Influence of Landscape Structure on Habitat Availability and Use by Sandhill Cranes in Four Geographic Regions of the Platte River, Nebraska

by

David T. Smith

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David T. Smith, M.S.

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Adviser: Dennis E. Jelinski

The 340 kilometer reach of the Platte River from Sutherland to Chapman, Nebraska plays host to approximately 500,000 sandhill cranes (*Grus canadensis*) during the spring migration. Critical crane habitat, specifically wet meadows and roosting sites are essential for crane use of an area, while encroaching forest negatively impacts suitable crane habitats. Coinciding with habitat changes along the Platte River is historical evidence that cranes have shifted their use of the river.

The Platte River floodplain was divided into four geographic regions to compare habitat use by cranes in each area. Since 1957, the North Platte to Lexington and Lexington to Kearney regions have no or limited use by cranes. The Kearney to Chapman region has had an increase in use by cranes, while the Sutherland to North Platte region has had consistent use. A land cover map was constructed for each area through the use of satellite imagery, GIS, and GPS technology, and each region was classified into major land use and land cover categories. Landscape patterns were quantified in terms of patch and class characteristics and proximity. The North Platte to Lexington study region had a small percentage of the landscape in water, and large amounts of contiguous forest patches. The Lexington to Kearney region had adequate water patches for crane use, but forest characteristics resulting in lower quality roosting sites. The Kearney to Chapman region had large amounts of water, the least amount of forest, and significant amounts of foraging

habitat. The Sutherland to North Platte region had the highest percentage of the landscape in foraging habitat, with the largest patch size and the most contiguous arrangement.

This research demonstrates the likely influence of landscape structure on the quality of crane habitat by correlating habitat use patterns by cranes with landscape characteristics. It also provides data that can be used to examine more specific relationships between sandhill cranes and landscape pattern.

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Introduction

The 340 kilometer reach of the Platte River from Sutherland to Chapman, Nebraska (Figure 1) is an important stopover point during the annual spring migration of sandhill cranes (*Grus canadensis*). Some 500,000 individuals, or 80% of the midcontinental crane population, spend approximately six weeks in mid-March and April along the Platte River (Krapu et al. 1984, Krapu et al. 1987), where they prepare for further migration to more northern nesting grounds (Iverson et al. 1987, Norling et al. 1992). During this time cranes gain weight and accumulate over 75% of the lipids essential for migration and reproduction (Krapu et al. 1985) and also establish pair bonds and engage in courtship activities (Krapu et al. 1985). Sandhill cranes require foraging and roosting habitat along the Platte River that enables them to fulfill these requirements (Norling et al. 1992, Folk and Tacha 1990, Iverson et al. 1987, Krapu et al. 1984).

Critical crane habitats, specifically wet meadows and roosting sites, have been altered by the diversion and use of water from the Platte River for irrigation and other purposes (Sidle et al. 1989, Johnson 1994). Agriculture has further threatened essential areas used by cranes, converting wetlands and wet meadows into cropland and pasture (Sidle et al. 1989, Johnson 1994). Coincident with these habitat changes is evidence that cranes have shifted their use in some sections of the Platte River from west to east, abandoning stretches of the river that do not meet their roosting and foraging requirements (Faanes and Levalley 1993). These changes in the Platte River landscape have resulted in no sandhill cranes using the region from North Platte to Lexington, a sharp decrease in the number of cranes using the region from Lexington to Kearney, and an increase in crane densities from Kearney to Chapman. Further, the area from Sutherland to North Platte has had consistent densities of cranes irrespective of the Platte river landscape changes that have occurred since 1957.

Previous research has suggested that the quality and availability of habitats for roosting and foraging have impacted the use of specific regions of the Platte River by sandhill cranes during the spring migration. Cranes historically used a much larger portion of the Platte River, but are now constricted to basically two regions of the river, while the rest of the Platte has limited or no concentrations of cranes during the spring migration. Within these two regions (Sutherland to North Platte vs. Kearney to Chapman), habitat availability and use is different, with cranes in the region from Kearney to Chapman roosting in wide river channels, that are unobstructed by woody vegetation (Krapu et al. 1984, Norling et al. 1992, Sidle et al. 1993). In the region from Sutherland to North Platte, where cranes roost in river channels that are smaller in width and closer to visual obstructions (Folk and Tacha 1990). In the Sutherland to North Platte region, a substantial portion of the crane population also uses wet meadows for roosting habitat (Iverson et al. 1987).

Habitat availability and quality can be examined by quantifying the structure of the landscape in which the habitats occur. Landscape structure is defined as the spatial pattern of habitats (patches) in a landscape and can be quantified by the use of measures such as: patch size, distance to similar habitats, percent composition of the landscape in an individual patch type, and the clumpiness or aggregation of similar habitats throughout the landscape. Correlating spatial pattern with biological data has been used to assess potential nest sites for kestrels (Lyon 1983), for monitoring foraging habitat of wood storks, (Hodgson et al. 1988) and to examine kangaroo habitat (Arnold et al. 1993). These studies show that landscape structure is an important tool for assessing habitat availability and the effect that landscape structure imparts on habitat use by individual species.

Lyon (1983) found that measurements such as distance, contiguity, shape, and area could be correlated with kestrel nesting requirements and used to predict potential nesting habitats. Hodgson et al. (1988) found that use of foraging habitats by wood storks was related to the amount and availability of such habitats within a certain proximity distance of nesting locations, and that changes in the structure of foraging habitats throughout the landscape resulted in a shift in wood stork foraging behavior. Arnold et al. (1993) showed that habitat patch size and distance to other patches influenced the use of an area by kangaroos. These studies required the use of extensive geographic data to adequately quantify the available habitat and the use of geographic tools such as remote sensing and Geographic Information Systems (GIS) to measure the patterns of the landscape.

Landscape level phenomena may impact cranes because they use the entire landscape of the Platte River floodplain for a variety of activities. Cranes have foraging patterns that extend over a large geographic area, and they use a number of habitats within the landscape including, wet meadows, river channels and crop fields (Iverson et al. 1987, Krapu et al. 1985). An understanding of the structure of the Platte River landscape may provide insight into why cranes use or avoid certain areas, and why activities (e.g., roosting, foraging) associated with particular habitats differ in each of the four study areas.

The overall focus of this study was to compare the availability and quality of sandhill crane habitat in four regions of the Platte River by the use of landscape level analysis, and to correlate this data with sandhill crane habitat use to obtain a better understanding of the influence of landscape structure on sandhill cranes during the spring migration. This study elaborates on previous sandhill crane research by examining the relationship between landscape structure and sandhill crane habitat use. The specific objectives included (1) map the dominant land use and land cover in the four geographic regions by the use of remote sensing, GIS and GPS technology and (2) apply landscape metrics to the land use/land cover map to quantify spatial structure. Finally, the possible implications of the landscape structure on sandhill crane habitat use will be examined and discussed.

Methods

Study Area

The research area included the Platte River, and surrounding habitats (approximately 10 km bordering each side of the river) from Sutherland to Chapman, Nebraska (Figure 1). The area was divided into four regions: Sutherland to North Platte, North Platte to Lexington, Lexington to Kearney, and Kearney to Chapman. These divisions are based on the work of Faanes and LaValley (1993), which suggested that the distribution of cranes along the Platte has changed since 1957 (Figure 2). In the four study areas density and habitat use patterns of sandhill cranes differ. Cranes are currently not using the North Platte to Lexington region (Table 1). Landscape patterns derived from the North Platte to Lexington region can be compared to patterns in areas that are used by cranes, namely the Sutherland to North Platte region and the Kearney to Chapman region. The Lexington to Kearney region has intermediate concentrations of cranes (Table 1). The other two areas, Sutherland to North Platte and Kearney to Chapman have consistently high concentrations of cranes each spring (Table 1), but differ in how cranes use available habitat. This relationship between the use of a region by cranes, and the number of cranes concentrated in each of the four regions posed the question of whether the landscape has an influence on the use of a geographic region and associated habitats by cranes.

The study area also encompassed a region 10 km on both sides of the river channel. Iverson et al. (1987) determined that cranes used the area within 5 km of the river for most of their foraging and roosting activities. We extended the area to 10 km to analyze a larger portion of the landscape and determine if the mosaic beyond 5 km had an influence on crane use.

To examine the landscape pattern relating to sandhill crane habitat usage, a large-scale approach was taken. Remote sensing, in the forms of satellite imagery and aerial

Figure 1. North Platte, South Platte, and Platte Rivers, Nebraska, with associated towns that define four floodplain study regions

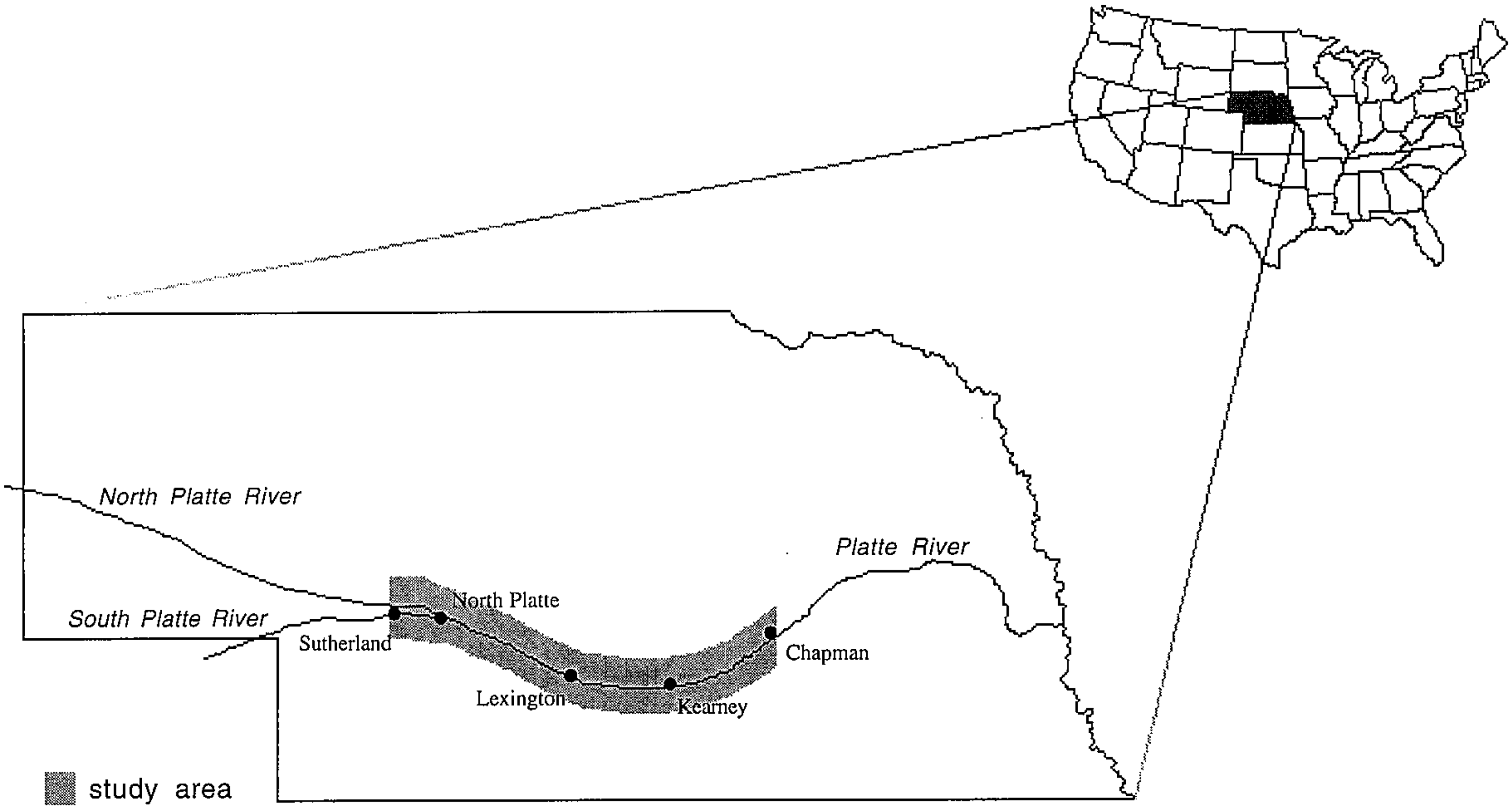
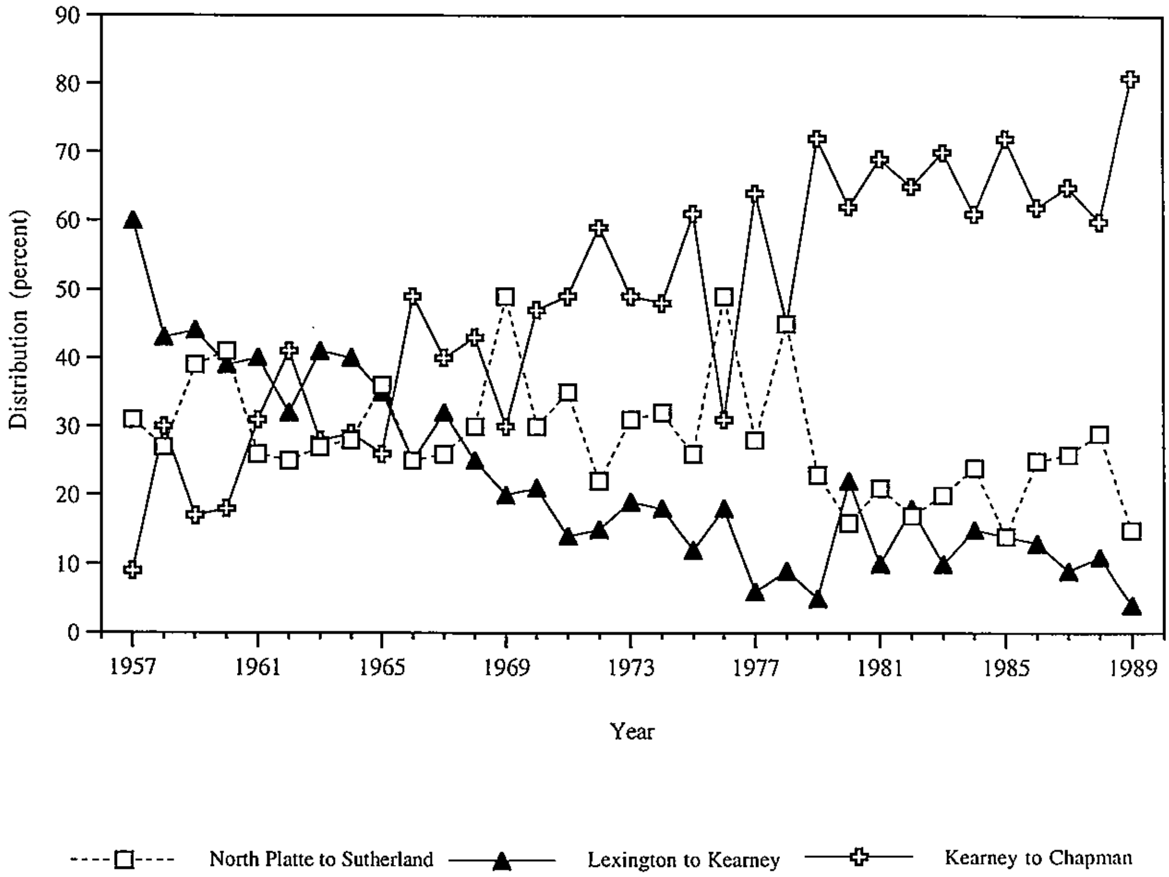


Table 1: Population density of migating sandhill cranes in four geographic study areas of the Platte River, Nebraska. (Faanes and LeValley, 1993)

Study Area	Density (per km of river)
Sutherland to North Platte	482
North Platte to Lexington	0
Lexington to Kearney	143
Kearney to Chapman	560

Figure 2: Changes in distribution of sandhill cranes in Platte River staging areas, 1957-1989.



From Faanes & LeValley, 1993

photography, GIS, and GPS were combined to obtain an accurate representation of the landscapes available to cranes in each of the four study regions.

Satellite Imagery

Because cranes use large sections of the landscape daily, Landsat Thematic Mapper imagery, with 30 m pixel resolution, was adequate in providing the data needed to classify important land cover and land use. Four scenes were used to obtain the study area from Sutherland to Chapman. The scenes were taken on August 19, 1992, July 28, 1993, and July 14, 1991. Although cranes inhabit the Platte River region in the spring, satellite imagery taken in the summer months was used because the spectral characteristics used to distinguish classes of vegetation such as corn and forest are best detected when vegetation is actively growing. NAPP photos taken in 1995 were obtained and used as ancillary data to help in the classification of the Landsat images.

Rectification

Rectification is the process of assigning a known earth coordinate system to the satellite images, and therefore conforming each of the images into a system of coordinates whereby each pixel on the image then has a known coordinate corresponding to an earth location. This step is extremely important because it allows the use of geographic analysis, such as the incorporation of the data into a GIS, which relies on a common geographic coordinate system among databases. Location of features for ground truthing, measurement of patches, and the application of landscape level indices also rely on images in a known coordinate system.

For purposes of rectification, each scene had at least 50 ground control points (GCPs) chosen from United States Geological Survey 7.5' Quadrangle maps, corresponding Universal Transverse Mercator (UTM) coordinates were applied to the scenes using Imagine software (ERDAS, Atlanta, GA. ver. 8.2). A linear regression model was used to determine the final root mean squared error (RMS), and the geometric accuracy of the image. An RMS of no higher than 0.6 pixels was obtained for the four images, using 25-35 final GCPs. Therefore, the 30 m Landsat TM image average pixel position accuracy was no more than 18 m from the true map position. The images were then conformed to UTM coordinates by resampling using a nearest neighbor resampling algorithm.

Classification

A hybrid unsupervised/supervised scheme of classification was used to classifying the images according to major land use/land cover categories (Narumalani et al. 1995) and the important crane habitats. The images were divided into 100 clusters using an unsupervised approach. Spectral reflectance, *a priori* knowledge of specific land use and land cover in the Platte River floodplain, aerial photographs, and field data were then used to group these 100 clusters into the major landscape classes: water, bare/urban, agriculture, grassland, and forest. These classes were chosen because they represent the major sandhill crane habitats and landscape features that directly influence sandhill crane habitat use. Agriculture includes all row crops such as corn and soybeans, that are rapidly growing during the summer months when the imagery was taken. Four of the five land cover classes were focused on for landscape analysis: water, forest, floodplain grassland, and agriculture. All of these classes have a definite use by cranes for foraging and roosting or as an influence on habitat use. The class "bare" does not play a major role in the habitat use behavior of cranes, and was not included in the final results and analysis. The bare/urban class encompasses urban areas and major roads such as Interstate 80, and bare fields in the summer such as winter wheat. Although winter wheat could be considered agriculture, it is generally harvested by the time the satellite images were taken, and occurs in the summer months as bare fields. Furthermore, winter wheat fields are not used by cranes for foraging and therefore do not influence sandhill crane foraging or roosting behavior. Because of these factors, winter wheat and other agriculture that is bare in the summer months, were grouped into the class "bare/urban". Appendix A provides the final classifications for each of the four study areas.

Accuracy Assessment

GIS and GPS data were employed to construct a ground truth data layer that was used in quantifying the level of error of the four final classifications. The use of GPS for ground truthing and accuracy assessment offers extremely high levels of accuracy when differentially corrected.

The final classifications in each image were subsetted into individual classes, and these classes were then converted to arc coverages in Arc/INFO (ESRI, Redlands, CA. ver. 7.0.2). Within each of these separate class coverages, every polygon was assigned a unique number, and polygons smaller than a 5x5 pixel area were eliminated. These numbered polygons represented the total available polygons for each class that could be visited with the GPS. Polygons less than 5x5 pixels were eliminated because of the potential error when navigating to a polygon with the GPS field unit. The Trimble BasicPlus (Sunnyvale, CA.) GPS unit that was used has a +/-100 m. level of accuracy when used for navigating to a certain point, therefore, smaller patches may not be found because they are not at least as large as the 100 meter possible level of accuracy of the unit.

A random number generator was used to select at least 30 polygons from each class in the four separate classified areas to be visited for ground truthing with the GPS. For each GPS coordinate visited, a 3x3 pixel area, or 90x90 meters was measured and the land use/ land cover recorded (Figure 3). Therefore, at each GPS coordinate, a satellite position was taken to determine the location in UTM coordinates, and a 3x3 pixel grid surrounding the satellite derived position was measured and ground truthed.

A Trimble base station was used to provide differential correction for the GPS positions collected. United States Coastal and Geodetic Survey horizontal control markers, were located and used as geodetic control for the base station. The generally accepted level

Figure 3: GPS sample grid used for accuracy assessment,with known geographic coordinate used for navigation as the center of the grid. Each square represents a 30 m. pixel area for ground truth determination.

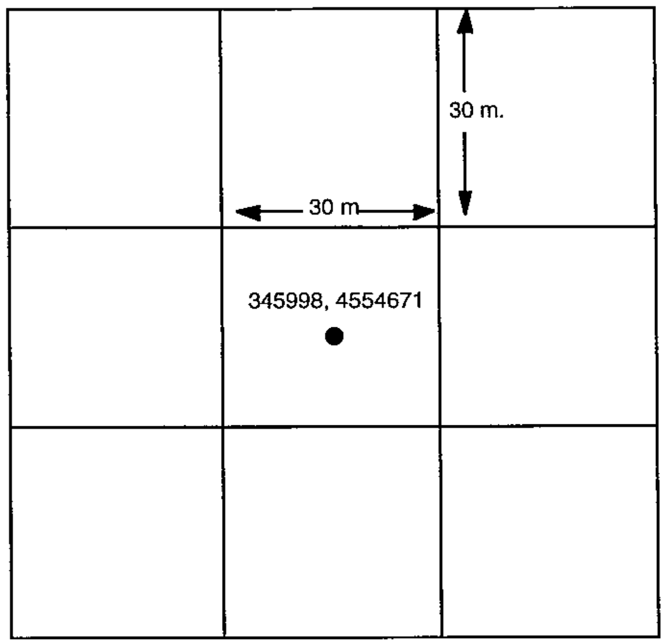


Figure 4: Example of GPS sample grid, with corresponding ground truth data for each land cover sampling pixel.

Bare	Water	Grassland
Bare	Water	Grassland
Bare	Grassland	Grassland

of accuracy for corrected GPS positions is 2-5 feet. Field tests, where GPS positions were taken and corrected in the field to determine the level of accuracy obtainable with the use of the base station, were consistently less than 2 m in accuracy.

At each location, land cover values for each 30m area in the sample grid were determined and recorded for comparison with classified data (Figure 4) to be used for accuracy assessment. Each sample grid was constructed in Arc/INFO and the corresponding ground truth added to each cell.

Sample grids were then overlaid on the classified data, and comparisons made per cell between the reference data (ground truth) and the classified data. Accuracies were 83% for the Sutherland to North Platte classification (Table 2), 86 % for the North Platte to Lexington classification (Table 3), 87 % for the Lexington to Kearney classification (Table 4), and 86 % for the Kearney to Chapman classification (Table 5).

Floodplain Delineation

A distinction was made between upland grassland and floodplain grassland. Grasslands in the floodplain, which included wetlands and wet meadows, are essential to cranes (Iverson et al. 1987, Sparling and Krapu 1994, Krapu et al. 1984), and therefore needed to be distinguished from other grassland types not used as extensively by cranes. To accomplish this, the floodplain was separated from the rest of the image in all four scenes using Arc/INFO software. USGS 7.5 minute Quadrangle maps were used to digitize the 25-30 foot contour above the river channel, which was considered an accurate representation of the Platte River floodplain (P. Currier, pers. comm.). This floodplain layer was then overlaid on the Landsat scenes, and the floodplain delineated on the images using on-screen digitizing. The grasslands in this area were then reclassified into floodplain grassland for further analysis.

Table 2. Error matrix for Sutherland to North Platte classification.

Reference Data

Classified Data	Water	Forest	Grassland	Bare	Agriculture	Row Total	Correct (%)
Water	15	0	1	0	0	16	94
Forest	0	50	10	1	0	61	82
Grassland	4	12	170	18	12	216	79
Bare	3	2	3	85	0	93	91
Agriculture	0	0	8	0	29	37	78
Column Total	22	64	192	104	41	349/428	83

Table 3. Error matrix for North Platte to Lexington classification.

Reference Data

Classified Data	Water	Forest	Grassland	Bare	Agriculture	Row Total	Correct (%)
Water	52	4	1	2	1	60	87
Forest	1	69	4	4	0	78	88
Grassland	1	7	156	10	13	187	83
Bare	2	2	12	130	3	149	87
Agriculture	1	0	5	3	77	86	90
Column Total	57	82	178	149	94	484/560	86

Table 4. Error matrix for Lexington to Kearney classification.

Reference Data

Classified Data	Water	Forest	Grassland	Bare	Agriculture	Row Total	Correct (%)
Water	49	2	0	1	0	52	96
Forest	3	115	5	3	0	126	91
Grassland	2	4	95	2	11	114	83
Bare	1	1	2	71	1	76	93
Agriculture	4	14	6	2	100	126	79
Column Total	59	136	108	79	112	430/495	87

Table 5. Error matrix for Kearney to Chapman classification.

Reference Data

Classified Data	Water	Forest	Grassland	Bare	Agriculture	Row Total	Correct (%)
Water	11	1	1	0	0	13	85
Forest	1	65	2	1	0	69	94
Grassland	3	7	177	14	6	227	78
Bare	0	2	4	106	3	115	92
Agriculture	0	4	10	3	154	171	90
Column Total	15	79	194	124	163	513/595	86

Image Smoothing

A neighborhood analysis was performed on the classified images to remove the "salt and pepper" effects of single pixels. Using Imagine software, a 3x3 window using a majority pixel rule was applied to each image to remove single pixels and smooth the images. Cranes do not use river channels that are less than 48 m in width in any of the regions of the Platte River (Krapu et al. 1984, Folk and Tacha 1990, Norling et al. 1992), therefore the removal of single water pixels only eliminate water that would not be utilized by cranes for roosting. Cranes also prefer grasslands that are 0.2-10 ha in size for roosting (Iverson et al. 1987), an area larger than the 30x30 m area of single floodplain grassland pixels. Single grassland pixels then represent areas that are not used by cranes for foraging or roosting habitat, and were removed.

Distance Buffer Construction

A series of buffers were constructed for each of the four study regions at specified distances from the river channel. Each morning, cranes leave river channel and wet meadow roosting sites to forage for corn and macroinvertebrates in patches throughout the landscape. These roosting sites serve as a base for the cranes, to which they continually return each day after foraging. The distance of suitable foraging habitats from roosting sites along the Platte river may impact the use of an area by cranes (Iverson et al. 1987, Sidle et al. 1993). Further, patches that negatively influence crane usage, such as forest, may be influential at certain distances from roosting sites. Distance buffers of 1.5, 3.0, 4.5 km, and distances greater than 4.5 km from the Platte River channel were applied to each of the classified images in the study regions and each of these areas divided into separate coverages. We realize the use of a certain static distance for the total study area (10 km) and each buffer distance applies artificial boundaries to the images that may influence some index values of patches on the borders of the buffer zones and study area. However, to examine the landscape structure at a series of distances from the river channel these boundaries were necessary, and constructed based on the biology and habitat behavior of cranes. The landscape pattern in each of these distance buffers was examined and compared with other buffers of the same distance in the four study areas. This analysis was correlated with crane habitat use data and used to further examine the question of the impact that landscape structure imparts on crane habitat usage.

Landscape Measurement and Analysis

Landscape indices have been used extensively to examine and quantify spatial structure in a wide variety of applications, including land use change (Turner 1988, Iverson 1988), ecological mechanisms (Weins et al. 1993), forestry (Rex and Malanson 1990, Li and Reynolds 1993, Mladenoff et al. 1993, Vogelman 1995), and species-landscape interactions (Johns 1993, Arnold et al. 1993, McGarigal and McComb 1995).

FRAGSTATS (McGarigal and Marks 1995) was used to calculate the area and spatial configuration for each of the four classified study areas. FRAGSTATS has the capability of measuring a number landscape patterns over large geographic areas and in a variety of different formats. Both landscape and class level indices were applied to all four study areas, and each of the buffer distance subsets for the four study regions. Six measurements were used to examine the structure of each of these landscapes: total floodplain area, total class area, number of patches, mean patch size, percent of landscape, and mean proximity.

Indices of total landscape area, total class area, number of patches, mean patch size, and percent of landscape provide base measures for landscape pattern of the four study areas, and contain direct information on the pattern of the landscape (Hulshoff 1995). Total landscape area equals the entire landscape area measured in hectares, and is used for calculating other measurements such as class percent of landscape.

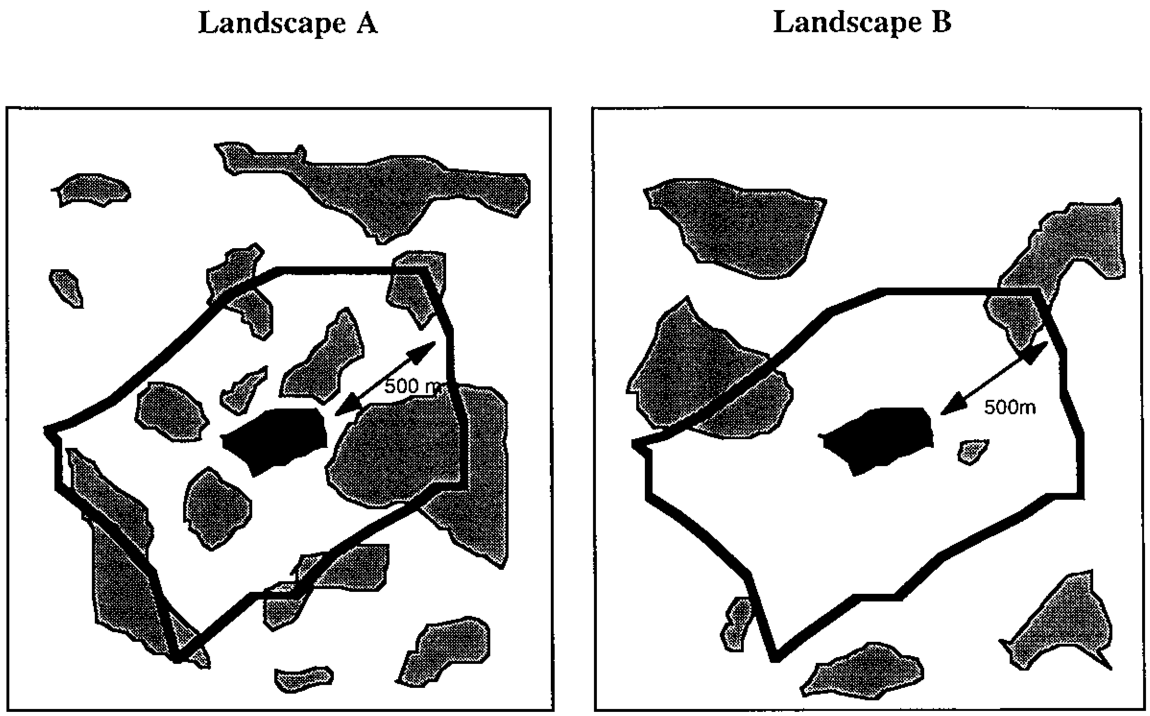
Total class area is the sum of all patches of the same class type expressed in hectares. This measurement has been used in numerous landscape analysis projects to quantify the area of a landscape consisting of a certain patch (Turner et al. 1987, Iverson 1988). Number of patches per class has been used to examine spatial structure in landscapes (Iverson 1987, Mladenoff et al. 1993, Hulshoff 1995) and as a component of other landscape indices that are used to quantify pattern (Romme and Knight 1982, Iverson 1987, McGarigal and McComb 1995). Number of patches may be an important influence on crane habitat use patterns, especially for foraging. Cranes are reliant on the availability of macroinvertebrates (Davis and Vohs 1993), thus a large number of grasslands which provide that essential food source could make a landscape more desirable to cranes.

Mean patch size has been used in many applications to examine the effect of landscape structure on species processes, and is calculated by dividing the total class area by the total number of patches per class. Species movement between patches (Arnold et al. 1993) and species use of a patch (Johns 1993, Arnold et al. 1993, Herkert 1995) have been examined using patch size. Mean patch size has also been used to quantify general spatial structure of landscapes (Turner 1987, Hulshoff 1995, Mladenoff et al. 1995). Class percent of landscape is the sum of all areas of a corresponding patch type divided by the total landscape area converted into hectares. Class percent of landscape has been used to quantify landscape pattern (Romme and Knight 1982, Turner 1987, O'Neill et al. 1988) and as a component of other landscape indices such as dominance (Iverson 1987, Turner 1987, O'Neill et al. 1988, Mladenoff et al. 1993). This index is important for this research because of the different total areas of the four study regions. Regions that have a larger total landscape area may also have more total area per class simply because of geographic size and extent of the region. Therefore, the extent of landscape dominance exhibited by each class can not be determined solely by using total class area. The dominance of a class in a landscape can be inferred from the percentage of the landscape because it provides a common comparison measurement that is not as easily gathered by comparing total class area.

Proximity incorporates the use of nearest neighbor values and patch area to quantify the isolation and fragmentation of patches within a specified focal distance. A proximity index was developed by Gustafson and Parker (1992) to distinguish isolated patches from those that are part of a complex of patches. The index uses a specific measurement distance around each patch with which to focus the search for like patches in the landscape. Within that focal distance, the distance to all similar patches is calculated along with the area of each of the patches that occur inside the focal distance. As the area of the patches increase, thus filling more of the focal distance surrounding the focal patch, and the nearest neighbor distance of the patches decreases, the region around the patch examined becomes less fragmented, filled with larger and closer patches of the same type. As the areas of similar patches in the focal distance decrease, and the nearest neighbor values of patches increases, there are fewer patches at a larger distance surrounding the focal patch, making it more isolated or fragmented.

Figure 5 demonstrates a proximity analysis of 500 m placed around a patch in two different landscapes. In Landscape A, the black analysis patch, would have a higher proximity index than the analysis patch in Landscape B. Patches in Landscape A have smaller nearest neighbor distances to the analysis patch, along with more of the 500 meter focal area filled with same type patches, resulting in a higher proximity value for the analysis patch than in Landscape B, where there is less area of same patch type and greater nearest neighbor distances. The class represented by the patches in Landscape A is more clumped into a complex of patches and patches are less isolated than those in Landscape B. Similar patches that are outside of the proximity distance are not factored into the calculation. The index is an absolute measurement and can be used to compare any two or more landscapes provided the proximity distance used is constant for all landscapes (Gustafson and Parker 1992). Although the proximity index is used to examine isolation in the landscape, it is slightly different than the nearest neighbor measurement. Proximity

Figure 5. Example landscapes with proximity analysis of 500 m for each center patch. Landscape A has a higher proximity index than Landscape B due to smaller nearest neighbor distances between patches and class patch area that fills more of the focal distance.



calculates the degree of isolation and fragmentation of a patch in a neighborhood by determining the amount of like patches in the neighborhood and the distance to the patch in question. For example, a radius of 500 m may be used as the distance around a wetland in which to find similar wetland habitats. The index value of wetlands calculated would provide a measure that can be compared to proximity values in other areas to quantify how isolated wetland habitats are in other landscapes. The same process can be applied to all other crane habitat areas to obtain a comprehensive understanding of the influence that isolation has on crane habitat use. A high proximity value would be indicative of a landscape in which habitats are less isolated from one another, and thus less fragmented.

The focal distance used for this proximity analysis was 500 m. The 500 m measure is similar to the focal distance used by Gustafson and Parker (1992) to develop the proximity index, and given the mobility of cranes, 500 m is not a prohibitively large distance for them to travel in foraging activities. At distances > 500 m, the landscape may become too similar in structure, with no pattern or difference between study areas.

These landscape indices provided the means to quantify the landscape pattern of the four study regions, and enable the landscape structure of the four regions to be compared, based on the measurements and output generated by the application of these indices. Crane habitat use patterns evident in each of the four study regions were then be correlated with the landscape structure data and conclusions drawn on the influence of pattern on the quality and use of habitats by cranes in different geographic regions during the spring migration.

Results

Total Landscape Area - The Kearney to Chapman region had the highest total floodplain area with 147,403 ha, the North Platte to Lexington area had 82,885 ha, and the Lexington to Kearney area 72,951 ha of floodplain landscape. The Sutherland to North

Platte area was the smallest of the four regions with 36,393 ha of total floodplain area. The Kearney to Chapman region was the only area of the four that extended to the 10 km study area boundary.

Landscape Characteristics

Total class area, class percentage of landscape, number of patches and mean patch size provide base landscape measurements and contain direct information about the structure of the landscapes in each of the floodplain study areas.

Water class- In all four study regions the Platte River was totally contained within the 1.5 km buffer category. Water in the other buffer distances (3.0 km, 4.5 km, and 4.5+ km) occurred as water impoundments throughout the landscape such as farm ponds, irrigation pits and small lakes which are not used by cranes as roost sites. Therefore, only water patterns at the 1.5 km distance were used in the results. Due to the spatial resolution of Landsat TM imagery, river channels less than 30 m in width may not be detected by the sensor, leading to a possible underrepresentation of total water area. Furthermore, single classified water pixels were removed by the application of the smoothing algorithm, thus eliminating some of the water class in each study region. Because cranes prefer channels with a minimum width >100 m in the Kearney to Chapman region (Krapu et al. 1984, Norling et al. 1992) and >48 m in the Sutherland to North Platte region (Folk and Tacha 1990), river channels <48 m in width would be used less by cranes in all study areas. Therefore, the results coincided well with detecting the usable river channel roosting sites in the four scenes, and eliminate patches of water that do not meet the minimum roosting requirements for cranes.

The Kearney to Chapman region had the highest values for all six of the water indices of the four study regions (Table 6). The water class in the region from Lexington to Kearney had values similar to the Kearney to Chapman region for percent of landscape, 6.3 % and patch size, 4.1 ha, but differed in the other index values. The Sutherland to

Table 6. Landscape measurements for water class at the 1.5 km distance.

Study Region	Class Area (ha)	Mean Patch Size (ha)	% of Landscape	# of Patches	Proximity Index
Sutherland - North Platte	601	2.9	3.0	209	42.4
North Platte - Lexington	1375	3.4	4.0	399	148.6
Lexington - Kearney	1280	4.1	6.3	311	118.8
Kearney - Chapman	2840	4.7	7.2	608	297.1

Table 7. Landscape measurements for forest class at the 1.5 km distance.

Study Region	Class Area (ha)	Mean Patch Size (ha)	% of Landscape	# of Patches	Proximity Index
Sutherland - North Platte	3027	15.3	15.3	198	1633.1
North Platte - Lexington	8289	26.8	24.1	309	7832.8
Lexington - Kearney	6783	48.4	33.5	141	11447.7
Kearney - Chapman	5072	6.9	12.9	737	526.9

North Platte region had the smallest index values measured for the water class of any of the four study regions. The Kearney to Chapman region had the largest amount of potential river roosting habitat of the four regions, while the Sutherland to North Platte region had the least amount of river roosting habitat available.

Forest class- The majority of forest in the Platte river landscape is present along the river channel due to the encroachment and growth of woody vegetation (Sidle et al. 1989, Johnson 1995). The North Platte to Lexington region, which is not used by cranes during the spring migration, was the only study area that has forest outside of the 1.5 km buffer distance (Appendix B, Tables 5-8).

All four study regions had forest present in the 1.5 km buffer, while forest in the North Platte to Lexington and Lexington to Kearney regions, both of which have minimal or no use by cranes, was the most extensive with more area, larger patches, and comprising a larger percentage of the landscape (Table 7). Areas that are used extensively by cranes, Sutherland to North Platte and Kearney to Chapman, had forests with smaller patch size, less area in forest, and represent a smaller percentage of the landscape, than either the North Platte to Lexington or Lexington to Kearney regions (Table 7).

Floodplain grassland class- In the 1.5 km buffer zone, the Sutherland to North Platte region had the greatest percentage of the landscape in floodplain grassland (50.0%; Table 8), and the largest mean patch size of the four regions (21.2 ha; Table 9). The Kearney to Chapman region had the most geographic area in floodplain grassland (14755.9 ha; Table 8). The North Platte to Lexington region had relatively high values for floodplain grassland in total area and percent of the landscape (Table 8), comparable to the Kearney to Chapman region. In all categories, the Lexington to Kearney region had the least amount of floodplain grassland. At the 1.5 km distance, the North Platte to Lexington region had the most grassland patches (1497; Table 9), and the Sutherland to North Platte region had the smallest number of patches of the four study regions, with 469 (Table 9).

Table 8. Total class area (ha) and percent of landscape for floodplain grassland class at each buffer distance from the river channel.

Total Class Area (percent of landscape) - Floodplain Grassland

Study Region	1.5 km	3.0 km	4.5 km	4.5+km	Floodplain Total
Sutherland-North Platte	9925.2(50.0)	7725.0(51.9)	886.2(52.5)	*	18536(50.9)
North Platte-Lexington	12080.7(35.1)	9537.1(35.9)	3883.3(25.6)	1333.9(19.7)	26835(32.3)
Lexington-Kearney	4052.6(20.0)	3302.1(19.7)	3646.5(28.3)	6300.4(27.4)	17301(23.7)
Kearney-Chapman	14755.9(37.4)	4829.1(22.0)	4568.2(22.6)	12107.1(18.4)	36260(24.6)

* Indicates absence of class at buffer distance

Table 9. Mean patch size (ha) and number of patches for floodplain grassland class at each buffer distance from the river channel.

Mean Patch Size (number of patches) - Floodplain Grassland

Study Region	1.5 km	3.0 km	4.5 km	4.5+km	Floodplain Total
Sutherland-North Platte	21.2(460)	38.2(292)	14.3(62)	*	27.5(673)
North Platte-Lexington	8.0(1497)	13.7(697)	8.7(446)	6.5(204)	10.7(2499)
Lexington-Kearney	5.7(714)	6.9(478)	9.1(398)	11.2(561)	9.6(1909)
Kearney-Chapman	10.2(1443)	7.4(649)	6.7(678)	6.5(2332)	7.5(4811)

* Indicates absence of class at buffer distance

At the 3.0 km and 4.5 km buffer distances in the Sutherland to North Platte region, floodplain grasslands accounted for 51.9% and 52.5% (Table 8) of the landscape, respectively, and had mean grassland patch sizes of 38.2 ha and 14.3 ha (Table 9), respectively. Therefore in the overall Sutherland to North Platte landscape, grasslands were the dominant patch type, and they occurred in relatively large, contiguous patches.

At the 3.0 km distance from the river channel the North Platte to Lexington region had the most area in floodplain grassland, 9537 ha (Table 8) and the most patches (697; Table 9). The North Platte to Lexington study region had a larger percent of the landscape in floodplain grassland than either the Kearney to Chapman region or the Lexington to Kearney region (Table 8). At both the 4.5 and 4.5+ buffer distances from the river, the Kearney to Chapman region had the most patches (Table 9) and the largest total area (Table 8) in the floodplain grassland class.

For all indices measured, the areas that have high cranes usage, Sutherland to North Platte and Kearney to Chapman, had the highest values at the 1.5 km distance from the river. This distance is the most important area for crane roosting and foraging, and the Sutherland to North Platte region had the largest patch size, and the highest percentage of the landscape in grassland, with the Kearney to Lexington region ranking second in both categories. The Kearney to Chapman region had the highest total area in grassland, and the most patches. The regions that are not used by cranes had smaller grassland patches and a smaller percentage of the landscape in grassland, than either of the areas used by cranes, with the Lexington to Kearney also having less total area in grassland, than either of the Sutherland to North Platte or the Kearney to Chapman regions. The Sutherland to North Platte study area consistently had the highest percentage of landscape in grassland and the largest patch size in the buffer distances beyond 1.5 km. The Kearney to Chapman region had large numbers of grassland patches at buffer distances beyond 1.5 km, and the most geographic area in grassland, indicating the presence of substantial amounts of floodplain grassland habitats throughout the landscape.

Agriculture class - For most of the Platte River landscape agriculture is the dominant land cover class. This was consistently the case in the regions beyond the 1.5 km distance for the North Platte to Lexington, Lexington to Kearney and Kearney to Chapman regions. In each of these distances (3.0 km, 4.5 km, 4.5+ km), the agriculture class comprised the highest percentage of the landscape, the most total area (Table 10), and the largest patch size (Table 11) when compared to the other four classes. In only one area (North Platte to Lexington, 3.0 km) was the percentage of the landscape in agriculture below 64%, showing the dominance of agriculture in most of the Platte River floodplain. The pattern of the agriculture class in the Sutherland to North Platte region showed less dominance with 36 and 39.6 percent of the landscape in agriculture at 3.0 km and 4.5 km, respectively (Table 10). In these two buffer zones in the Sutherland to North Platte region, the agriculture class also had smaller patch size than any of the other three study areas (Table 11), and less total area (Table 10).

At the 1.5 km distance, the Kearney to Chapman region had the most area in agriculture, (Table 10), the largest percentage of the landscape in agriculture, and the largest mean patch size (Table 11). The Sutherland to North Platte study area had the smallest percent of the landscape in agriculture and the least amount of area (Table 10). The North Platte to Lexington region had the second largest amount of area in agriculture, and the most agriculture patches, but the smallest mean patch size of the four areas. Although there was a relatively small mean patch size for the North Platte to Lexington region at the 1.5 km distance, the total area in agriculture was still extensive throughout the landscape and accounted for 25.7% of the area (Table 10). The Lexington to Kearney region ranked second of the four areas in total agriculture class area, percent of the landscape, (Table 10), and mean patch size, (Table 11). The Lexington to Kearney area

Table 10. Total class area (ha) and class percentof landscape for agriculture class at each buffer distance from the river channel.

Total Class Area (percent of landscape) - Agriculture

Study Region	1.5 km	3.0 km	4.5 km	4.5+km	Floodplain Total
Sutherland-North Platte	4653.5(23.5)	5359.7(36.0)	668.7(39.6)	*	10681(29.3)
North Platte-Lexington	8848.6(25.7)	13548.1(51.1)	10335.7(68.1)	5015.5(74.2)	37747(45.5)
Lexington-Kearney	7055.0(34.9)	12814.7(76.3)	8325.3(64.6)	15582.6(67.7)	43777(60.0)
Kearney-Chapman	14038.9(35.6)	15870.8(72.4)	13809.8(68.2)	46602.1(70.8)	90321(61.3)

* Indicates absence of class at buffer distance

Table 11. Mean patch size (ha) and number of patches for agriculture class at each buffer distance from the river channel.

Mean Patch Size (number of patches) - Agriculture

Study Region	1.5 km	3.0 km	4.5 km	4.5+km	Floodplain Total
Sutherland-North Platte	40.5(115)	37.5(143)	12.9(52)	*	50.2(213)
North Platte-Lexington	27.0(328)	46.1(294)	68.4(151)	70.6(71)	65.9(572)
Lexington-Kearney	47.0(150)	100.9(127)	51.1(163)	103.2(151)	104.7(418)
Kearney-Chapman	63.5(221)	138.0(115)	79.4(174)	100.4(464)	115.5(782)

* Indicates absence of class at buffer distance

was also the only area of the four at the 1.5 km distance where agriculture was the most dominant class with 34.9% of the landscape in agriculture.

Proximity

Proximity is a measure used to quantify the clumpiness or aggregation of patches in a landscape (Gustafson and Parker 1992). The spatial pattern of individual classes can be examined to quantify the amount of fragmentation occurring within a class. As the value of the proximity index increases, the class becomes more clumped with more patches of the same class being closer to one another or in closer proximity. Patches also become larger, filling more of the focal distance of 500 meters surrounding each patch. Proximity is measured on a continuing scale of increasing values relating to the aggregation of patches. Proximity values can be compared between regions, and among buffer zones based on the fact that as the values increase, patches become closer together and more contiguous, resulting in less isolation of similar patches.

Proximity Characteristics

Water class - Water that is potentially used by cranes only occurs in the 1.5 km buffer distance form the river. Therefore, the mean proximity index was used to examine only the 1.5 km distance for each of the four study areas. The Kearney to Chapman region had the highest proximity value with 297.1, while the Sutherland to North Platte region had the smallest value at 42.4 (Table 6). This pattern indicates that the Kearney to Chapman region had the least fragmented and most contiguous water class of the four areas. More water patches were in closer proximity to one another and the water class was more clumped and contiguous than the other study regions. The Sutherland to North Platte had a proximity index that indicated an extremely fragmented water class. Fewer patches were in close proximity to other water patches, resulting in a more fragmented landscape pattern for the class. The other two study areas, North Platte to Lexington and Lexington to Kearney had similar values for proximity index, but lower than the Kearney to Chapman region.

These areas also had patterns indicative of a more fragmented and less contagious structure for the water class, when compared to the Kearney to Chapman region.

Forest class - As stated previously, the vast majority of the forest class occurred within the 1.5 km buffer distance for the four study regions. Only the North Platte to Lexington region had forest present beyond 1.5 km in significant amounts to examine specific forest class patterns. In the 3.0 km buffer, the North Platte to Lexington region had a forest proximity index of 878 (Appendix B, Table 10), indicating forest that was relatively contiguous at greater distances from the river channel.

At the 1.5 km buffer distance proximity indices for the North Platte to Lexington region, 7,832, and the Lexington to Kearney region, 11,447 (Table 7) showed an extremely contiguous pattern for the forest class. The Sutherland to North Platte regions and the Kearney to Chapman regions had proximity values of 1,663 and 527, respectively (Table 7), which were significantly lower than the proximity values determined for the other two areas. The high proximity value in the North Platte to Lexington and Lexington to Kearney study areas, indicated a spatial arrangement of large contiguous patches that were tightly clumped. In both areas the forest occurred in primarily a single continuous strip of forest along the river channel. This pattern can easily be seen in the classified images (Appendix A) in which the forest class along the river is comprised of patches that are highly contiguous and occur along the entire length of the river channel throughout the North Platte to Lexington and Lexington to Kearney study areas. In the Sutherland to North Platte and Kearney to Chapman regions, forest patches were more isolated from other forest patches, separated by other classes more frequently, and occurred in a spatial arrangement that does not totally surround the river channel.

Floodplain grassland class - At the 1.5 km distance the Sutherland to North Platte region had the largest proximity value (3,115), while the Lexington to Kearney region had the lowest proximity value (313; Table 12). In the Sutherland to North Platte region,

Table 12. Proximity index for floodplain grassland class at each buffer distance from the river channel.

Proximity Index - Floodplain Grassland

Study Region	1.5 km	3.0 km	4.5 km	4.5+km	Floodplain Total
Sutherland-North Platte	3115.7	1520.4	157.9	*	10179.6
North Platte-Lexington	699.2	484.8	153.6	70.76	2883.3
Lexington-Kearney	313.2	91.7	127.5	260.3	402.5
Kearney-Chapman	960.2	166.6	154.9	169.1	502

* indicates absence of class at buffer distance

Table 13. Proximity index for agriculture class at each buffer distance from the river channel.

Proximity Index - Agriculture

Study Region	1.5 km	3.0 km	4.5 km	4.5+km	Floodplain Total
Sutherland-North Platte	339.3	523.4	66.3	*	1116.2
North Platte-Lexington	544.1	1970.5	1274.8	1769.6	7211.6
Lexington-Kearney	1500.8	4965.4	1733.9	2658	46928.6
Kearney-Chapman	1662.4	6445.5	3617.1	47829.3	71087.2

* Indicates absence of class at buffer distance

floodplain grassland was in closer proximity and formed an arrangement of patches that was less isolated from other floodplain grassland patches. The Kearney to Chapman region had grassland patches that were more clumped than either of the North Platte to Lexington or the Lexington to Kearney regions. The Lexington to Kearney region had patches that are the most isolated of the four areas.

At the 3.0 km distance, Sutherland to North Platte also had the highest value for proximity (1520; Table 12) for the floodplain grassland class of the four areas. The other areas had significantly lower values than the Sutherland to North Platte region, with the North Platte to Lexington region having the highest value of the three areas with (484; Table 12). At both 1.5 km and 3.0 km, the Sutherland to North Platte region had patches that were less fragmented and in closer proximity than grassland patches in the other study areas. In the 4.5 km and 4.5+ km distances, proximity values for all areas were relatively low (Table 12). This was due to the dominance of agriculture in these areas. Because more of the landscape is agriculture, grassland patches were more evenly spread out across the landscape, and did not occur in complexes of patches that were close together, which was the pattern seen in the 1.5 km buffer zone. This pattern resulted in very low proximity values due to the dominance of agriculture.

Agriculture class - At the 1.5 km buffer zone, the Kearney to Chapman and the Lexington to Kearney regions had the highest proximity for the agriculture class, with 1662 and 1500, respectively (Table 13). The Sutherland to North Platte region had the smallest value at 339 (Table 13). This would indicate that agriculture patches in the Sutherland to North Platte and the North Platte to Lexington study areas were less contiguous and more spread out across the landscape than in the other two areas with higher proximity values. This is supported by the fact that the majority of the landscape in these two regions was composed of forest and floodplain grassland, and that agriculture was not the dominant feature in the landscape.

At the 3.0 km and larger buffer zones, the proximity values increased for all areas (Table 13). At greater distances from the river, agriculture became more dominant in landscape composition, and there was less forest, water, and grassland patches. At the 1.5 km distance there was less area for agriculture and the water, grassland, and forest classes were more prominent and occurred in greater quantities. Agriculture was not the dominant class and did not occur in large continuous patches because the other classes served to divide agricultural patches into smaller areas. In the buffer distances 3.0 km and greater, agriculture became much more contiguous, with larger patches (Table 11) and a larger portion of the landscape comprised of agriculture (Table 10). Furthermore, there was less of the other classes than at the 1.5 km distance to separate agricultural areas, resulting in a agriculture class that formed a much more extensive complex of patches in closer proximity to other agriculture patches. This was especially true in the Kearney to Lexington region which had a proximity value of 47,829 (Table 13) at the 4.5+ km distance. For the North Platte to Lexington, Lexington to Kearney and Kearney to Chapman regions, the landscape beyond the 1.5 km buffer distance was basically large, continuous patches of agriculture with small patches of floodplain grassland, forest, water, and bare scattered throughout.

Discussion

Correlating landscape pattern and biology has been used to help explain species habitat use over large geographic areas. The use of landscape indices to quantify habitat structure has been especially useful in examining the habitat use patterns of avian species, such as kestrels (Lyon 1983), wood storks (Hodgson et al. 1988, Hodgson et al. 1987), and sandhill cranes (Baker et al. 1995, Herr and Queen 1993), which use an extensive landscape for foraging activities. Lyon et al. (1983) found that spatial measurements such as distance, contiguity, shape, and area could be correlated with nesting requirements of kestrels to predict nesting locations on a classified satellite image. Hodgson et al. (1988)

showed that use of foraging habitats by wood storks was directly related to the condition of foraging patches and their distance from nesting sites. As the structure of the foraging habitats changed, wood storks changed their use patterns to adapt to landscape level conditions.

Landscape structure research for cranes has primarily focused on nesting habitat. Baker et al. (1995) constructed a series of buffers around greater sandhill crane nesting locations in Michigan to analyze crane habitat at a variety of spatial scales. They found as the buffer distance surrounding crane roost sites increased, the landscapes became increasingly similar, and showed no distinction in landscape pattern between roost and non-roost sites. Herr and Queen (1993) used the amount of foraging habitat and distance to foraging habitats to evaluate nesting habitat of sandhill cranes in Minnesota.

The landscape pattern determined for the four study regions of the Platte River can be used to examine sandhill crane habitat use in each area. This approach of correlating biological data and habitat requirements with landscape structure is applicable in examining the influence of landscape pattern on sandhill crane spring migration habitat as well. The biology of cranes is an important link between landscape pattern and the use of a landscape by sandhill cranes. Biological data describes cranes requirements for habitation of a region, such as foraging and roosting habitat characteristics, while the landscape pattern provides data that may influence the biology of cranes and the use of an area.

Water- The Platte River is a critical feature of the landscape for cranes, providing the majority of roosting habitat during the spring migration (Iverson et al. 1987, Krapu et al. 1984). Adequate roosting sites are a prerequisite for the use of an area by sandhill cranes. These roost sites allow cranes to rest and engage in a number of social activities, such as courtship, preening, and agnostic behavior (Norling et al. 1992).

The two regions that have sandhill crane concentrations in the spring, Sutherland to North Platte and Kearney to Chapman, are used differently by cranes in their roosting activities. In the Kearney to Chapman region, cranes avoid channels that are less than 50 m in width (Krapu et al. 1984) with the majority of cranes using river channels that are 150-200 m wide for roosting activities (Norling et al. 1992, Sidle et al. 1993). Roosting habitats of cranes are very different in the Sutherland to North Platte region. Folk and Tacha (1990) found that cranes used roosting sites greater than 16 m in width, but preferred sites greater than 48 m in width, with the largest amount of roosting occurring in channel widths of 60-75 m wide.

Cranes must have roost sites to return to after foraging each day, thus the absence of adequate roost sites precludes the use of an area by cranes. Channel width is very important in the Kearney to Chapman region, where cranes prefer channels that are wide and unobstructed (Norling et al. 1992, Sidle et al. 1993), and restrict their roosting to available river channels. The landscape structure of water derived for the Kearney to Chapman region supported this notion, with the largest patch size, the most contiguous arrangement of these patches, and the largest amount of water for roosting habitat of the four study regions. The two regions that are not used by cranes (North Platte to Lexington and Lexington to Kearney) had water patches that were smaller in size, comprised a smaller portion of the landscape, and were not as clumped as water patches in the Kearney to Chapman region. These landscape patterns of water point to the fact that river roosting habitat was of lower quality in the North Platte to Lexington and Lexington to Kearney regions, consistent with their limited or no use by cranes. The large patches of water and the amount of water that was characteristic of the Kearney to Chapman region were not present in the regions not used by cranes (North Platte to Lexington and Lexington to Kearney), thus influencing the availability and quality of crane roosting habitat in these regions.

Channel width is also important to cranes in the Sutherland to North Platte region for roost sites that are used in the river, but the lack of adequate river roost sites has caused cranes to use other habitats for roosting, namely wet meadows. Landscape patterns quantified for the Sutherland to North Platte area showed that water occurred in smaller patches, comprised a smaller portion of the landscape and was less clumped than any of the other three regions. Water patches usable for roosting were limited in the Sutherland to North Platte region, and as a result, cranes have shifted their habitat use to existing channels which are smaller and more visually obstructed. The fact that cranes use the Sutherland to North Platte area consistently makes these results surprising given that both areas not used by cranes (North Platte to Lexington and Lexington to Kearney) had a higher percent of the landscape in water, more water patches, a larger mean patch size of water, and water patches that were more clumped (Table 6) than the Sutherland to North Platte study region. Landscape in the Sutherland to North Platte region had a definite impact on crane biology, having forced cranes to alter their characteristic use of wide river channels for roosting and to adapt to existing conditions in the landscape. Although river roosting habitat in the Sutherland to North Platte region is the lowest quality of the four regions, cranes consistently use the area during the spring migration, suggestion that other landscape factors influence the use of roosting habitats by cranes.

Forest- Roost site quality is affected by forest adjacent to river roosting channels. The presence of forest, and characteristics such as vegetation height have been shown to influence the use of roosting sites by cranes. Indeed, it is likely that the constant encroachment of woody vegetation along the Platte River is one of the main causes for the shift in cranes from the North Platte to Lexington and Lexington to Kearney regions to the area between Kearney and Chapman (Faanes and LeValley 1993).

Channel obstruction in the form of forest or woody vegetation imparts another influence on the roosting behavior of cranes. This category is closely related to channel width, with cranes being less influenced by obstructions in the form of vegetation with greater channel width (Krapu et al. 1984). Crane use of sites is negatively influenced by vegetation greater than 8 m in height. Krapu et al. (1984) found that cranes will roost in channels regardless of vegetation height if the channel width is greater than 150 m. In the Kearney to Chapman reach of the river, cranes tend to roost away from vegetated banks and islands, 50 m from vegetated banks and 27 m from vegetated islands (Norling et al. 1992). In the Sutherland to North Platte region, cranes were not as influenced by obstructions, 48 % of the time roosting within 4-25 m from a visual obstruction, and 52 % of the time roosting at distances greater than 25 m from a visual obstruction (Folk and Tacha, 1990).

The amount and height of woody vegetation that surround river channels influences the use of roosting sites by cranes, by negatively impacting the suitability of the roost sites for cranes. Cranes prefer roost sites that have less forest surrounding them. The majority of forest in the Platte River landscape is present along the river channel due to the encroachment and growth of woody vegetation (Sidle et al. 1989, Johnson 1995). Woody vegetation has encroached on river channels and on wet meadows along the river, changing these valuable crane habitats into forested patches (Sidle et al. 1989). Many wet meadows in the North Platte to Lexington and Lexington to Kearney regions that border river channels and provide foraging habitat in close proximity to river roosting sites have been converted to forested areas, thus eliminating important foraging habitat. Cranes consistently use roosting sites within the river channel or wet meadow areas that border river channels, preferring sites that do not contain large amounts of woody vegetation. As encroachment of woody vegetation has increased along the Platte, especially in the North Platte to Lexington and Lexington to Kearney regions, cranes have shifted their use of the area to regions that have less forest in the landscape, namely the Kearney to Chapman region. The existing landscape structure of forest supports the decline or non-use of the North Platte to Lexington and Lexington to Kearney regions, with more forest, larger forest patches, and a higher percentage of the landscape in forest than either the Kearney to

Chapman or Sutherland to North Platte regions. Furthermore, these two regions have forests that are highly contiguous, forming a continuous strip of forest that surrounds river channels and potential roosting sites. The influence of forest may also extend past the immediate vicinity of the Platte River in the region from North Platte to Lexington. This is the only region with substantial amounts of forest past the 1.5 km distance from the river channel, which occurred in large and clumped patches. Forest encroachment at greater distances from the river channel would further reduce the quality and availability of foraging habitats in the region and may be a possible factor in the absence of cranes in this reach of the river.

The Kearney to Chapman region had forest patterns that did not influence roosting and foraging habitat as heavily as in the North Platte to Lexington or Lexington to Kearney regions. The patterns included smaller patch size, a low proximity index and a relatively low percent composition of the landscape. Patches in this region were less extensive and less contiguous in structure. There was less forest encroachment on wet meadows and river channels in the region, resulting in more available and consequently higher quality foraging and roosting habitats than in the North Platte to Lexington and Lexington to Kearney regions.

The Sutherland to North Platte region had forest patterns that were similar to the Kearney to Chapman region, with smaller patch size, more fragmented patches, and a smaller percent of the landscape than in either of the two regions not used by cranes. The values for these measurements were higher than the Kearney to Chapman region, which is consistent with cranes habitat use in the area. Forest patches in the Sutherland to North Platte region were more extensive and imparted a larger influence on sandhill cranes by limiting the number of available river roosting sites. The amount of forest in the region coupled with the patterns derived for water demonstrate the low number of available river roost sites in the region. These patterns have influenced the potential roost sites of cranes, and lead to the use of wet meadows adjacent to the river for roosting habitat.

Floodplain Grassland- Floodplain grasslands are critical habitats for cranes in the Platte River region, providing essential foraging habitat (Davis and Vohs 1993). Sparling and Krapu (1994) found that cranes used grasslands and haylands more often than expected, and foraged there longer than in corn fields. They attribute this pattern to the limited distribution of grasslands and haylands in relation to corn fields, resulting in a larger energy expenditure to acquire needed protein in the form of macroinvertebrates. The limited number of grassland areas makes the prolonged foraging at one grassland site more beneficial than locating and foraging in other grassland sites. Because of the abundance of cornfields, wetlands are the limiting foraging habitat for cranes, and their proximity to roosting sites is a factor in the use of the Platte River landscape by cranes (Sidle et al. 1993, Iverson et al, 1987). Proximity of floodplain grasslands to river channels is also an important factor for crane habitat quality and use. Tacha (1981) found that wet meadows within 0.8 km of major roosting sites served as the primary areas for crane pair bonding activities. Areas with grasslands adjacent or in close proximity to the Platte River are used more often by cranes than areas without adjacent grasslands (Sidle et al. 1989, Folk and Tacha 1990).

In the Sutherland to North Platte region, wet meadows also serve as important roosting habitat. Iverson et al. (1987) found that 33% of all roost sites where in wet meadows adjacent to the North Platte River, with 45% of the cranes in the region using those wet meadows for roosting. Folk and Tacha (1990) also showed that semipermanent wetlands along the North Platte River greater than 23 m in width were used extensively by cranes as roost sites. As suitable river roost sites are occupied by cranes, wet meadow and grassland sites adjacent to the river are used as alternative roosting habitat (Iverson et al. 1987). Cranes generally will not leave this region of the river for alternate staging grounds to obtain more suitable river roost sites, making floodplain grasslands extremely important for use of the region by cranes.

In the Lexington to Kearney and the North Platte to Lexington regions, floodplain grassland foraging habitat is of lower quality then in regions used by cranes, due to a number of landscape factors. The Lexington to Kearney region had the smallest amounts of floodplain grassland in both area and percent of landscape, smallest grassland patch size, and the most fragmented arrangement of patches of the four study regions. The structure of forest also contributes to the quality of floodplain grassland in the Lexington to Kearney region, with large patches, a large percent of the landscape in forest, and a very high level of aggregation of forest patches. Grassland has been converted to forest by the encroachment of woody vegetation, and due to the contiguous structure of forest, there is limited amounts of grassland adjacent to the river channel. This has resulted in low amounts of foraging habitat in the region, and limited grassland habitat adjacent to river channels. Due to the structure of forests along the river channel, the Lexington to Kearney region does not have adequate river roost sites or grasslands that could serve as potential roost sites adjacent to river channels. Furthermore, potential foraging sites are more isolated and not in a spatial arrangement that provides cranes with close foraging in relation to roost sites.

In the North Platte to Lexington region, floodplain grassland structure is similar to the Kearney to Chapman region with a large amount of grassland area, a high percentage of the landscape in grassland, and similar patch size. Floodplain grassland habitat is available and of comparable quality to floodplain grassland in the Kearney to Chapman region, which is used by cranes. However, forest landscape pattern is not conducive to sandhill crane use of the area, with large patch size, a large percent of the landscape in forest and a highly contiguous arrangement. Floodplain grasslands adjacent to the river channel are now forests and do not provide foraging habitat in close proximity to roost sites, or grassland roosting sites adjacent to river channels.

Sparling and Krapu (1994) showed that cranes prefer foraging habitat that is close to other grasslands, where they can more easily access other grasslands once food has been exhausted in patches. Grassland patches that are located in close proximity to one another reduce the distance that cranes must travel to find other patches, and reduce the time spent in locating these patches. Because cranes spend up to 50 % of their foraging time in grasslands obtaining only 5 % of their diet, this is an important factor. A spatial pattern of grasslands that is more aggregated allows cranes to spend less time locating grasslands and more time foraging and obtaining valuable nutrients.

The Sutherland to North Platte region had the highest proximity value of the four regions with floodplain grassland patches that are less isolated from one another. This provides cranes with foraging habitat that can be more easily accessed than in the other regions, with a potential of more foraging time being spent obtaining macroinvertebrates and less time and energy spent locating patches in the landscape.

Grasslands within 0.8 km of roost sites (river channels and grasslands adjacent to the river) are the most important habitat in the landscape, providing habitat for social and foraging activities. The Sutherland to North Platte region has the highest percentage of the landscape in floodplain grassland and the largest patch size of the four study areas at the 1.5 km distance. Therefore, there is an abundance of large patches that provide potential roosting and foraging habitats. The Sutherland to North Platte region had the highest quality and most available floodplain grassland habitat of the four regions. There was also an abundance of grasslands adjacent to the river channels that serve as overflow roosting habitat due to the limited number of river roost sites. Forests in the region occupied a smaller portion of the landscape, were less clumped and did not totally constrict the river channel, which was the pattern in the North Platte to Lexington and Lexington to Kearney regions. Unlike the North Platte to Lexington and Lexington to Kearney regions, there are available grasslands directly adjacent to the river channels to compensate for the limited number of suitable river roost sites. Thus, the high quality of floodplain grassland habitat facilitates the use of the Sutherland to North Platte region by cranes.

The Kearney to Chapman region has floodplain grassland patterns that are characteristic of quality crane habitat, with a large total grassland area, a high percentage of the landscape in grassland, and patches that are relatively aggregated. At distances farther from the river there was also adequate amounts of grassland for foraging habitat, with the region having the most grassland patches of the four study areas at the 1.5 km, 4.5 km, and 4.5+ km distances from the river. There is more total floodplain grassland area within the 1.5 km distance from the river than in the Sutherland to North Platte region, providing cranes easily accessible foraging sites in close proximity to river roosting sites. Furthermore, the spatial structure of forests in the region does not constrict river channels, with a less clumped arrangement and smaller amounts of forest in general. This arrangement results in sections of the river that are bordered by floodplain grassland instead of forest, which is characteristic of the North Platte to Lexington and Lexington to Kearney regions. There is also relatively large amounts of grassland throughout the floodplain landscape to support the large concentrations of cranes in the region. Although cranes prefer foraging habitat within 0.8 km of their river roost sites, they do travel as much as 5 km from roost sites to forage (Iverson et al. 1987). There are adequate numbers of grassland foraging patches throughout the Kearney to Chapman landscape to provide good quality foraging habitat for cranes. The floodplain grassland patches are more isolated than in the Sutherland to North Platte region and require more time and energy for cranes to locate patches, however, they are still accessible and provide more potential foraging habitat than either of the North Platte to Lexington or Lexington to Kearney regions.

Agriculture- Although agricultural areas, and especially corn, are very important to cranes, the landscape patterns quantified for agriculture do not strongly support the use of a region by cranes. Agriculture is a common feature of the landscape, and can be easily found and used by a species as mobile as the sandhill crane. Even a landscape that is comprised of only 24 % agriculture (Sutherland to North Platte) provides adequate amounts of waste grain to support crane use of an area. Conversely, regions that are comprised of more agriculture such as the Kearney to Chapman region, which is 37 % of the landscape at distances close to the river channel and as large as 76 % of the landscape farther away from the river channel are also used extensively by cranes. Landscape patterns of the regions that are not used extensively by cranes (North Platte to Lexington and Lexington to Kearney) are similar to those in the Kearney to Chapman region, where agriculture comprised a large portion of the landscape, had large patch size, and was highly clumped. These patterns point to the fact that cranes are not heavily influenced by agriculture, using an area regardless of whether it has relatively low or high amounts of agriculture. This also supports the assertion that the use of an area by cranes is reliant on other landscape features, namely water, floodplain grassland and forest.

Research Implications

The findings of this research pose some interesting questions and the possibility of further research that can lead to a more complete understanding of the influence of landscape structure on sandhill cranes during the spring migration. The implications of this research are that landscape patterns in the four study regions have an influence on sandhill crane use of the area. However, specific roost sites and foraging areas were not examined, instead the entire landscape was focused on to determine if large scale patterns may be influencing species patterns at smaller scales. Research on a smaller scale that examines individual roost sites and foraging sites in the four study regions is the next step to determine if the small scale patterns are consistent with the results of this study.

Conclusions

This research demonstrates the possible influence that elements of landscape structure impart on sandhill crane habitat in each of the study regions. Crane biology and habitat requirements, such as minimum width of roosting sites, proximity of foraging habitat to roosting sites, and avoidance of forested areas, were correlated with the landscape structure determined in order to examine the effect structure has on habitat availability and quality. In the Kearney to Chapman and Sutherland to North Platte regions, foraging habitat was extensive and available to cranes throughout the landscape, including important grassland areas in close proximity to roost sites. Both of these regions also contained river roosting habitat that was less influenced by forest than either of the North Platte to Lexington or Lexington to Kearney regions. Furthermore, the Sutherland to North Platte region had floodplain grassland patterns that allow cranes to compensate for limited river roosting sites by roosting in floodplain grasslands adjacent to river channels.

In both the North Platte to Lexington and Lexington to Kearney regions, forest structure affected the availability of river roost sites with large, contiguous patches that surround potential roosting habitat. Forest structure also has influenced floodplain grassland structure by eliminating many of the grassland patches bordering river channels. Because of this, sandhill crane foraging and roosting habitat in these regions was not as available and of lower quality than in either the Sutherland to North Platte or Kearney to Chapman regions.

Combining ecology and landscape structure to examine habitat availability and quality provides insight into the role of the landscape in the use of a region by sandhill cranes. The structure of the landscape in the four study regions influences the availability and quality of crane habitats, and thus contributes to the use of the entire region by sandhill cranes. Landscape patterns that are relevant to a species' habitat requirements can be effectively used to quantify landscape structure, which can in turn be used to provide information about species use of a region. This research offers an approach that can be used to examine landscape/habitat use relationships in heterogeneous landscapes.

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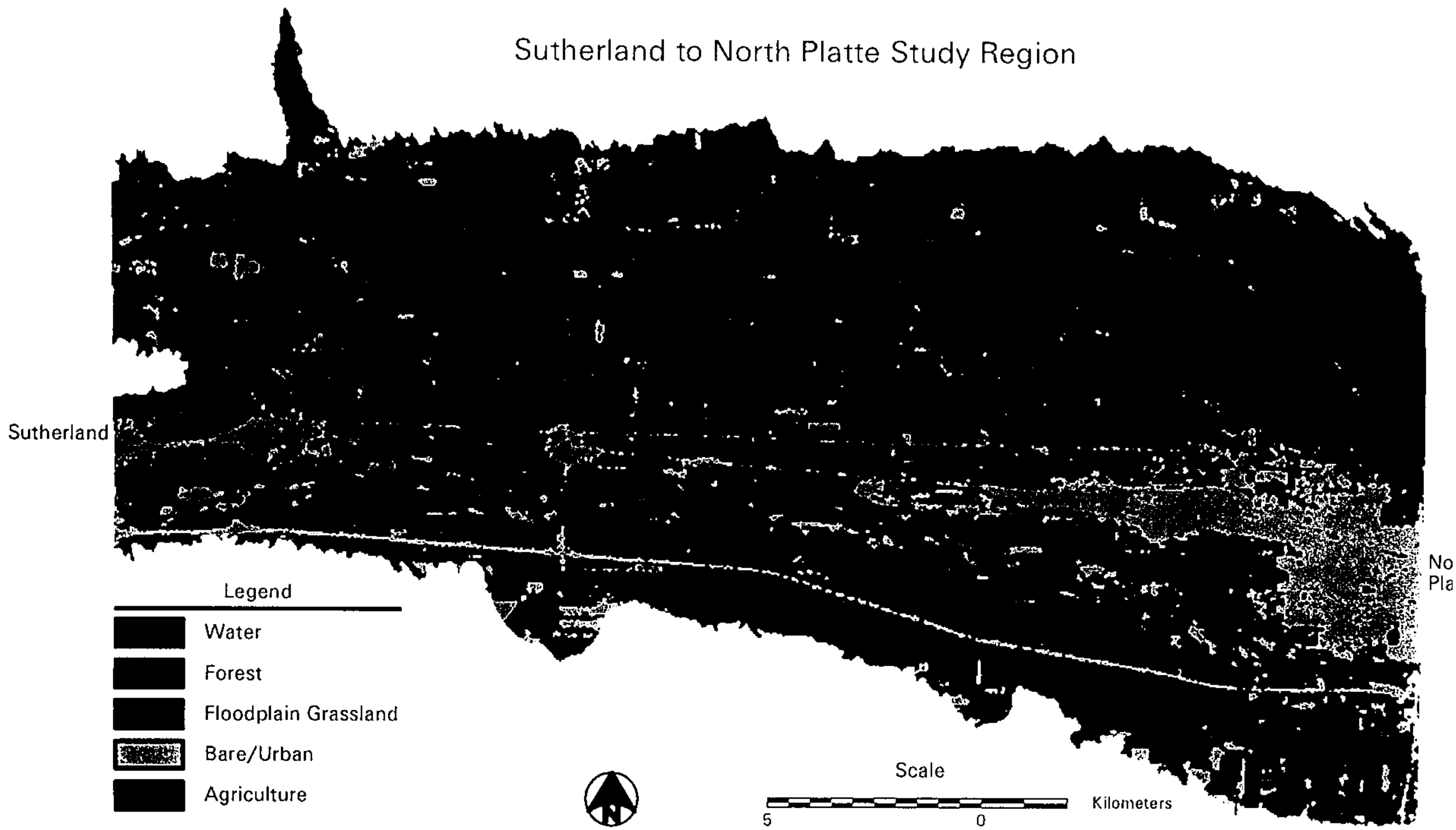
APPENDIX A

CLASSIFIED LANDSAT TM IMAGES OF FOUR PLATTE RIVER STUDY REGIONS


Sutherland to North Platte Study Region
Sutherland
No
Pla
Legend
Water
Forest
Floodplain Grassland
Bare/Urban
Agriculture
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Scale
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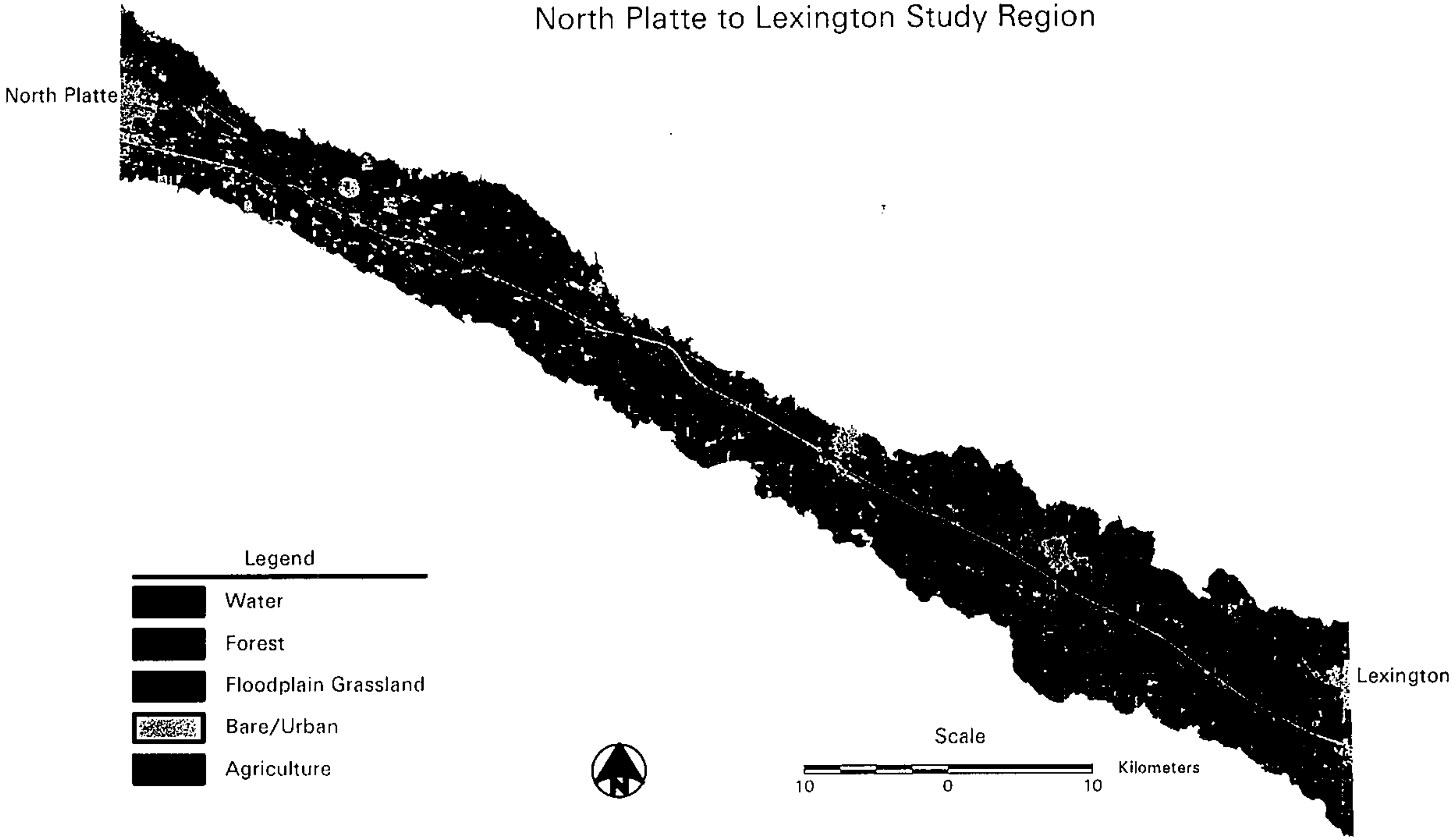
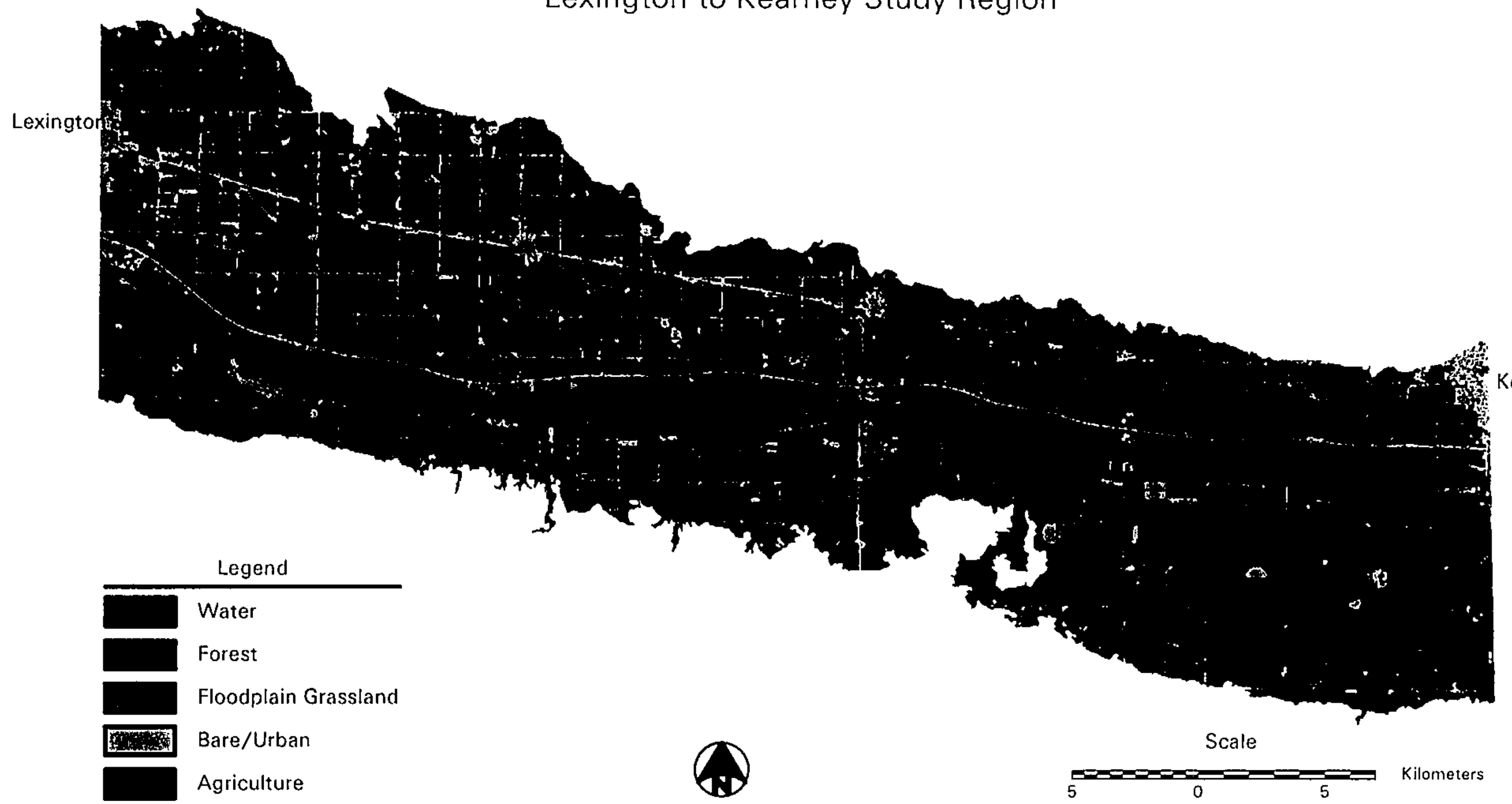
Kilometers

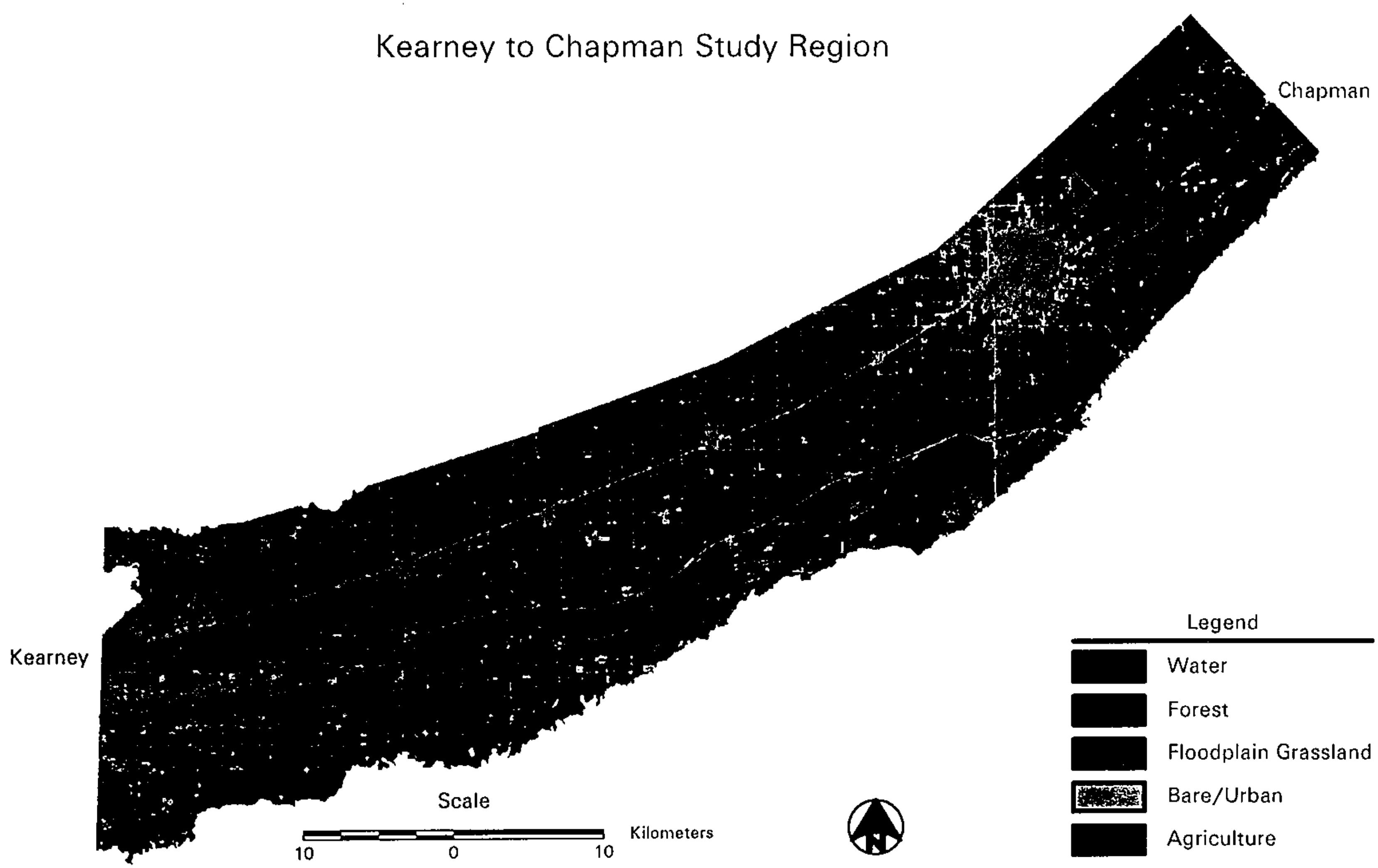
North Platte to Lexington Study Region



Lexington to Kearney Study Region



Kearney to Chapman Study Region



APPENDIX B

RESULTS TABLES FOR LANDSCAPE INDICES

Table 1. Total area for water class at each buffer distance from river channel.

Total Class Area(ha) - Water

Study Region	1.5 km	3.0 km	4.5 km	4.5+km	Floodplain Total
Sutherland-North Platte	601.6	57.3	19.2	*	678
North Platte-Lexington	1375.1	114.9	102.7	21.3	1614
Lexington-Kearney	1280.6	103.9	*	53.5	1488
Kearney-Chapman	2840.9	59.4	195.3	134.1	3229

* Indicates no presence of class at buffer distance

Table 2. Percentage of landscape in water class at each buffer distance from the river channel.

Percent of Landscape - Water

Study Region	1.5 km	3.0 km	4.5 km	4.5+km	Floodplain Total
Sutherland-North Platte	3.0	.4	1.1	*	1.9
North Platte-Lexington	4.0	.4	.6	.2	1.9
Lexington-Kearney	6.3	.6	*	.2	2.0
Kearney-Chapman	7.2	.3	.9	.3	2.20

* Indicates abssence of class at buffer distance

Table 3. Number of patches for water class at each buffer distance from the river channel.

Number of Patches - Water

Study Region	1.5 km	3.0 km	4.5 km	4.5+km	Floodplain Total
Sutherland-North Platte	209	39	17	*	251
North Platte-Lexington	399	63	61	16	525
Lexington-Kearney	311	80	*	45	451
Kearney-Chapman	608	27	56	110	791

* Indicates absence of class at buffer distance

Table 4. Mean patch size for water class at each buffer distance from the river channel.

Mean Patch Size(ha) - Water

Study Region	1.5 km	3.0 km	4.5 km	4.5+km	Floodplain Total
Sutherland-North Platte	2.9	1.5	1.1	*	2.7
North Platte-Lexington	3.4	1.8	1.7	1.33	3.1
Lexington-Kearney	4.1	1.3	*	1.2	3.3
Kearney-Chapman	4.7	2.2	3.48	1.2	4.1

* Indicates absence of class at buffer distance

Table 5. Total class area for forest class at each buffer distance from the river channel.

Total Class Area(ha) - Forest

Study Region	1.5 km	3.0 km	4.5 km	4.5+km	Floodplain Total
Sutherland-North Platte	3027.6	*	*	*	3027
North Platte-Lexington	8289.9	1456.3	172.9	2.0	9920
Lexington-Kearney	6783.3	*	*	*	6819
Kearney-Chapman	5072.4	13.7	*	*	5086

* Indicates absence of class at buffer distance

Table 6. Percentage of landscape for forest class at each buffer distance from river channel.

Percentage of Landscape - Forest

Study Region	1.5 km	3.0 km	4.5 km	4.5+km	Floodplain Total
Sutherland-North Platte	15.3	*	*	*	8.32
North Platte-Lexington	24.1	5.5	1.1	.02	11.97
Lexington-Kearney	33.54	*	*	*	9.36
Kearney-Chapman	12.9	.06	*	*	3.45

* Indicates absence of class at buffer distance