LANDSCAPE LINKAGES AND RIPARIAN
CHANGES IN CENTRAL
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CHAPTER I

INTRODUCTION

This thesis is composed of 2 distinct manuscripts formatted for submission to The American Midland Naturalist. Each manuscript is complete as written and requires no additional material for support. Manuscripts are arranged in the order of text, literature cited, tables, and figures.

CHAPTER II

RIPARIAN LANDSCAPE CHANGES RESULTING FROM AGRICULTURAL AND URBAN EXPANSION (1872-1991)

ABSTRACT.— This study evaluates the presettlement landscape structure and composition along the North Canadian River riparian corridor in central Oklahoma and measures landscape change over the past century. Results of the study depict the presettlement (1872) landscape of the riparian corridor to have been a *Populus deltoides* dominant forest community with dominant upland species *Quercus stellata* and *Q. velutina*. The surrounding matrix was rolling prairie. Major changes through time have been the result of human development, agriculture, urbanization, and river impoundments. The North Canadian River has greatly been reduced in breadth and is much straighter. A majority of the 1872 rangeland, 98%, was replaced by other land uses, mostly agriculture. Urban land use increased almost 2,000% by 1941. Forested land decreased 71% by 1941 and another 27% by 1991. Mean patch size for the entire study area decreased approximately 94% by 1941. Landscape diversity and evenness steadily increased through time. Though the riparian corridor has been greatly altered, reconstruction of the riparian corridor would serve to restore an ecologically valuable community having benefits for both wildlife and humans such as habitat, water purification, esthetics, and recreation.

INTRODUCTION

At the time of colonial settlement, the United States had an estimated 87 million ha of wetlands. Only half of that amount remains today. Between the mid-1950's and mid-1970's, an annual average of 185,490 ha of wetlands was lost mainly to drainage for agriculture and some for urban development (Tiner, 1984). The perception of wetlands as wastelands of little practical use was a major cause of this reduction (Adams and Dove, 1989). Only 15% of the bottomland hardwoods in eastern Oklahoma that existed before European settlement remain today (Brabander et al., 1985). In western Oklahoma only 3% of the historic riparian habitat remains. Currently, 21.6% to 27.7% of that area is forested (Stinnett et al., 1987). Over 80% of riparian corridors in North America and Europe have disappeared during the last two centuries (Naiman et al., 1993).

Wetlands, especially riparian corridors, have been recognized for their high biodiversity and environmental value. Benefits include flood and erosion control, water purification, wildlife habitats, and recreational and aesthetic values (Forman and Godron, 1986; Adams and Dove, 1989; Lant and Tobin, 1989; Naiman et al., 1993; Vought et al., 1995). Despite these benefits, modification continues to these wetlands with little attention given to the possible consequences. The movement of water, sediment, and woody debris all affect the characteristics of riparian corridors. The alteration of the landscape greatly affects this dynamic system (Naiman et al., 1993).

Naiman et al. (1993) stated that riparian corridors should be protected and used in water and landscape planning because of the associated diversity of landforms and wildlife. However, few if any riparian conservation strategies are based on wildlife habitat requirements. Instead they are often based only on water-related or fisheries criteria (Schaefer and Brown, 1992; Roper et al., 1997). Strategies should address habitat requirements of terrestrial plant and animal species using riparian corridors as routes for movement across the landscape. Some species are tolerant of the wet environment of the flood plain while others require upland community structure (Forman and Godron, 1986). Therefore, to accomplish riparian conservation or restoration goals, projects should cover associated uplands as well as flood plains (Forman and Godron, 1986; Roper et al., 1997).

Land managers promote including corridors in the landscape to connect patches of isolated habitat without fully understanding the function of riparian corridors in a landscape. This may increase expansion and genetic mixing of populations and may raise local species richness. However, many native species found in isolated habitats would not travel along connecting riparian corridors (Knopf, 1992). Instead of providing new sources of habitat for target species, riparian corridors may increase the occurrence of alien species that out-compete and alter integrity of local communities within connected habitats or regions (Knopf and Scott, 1990; Knopf and Samson, 1994). Before plans are made for the inclusion or conservation of a riparian corridor, it is important to know if the vegetation associations are native or introduced. Therefore, baseline or historic conditions must be defined (Knopf and Samson, 1994). This will reduce the chance of compromising the integrity of a region's natural biodiversity (Knopf, 1992; Samson, 1992).

Efforts have been made to restore presettlement landscape conditions as found by early explorers and settlers. To fully reconstruct the landscapes requires description of presettlement landscape structure and composition. This description provides a baseline for setting restoration goals (Kreiter, 1995; Wilson et al., 1995). For studies in landscape restoration, historical land use records such as the General Land Office (GLO) survey notes have been essential sources for presettlement information (Nelson, 1997).

According to Knopf (1992), emphasizing riparian corridors in the Great Plains region confounds conservation of native species in the region because forest riparian vegetation corridors did not historically link distant patches of habitats. The objective of this study is to describe presettlement landscape structure and composition along a central Oklahoma riparian corridor to determine whether or not a forested riparian corridor existed prior to human settlement. This study also measures the degree of landscape change that has occurred over the past century. Data presented in this paper are intended to describe how the landscape looked before settlement and to quantify landscape level alteration caused by anthropogenic influences over the years since. Further, data from this study will serve as a baseline for possible future land use planning and habitat restoration of central Oklahoma riparian corridors.

STUDY AREA

The study is centered on the riparian corridor along approximately 48 km of the North Canadian River in eastern Canadian County and continuing into western Oklahoma County in central Oklahoma (Fig. 1). Riparian corridor is defined as the unique forested community surrounding the river that differs from the surrounding matrix of prairie vegetation. The North Canadian River flows across New Mexico, Oklahoma, and Texas with approximately 61.3% of the drainage area situated in Oklahoma. The topography of the river basin in Oklahoma ranges from gently sloping plains in the Panhandle to rough and rolling hills in the far eastern portion of the basin (Ghermazien and Zipser, 1980).

The exact study area boundary begins at the river intersection with the public land survey system (PLSS) line between sections 9 and 10 of township 12 north, range 6 west based on the 1991 river position. The riverbanks have moved considerably through time. Therefore, the north and south boundaries of the study area are not constant throughout the study. The east and west boundaries remain constant. The study area continues down river to the east ending at the river's intersection with the line between sections 9 and 10 of township 11 north, range 3 west. Along both sides of the river, a 1mi (1.609 km) buffer radius establishes the north and south boundaries.

Lake Overholser, located in western Oklahoma City, divides the study area into east and west sections. Lake Overholser is one of six major lakes impounded by the North Canadian River. The western half of the study, upstream from Overholser, and the eastern half, downstream, belong to two separate sub-basins. Annual precipitation in the sub-basin including Lake Overholser and continuing upstream to the Canton Lake Reservoir is 73 cm. Downstream of Lake Overholser in the eastern sub-basin, the annual precipitation is 95 cm. The study area's climatic zone is moist sub-humid. (Ghermazien and Zipser, 1980). Locally, the study area has an average precipitation of approximately 84 cm annually with a mean annual temperature of 16 °C (Oklahoma Water Resources Board, 1990).

Plant species present in the upland watershed area west of Oklahoma City typically consists of blackjack oak (*Quercus marilandica*), post oak (*Quercus stellata*), plum (*Prunus* spp.), sage (*Artemisia* spp.), skunk bush (*Rhus aromatica*), and various grass species. Hackberry (*Celtis occidentalis*), elm (*Ulmus* spp.), cottonwood (*Populus deltoides*), and chittamwood (*Bumelia lanuginosa*) are common along the moist soil riverbanks. Beyond the study area east of Oklahoma City, the basin's vegetative cover is predominately oak forests and cleared pasture (Ghermazien and Zipser, 1980).

The study area was selected based on this rural-urban transition to provide information on how varying land use has changed presettlement riparian vegetation structure. Land use in the western half of the study area is predominately cropland and residential development. In the eastern portion, the North Canadian River flows through heavy urban, industrial portions of Oklahoma City. Also, Lake Overholser is one of the State's oldest impounded lakes, constructed in 1916 as the municipal water source for Oklahoma City (Ruth, 1957; Ghermazien and Zipser, 1980).

METHODS

Data collection.—U.S. General Land Office (GLO) 1872-1873 survey notes and plat maps were obtained from the Archives Division of the Oklahoma Department of Libraries in Oklahoma City. To aid in future relocation of section corners, the original surveyor, Theodore H. Barrett, recorded common names and diameter breast height (dbh) of up to four trees as well as their distances and compass bearings from each of the public land survey system (PLSS) section corner, quarter section corner posts. Each of the trees, referred to as bearing trees, were marked with the section, township, and range on the side facing the post. The surveyor also recorded data from trees located at the intersection of a section line with the right or left bank of the river. Bearing tree data on or within a 1 mi (1.609 km) radius of the North Canadian River between section 9 of township 11 north, range 3 west and section 10 of township 12 north, range 6 west were recorded to estimate tree density. The surveyors also recorded the type of terrain, soil, undergrowth vegetation, timber, any unusual features, and major vegetation changes along section lines.

Survey notes were used to interpret land use and land cover for the study area as mapped on the GLO plat maps at a 1:31,680 scale. To evaluate land use and land cover for subsequent years, U.S. Department of Agriculture black and white aerial photographs for 1941 and 1970 at a 1:20,000 scale were obtained from the Oklahoma State University Library. Copies of 1991 aerial photographs at a 1:7,920 scale were obtained from the Canadian County and Oklahoma County Natural Resources Conservation Service offices. Land use and land cover types for each of the four time periods were interpreted based on a modification of the 1976 USGS Land Use and Land Cover Classification (Anderson et al. 1976) (Table 1).

The interpreted boundaries around each land use or land cover were traced from the plat maps and aerial photographs onto acetate sheets. Completed acetate coverages were then digitized using a digital scanner. Registration points for rectification were hand digitized from topographic quadrangle maps. The digitized coverages were imported into the graphics software package, LTPlus (Line Trace Plus, version 2.22) to be edited and rectified. The edited coverages from LTPlus were imported as vector files into GRASS (Geographic Resource Analysis Support System) (Shapiro et al., 1992) where each year's coverages were patched together to form a complete map of the study area for that year. The completed maps were then labeled according to interpretation and rasterized with 5m resolution.

Ground truthing to verify photo-interpretation was performed for the 1991 coverage in fall, 1995. Field observations were made following a predetermined route along city and county roads corresponding to PLSS section and quarter section lines. Each delineated polygon was located in the field, and all polygons were compared with photo-interpretation results. Needed changes or changes in land use classification were made accordingly.

Data analysis.— Surveyors recorded up to four bearing trees per sample point. Data from 265 sites were treated as point-centered quarter samples. Total number of trees recorded for the study area and used in the analysis was 541 of which 252 trees were located in the eastern half and 289 in the western half (Cottam and Curtis, 1956; Mueller-Dombois and Ellenberg, 1974; Metzger, 1997; Nelson, 1997). Distance to nearest tree and dbh were used to calculate average distance to nearest tree, absolute density, and basal area. Mean basal area, dominance, and frequency of occurrence were calculated by tree species.

All four digitized coverages were imported into Arc/Info's GRID module, or raster based geoprocessing system (ESRI, 1994). FRAGSTATS, a spatial pattern analysis program for quantifying landscape structure (McGarigal and Marks 1995), accepts Arc/Info SVF files and was used for the landscape analysis of this study. Temporal changes in landscape composition and relative abundance were measured using the metrics for area and diversity. Because the study area is split into two unique halves, analysis was conducted separately on each half to provide a comparison of the urban and rural influences.

FRAGSTATS was used to calculate area for each patch type as well as to measure total landscape size. Percentage of the landscape occupied by each patch type was calculated to quantify area in more relative terms. The largest patch index was used to compute percentage of the landscape area comprised by the largest patch present.

Several statistics were used to quantify diversity at the landscape level. Two components of diversity are richness and evenness. Richness is simply the number of patch types present. Relative richness relates richness as a percentage of the total possible patch types present. Two diversity indices were used along with their corresponding evenness indices. Shannon's diversity index (Shannon and Weaver, 1962) is the negative of the sum, across all patch types, of the proportional distribution of each patch type multiplied by that proportion. Shannon's diversity index equals 0 when only one patch occurs in the landscape. Shannon's diversity increases as patch richness increases and/or as the proportional distribution of area becomes equal among patches. Simpson's diversity index (Simpson, 1949) calculates the probability that any two patches selected at random will be different types. Landscapes with only one patch type have values of 0. As the number of different patch types increases and the proportional distribution of area among patch types becomes more even, the index value approaches 1. Shannon's evenness and Simpson's evenness are expressed as the observed level of diversity divided by the maximum possible diversity for a given patch richness. The closer the evenness index is to 1, the more even the distribution of area among patch types.

RESULTS

Bearing tree data.—Of the 541 trees recorded from the GLO survey notes, 19 taxa were identified and recorded (Table 2). Of the 19 taxa, only 15 were present in the western half and 17 in the east (Table 3). The surveyor identified trees by common name only and not always to species. For example, trees of genus *Ulmus* were all identified as "elm" even though two species, *U. Americana* and *U. rubra*, could have been present within the study area (Little, 1996).

Elm was second highest in both dominance and absolute frequency to cottonwood. Both elm and cottonwood were common stream border species. Post oak, an upland species, was third in dominance rank but had a much lower density (3.6 trees/ha) to that of willow (*Salix nigra.*) (15.9 trees/ha), which was fourth in dominance. This is because post oak had a larger average dbh than all species present while willow had a higher frequency than post oak. Willow is most often found with cottonwoods in wet soils bordering streams (Little, 1996). In just the western half, willow had a greater frequency (51) than elm (34) or post oak (13). However, average dbh for willow was again much smaller. Only 5 post oaks were recorded in the east with an average dbh of 26.4 cm. Though basal area was the same for post oak and willow (0.1m^2/ha), post oaks low density and frequency values lowered its dominance rank to fourth and raised willow to fifth. The average tree density of the study area was 109 trees/ha.

Post oak was the dominant upland species found within the forested riparian corridor. Another upland species recorded, black oak, *Quercus velutina*, was fifth in dominance rank. The average dbh of the 14 black oak trees recorded was only 17.2 cm with a basal area of $0.1 m^2/ha$. Species following black oak in dominance were mostly species associated with valleys, wet soils, or stream banks.

Area indices.—The greatest change in existing land use occurred between 1872 (Fig. 2) and 1941 (Fig. 3) as urban or developed land increased 1,987% (Table 4). In association with the developed land, urban grassland increased 379% between 1941-1991. Barren land also increased through each time period.

Not present in the study area prior to settlement, 9,000 ha of agricultural land use displaced a majority of the rangeland. A 98% loss of rangeland occurred between 1872 and 1941. Rangeland decreased at a slower rate through 1970 (Fig. 4) and currently is 6% less than that measured in 1941. Agricultural lands have since decreased 41%. Forested lands decreased 71% by 1941 but have only dropped 27% over the past 50 years.

With the impoundment and creation of Lake Overholser, the amount of open contained water in the study area increased from 0 to 648 ha by 1941. Numerous farm ponds were built after the dust bowl and also contributed to the increase in water present. Lake Overholser created an increase in wetlands directly up stream. Forested and non-forested wetlands nearly doubled by 1941. Over the past 50 years, forested wetlands have continued to increase slowly while non-forested wetlands decreased by 64%, which is less than 1872 amounts.

The North Canadian River was reduced in size by 50% by 1941 and another 50% by 1970. The reduction corresponds to the straightening of the river as well as the narrowing of its width. The straightening of the river caused an overall reduction in the size of the study area even though the east and west boundaries remain the same and the buffer area surrounding the river remains the same at 1mi (1.609 km). The size of the study area in 1872 was 17,570 ha; and in 1991 it was 13,567 ha, a 23% drop (Fig. 2 and 5). It is important to note that the change in overall size of the study area will affect the analysis of indices for total patch type indices. For example, the total area of forested land in 1872 was 5,000 ha and 1,088 ha in 1991. The total landscape area in 1872 was 17,570 ha and 13,567 ha in 1991. Therefore, the decrease in area may be misleading and should be taken into consideration. However, the individual patch indices are not as affected by the overall size change because they are considered separately to the total landscape size.

Patch size indices.—The mean patch size for the entire study area dropped approximately 94% from 1872-1941 (Table 5). Rangeland and forested lands separately had mean patch size reductions of over 97% from 1872 to 1941. For example, the mean patch size for rangeland in the eastern half of the study area dropped to 3.41 ha from 1012.92 ha. Average patch size for forested lands remained about the same from 1941-1970 but again dropped in 1991. Mean patch size of rangeland in the western half of the study area increased by 28% since 1941. In contrast, mean patch size of rangeland in the eastern half has decreased 28%.

In 1872 and 1941, wetlands were mainly in the western half of the study area. By 1970, there were no wetlands found downstream of Lake Overholser. Average patch size for non-forested wetlands decreased 63% between 1872 to 1941. Since 1941 non-forested wetlands have increased by nearly 43%. Forested wetlands increased in average patch size from 26.18 ha in 1872 to 30.66 ha in 1941. Average patch size for forested wetlands increased again to 108.73 ha in 1970 but decreased to 23.47 ha in 1991.

Landscape diversity indices.—The maximum number of patch types possible for the study area is 10. Therefore, the maximum richness of the study area is also 10. Richness varied from 5 in the eastern half of the study area in 1872 to the maximum 10 in the western half for 1941, 1970, and 1991 (Table 6). Patch richness density was lowest also in 1872 at 0.06 patch types/100 ha and highest in the eastern half in 1941 at 0.15 patch types/100 ha. The only cover type not present in the eastern half in 1941 was forested wetland.

Overall, diversity indices increased through each time period. Shannon's Diversity showed the greatest increase, 60%, in diversity from 1872 to 1941. Otherwise, the changes in diversity ranged from 3% to 20% higher. About the same increase overall occurred with the evenness indices. Both Shannon's and Simpson's evenness indices increased from 0% to 23%.

DISCUSSION

Based on the measures of area, patch size, and diversity indices it is apparent that over the past century the riparian corridor and surrounding land use and land cover of this study has greatly changed. Much of the original plant community that dominated the riparian corridor has been replaced by human developments (Fig. 2-5). In 1872, the riparian corridor was dominated by cottonwood mixed with willow, elm, post oak, and several other species. Occasionally surveyors would also reference undergrowth species such as plum or redbud. Surface descriptions were also given. Predominately given were "gently rolling prairie" in the uplands and "level" in the bottoms with "timber."

The surveyor described the riparian corridor as timbered. The low frequency of upland species suggests that the forested community surrounding the river was predominately species that are true riparian or flood tolerant species such as cottonwood and willow. Dominant upland species present in the study area were post oak and black oak. These upland and bottomland communities were similar across the whole study area. The total tree density of the study area was 109 trees/ha. According to Nelson (1997), >99 trees/ha suggests a closed forest community. However, it is difficult to consider 109 trees/ha a closed forest in comparison to a study estimating recent tree density up to 615 trees/ha (Kreiter, 1995).

In a recent study by Kreiter (1995), the presettlement (1896) tree density in the McCurtain County Wilderness Area of the Quachita Mountain region of southeast Oklahoma was estimated much lower, 70.8 trees/ha, than the presettlement (1872) tree density along the North Canadian River. In a study by Nelson (1997), average estimated presettlement (1815) tree density was 92 trees/ha along the 5th Principal Meridian in eastern Arkansas and Missouri. Breaking his study area down into three physiographic regions, Nelson estimated 79 trees/ha in the Ozark Plateau and 68 tree/ha in the Dissected Till Plain. In the Mississippi Alluvial Plain, he estimated tree density to be 146 trees/ha. Mississippi Alluvial Plain is a topographically low, flat, river-floodplain as is the study area surrounding the North Canadian River. The flood plain soils may therefore be the cause for higher presettlement tree density estimates.

The method of tree selection by the surveyor has significant implications on the reconstruction of presettlement tree densities. Surveyors were instructed to select trees that were the soundest in appearance, of good size and type that were most likely to be permanent and lasting (Kreiter, 1995; Nelson, 1997). Trees selected by the surveyor were not always the nearest to the corner post and therefore biased the tree-to-post measurements used in point-quarter sample analysis. This bias would then create an underestimation of true presettlement tree density estimates. As a result, the reconstruction may not be to absolute densities but the estimates do provide data for relative comparisons (Nelson, 1997). Methods of tree selection could also have varied from surveyor to surveyor. However for this study, only one surveyor conducted measurements, which provided more consistent recordings throughout the study area.

Washington Irving, during his travels through Oklahoma in autumn of 1832, crossed the North Canadian River in close proximity to this study area. He described the valley of the North Canadian as follows: "A beautiful meadow about half a mile wide, enamelled with beautiful autumnal flowers, stretched for two or three miles along the foot of the hills, bordered on the opposite side by the river, whose banks were fringed with cottonwood trees, the bright foliage of which refreshed and delighted the eye," (Irving, 1955). His description is far from the scene today. The plant cover has changed and reduced to the point that there were not enough timbered points from which to gather bearing tree data to conduct a comparable analysis of tree density for present day composition. Mueller-Dombois and Ellenberg (1974) recommend at least 20 points. In the study area, only 4 survey points currently existed from which bearing trees could be measured.

Based on the classification system designated for this study, the landscape in 1872 had a richness of 6. Patch types present were all natural systems except for urban or developed land. The 67 ha of land designated as urban in 1872 may also be exaggerated due to the inclusion of a cattle trail and, in today's standards, an unimproved road. Neither trails or unimproved roads were singled out and mapped on the successive years' coverages. Roads and cattle trails through agricultural land were simply included as agricultural; those through urban areas were treated as urban; and so on in the later time periods. Identification of the 67 ha as urban in 1872 indicates minimal human activity in the region.

The 1872 study area was dominated by rangeland and forested land, 67% and 30% of the landscape respectively. The mean patch size of rangeland cover type in the eastern half of the 1872 landscape was 1,012 ha with a standard deviation of 1,073 ha. The largest single contiguous patch of rangeland consisted of 31% of the total landscape. The remainder of the landscape in 1872 consisted of the 67 ha of urban land use, small isolated patches of forested and non-forested wetlands, and the North Canadian River. The low values of the diversity indices produced for this time period are indicative of a landscape dominated by a few of several patch types and that the area distribution is not even among patch types (McGarigal and Marks 1995).

The most apparent change by 1941 was the presence of human development. Almost all of 1872 native rangeland and forested land gave way to 9,040 ha of agricultural land and 1,407 ha of urban land use by 1941. Agricultural land use consisted of primarily wheat along with grain sorghums, barely, oats, and some cotton. Urban land use within the study area was light development or residential housing of Oklahoma City. The population of Oklahoma County in 1940, predominately clustered around the Oklahoma City metropolitan area, was around 116,000 (Morris, 1954).

As urban development in Oklahoma City has continued to rise, agricultural land has steadily declined, especially in the eastern half of the study area. Agricultural property within Oklahoma City has been developed into residential areas. Reduction in the amount of agricultural land in the rural areas west of the city has come about because of the reversion of cropland and pastures to unmanaged grasslands. The amount of rangeland has increased to proportions closer to that found in 1941. Due to the development of heavily wooded parks, the establishment of trees in drainage basins, and the reestablishment of trees directly along the river, forested land in the eastern half has slightly increased since 1970. However, the overall percentage of forested land present is lower than in 1872.

Several studies have shown changes in or the elimination of natural vegetation caused by human activities such as agriculture and urbanization have created a modified landscape mosaic of habitat fragments (Forman and Godron, 1986; Adams and Dove, 1989; Kattan et al. 1994). This is quite apparent in this study with the 97% reduction in the patch size of rangeland and forested land by 1941. Corresponding with the drop in patch size was the drop in patch size standard deviation. Anthropogenic land alterations create more patch size uniformity than in unaltered patch mosaics (McGarigal and Marks, 1995) as well as simplifying patch shape (Farley, 1997). This can also be seen when comparing rural and urban landscapes. Patch size standard deviations are larger for the western half or rural portion than the urban eastern half. The landscape though time has changed from being dominated by a few patch types clumped closely together, to a fragmented landscape of greatly interspersed patches of different types (Farley, 1997).

The major alteration in the North Canadian River, first seen in the 1941 study area photos, was the impoundment by Overholser Dam. Lake Overholser was constructed in 1916 as Oklahoma City's municipal water source, capable of holding 7 billion gallons (26.5 GL) of water (Gould, 1928; Morris, 1954; Ruth, 1957; Ghermazien and Zipser, 1980). A large area of wetlands consequently extends directly upstream from the lake, consisting of forested and non-forested wetlands, as well as small shallow lakes. This area is now the Stinchcomb Wildlife Refuge. A patch of forested wetland 31 ha in size existed in 1872 according to the GLO survey notes in the same area as these wetlands. The lake composes a majority of the 648 ha of water cover type found in 1941 coverages.

The North Canadian River is remarkably more narrow than historical widths and much straighter. Stream width reductions are most likely due to alterations in dynamics of forested riparian systems below impoundments constructed for control of flood frequency and magnitude as well as sedimentation rates and river meandering (Knopf and Scott, 1990). Human alterations in the landscape have been changing flood regimes ever since settlement (Kauffman et al., 1997; Maekawa and Nakagoshi, 1997). After a record flood in 1923 broke the Overholser Dam, even more upstream impoundments were initiated to control flooding (Oklahoma Water Resources Board, 1990).

The most obvious trend in land use change is increasing urban development. Increases in the number of transportation corridors, housing developments, utility and water services, have occurred since settlement. These types of changes in the landscape were made with little thought as to the ecological impact (Dix et al., 1997). Thomlinson et al. (1996) viewed anthropogenic landscape alteration as a long-term disturbance both in duration and consequence. A study by Boren et al. (1997) suggests that conservationists should focus on the loss of biodiversity caused by increased human activity in densely populated rural areas surrounding urban centers.

Conversion of rangeland to cropland, impoundment of the North Canadian River, and growth of Oklahoma City infrastructure have all occurred to benefit human habitat conditions and are now permanent factors affecting the riparian corridor. Although succession to a native condition simply cannot occur due to the presence of impoundments (Knopf and Scott, 1990), restoration efforts are imperative to preserve aquatic and riparian biodiversity (Kauffman et al., 1997). The cottonwood is no longer the predominant tree species along the riparian corridor. Species such as elm and hackberry are now more prevalent. The next important step in restoring the corridor is to empirically analyze the current vegetation composition found within the study area and to begin reestablishing historic plant community structures through exotic plant control and native plant reintroductions. Studies evaluating faunal composition and frequency changes in the riparian corridor are of equal importance.

Restoration is the not just the reconstruction of historic, native vegetation at a local level. It is the reestablishment of the functions, processes, and products of a self-sustaining ecosystem and should be addressed at a regional or watershed level (Wyant et al., 1995; Kauffman et al., 1997). Additional research has assessed the effects of urbanization on landscape patterns along the riparian corridor (Farley, 1997), but even more research is needed to understand the function of the riparian ecosystems at regional scales before implementing local conservation or restoration efforts.

Data shows that the riparian vegetation community along this portion of the North Canadian River was historically forested. In response to the concerns of Knopf (1992), the inclusion of a forested riparian community along this portion of the North Canadian River would not create a habitat that was historically absent. Reconstruction of the riparian corridor would serve to restore an ecologically valuable community having benefits for both wildlife and humans such as habitat, water purification, esthetics, and recreation.

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Table 1. 1976 USGS Land Use Land Cover Classification (Modified)

Classification	*Description*
Urban or Built-up Land (1)	Residential Commercial and Services Transportation, Communications, and Utilities Industrial and Commercial Complexes
Agricultural Land (2)	Cropland and Pasture Orchards, Groves, Nurseries, and Ornamental Horticulture Areas Confined Feeding Operations Other Agricultural Land
Urban grasslands (3)	Urban Grasslands City Parks (<40% forested)
Rangeland (4)	Herbaceous Rangeland (<25% shrub or brush)
Forested Land (5)	Deciduous Forest Land (<10% cedar)
Water (6)	Rivers (7) Streams and Canals Lakes and Reservoirs
Wetland	Forested Wetlands (8) Non-forested Wetlands (9)
Barren Land (10)	Beaches Sandy Areas other than Beaches Transitional Areas Bare Exposed Rock Strip Mines, Quarries, and Gravel Pits

Table 2. Presettlement bearing tree frequency, diameter breast height, basal area, density, and dominance by species and total.

Species	Frequency	Diameter Breast Height (cm)	Basal Area (m^2)/ha	Trees/ha	Absolute Frequency	Dominance Ranking
Acer negundo	6	15. 5	<0.1	1.2	2.3	9
Alnus serrulata	5	7.6	<0.1	1.0	1.5	14
Bumelia lanuginosa	1	15.2	<0.1	0.2	0.4	15.5
Carya illinoensis	4	21.6	<0.1	0.8	1.5	8
Celtis occidentalis	19	14.0	0.1	3.8	5.7	6
Cercis canadensis	8	9.8	<0.1	1.6	2.3	11
Cornus drummondii	2	10.2	<0.1	0.4	0.4	17
Diospyros virginiana	5	10.9	<0.1	1.0	1.5	12
Fraxinus spp.	2	22.9	<0.1	0.4	0.8	10
Gymnocladus dioicus	1	15.2	<0.1	0.2	0.4	15.5
Juglans nigra	12	15.5	0.1	2.4	3.8	7
Morus rubra	3	8.5	<0.1	0.6	1.1	18
Populus deltoides	275	23.9	3.3	55.4	61.9	1
Prunus spp.	3	11.0	<0.1	0.6	1.1	13
Quercus stellata	18	25.5	0.2	3.6	3.4	3
Quercus velutina	14	17.2	0.1	2.8	3.0	5
Robinia pseudoacacia	1	7.6	<0.1	0.2	0.4	19
Salix nigra	79	11.6	0.2	15.9	20.0	4
Ulmus spp.	83	20.5	1.1	16.7	20.4	2
Total	541	—	5.2	109.0	131.7	—

Table 3. Presettlement bearing tree frequency, diameter breast height, basal area, density, and dominance by species and total for the east and west study areas.

	Frequency		Diameter Breast Height (cm)		Basal Area (m^2)/ha		Trees/ha		Absolute Frequency		Dominance Ranking	
Species	West	East	West	East	West	East	West	East	West	East	West	East
Acer negundo	5	1	17.0	7.6	0.1	<0.1	1.9	0.4	3.6	0.8	7	16
Alnus serrulata	0	5	—	7.6	—	<0.1	—	2.1	—	3.2	—	10
Bumelia lanuginosa	1	0	15.2	—	<0.1	—	0.4	—	0.7	—	14	—
Carya illinoensis	3	1	22.0	20.3	<0.1	<0.1	1.1	0.4	2.2	0.8	8	8
Celtis occidentalis	11	8	14.9	12.7	0.1	0.1	4.2	3.4	5.8	5.6	6	6
Cercis canadensis	6	2	9.7	10.2	<0.1	<0.1	2.3	0.9	2.9	1.6	11	14
Cornus drummondii	0	2	—	10.2	—	<0.1	—	0.9	—	0.8	—	13
Diospyros virginiana	2	3	12.7	9.7	<0.1	<0.1	0.8	1.3	1.4	1.6	12.5	9
Fraxinus spp.	1	1	30.5	15.2	<0.1	<0.1	0.4	0.4	0.7	0.8	9	11.5
Gymnocladus dioicus	0	1	—	15.2	—	<0.1	—	0.4	—	0.8	—	11.5
Juglans nigra	4	8	12.7	16.8	<0.1	0.1	1.5	3.4	2.9	4.8	10	5
Morus rubra	3	0	8.5	—	<0.1	—	1.1	—	2.2	—	15	—
Populus deltoides	144	131	23.4	24.4	3.1	3.6	54.9	56.0	60.4	63.5	1	1
Prunus spp.	2	1	12.7	7.6	<0.1	<0.1	0.8	0.4	1.4	0.8	12.5	16
Quercus stellata	13	5	25.2	26.4	0.3	0.1	5.0	2.1	4.3	2.4	3	4
Quercus velutina	9	5	19.8	12.7	0.1	<0.1	3.4	2.1	3.6	2.4	5	7
Robinia pseudoacacia	0	1	—	7.6	—	<0.1	—	0.4	—	0.8	—	16
Salix nigra	51	28	12.0	11.0	0.3	0.1	19.4	12.0	25.2	14.3	4	3
Ulmus spp.	34	49	23.2	18.6	1.1	1.1	13.0	20.9	15.8	25.4	2	2
Total	289	252	—	—	5.2	5.2	110.2	107.7	133.1	130.2	—	—

Table 4. Total area of each patch type in the landscape and total area of the landscape during each time period. Percent change in area from 1872-1941 and 1941-1991.

	Patch Type Area (ha)					
	Years				%Change	
Patch Type	1872	1941	1970	1991	1872-1941	1941-1991
Urban Land	67.5	1407.7	2883.3	4162.1	1985.5	195.7
Agricultural Land	0.0	9039.7	7605.8	5313.4	>2000	-41.2
Urban Grassland	0.0	305.9	860.6	1466.7	>2000	379.5
Rangeland	11734.8	292.9	130.7	274.8	-97.5	-6.2
Forested Land	5199.7	1511.3	1099.3	1087.5	-70.9	-28.0
Water	0.0	648.8	605.6	675.3	>2000	4.1
River	400.9	207.7	104.0	108.1	-48.2	-48.0
Forested Wetland	104.7	214.6	217.5	234.7	104.9	9.4
Non-forested Wetland	62.7	121.3	65.2	43.7	93.4	-64.0
Barren Land	0.0	85.3	99.5	200.5	>2000	135.2
Total Landscape	17570.4	13835.0	13671.3	13566.9	-21.3	-1.9

Table 5. Mean patch size and standard deviation in hectares for rangeland, forested land, forested wetland, non-forested wetland, and total landscape during each time period for the eastern half of the study area and the western half of the study area. Percent change in mean patch size from 1872-1941 and 1941-1991.

	Year									
	1872		1941		1970		1991			
Patch Type	Mean Patch Size (ha)	Standard Deviation (ha)	Mean Patch Size (ha)	Standard Deviation (ha)	Mean Patch Size (ha)	Standard Deviation (ha)	Mean Patch Size (ha)	Standard Deviation (ha)	%Change 1872-1941	% Change 1941-1991
Eastern										
Rangeland	1012.92	1073.02	3.41	3.07	7.40	4.90	2.46	3.07	-99.66	-27.86
Forested Land	299.11	318.45	6.46	10.08	6.25	8.22	3.21	5.28	-97.84	-50.31
Forested Wetland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	—	—
Non-forested Wetland	39.09	0.00	1.71	1.67	0.00	0.00	0.00	0.00	-95.63	-100.00
Total Landscape	470.31	722.80	27.05	93.10	28.53	96.18	13.91	107.55	-94.25	-48.58
Western										
Rangeland	833.77	597.19	9.16	13.07	6.74	6.42	11.74	17.72	-98.90	28.17
Forested Land	278.63	322.98	8.38	20.71	8.37	21.62	5.50	14.43	-96.99	-34.37
Forested Wetland	26.18	16.55	30.66	34.14	108.73	23.81	23.47	41.50	17.11	-23.45
Non-forested Wetland	11.82	6.37	4.37	11.86	4.66	4.66	6.24	5.44	-63.03	42.79
Total Landscape	341.97	493.82	22.57	65.93	25.16	68.92	18.47	60.83	-93.40	-18.17

Table 6. Landscape indices for patch richness and density, diversity, and evenness for the east and west study areas during each time period.

	Year							
	1872		1941		1970		1991	
Landscape Indices	West	East	West	East	West	East	West	East
Patch Richness	6.00	5.00	10.00	9.00	10.00	8.00	10.00	8.00
Patch Richness Density	0.06	0.06	0.13	0.15	0.13	0.13	0.13	0.13
Shannon's Diversity	0.78	0.78	1.25	1.09	1.30	1.28	1.45	1.33
Simpson's Diversity	0.45	0.49	0.54	0.54	0.57	0.66	0.63	0.65
Shannon's Evenness	0.44	0.48	0.54	0.50	0.56	0.61	0.63	0.64
Simpson's Evenness	0.54	0.61	0.60	0.61	0.64	0.75	0.70	0.74

Figure 1. Study area along the North Canadian River in Canadian County and Oklahoma County, Oklahoma overlaid with the public land survey section grid.

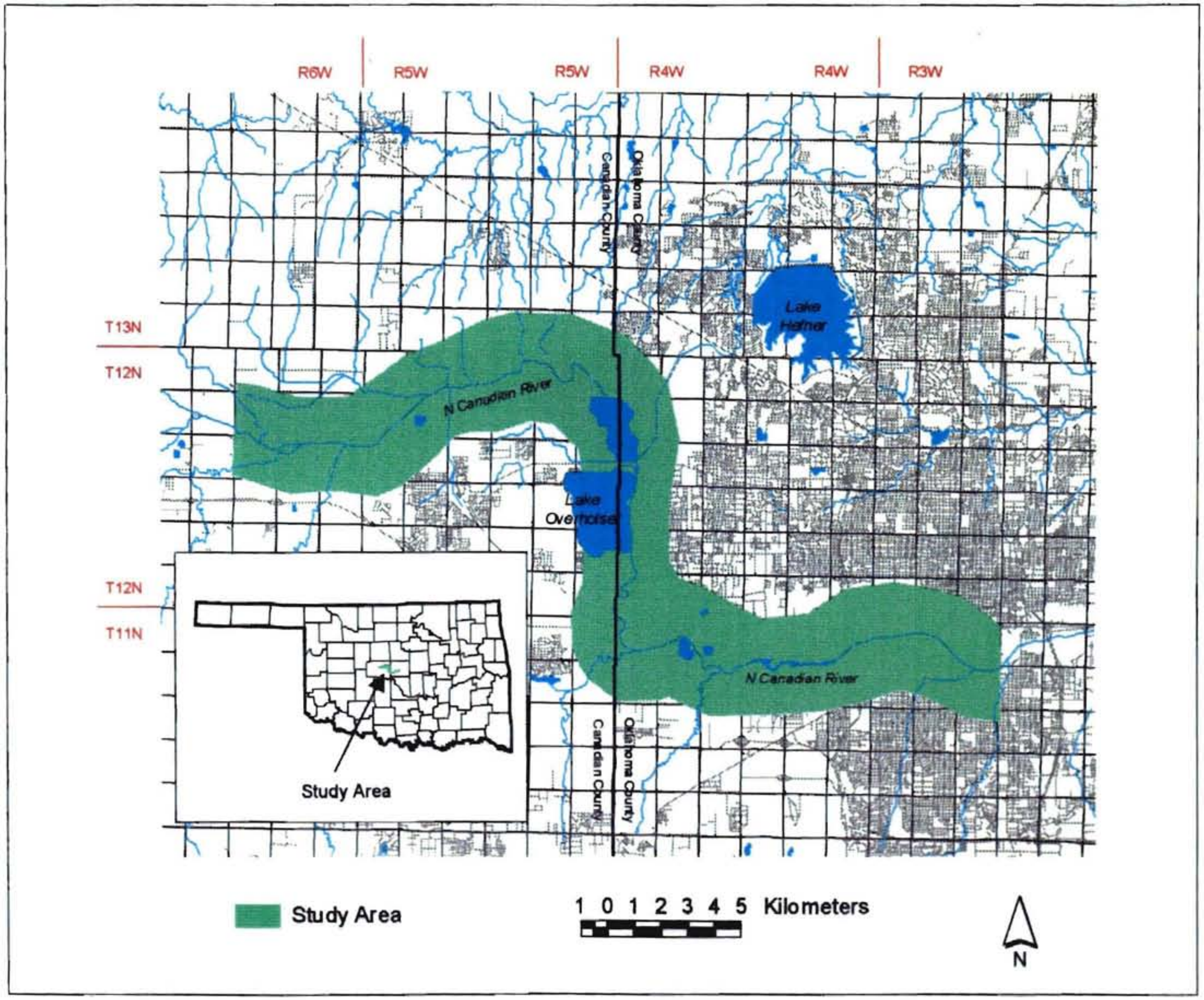

R6W
R5W
R5W
R4W
R4W
R3W
T13N
T12N
T12N
T11N
Canadian County
Oklahoma County
Lake Hefner
N Canadian River
Lake Overholser
N Canadian River
Canadian County
Oklahoma County
Study Area
Study Area
1 0 1 2 3 4 5 Kilometers
N

Figure 2. Land use and land cover map for a portion of the North Canadian River riparian corridor in central Oklahoma derived from the General Land Office Survey of 1872-1873.

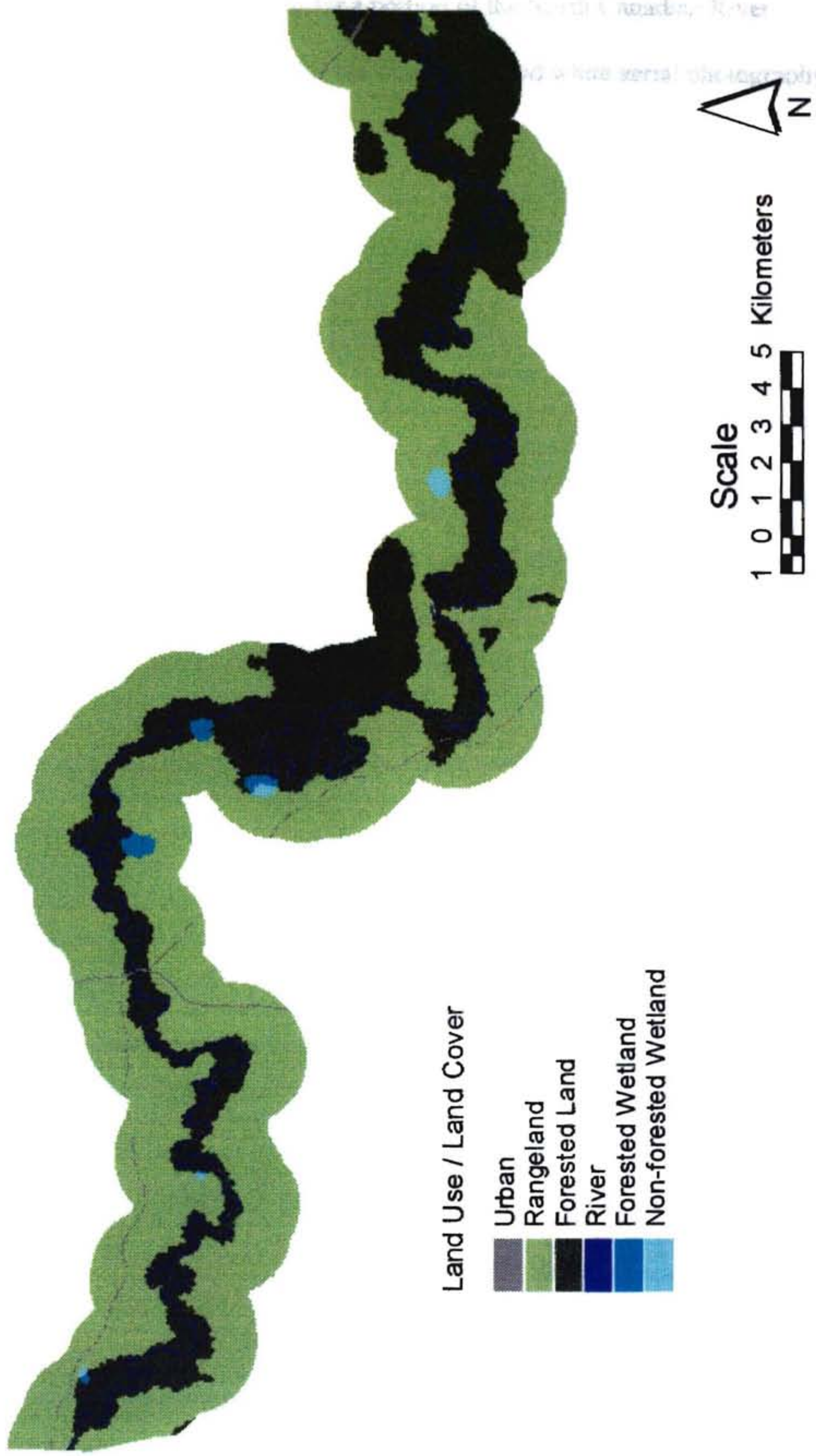

Land Use / Land Cover
Urban
Rangeland
Forested Land
River
Forested Wetland
Non-forested Wetland
Scale
1 0 1 2 3 4 5 Kilometers
N

Figure 3. Land use and land cover map for a portion of the North Canadian River riparian corridor in central Oklahoma derived from black and white aerial photography taken in 1941.

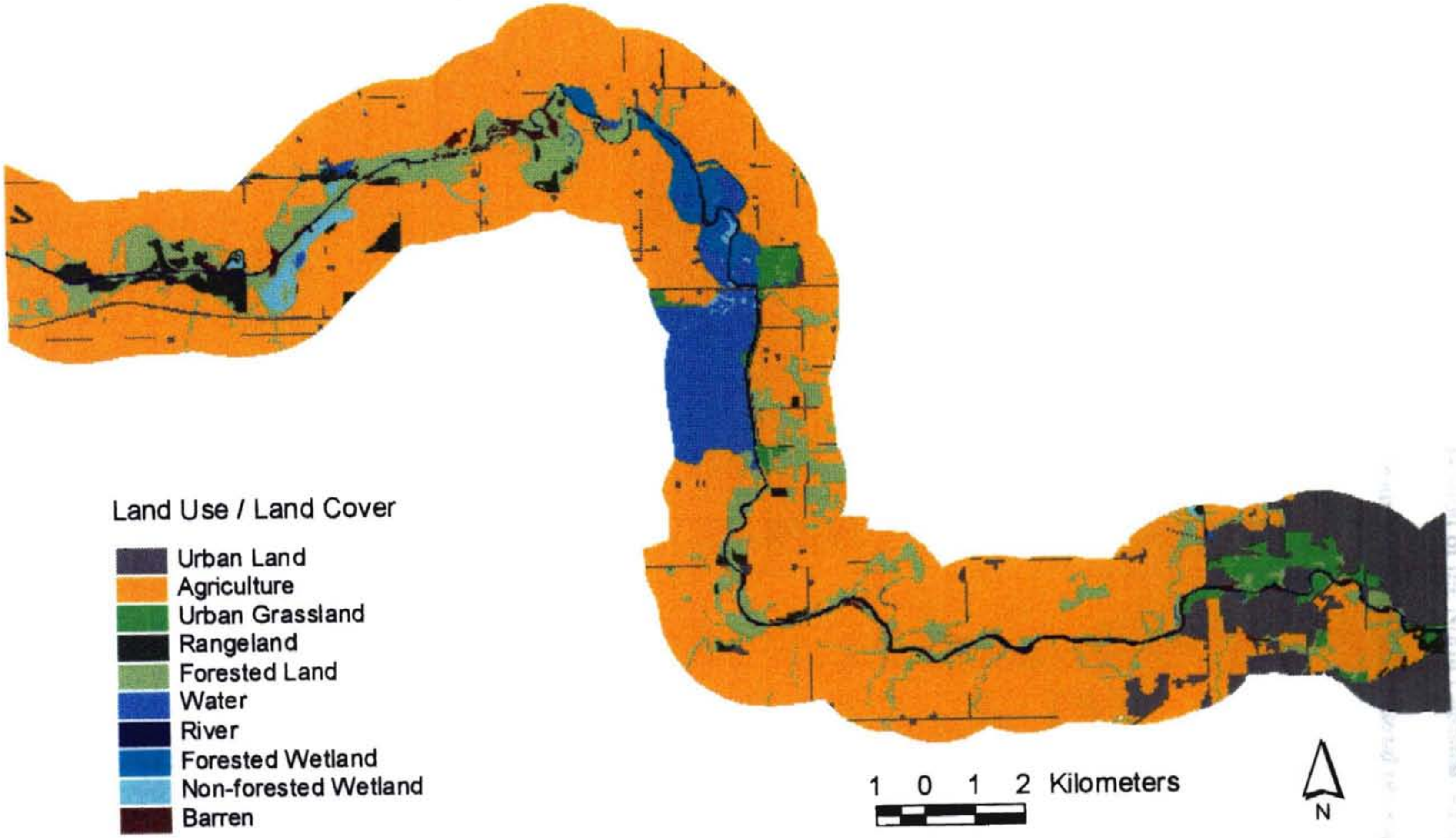

Land Use / Land Cover
Urban Land
Agriculture
Urban Grassland
Rangeland
Forested Land
Water
River
Forested Wetland
Non-forested Wetland
Barren
1 0 1 2 Kilometers
N

Figure 4. Land use and land cover map for a portion of the North Canadian River riparian corridor in central Oklahoma derived from black and white aerial photography taken in 1971.

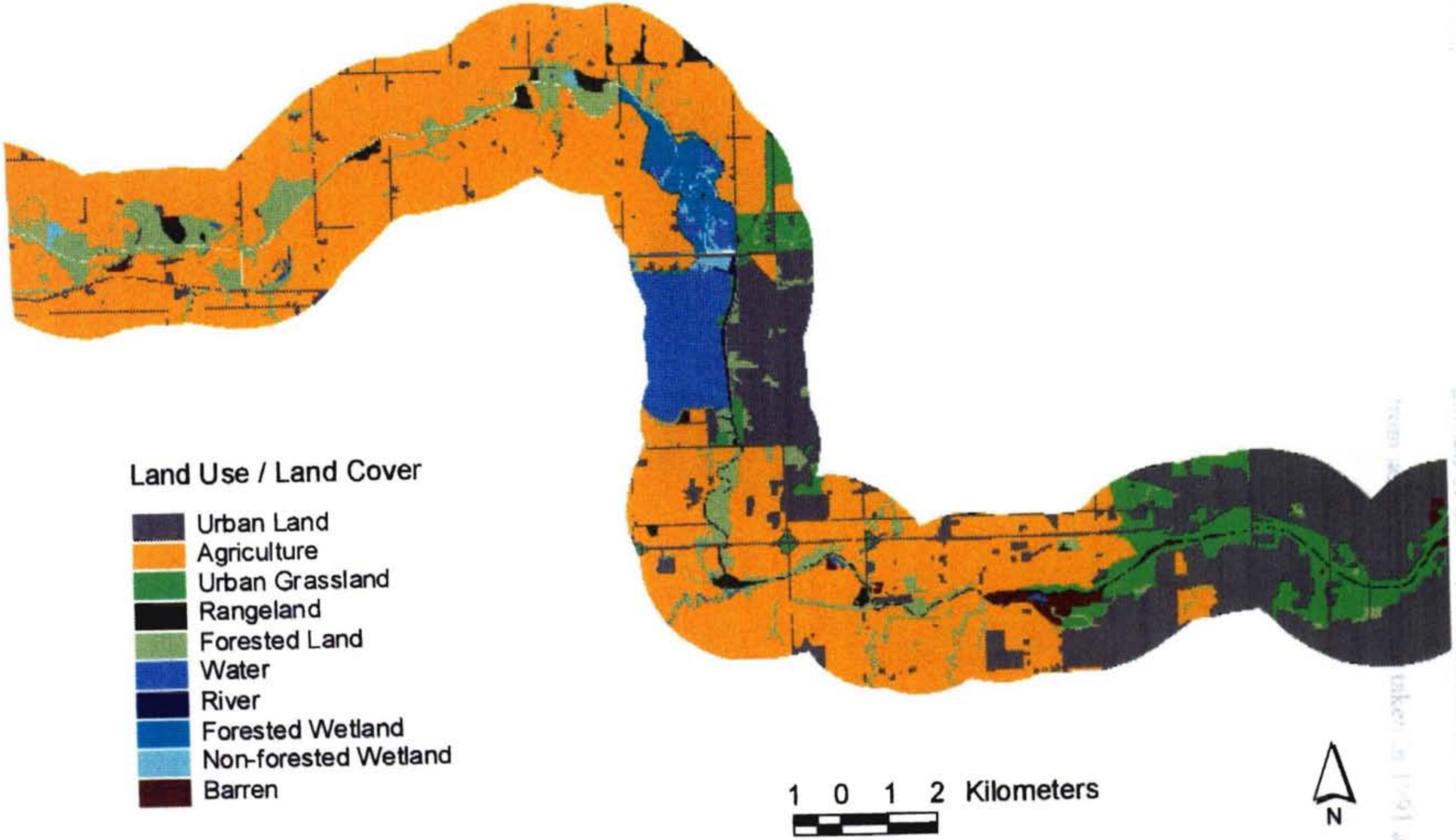
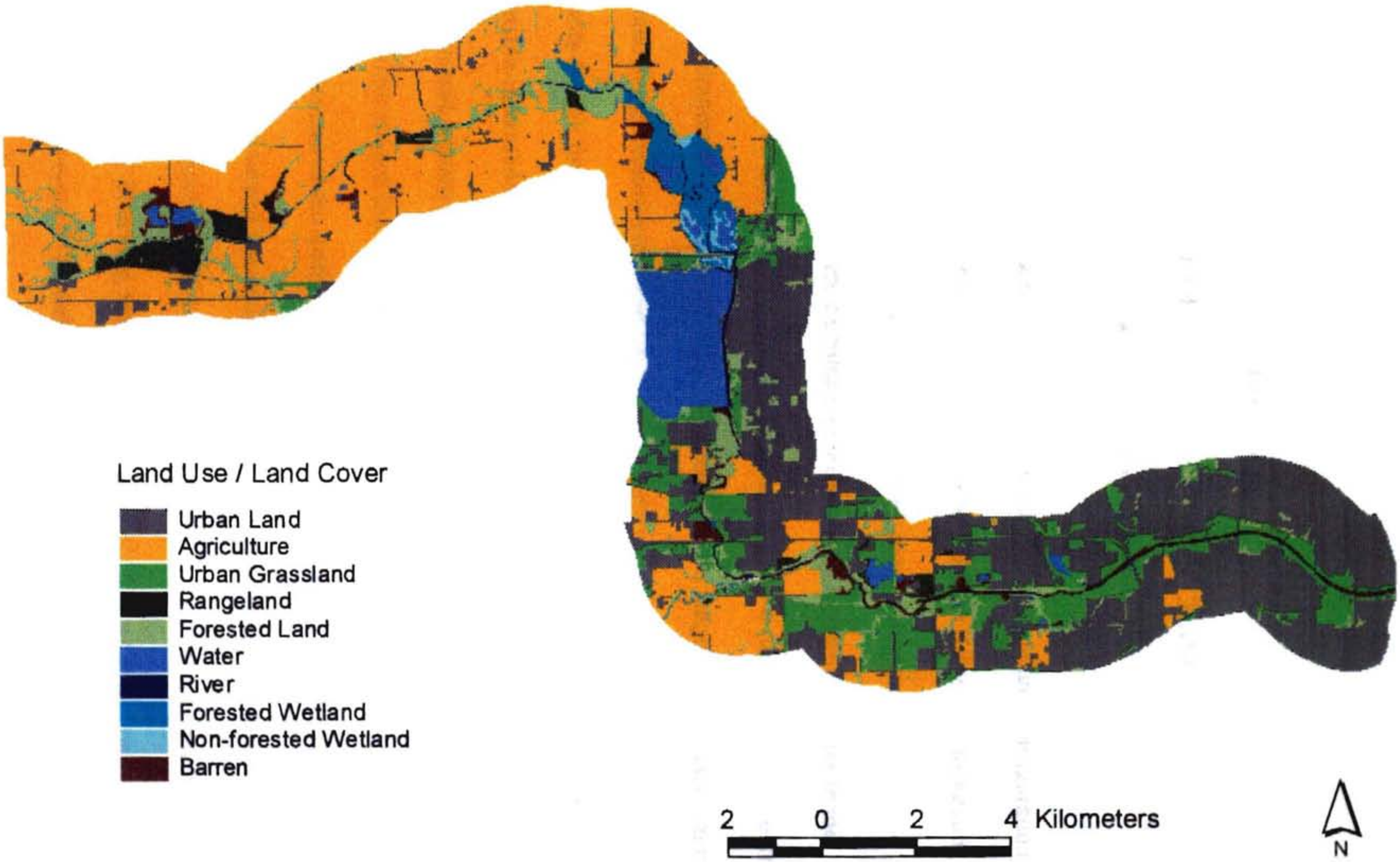

Land Use / Land Cover
Urban Land
Agriculture
Urban Grassland
Rangeland
Forested Land
Water
River
Forested Wetland
Non-forested Wetland
Barren
1 0 1 2 Kilometers
N

Figure 5. Land use and land cover map for a portion of the North Canadian River riparian corridor in central Oklahoma derived from aerial photography taken in 1991 and verified by field observations.


Land Use / Land Cover
Urban Land
Agriculture
Urban Grassland
Rangeland
Forested Land
Water
River
Forested Wetland
Non-forested Wetland
Barren
2 0 2 4 Kilometers
N

CHAPTER III

INFLUENCE OF LAND USE PATTERN CHANGES ON A RIPARIAN CORRIDOR

ABSTRACT.—This study measured the landscape structure and configuration of a central Oklahoma riparian corridor that links an urban wildlife refuge to surrounding rural habitats. Metrics such as patch shape complexity, mean nearest neighbor, interspersion, and contagion were calculated to measure any temporal changes in the landscape from 1872 through 1991. Results of the study show a remarkable change from a landscape dominated by two patch types, forested land and rangeland, to a landscape fragmented by agriculture and urban land uses. Nearly all patch shapes decreased in complexity though time. Mean nearest neighbor distances also decreased through time. Interspersion increased while contagion values decreased for the total landscape. Historic forested corridor widths averaged 500 m. By 1991 the average width of the riparian corridor ranged from 46-154 m. The ability of the riparian corridor to function properly can depend on the spatial distribution of habitat patches in relation to each other. Because structure of the study area has been greatly altered and fragmented through time, it may not be possible to completely restore functionality of the historical corridor communities. However, there are several ecological benefits and reasons for restoring the riparian system. Benefits include water purification, flood control, wildlife habitat, esthetics, and recreation.

INTRODUCTION

Natural resource managers face the unyielding dilemma of conserving biological diversity while at the same time providing for the economic growth, health and well-being of man. Noss (1987) recommended that biologists work with landscape architects and planners to develop land use designs that optimize quality of life for humans and for the natural environment. We must intentionally design, preserve, and protect various networks of natural areas, especially riparian habitats or corridors (Hay, 1987). Ideally, these corridors should link metropolitan areas with rural communities and state and federal conservation areas.

Riparian corridors are ecologically valued for their ability to control water and mineral influxes, reducing sedimentation rates, providing habitat for wildlife movement across landscapes, and recreational and aesthetic values (Forman and Godron, 1986; Adams and Dove, 1989; Lant and Tobin, 1989; Knopf, 1992; Naiman et al., 1993; Vought et al., 1995). Modification of landscape structure greatly affects dynamic riparian systems and can result in loss of ecological benefits. Despite this, alteration continues to riparian vegetation with little attention given to possible consequences (Naiman et al., 1993).

Studies on landscape change in North America have focused on reduction of natural vegetation by agricultural and urban land uses (Allan et al., 1997; Boren, 1997; Wigley and Roberts, 1997). Landscape ecology includes reduction of natural vegetation and other impacts of human activities when addressing ecological processes (Risser et al. 1984). Landscape functions depend on the species, materials, and energy flowing among different landscape elements. These flows are essential in every natural system. Human influences can change or disrupt these flows, having negative results (Forman and Godron, 1986). For example, a highway can bisect a contiguous habitat creating a barrier to species movement. One challenge for landscape ecologists is to identify landscape structures that permit natural landscape functions as well as sustainable human land use (Ahern 1991). By determining relationships between landscape function and landscape structure (land use/land cover) and integrating this information with assessments of heterogeneity and connectivity, land managers and biologist can design overall management plans for sustainable development (Forman and Godron 1986, Ahern 1991).

There is a great deal to be learned about the structure and function of natural communities in both disturbed and undisturbed ecosystems. Urban reserves and corridor networks provide ecological and environmental quality values as well as scientific value (Adams and Dove, 1989). By studying these habitats temporally and spatially, land managers can understand more about the ecological requirements necessary to provide for wildlife habitat, recreation, agriculture, and development (Boren et al., 1997).

This study measures landscape structure and configuration of a central Oklahoma riparian corridor that links an urban wildlife refuge to surrounding rural habitats. Several metrics are calculated to measure temporal changes in the landscape from 1872 to 1941, 1970, and finally to 1991. The purpose of the study is to evaluate the current functional value of the riparian corridor in connecting the urban wildlife habitat to areas outside the urban center. Results of the study are meant to aid future land use planning surrounding the wildlife refuge and as a site-specific reference to be used in collaboration with other such studies developing larger scale or regional conservation or restoration plans.

STUDY AREA

The study area is a riparian corridor along approximately 48 km of the North Canadian River in eastern Canadian County and continuing into western Oklahoma County in central Oklahoma (Fig. 1). The North Canadian River flows across New Mexico, Oklahoma, and Texas with approximately 61.3% of the drainage area situated in Oklahoma. The topography of the river basin in Oklahoma ranges from gently sloping plains in the Panhandle to rough and rolling hills in the far eastern portion of the basin (Ghermazien and Zipser, 1980).

The exact east and west boundaries of the study area remain constant. The west boundary begins at the river intersection with the public land survey system (PLSS) line between sections 9 and 10 of township 12 north, range 6 west based on the 1991 river position. The riverbanks have moved considerably through time. Therefore, the north and south boundaries of the study area are not constant throughout the study. A 1mi (1.609 km) buffer radius establishes the north and south boundaries along both sides of the river. The study area continues down river to the east ending at the river's intersection with the line between sections 9 and 10 of township 11 north, range 3 west.

Lake Overholser, one of six major lakes impounded by the North Canadian River, divides the study area into east and west sections. The western half of the study is upstream from Lake Overholser, and the eastern half is downstream. The two sides belong in separate sub-basins. Annual precipitation in the western sub-basin continuing upstream to the Canton Lake Reservoir is 73 cm. In the eastern sub-basin, the annual precipitation is 95 cm. The climatic zone for the entire study area is moist sub-humid. (Ghermazien and Zipser, 1980). The study area has a local average precipitation of approximately 84 cm annually with a mean annual temperature of 16 °C (Oklahoma Water Resources Board, 1990). Oklahoma City has a population of approximately 445,000 with a projected growth of 5% by the year 2000. The growth trend of the city is moving towards the northwest.

Lake Overholser was constructed in 1916 as Oklahoma City's municipal water source (Gould, 1928; Morris, 1954; Ruth, 1957; Ghermazien and Zipser, 1980). It was originally capable of holding 7 billion gallons (26.5 GL) of water (Gould, 1928). Due to the impoundment, a large area of forested and non-forested wetlands was formed directly upstream from the lake as well as four shallow, small lakes. This area is the Stinchcomb Wildlife Refuge and is the core reserve of interest in this study. The refuge is located 10 miles northwest of downtown Oklahoma City. It follows an approximate 4 mile section of the North Canadian River. The Oklahoma City Water and Waste Water Department owns the area and designated it a wildlife refuge in the 1980's.

The study area was selected based on its rural-urban transition to provide information on how two major land uses have changed the structure of riparian vegetation since 1872. Land use in the western portion of the study area is predominately agriculture and residential development. The eastern half consists of heavy urban areas and industrial portions of Oklahoma City. The land immediately east of and surrounding the wildlife refuge is slated as single family residential or as planned unit developments.

METHODS

Data collection.—U.S. General Land Office (GLO) 1872-1873 survey notes and plat maps from the original land survey of the area were obtained from the Archives

Division of the Oklahoma Department of Libraries in Oklahoma City. Surveyors recorded bearing tree data as they traveled along the public land survey section lines (PLSS). Bearing tree data included common names and diameter breast height (dbh) as well as distance and compass bearings of up to four trees from each section and quarter section corner. Surveyors also recorded bearing tree data from trees located at the intersection of a section line with a bank of the river. For this study, bearing tree data on or within a 1 mi (1.609 km) radius of the North Canadian River between section 9 of township 11 north, range 3 west and section 10 of township 12 north, range 6 west were recorded to estimate tree density. The surveyors also recorded terrain, soil, any unusual features, and major vegetation changes along section lines.

GLO plat maps at a 1:31,680 scale along with survey notes were used to interpret 1872 land use and land cover. U.S. Department of Agriculture black and white aerial photographs at a 1:20,000 scale were obtained from the Oklahoma State University Library to evaluate land use and land cover for 1941 and 1970. Copies of 1991 aerial photographs at a 1:7,920 scale were obtained from the Canadian County and Oklahoma County Natural Resources Conservation Service offices. Land use and land cover designations were based on a modification of the 1976 USGS Land Use and Land Cover Classification (Anderson et al. 1976) (Table 1).

Boundaries around each land use or land cover type were traced from plat maps and aerial photographs onto acetate sheets that were then digitized using a digital scanner. Registration points from topographic quadrangle maps were digitized for rectification. Digitized coverages were imported into LTPlus (Line Trace Plus, version 2.22) graphics software package to be edited and rectified. Edited coverages were next imported as vector files into GRASS (Geographic Resource Analysis Support System) (Shapiro et al., 1992) to patch each year's coverages together forming a complete map of the study area for that year. The completed maps were then labeled and rasterized at 5 m resolution.

To verify photo-interpretation, ground truthing was performed for the 1991 coverage in fall, 1995. Field observations were made following a predetermined route along city and county roads corresponding to PLSS section and quarter section lines. Each delineated polygon was located in the field, and all polygons were compared with photo-interpretation results. Needed changes or changes in land use classification were made accordingly.

Data analysis.—All four digitized coverages were imported into Arc/Info's raster based geoprocessing system GRID module (ESRI, 1994). Using ArcView GIS software (ESRI, 1997) complete coverages for each of the four years were projected with the corresponding PLSS grids. At each intersection of a section line with the bank of the river, average corridor width was measured. All forested patches directly adjacent to the river were measured and considered as part of the corridor. Riparian corridor is defined as the unique forested community surrounding the river that differs from the surrounding matrix of prairie vegetation.

FRAGSTATS, a spatial pattern analysis program for quantifying landscape structure (McGarigal and Marks, 1995), was used for landscape analysis. Temporal changes in landscape structure and configuration were measured using the metrics for patch shape, nearest neighbor, and interspersion. Analyses were conducted for each time period and separately on each half of the study area to provide a comparison of the urban and rural influences.

Two types of shape indices were computed. The first was the mean shape index. Mean shape index measure the average patch shape for a particular patch type and for all patches in the landscape. Patch shape complexity is evaluated based on a standard shape. For raster coverages the standard shape is a simple square. Mean shape index equals 1 when patch shapes are simple squares. The index value increases without limit as the patch shapes become more irregular. The second shape index is the area-weighted mean patch shape index. This index weights patches according to their size. Larger patches are weighted more than smaller patches in the patch shape calculation.

To quantify configuration, FRAGSTATS uses nearest neighbor, interspersion, and contagion metrics. Mean nearest neighbor distance is the average distance to the nearest neighboring patch of the same type. Mean nearest neighbor distance was calculated for each patch type and for the whole landscape. Mean nearest neighbor coefficient of variation was also derived. Based on the percent change in mean nearest neighbor from 1970 to 1991, average distances between like patch types and for the landscape are projected for the year 2012.

Interspersion index evaluates each patch for adjacency with all other patch types. The index measures the extent to which patch types are interspersed. Landscapes with patches equally adjacent to each other result in high values, while landscapes with disproportionate distributions of patch type adjacencies result in low values. The observed level of interspersion is given as a percentage of the maximum possible given the total number of patch types. Interspersion index was calculated for each patch type as well as the landscape.

The final FRAGSTATS configuration metric calculated was contagion. Contagion measures the extent of aggregation and clumping of landscape elements. The index is based on raster cell adjacencies, not patch adjacencies. Contagion therefore, can measure both patch type interspersion as well as patch dispersion. A landscape consisting of large, continuous patches have many internal cells with like adjacencies and therefore a higher contagion than a landscape highly fragmented into many small patches. Contagion index is calculated as a percentage of the maximum number of patch types possible.

RESULTS

Patch shape indices.—Mean patch shape for the west and east sides of the study area decreased 44% and 49% respectively (Table 2). The highest mean patch shape values, or complexity values, measured were for the river in 1872, 22.89 in the west and 20.13 in the east. These values decreased by 77% and 51% to 5.39 and 9.91 respectively by 1991. Urban land also decreased in patch shape complexity by 1991. Urban mean patch shape fell from 8.37 in the west and 10.82 in the east down to 2.88 and 2.85 respectively. The smallest mean patch shape value, 1.22, was for non-forested wetlands in 1872. Non-forested wetlands were only found in the western half of the study area by 1991. By that time, patches of non-forested wetlands increased in complexity by 103%. All patch types that were present prior to settlement, with the exception of wetlands, decreased in patch complexity by 1991. The complexity values calculated for the total landscape and all patch types, excluding river, in 1991 were all less than 3.

Overall, the shape index values did not change much when weights were added to the 1872 landscape patches as compared to the non-weighted patch calculations. However, by adding size-associated weights to the calculations, percent change in mean patch shape values varied considerably from non-weighted index values (Table 2). Total landscape mean patch shape in the east did not decrease over the 119 years as in the non-weighted index. Instead, it increased by 39%. A decrease of less than 2% was calculated for total landscape in the west. Urban land patches in the western half gained in complexity by 18% from 1872 to 1991 as compared to the 66% drop through time with the non-weighted index. By weighting forested wetland patches, complexity value increased from 1.43 in 1872 to 4.57, a 220% increase. Shape complexity of forested wetland patches only increased by 65% when not weighted. Almost all patch shape index values for 1991 were greater in comparison with values determined by the non-weighted index.

Spatial pattern indices.—Mean nearest neighbor distances increased considerably from 1872 to 1941 for rangeland and forested land patches. For rangeland the increase was over 3,376% in the western half of the study area, and forested land in the west had an increase of 464% (Table 3). Rangeland increased over 700% in the eastern half by 1941 (Table 4). Distance between nearest wetland patches decreased by almost 100% through the same time period. Mean nearest neighbor distance for the total western half in 1872 was 1,416 m. This contrasted with the eastern half in 1872, which had a mean nearest neighbor distance of only 92 m. The mean distances by 1941 for west and east total landscapes were 154.6 m and 188.2 m, respectively. Urban land nearest neighbor distance dropped from 812.5 m to 304.2 m, a 63% reduction. Mean nearest neighbor coefficient of variation was relatively low in 1872 for rangeland and forested land in the western half of the study area compared to the eastern half. However, total landscape coefficient of variation for the western side was 215% while the eastern total landscape had a coefficient of variation of 171%.

Continuing through 1991, total landscape, mean nearest neighbor distance for the western half decreased to 106.2 m. The eastern half decreased as well to 70.2 m. Urban land mean nearest neighbor distances steadily reduced through time. Mean distance in 1991 for urban land in the west was 121.6 m and 73.9 m in the east. Urban grasslands and water followed a similar trend. Coefficient of variation for urban mean nearest neighbor distance also decreased through time. Both rangeland and forested lands followed a trend of increasing distances between neighbors through 1971 and then by 1991 having a decrease in distance between like patches. For total landscape, mean nearest neighbor coefficient of variation was higher in 1941 and 1971 but decreased in 1991 along with the average of nearest neighbor distances.

Future projections estimate that the mean nearest neighbor distances for the landscape will continue to decrease (Table 5). The eastern half of the study area might have an average distance between neighboring like patches of only 31.1 meters. The greatest mean distances are estimated for between patches of agriculture land in the east, 210.8 m, and 1513.8 m between forested wetlands in the west. For rangeland and forested land, projected values are near to recorded 1872 distances.

Percent interspersion for both the east and west landscapes increased through time (Table 6). In contrast, the contagion index values decreased through time. Urban patches showed the greatest increase in interspersion through time. For urban patches in the west, interspersion increased from 12% to 61%. Agricultural land remained fairly constant at around 50% interspersion. Interspersion values for rangeland closely followed total landscape values for interspersion. Water cover type patches had the highest interspersion percentages, 87% in the west and 74% in the east. Forested land and barren land patches had the next highest interspersion values.

Average corridor width.—Corridor width dropped dramatically from 1872 to 1941 (Fig. 2). Average corridor width in 1872 for the eastern half of the riparian corridor was 546.4 m. By the 1941 the average width had fallen to only 29.5 m in the east. From 1872 to 1941 in the western half, the drop was slightly less. In 1872 the average width was 436.6 m. By 1941 it was 186.5 m. Average corridor width continued to decrease in the west through 1970 but increased in the east. Both the east and west sides increased from 1970 to 1991. For the western half, the average width in 1991 was 164.1 m, and for the east, the average width rose only slightly to 46.0 m.

DISCUSSION

Temporal changes in landscape indices.—As a patch shape index value approaches a low of 1 the patch shape becomes more like a simple square. Human activities such as agriculture and urbanization result in simple patch shapes such as a square field or city block (McGarigal and Marks, 1995; Boren, 1997; Wigley and Roberts, 1997). Reflecting this, patch shape values in 1991 were lower compared with

1872 values with a greater percentage of human development land use (Farley, 1997). The urban land patches present prior to settlement were narrow transportation trails crossing the landscape. These elongated patches had high patch shape values. By 1991, the more urban patch shape had the expected lower values. However, urban patches in the western half actually had higher shape values in 1991 when calculated using the area-weighted method. The increase might be associated with the larger average patch size for urban patches in 1991. It may also be due to the complexity of patches of roads, railroads, and other more linear features designated as urban in comparison to the more smaller or simpler patches of other land uses such as agricultural fields or ponds.

The river was highly complex in 1872 and therefore had the highest shape values. With impoundments and straightening, the river's shape complexity greatly decreased by 1991. Area-weighted values of the river were higher in 1991 than the not-weighted values for the same time. Again, this could be associated with the long linear nature of a relatively large patch in comparison to small, simpler patch shapes on average. The effects of straightening and channelization of the river can result in cause accelerated channel erosion and reduced species richness, diversity, and relative abundance (Brabander et al., 1985).

The higher shape values of forested patches than rangeland patches suggest that edges of forested land patches are more complex. The area-weighted values support this. Patch complexity decreased through time for both weighted and non-weighted values. Forested wetlands and non-forested wetlands increased in patch shape values using both area-weighted and non-weighted indices. A possible explanation could be a difference in boundary interpretation between the surveyors' plat maps and aerial photograph interpretation.

Patch shape can influence a number of ecological processes such as small mammal migration, woody plant colonization, and animal foraging strategies (Weins et al., 1985; Forman and Godron, 1986; McGarigal and Marks, 1995). Shape relates to flows of energy, materials, or organisms. Simple boundaries between patches experience fewer resource exchanges while convoluted patches with high perimeter-to-area ratios have higher flows of energy, material, or organisms (Forman and Godron, 1986). Therefore in the riparian corridor, flows between patches of rangeland or forested lands and surrounding patches could be diminished while urban patches might have increased effects on energy and material flows with surrounding land uses.

Also affecting landscape flow or function is landscape configuration, the spatial location of patches relative to each other in the landscape. Distance or isolation from other populations of the same or competing species influences dynamics of plant and animal populations (Bennet, 1990; Opdam, 1991; Metzger, 1997). Nearest neighbor indices measure the distance from a patch to the nearest neighboring patch of that same type. Results of the nearest neighbor analysis indicates that land use such as urban land, urban grassland, and water tended to become less isolated through time. By 1941, rangeland and forested land had become greatly fragmented by increasing human development. However, from 1970 to 1991, forested land and rangeland experienced decreases in mean nearest neighbor distances. An increase in the distance between patches of agricultural land may have had some affect on those results.

By observing the coefficient of variation for mean nearest neighbor distances, a few minor trends in patch dispersal can be recognized. Rangeland and forested land were more equally dispersed through the landscape in 1872 in the western half of the study area than in the east. However, the total landscape coefficient of variation was greater for the western side. This suggests that the remaining patches in the west were more irregularly dispersed through the landscape. Urban patches became more evenly dispersed through time. The total landscape had increases in coefficient of variation for mean nearest neighbor distances through 1970 but decreased by 1991. The decrease in coefficient of variation for the total landscape by 1991 also resulted in dispersion similar to that found in 1872.

Following the trends from 1970 to 1991, the projected mean nearest neighbor results for 2012 were low. Total landscape mean nearest neighbor distances were much lower than original values. For rangeland and forested land the projected values were quite close to 1872 values. In the urban portion of the study area, west, average distances between patches of agriculture are greatest. This is possibly due to the abandonment of agricultural land or conversion into urban developments within Oklahoma City.

Percent interspersion is the measurement of how well mixed a patch type is with all other patch types in the landscape as compared to the maximum possible interspersion. If a patch type is well interspersed it will have a high value. Percent interspersion for the study area increased through time. Therefore, any given patch type was more equally distributed among the other patch types in 1991 than in earlier years. Urban patches became more scattered through the landscape from 1872 to 1991. Forested land patches remained well interspersed and rangeland increased its interspersion through time. Based on the contagion results, the study area landscape has changed from having a few large, contiguous patches to a landscape of several small patches well dispersed throughout the landscape.

Corridor width.—The ability of riparian vegetation to function as a corridor depends on the width of the riparian vegetation strip (Forman and Godron, 1986) as several studies have addressed (Schaefer and Brown, 1992; Roth et al., 1996; Vander Haegen and DeGraaf, 1996; Allan et al., 1997). Since the ecological purpose of riparian vegetation is to control water and mineral influxes, reduce sedimentation rates, and provide habitat wildlife movement across landscapes, riparian corridors should be wide enough to accomplish all these objectives (Forman and Godron, 1986). According to Forman and Godron (1986), a stream corridor should encompass the flood plain, both banks, and an area of upland on at least one side. Along the riparian corridor of this study, a band of riparian vegetation that wide existed only prior to settlement (Fig. 3). In 1872 the forested land adjacent to the North Canadian River was on average just below 500 m wide (Fig. 2), and both upland and bottomland tree species were present in the riparian corridor. Historically, the dominant tree species present were cottonwood mixed with willow. Now species such as elm and hackberry are more prevalent (Farley, 1997). Vander Haegen and DeGraaf (1996) suggest riparian buffer strips should be at least 150 m wide to combat the deleterious effects of edge-related parasitism. Other studies have supported narrower buffers, 10-100 m (Allan et al., 1997; Darveau et al., 1997, Garrett and Buck, 1997). Smaller buffers have been supported due to evidence of decreased predation associated with much smaller buffers (Darveau et al., 1997) and because narrower buffers were adequate to assure stream water quality (Garrett and Buck, 1997).

In this study the riparian corridor width dropped dramatically from 1872 to 1941. There is also a great difference in widths between the west and east sides of the study. The eastern side, predominately urban, has experienced a slight increase in corridor width. It was at an average low of less than 30 m in 1941 and rose to 46 m by 1991. The west half's average corridor width fluctuated from 186 m in 1941 to 154 m in 1991. The width difference can be explained by examining the riparian vegetation within the boundaries of the wildlife refuge. The river, which is very convoluted within the refuge, and wetlands surrounding the river increase the actual size of the buffer area. Current corridor widths are far from 1872 dimensions but still fall within the 10-100 m recommendations for some corridor functions.

Viability of urban wildlife reserves and corridors.—Looking at urban reserves as isolated habitats and inferring that local species composition and structure are related to patch characteristics such as shape, amount of edge, and degree of isolation are both applications of the controversial theories of island biogeography and metapopulations. With either theory, habitat patches or islands require outside recruitment or flows of energy, materials, and species. The greater the habitat fragmentation or other human related disturbance, the greater the isolation from like habitats or surrounding rural habitats. Isolation, typically, results in a reduction of species richness (Adams and Dove, 1989; Wigley and Roberts, 1997). Based on the results of this study's landscape analysis, patch edge simplification suggests that flows or population functions might be lessened through or between like habitat patches. Also, the reduction of contagion values through time could reflect the isolation of the reserve from the surrounding rural areas. Nearest neighbor distances for rangeland and forested land patches are approaching 1872 distances. This could improve the chances of patch interactions. However, the theories of island biogeography and metapopulations lack enough empirical evidence to be used without further research when planning for fragmentation mitigation (Simberloff et al., 1992).

Corridors, including riparian corridors, have been used in land management strategies to connect disjunct patches of habitat to enhance or preserve population expansion and genetic mixing (Knopf, 1992). However, there is little evidence to support the use and value of networks of corridors connecting habitat reserves (Adams and Dove, 1989). Possible negative aspects of corridors are transmission of diseases and increased exposure to predators including domestic animals and poachers (Adams and Dove, 1989; Simberloff et al., 1992; Hess, 1994). Corridors should be present in a landscape as long as the habitat was naturally occurring and not artificially constructed. A corridor should not join naturally isolated habitats. Knopf (1992) discussed the introduction of species into new areas via constructed corridors. Such introductions have resulted in increased competition between native species and a loss of biological integrity. The riparian vegetation surrounding the North Canadian River was historically present and thus can be theoretically used as a corridor. The width of the riparian corridor has greatly been reduced; but according to various research findings, the current vegetation width, averaging a little over 100 m is adequate to support several bird and small mammal species (Adams and Dove, 1989; Darveau et al., 1997). Forested patches within the 100 m riparian buffer remain fragmented (Fig. 4), however the distance between patches may be short enough not to be barriers to movement.

Land use surrounding the riparian corridor can have a large impact on stream conditions. Studies by Roth et al. (1996) and Allan et al. (1997) found regional land use was the primary determinant of stream conditions. Local riparian vegetation was the secondary predictor. Small habitats can be influenced by anthropogenic habitats approximately 5 km away (Janzen, 1983). To protect isolated reserve habitats in urban areas, the core area of the habitat must be protected and buffered from surrounding land use, and connected by corridors to outside rural habitats (Adams and Dove, 1989). An area of minimal activity currently borders and serves as a buffer for the Stinchcomb Wildlife Refuge (Fig. 4). Trails provide access to the area for fishing, wildlife observation, and other recreational activities. Immediately surrounding the refuge is an area of low-density housing and agriculture. Both are considered good transitions between the reserve habitat and heavy urban development and they serve as a second buffer layer (Noss, 1987; Adams and Dove, 1989). It is essential that the surrounding land use remain as low impact development to ensure the stability of the buffer.

The riparian corridor connecting the Stinchcomb Wildlife refuge may not function as it did prior to settlement in 1872. The composition and structure have been too greatly altered. The landscape is now a mosaic of land use patches far different from the historical landscape. The large, contiguous patches of rangeland gave way to agriculture and urbanization (Farley, 1997). The riparian corridor has been left much more narrow and fragmented. However, based on similar studies, the corridor can support a variety of wildlife and has several other ecological benefits. Therefore, its continued preservation and restoration can be of value. The viability of Stinchcomb Wildlife Refuge as a core reserve depends on understanding the functions of the connecting riparian corridor. There is still much uncertainty on how biotic communities are influenced by structure and function. Important research needs to be conducted to develop a local biological inventory and to determine the species utilizing or traveling to and from the refuge via the riparian corridor. Especially important is gaining an understanding of what landscape features act as barriers to natural processes (Wigley and Roberts, 1997).

Management implications.—The wildlife refuge itself is currently protected; and therefore, future restoration and protection priority should be given to areas along the riparian corridor. County and city governments should ensure proper zoning to buffer the area with no or low-intensity development. Private conservation groups can promote preservation of the riparian habitats by educating private landowners, companies, and governments about the values of riparian systems. Commercial and industrial operations could involve employees in planting native vegetation and planning other riparian improvements on company land. Finally, monetary incentives to landowners wishing to donate or manage riparian lands as conservation easements could help in obtaining valuable tracts of the riparian corridor.

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Table 1. 1976 USGS Land Use Land Cover Classification (Modified)

Classification	*Description*
Urban or Built-up Land (1)	Residential Commercial and Services Transportation, Communications, and Utilities Industrial and Commercial Complexes
Agricultural Land (2)	Cropland and Pasture Orchards, Groves, Nurseries, and Ornamental Horticulture Areas Confined Feeding Operations Other Agricultural Land
Urban grasslands (3)	Urban Grasslands City Parks (<40% forested)
Rangeland (4)	Herbaceous Rangeland (<25% shrub or brush)
Forested Land (5)	Deciduous Forest Land (<10% cedar)
Water (6)	Rivers (7) Streams and Canals Lakes and Reservoirs
Wetland	Forested Wetlands (8) Non-forested Wetlands (9)
Barren Land (10)	Beaches Sandy Areas other than Beaches Transitional Areas Bare Exposed Rock Strip Mines, Quarries, and Gravel Pits

Table 2. Mean shape index and area-weighted mean shape index for individual patch types and total landscape. Percent change in mean shape index and area-weighted mean shape index from 1872-1991.

Patch Type	Year 1872		Year 1991		% Change	
	West	East	West	East	West	East
Not weighted						
Urban Land	8.37	10.82	2.88	2.85	-65.6	-73.7
Agricultural Land	—	—	1.85	1.54	—	—
Urban grassland	—	—	2.38	2.01	—	—
Rangeland	2.15	2.33	1.92	1.89	-10.7	-18.9
Forested Land	3.67	3.08	2.44	2.20	-33.5	-28.6
Water	—	—	1.69	2.09	—	—
River	22.89	20.13	5.39	9.91	-76.5	-50.8
Forested Wetland	1.52	—	2.51	—	65.1	—
Non-forested Wetland	1.22	1.23	2.47	—	102.5	—
Barren Land	—	—	2.24	2.09	—	—
Total Landscape	4.11	4.21	2.30	2.13	-44.0	-49.4
Area-weighted						
Urban Land	8.32	10.82	9.78	8.26	17.5	-23.7
Agricultural Land	—	—	2.21	1.75	—	—
Urban grassland	—	—	2.87	2.82	—	—
Rangeland	2.45	3.34	1.73	2.03	-29.4	-39.2
Forested Land	4.98	4.34	4.63	2.94	-7.0	-32.3
Water	—	—	1.59	2.17	—	—
River	22.89	20.13	14.62	17.63	-36.1	-12.4
Forested Wetland	1.43	—	4.57	—	219.6	—
Non-forested Wetland	1.27	1.23	3.27	—	157.5	—
Barren Land	—	—	2.86	2.59	—	—
Total Landscape	3.59	4.07	3.53	2.13	-1.7	-47.7

Table 3. Mean nearest neighbor (NN) in meters and mean nearest neighbor percent coefficient of variation for individual patch types and total landscape for the western half of the study area. Percent change in mean nearest neighbor from 1872-1941 and from 1941-1991.

	Year									
	1872		1941		1970		1991			
Patch Type	Mean NN (m)	Coeff. of Variation (%)	Mean NN (m)	Coeff. of Variation (%)	Mean NN (m)	Coeff. of Variation (%)	Mean NN (m)	Coeff. of Variation (%)	%Change 1872-1941	% Change 1941-1991
Urban Land	812.5	136.5	304.2	152.4	201.2	110.3	121.6	103.7	-62.6	-60.0
Agricultural Land	—	—	15.8	117.7	35.18	304.7	19.5	211.3	—	23.4
Urban grassland	—	—	454.8	117.3	159.2	219.9	21.4	259.3	—	-95.3
Rangeland	14.3	52.5	497.1	112.0	504.0	125.5	292.5	145.4	3376.2	-41.2
Forested Land	12.6	31.0	71.0	207.2	83.2	175.4	65.3	170.9	463.5	-8.0
Water	—	—	242.2	317.8	149.7	126.1	167.6	146.6	—	-30.8
Forested Wetland	3563.1	83.0	154.7	173.4	5.0	0	87.0	204.1	-95.7	-43.8
Non-forested Wetland	10250.9	0	134.9	169.2	958.1	290.7	230.4	181.8	-98.7	70.8
Barren Land	—	—	137.2	271.9	1168.6	127.7	272.7	208.9	—	98.8
Total Landscape	1416.0	214.6	154.6	246.4	188.7	382.4	106.2	212.3	-89.1	-31.3

Table 4. Mean nearest neighbor (NN) in meters and mean nearest neighbor percent coefficient of variation for individual patch types and total landscape for the eastern half of the study area. Percent change in mean nearest neighbor from 1872-1941 and from 1941-1991.

	Year									
	1872		1941		1970		1991			
Patch Type	Mean NN (m)	Coeff. of Variation (%)	Mean NN (m)	Coeff. of Variation (%)	Mean NN (m)	Coeff. of Variation (%)	Mean NN (m)	Coeff. of Variation (%)	%Change 1872-1941	% Change 1941-1991
Urban Land	—	—	251.5	163.2	121.3	104.8	73.9	81.9	—	-70.6
Agricultural Land	—	—	24.5	181.6	25.0	161.2	72.6	192.8	—	196.3
Urban grassland	—	—	88.5	150.2	43.5	132.2	36.5	241.6	—	-58.8
Rangeland	93.0	173.1	749.8	160.9	2256.9	47.0	147.4	160.1	706.2	-80.3
Forested Land	91.8	169.6	85.5	157.7	140.6	192.9	85.8	161.0	-6.9	0.4
Water	—	—	1899.4	99.3	491.0	182.6	211.7	148.1	—	-88.9
Forested Wetland	—	—	—	—	—	—	—	—	—	—
Non-forested Wetland	—	—	40.3	0	—	—	—	—	—	—
Barren Land	—	—	213.8	116.9	145.3	240.2	32.6	246.9	—	-84.8
Total Landscape	92.3	170.9	188.2	295.0	158.6	277.3	70.2	205.4	103.9	-62.7

Table 5. Mean nearest neighbor distances in meters projected for the year 2012 based on percent change from 1971 to 1991.

Patch Type	Year					
	1970		1991		2012	
	West	East	West	East	West	East
			------------(m)-----------			
Urban Land	201.2	121.3	121.6	73.9	73.5	45.0
Agricultural Land	35.18	25.0	19.5	72.6	10.8	210.8
Urban grassland	159.2	43.5	21.4	36.5	2.9	30.6
Rangeland	504.0	2256.9	292.5	147.4	169.8	9.6
Forested Land	83.2	140.6	65.3	85.8	51.3	52.4
Water	149.7	491.0	167.6	211.7	187.6	91.3
Forested Wetland	5.0	—	87.0	—	1513.8	—
Non-forested Wetland	958.1	—	230.4	—	55.4	—
Barren Land	1168.6	145.3	272.7	32.6	63.6	7.3
Total Landscape	188.7	158.6	106.2	70.2	59.8	31.1

Table 6. Interspersion percentage for individual patch types and total landscape and landscape contagion for all years.

	Year							
	1872		1941		1970		1991	
Patch Type	West	East	West	East	West	East	West	East
			-----Interspersion (%)-----					
Urban Land	12.1	32.0	38.3	55.4	52.1	50.1	60.8	61.9
Agricultural Land	—	—	58.6	46.2	50.1	57.4	53.5	53.6
Urban grassland	—	—	75.1	59.4	63.1	58.7	43.6	61.5
Rangeland	52.5	43.0	64.4	74.7	69.3	72.3	61.8	72.3
Forested Land	50.4	54.0	74.1	54.7	66.2	69.7	73.8	85.5
Water	—	—	74.4	57.2	83.1	59.4	87.1	74.0
Forested Wetland	73.7	—	65.4	—	69.3	—	79.8	—
Non-forested Wetland	50.9	13.4	78.0	48.4	73.7	—	53.2	—
Barren Land	—	—	57.5	62.8	73.9	80.3	82.0	73.7
Total Landscape	47.3	45.1	69.9	56.9	64.3	66.2	68.9	72.1
Total Landscape Contagion Index (%)	77.0	74.6	70.8	73.2	69.8	67.2	66.1	65.3

Figure 1. Study area along the North Canadian River in Canadian County and Oklahoma County, Oklahoma overlaid with the public land survey section grid.

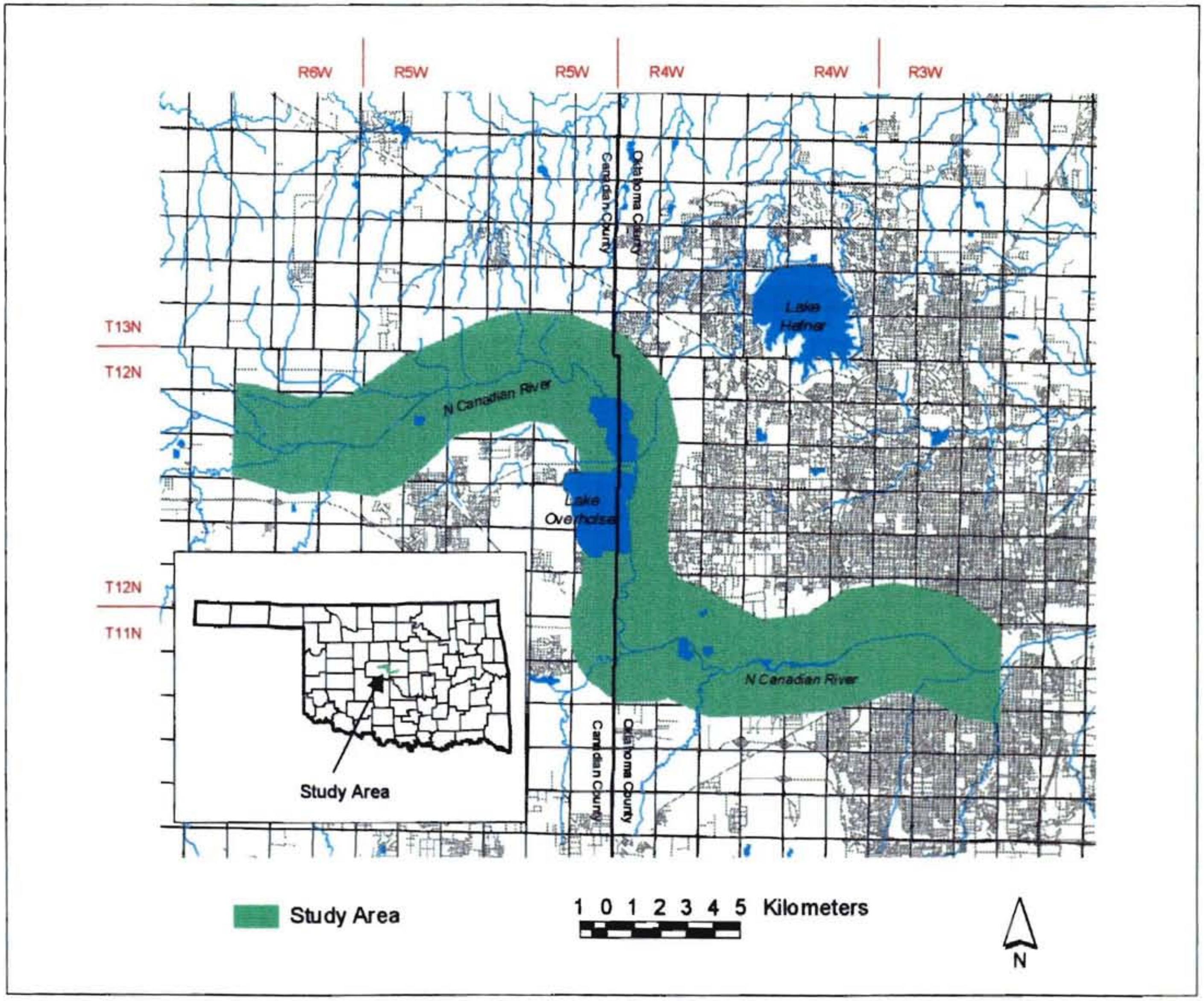

R6W
R5W
R5W
R4W
R4W
R3W
T13N
T12N
T12N
T11N
Canadian County
Oklahoma County
Lake Hefner
N Canadian River
Lake Overholser
N Canadian River
Oklahoma County
Canadian County
Study Area
Study Area
1 0 1 2 3 4 5 Kilometers
N

Figure 2. Average width of forested riparian corridor for the western and eastern sections of the study area from 1872-1991.

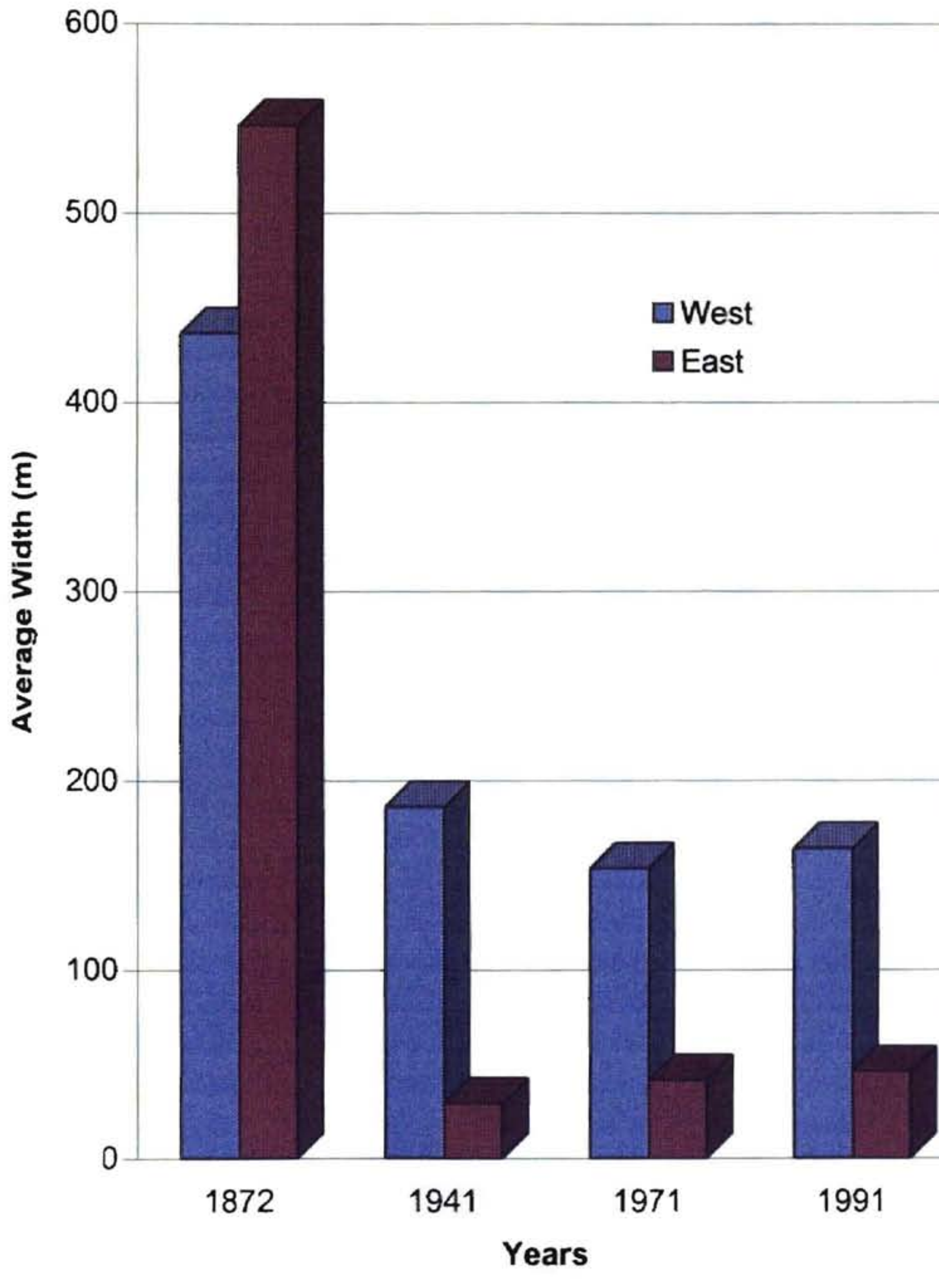

600
500
400
300
200
100
0
Average Width (m)
West
East
1872
1941
1971
1991
Years

Figure 3. Land use and land cover map for the riparian corridor and Stinchcomb Wildlife Refuge. Derived from the General Land Office Survey of 1872-1873.

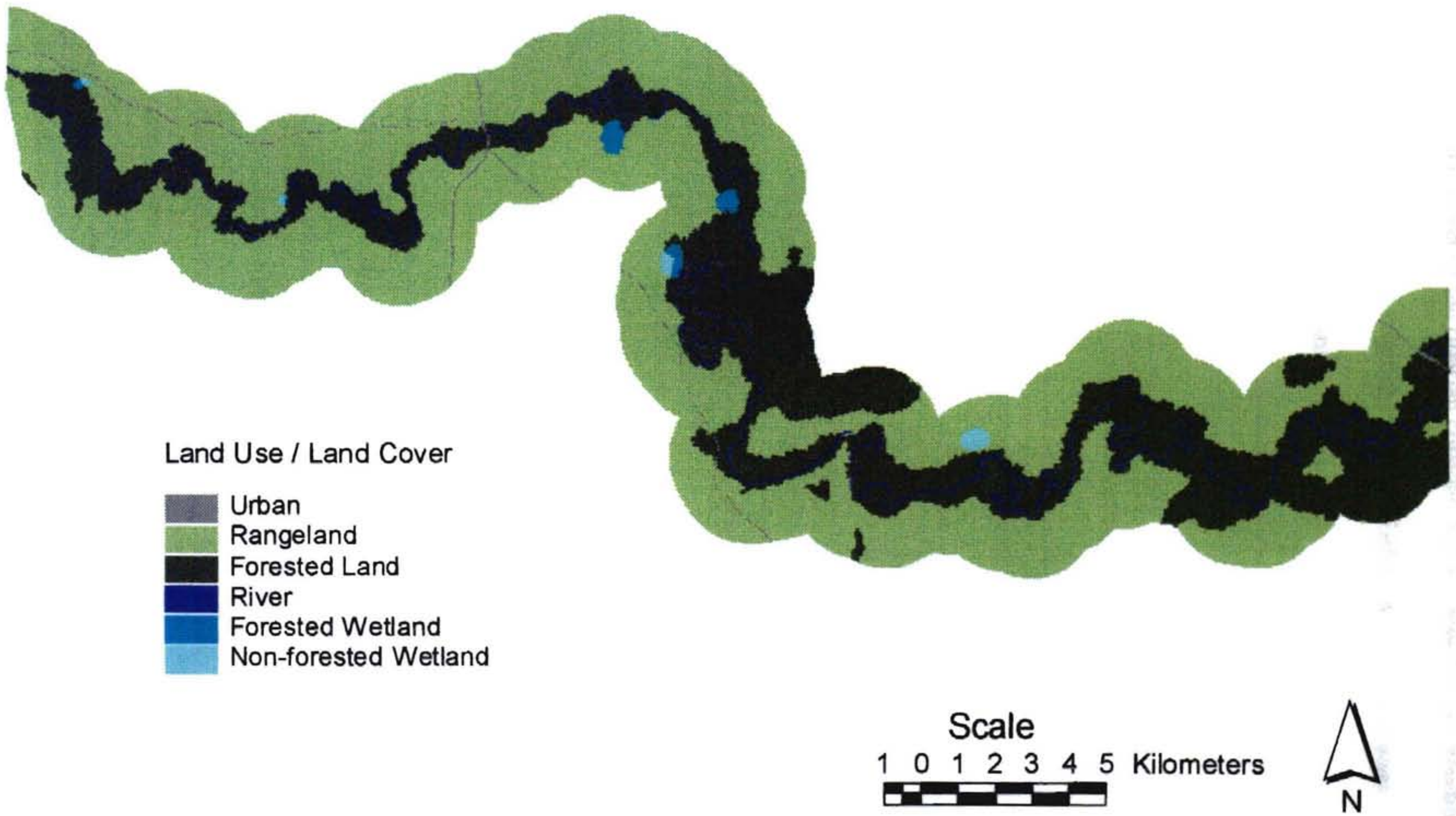
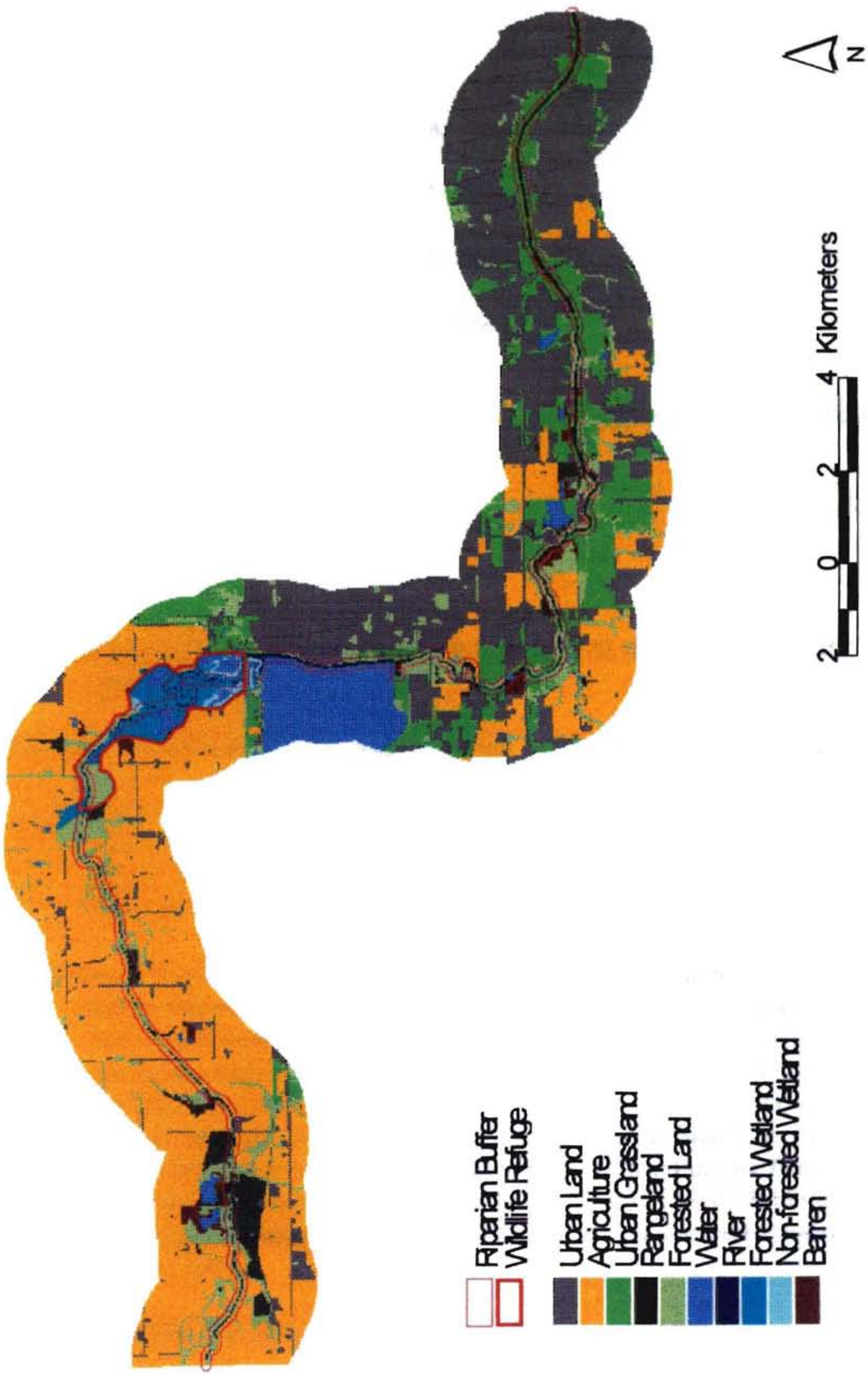

Land Use / Land Cover
Urban
Rangeland
Forested Land
River
Forested Wetland
Non-forested Wetland
Scale
1 0 1 2 3 4 5 Kilometers
N

Figure 4. Land use and land cover of the riparian corridor and the Stinchcomb Wildlife Refuge, 1991, as derived from aerial photography and verified by field observations. Corridor is buffered to 100 m from riverbank.



Riparian Buffer
Wildlife Refuge
Urban Land
Agriculture
Urban Grassland
Rangeland
Forested Land
Water
River
Forested Wetland
Non-forested Wetland
Barren
2 0 2 4 Kilometers
N

VITA

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