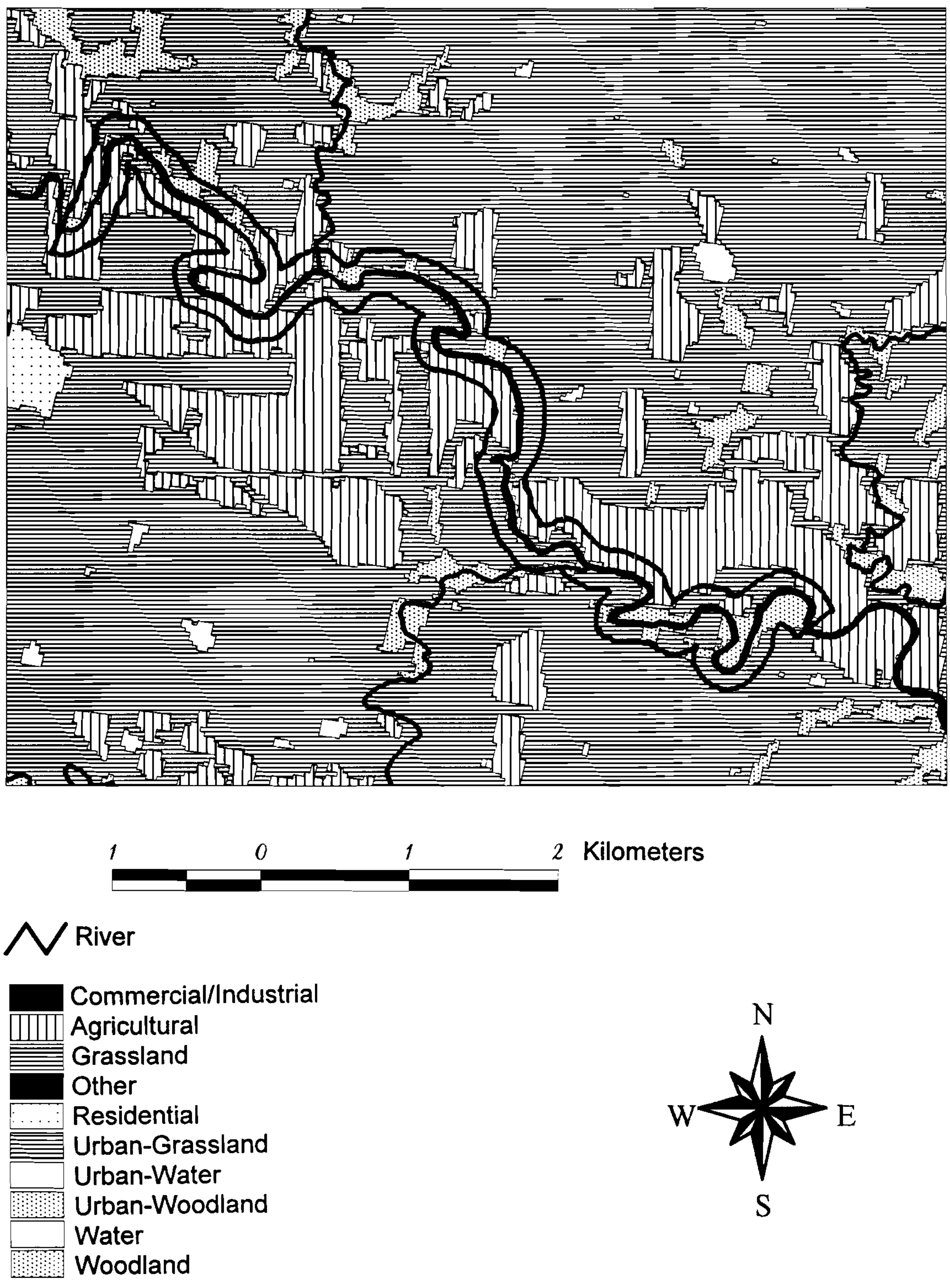
Marais des Cygnes River



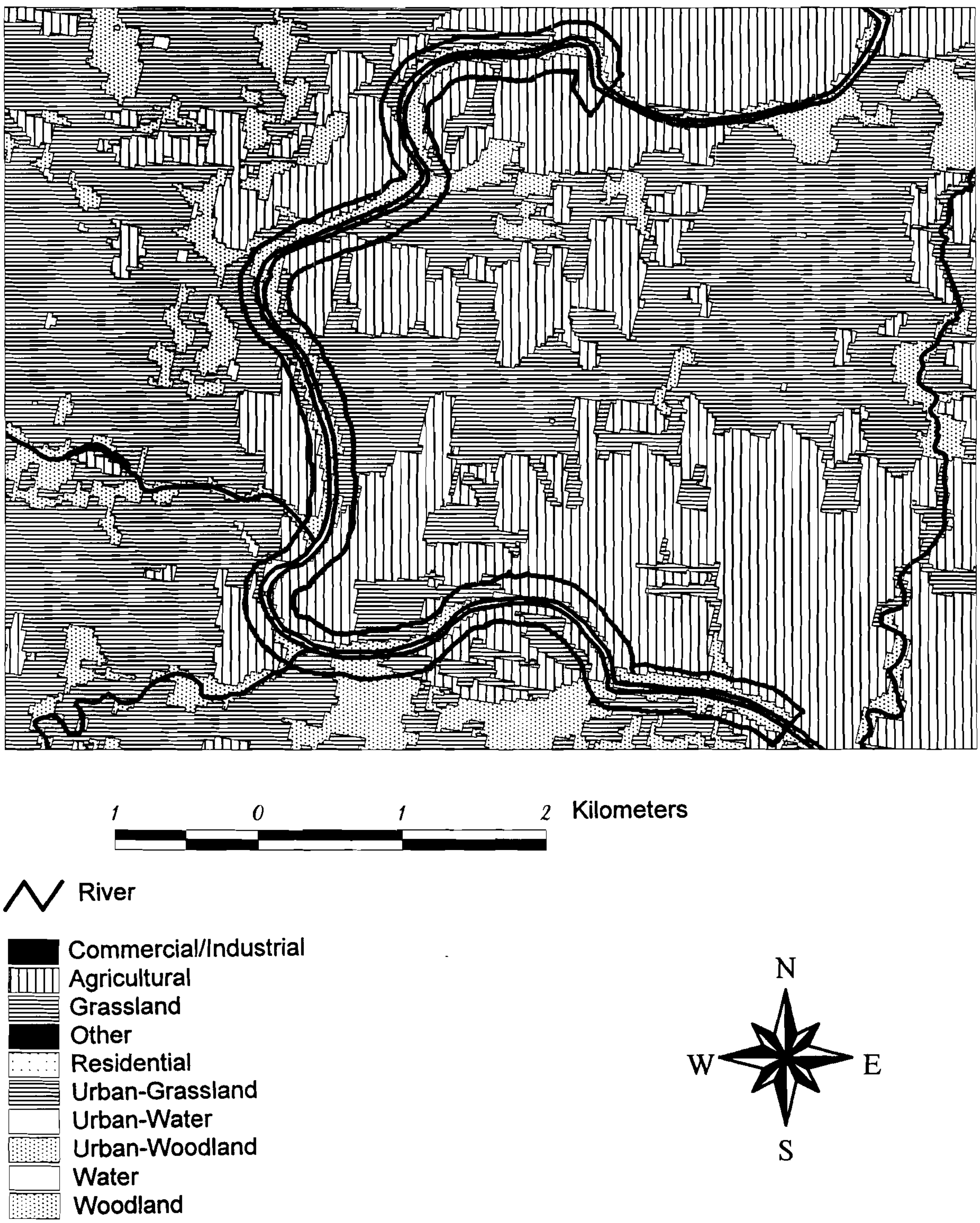
Upper stretch of the Neosho River



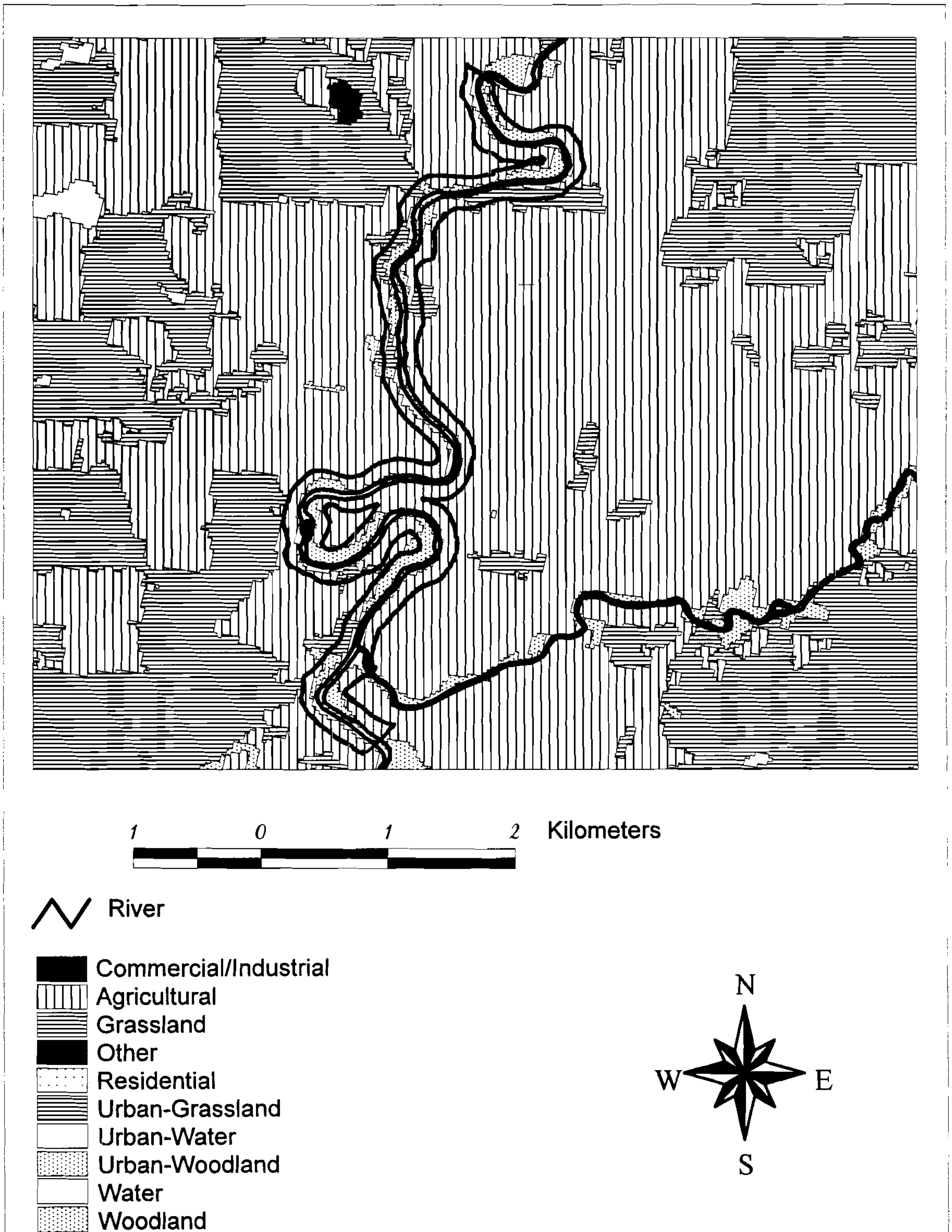
Lower stretch of the Neosho River



Upper stretch of the Verdigris River



Lower stretch of the Verdigris River



Walnut River

I, Chad V. Gatlin, hereby submit this thesis to Emporia State University as partial fulfillment of the requirements for an advanced degree. I agree that the Library of the University may make it available to use in accordance with its regulations governing materials of this type. I further agree that quoting, photocopying, or other reproduction of this document is allowed for private study, scholarship (including teaching) and research purposes of a nonprofit nature. No copying which involves potential financial gain will be allowed without the written permission of the author.

Chad V Gatlin
Signature of Author

Aug 13, 1998
Date

Beaver in the Great Plains: Habitat Suitability Index and Flooding
Title of Thesis

Signature of Graduate Office Staff

August 13, 1998
Date Received