LOCAL SCALE ANALYSIS OF SANDHILL CRANE USE OF LOWLAND GRASSLANDS ALONG THE PLATTE RIVER, NEBRASKA

by

Tammy L. VerCauteren

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Tammy L. VerCauteren, M.S.

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Advisor: Julie A. Savidge

Half a million, or 80%, of the world's sandhill crane (*Grus canadensis* spp.) population stops over annually along the Platte River of Nebraska, USA. Cranes occupy a mosaic of habitat types while in Nebraska, including native grassland/wet meadow complexes. To identify patterns of field use by sandhill cranes, I quantified crane use of all cover types within a 72-km stretch of the Platte River. I conducted bi-weekly aerial censuses in 1996 and 1997 and additional bi-weekly drive surveys in 1997. Crane use of grazed fields was greater than expected when compared to hayed fields. Various environmental parameters (soil moisture; litter depth; water table depth; visual obstruction, and percentages of cover, dead, live, grass, wood, and forb) were characterized on 44 and 49 lowland grassland study sites in 1996-1997, respectively. Numbers of cranes were negatively related to water table depth in both years ($P < 0.002$). In 1997 cranes on lowland grasslands were positively related to amount of standing water ($P < 0.001$) and negatively related to visual obstruction ($P \leq 0.034$). Depth to the water table and amount of standing water on a field were negatively related in 1996 and 1997 ($P = 0.027$, $P < 0.001$; respectively). Multiple regression models explained up to 60% of the variability in crane use of lowland grasslands. Results reiterate the importance of hydrology in the ecology of cranes.

Key words: *Grus canadensis*, habitat, hydrology, Platte River, sandhill crane

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CHAPTER 1: LITERATURE REVIEW

Sandhill crane biology

The sandhill crane is the oldest existing bird species known (Johnsgard 1991). A fossilized wing bone of a sandhill crane was found in Nebraska that dated back 9 million years. With an estimated population of over 500,000, the sandhill crane is the most abundant species of crane (Meine and Archibald 1996), and 6 subspecies are recognized. The lesser (*Grus canadensis canadensis*), greater (*G. c. tabida*), and Canadian (*G. c. rowani*) are all migratory. The Cuban (*G. c. nesiotes*), Mississippi (*G. c. pulla*), and Florida (*G. c. pratensis*) are sedentary. Size is the major discriminating factor among subspecies. The lesser is the most abundant subspecies followed by the Canadian (Walkinshaw 1981).

Sandhill cranes are gregarious, exhibit tight family bonds, and are rarely seen solitary. They are also long-lived, late maturing, and *K* selected. Sexual maturity for sandhill cranes is reached at 2 or 3 yrs of age (Grooms 1992). They are monogamous and provide extended biparental care for the first 9 to 10 months of a juvenile's life (Tacha 1988). There is no firm evidence that renesting behavior occurs in cranes (Boise 1976). They have a small clutch size of only 1-2 young, and usually 1 of the 2 young die due to sibling aggression (Grooms 1992). Considerable time and energy is expended protecting their offspring and reinforcing social bonds, with a cost of low recruitment rates (Grooms 1992).

Sandhill cranes postpone breeding until 2-7 yrs of age. Age at first reproduction varies for different species, subspecies, and populations of cranes. Initial pair formation in sandhill cranes typically occurs during the third year with 20% paired in 4 yrs and 90% in 7 yrs. Many pairs nesting for the first time fail to produce young that survive to the juvenile stage (Tacha et al. 1992). Typically pairs are not successful at maintaining a territory and rearing young until they are about 8 yrs of age (Tacha et al. 1989). The average life expectancy of sandhill cranes is 7 yrs, thus many cranes do not survive long enough to successfully add young to the population (S.A. Nesbitt and C.T. Moore, unpublished data, as cited in, Tacha et al. 1992). Juvenile survival averages 11%, ranging from 6.6-18.3 % (Tacha and Vohs 1984). The maximum life expectancy for the mid-continental population of sandhill cranes in the wild is 19.4 yrs (Tacha et al. 1984).

Sandhill cranes are omnivores feeding on plant materials (including waste grain), invertebrates, and small vertebrates. Cranes frequent open freshwater wetlands, shallow marshes, wet meadows, and adjacent uplands. A diversity of habitat types are used, including bogs, sedge meadows, fens, grasslands, stubble fields, and savannahs. Typically large marshes and riparian wetlands situated near agricultural areas are occupied along migration routes (Meine and Archibald 1996). Agricultural areas used include harvested grain fields, hay fields, and pastures (Melvin and Temple 1982, Soine 1982).

Mid-Continent population

The Central Flyway is the migratory route linking the wintering, staging, and breeding habitat of the mid-continent population. Their migration pattern has been described as an hour-glass shape with the Platte River at the center being the weak link (Figure 1) (Frith 1974). Wintering grounds for the mid-continent population of sandhill cranes include New Mexico, Texas, Arizona, Oklahoma, and Mexico (Lewis 1977, Tacha et al. 1984). They migrate north to the Platte River in the early spring where they spend approximately 4-6 weeks feeding, resting, and reinforcing social bonds. The spring staging season in the Platte and North Platte Valley is the largest concentration of cranes in the world (Safina 1993). They then journey to breeding grounds in Canada, Alaska, and Siberia.

Virtually all lesser sandhill cranes winter east of the Rocky Mountains and stop in the Platte River Valley to stage. Roughly 90% of the lessers, almost all of the Canadian, and an undetermined number of greaters are located in a few river miles of the Platte during the staging season (Lewis 1977, Johnsgard 1983).

Greater sandhill cranes are typically found in eastern staging areas around Grand Island, Canadian sandhill cranes in the middle staging areas of the Platte River, and lesser sandhill cranes in western staging areas including North Platte (Tacha et al. 1984). It has been suggested that the farther west the sandhill cranes winter, the farther west they migrate and stage in spring, and the farther northwest they breed in summer (Tacha 1984).

The mid-continent population of sandhill cranes is split geographically between western and Gulf coast subpopulations. Tacha (1981) found differences in the distribution of subspecies within the different subpopulations. Approximately 80% of the cranes in the western subpopulation are Canadian and 33% are in the Gulf Coast subpopulation. Juveniles comprise 11% of the western subpopulation and 20% of the Gulf Coast subpopulation (Tacha and Vohs 1984).

The existence of different subpopulations within Nebraska and other states may warrant different management strategies, including different limits for hunting permits based on the condition of the subpopulations (Tacha et al. 1984). Over-hunting is a potential risk to migratory populations of sandhill cranes in western and central North America. The total estimated annual kill of the mid-continent population of sandhill cranes ranges from 4-5.4% (Tacha et al. 1994). The sandhill crane has the lowest recruitment rate of any bird hunted in North America, and there is no long-term data on recruitment or survival (Meine and Archibald 1996).

Platte River

Midway between the Gulf Coast and the USA-Canadian border, the Platte River bisects the Great Plains as it flows east from the Rocky Mountains to the Missouri River. The Platte River is only one of several rivers that crosses the plains, forming a ladder of wetlands used by many species of migratory birds as they move between wintering and breeding grounds (VanDerwalker 1983). Historically, many rivers on the Great Plains had braided habitats similar to the Platte River. The Big Bend stretch of the Platte River is the only remaining example of this unique ecosystem that used to exist on the High Plains (W. Hoffman, personal communication, as cited in, Safina 1993). Migratory stop-over sites function as refueling locations for many birds including cranes. Stopover sites are essential because many avian species cannot complete an entire season's migration in one event (Winker et al. 1992).

Accounts of the Platte River by explorers in the mid 1800s record its width as between 1.2-4.8 km (Eschner et al. 1981). Depths ranged from 0.3-1.2 m during most of the year (James 1823, Warren 1858). Sandbars were spread throughout the river and it was a near treeless riparian zone (Currier et al. 1985). Scouring flows from high spring runoff would move great quantities of sediment, continually altering streambed configuration and preventing or minimizing the establishment of woody vegetation (Williams 1978, Eschner et al. 1981). The Platte River's open vistas, shallow and broad bed, and adjacent grasslands and wetlands provided ideal habitat for cranes.

Krapu et al. (1984) believe loss of habitat elsewhere in the Central Flyway has lead to increased use of Nebraska staging areas along the Platte River. Less than 20 salt lakes in Texas provide winter roosting habitat for the mid-continent population of sandhill cranes (Tacha et al. 1992). Nine out of every 10 wetlands in the United States have been drained or filled. Loss of strategic wetlands makes cranes vulnerable because they concentrate on these habitats in staging and wintering areas. Loss and degradation of wetlands, especially ecological and hydrological changes in stopover (staging) areas, are the greatest threat to sandhill crane populations (Meine and Archibald 1996).

Major habitat changes have occurred within the Platte River Valley. Diversion of water for agriculture began in the mid 1800s and quickly expanded throughout the Platte River Valley. Today the river is inundated with dams, hydroelectric plants, and irrigation canals, including the Tri-County Canal system and Lake McConaughy. Channel width has been reduced by 80-90% in some areas, and flows reduced by two-thirds (Eschner et al. 1981). Without scouring flows, seedling establishment has not been controlled and vegetation has encroached. Presently, riparian woodlands encompass a broad band of habitat from Kingsley Dam to Grand Island (Frith 1974). Johnson (1994) suggests water development altered flow patterns and disrupted the balance in woodland and channel area from pre-development conditions. His research indicates flow utilization has stabilized, increases in woodland area has ceased, and woodland and channel area have stabilized.

Vegetation encroachment concentrates cranes into fewer roost sites (Tiner 1984). The Platte River serves as the primary roost site of sandhill cranes and is an essential component in their habitat requirements. Cranes roost on the river during the night and use it during the day for loafing and drinking. Cranes prefer a wide-open channel free from disturbance (Reinecke and Krapu 1979). They typically maintain a water buffer between themselves and the shoreline, which helps warn them of the approach of predators and gives them ample time to respond to threats.

Changes in the river are also evident in adjacent meadows that serve as vital habitat for cranes during their staging season. The river and adjacent meadows are hydrologically linked (Hurr 1981, Wesche et al. 1994). With declines in river stage, ground water levels in adjacent fields are affected. As ground water tables drop, the amount of standing water on grassland habitats declines along with moisture making these habitats more suitable for row crops. Nearly 75% of the native meadows and prairies within 5.6 km of the Platte have been tilled or developed for urban sites (Krapu et al. 1982, Currier et al. 1985). Flood control structures, agricultural conversion, and gravel mining have lead to the destruction of native meadows adjacent to the river (Currier et al. 1985).

Proposed water projects are raising concern over additional habitat loss and the impacts they could have on future populations of sandhill cranes staging along the Platte (Norling et al. 1990). The few pristine areas that exist, areas not altered within past years, probably have not been affected to date because of their shallow underground aquifers.

Future water developments may alter or damage this hydrologically-linked system (Frith 1974).

Pristine river segments and their associated wet meadow complexes are sites for the largest crane roosts. The area between Grand Island and Kearney, one of the best remaining segments of the Platte River Valley, contains 59.5% of the wetland meadows and is inhabited by 45.3% of the crane population (Frith 1974). The concentration of cranes in this stretch has probably increased over time due to decreased habitat to the west forcing cranes to shift their roost sites east. In the North Platte River Valley, Iverson et al. (1987) found 20% of staging sandhill cranes roosted off the river on wetlands, typically shallow wet meadows. Maintenance of these habitats in the Platte River Valley may be crucial not only for diurnal use by sandhill cranes but future roosting opportunities.

Crane use of grasslands

Cranes spend approximately 50% of the day in grassland habitats, including wetland meadows, alfalfa fields, and hayfields (Krapu et al. 1982). The use of native grasslands exceeds availability which signifies their importance as habitat for cranes (Iverson et al. 1987). Sites along the North Platte River with at least 1 wetland were utilized 4 times greater by cranes than areas without wetland habitats (Iverson et al. 1987). Wetland meadows play a vital role in social interactions, including reinforcing and establishing new pair bonds (Tacha 1988). These sites are preferred for maintenance activities such as preening, feeding, drinking, and resting (Tacha 1981, Tacha et al. 1987).

Macroinvertebrate populations in grassland habitats are essential for staging sandhill cranes. Though invertebrates represent only 3% of the crane's diet, they are important for maintenance of skeletal structure, body functions, and reproduction (Krapu 1981). Cranes increase their protein content by 10-20% and calcium content by over 500% through the consumption of invertebrates (Krapu 1981). Invertebrates typically acquired in grasslands include: earthworms (*Lumbricidae*), snails (*Gastropoda*), crickets (*Gryllidae*), grasshoppers (*Acrididae*), sowbugs (*Isopoda*), spiders (*Arthropoda*), and adult and larval beetles (*Coleoptera*) (Krapu 1981). Beetle larvae (68%) and snail shells (18%) were the greatest proportion of the crane diet according to Davis (1993*a*), whereas Reinecke and Krapu (1979) found earthworms (39-56%) and snail shells (23-26%) predominated.

Earthworms are more available to cranes in soils that have high water tables because the lack of oxygen keeps them near the surface (Nagel and Harding 1987). It has been suggested that the activity and depth patterns of worms is a result of the combination of temperature and wetness (Gerard 1966). Diapause does not occur if the soil is wet, thus making worms more active (Gerard 1966). Water table depth is an important environmental factor influencing the distribution and abundance of earthworms in native grasslands along the Platte River (Davis 1993*b*). Water table depth and soil moisture are significantly related ($P < 0.05$) to earthworm and scarab beetle populations (Davis 1993*b*). Moderate water table depths, 40-80 cm, which provide soil moisture levels averaging between 25-30%, seem to provide good conditions for earthworm and scarab populations (Davis 1993*b*). Additionally, Savidge and Seibert (unpublished data), showed that beetles and snails are more abundant in fields with increased soil moisture.

Crane use of agricultural land

Cranes spend about 50% of their time in agricultural fields (Krapu et al. 1982). Ninety-nine percent of these fields are planted to corn, and 50% of corn fields used are grazed stubble. Corn represents about 97% of the crane's diet along the Platte River (Reinecke and Krapu 1979, 1986). Ninety percent of each crane's energy is accumulated from the consumption of waste grain. Seventy-five percent of lipids utilized for migration and reproduction are acquired while cranes are in the Platte River Valley (Krapu et al. 1984, Krapu et al. 1985). Approximately 97% of the land adjacent to the river is privately owned (Krapu et al. 1985). Alterations in agricultural practices, including improved harvesting techniques and changes in crop types, may result in less corn. Decreased availability of corn could reduce energy reserves needed by cranes to reach their breeding destinations and participate in reproductive activities.

Behavior and habitat selection

An understanding of sandhill crane habitat needs requires an understanding of their behavior. Behavioral work on common cranes (*Grus grus*), for instance, indicates a foraging preference for areas in proximity to roosting sites even if they are not the richest sources of food (Bautista et al. 1995). Subordinate common cranes may stay in lower quality feeding areas if the benefits of moving to richer zones are outweighed by the cost of energy expended traveling and interacting with dominant cranes. Thus, a good distribution of feeding sites may be crucial in areas with high concentrations of cranes to allow dominant and subordinate cranes to meet their nutritional requirements. Furthermore, since cranes are highly social and frequently interact, focusing on total bird-days may represent a better estimate of the carrying capacity of an area than interference with other birds (Alonso et al. 1994). Thus, any changes in length of stay along the Platte River may indicate possible changes in resources.

Common crane feeding patterns reflect Bayesian foragers which compromise maximizing intake of food to remain in a flock. Sacrificing food intake rate to remain in a foraging flock may provide additional benefits from exploring more patches per day (Alonso et al. 1995). Remaining in a flock may also provide security from predators and other disturbances.

Tradition plays a role in sandhill crane use of different habitat areas (Hoffman 1976, Lovvorn and Kirkpatrick 1982, Melvin and Temple 1983). Areas may be poor in foraging quality, but their familiarity may influence crane selection. At the Jasper-Pulaski Fish and Wildlife Area, sandhill cranes consistently returned to the same cornfields they had been feeding on despite the location of similar fields closer to roost sites (Lovvorn and Kirkpatrick 1982).

Vulnerability

Cranes formerly inhabited the entire Big Bend stretch of the Platte River from Sutherland to Chapman. Now they are concentrated into 3 primary staging areas which increases their vulnerability to disease, environmental conditions, and habitat alteration and loss.

Being gregarious, any actions that isolate individuals may decrease their success in locating food and good roost sites. Communal roosts may serve as information centers which promote the efficient utilization of food resources (Ward 1972). Cranes tend to key in on others in a field and join them because they typically congregate in areas of abundant food supplies. If habitat is further fragmented through loss and degradation, cranes may become more isolated and communication stiffled. Energy and time expended trying to locate food may produce net losses of energy. This may reduce fat reserves, and affect their ability to reach breeding grounds and successfully breed. Improved harvesting practices may also substantially decrease the availability of corn.

Reduction of suitable habitat has serious implications for the future of the sandhill crane. Increased concentrations of cranes may lead to alterations of behaviors due to social stress (Tacha et al. 1992). Crowding also makes cranes susceptible to storms, disease, and other hazards including pesticide contamination (Frith 1974, Currier et al. 1985).

Over 500,000 sandhill cranes are confined to a narrow stretch of the Platte River for 4 to 6 weeks in the spring. In large populations of a species, environmental variation is the main cause of population fluctuation, and can lead to extinction (Leigh 1981). Abiotic factors play a significant role in short and long-term effects on cranes (Meine and Archibald 1996). Environmental conditions including hail, blizzards, and lightning have resulted in losses of 90 to 1000 cranes at a time (Windingstad 1988). Mortality and severe injury arise from collision with power lines, fences, and billboards. Collisions are increased during high winds and fog. The largest loss from collision with powerlines, 51 cranes, was recorded along the Platte River east of Kearney, on 31 March 1981 (Windingstad 1988).

The gregarious nature of cranes on wintering and staging areas also creates ample opportunity for a disease outbreak. Currently, mortality from disease, avian botulism and avian cholera, is most prevalent in adult cranes (Windingstad 1988). Sixty sandhill cranes died of avian cholera at the Basque Del Apache NWR, New Mexico during the winter of 1984-1985 (Windingstad 1988). About 10,000 sandhill cranes used this habitat during the time of the die-off. An avian cholera outbreak in the Rainwater Basin, a few kms from important staging areas for cranes along the Platte, resulted in an estimated 80,000 dead waterfowl in 1981 (Frith 1974). Overcrowding and concentration of individuals are typically cited as variables associated with avian cholera outbreaks (Klukas and Locke 1970). When droughts occur in the Rainwater Basin, waterfowl typically flock to the Platte River which increases the concentration of avifauna and the likelihood of disease. In the springs of 1996 and 1997, 500,000 snow geese (*Chen caerulescens*), thousands of Canada geese (*Branta canadensis*), and cranes were concentrated in the Platte River Valley (personal observation). Reduced flows of the Platte River from manipulation and diversion increase the potential for a disease outbreak.

Additional loss of lowland grassland habitats in the Platte River Valley and North Platte River Valley could be devastating for sandhill cranes. Though some extensive meadow habitats still exist, they are fragmented by fences, dirt roads, trails, and gates. Fences help isolate cranes from human disturbances (Krapu et al. 1984), but they may fragment fields creating edge effects that can alter the function and structure of patches. Cranes may be hesitant to use these patches due to alterations in the habitat. It is crucial that managers understand what characteristics influence crane selection of habitats. Various site characteristics, including grass height, soil permeability, water, and food availability may influence crane use of specific lowland grasslands. Furthermore, landscape scale parameters, such as distance to primary roost and juxtaposition of essential habitat types may also be important. Cranes utilize a complex of habitat types including roosting, wetland, and upland areas. The juxtaposition of roost sites and adjacent off-river habitats may control crane distribution and abundance (Folk and Tacha 1990) and lead to chronic use of some sites. According to Iverson et al. (1987), 90% of the variability in the distribution of cranes along the Platte may be related to the composition and juxtaposition of essential habitat types. It is important to identify what components, within and adjacent to wetland meadows, attract sandhill cranes so future management efforts can be geared at maintaining these habitat complexes. Unless loss of these habitats is controlled, crowding will increase and available food supplies may become inadequate (Sidle et al. 1989). With roughly 80% of the sandhill crane population using the Platte River in the spring, the loss of habitat quality at this site over time constitutes the most critical threat to the species (Meine and Archibald 1996).

CHAPTER 2: LOCAL SCALE ANALYSIS OF SANDHILL CRANE USE OF LOWLAND GRASSLANDS ALONG THE PLATTE RIVER, NEBRASKA

INTRODUCTION

Eighty percent of the world's sandhill crane (*Grus canadensis* spp.) population annually stage along the North Platte and Platte Rivers of Nebraska from late February to mid-April (Krapu et al. 1982). Stopover sites like the Platte are traditional, selected for, and used on an annual basis because they provide an abundant food supply and good roosting habitat (Melvin and Temple 1982). Cranes occupy a mosaic of habitats while along the Platte River including grasslands; wet meadows; corn, alfalfa, and winter wheat fields. Half of their time is allocated to lowland grasslands and tame haylands of alfalfa; invertebrates consumed in these areas represent about 3% of the crane's diet (Reinecke and Krapu 1979, 1986), but they increase crane protein intake by 10-20% and calcium intake by >500% (Krapu 1981). Cranes function at a net loss of energy while searching for invertebrates to increase their protein and calcium content (Krapu 1981). Lowland grasslands, including native grassland/wet meadow complexes, are also important habitat for loafing, socializing, and for obtaining water.

Major habitat changes that affect cranes have occurred within the Platte River Valley over the past century. Peak river flows have been reduced by 68% and mean discharge by 66% due to water development and ground water pumping for irrigation and consumption (Currier et al. 1985). Without seasonal scouring flows, tree seedlings have established along the banks and sandbars of the Platte and aided in reducing channel widths from 65-90% in some areas (Williams 1978, Currier et al. 1985). Changes in the hydrology of the Platte River also affect adjacent wet meadows because a hydrologic link exists between these habitats (Hurr 1981, Wesche et al. 1994). Approximately 75% of lowland grasslands, including wet meadows, within 5.6 km of the Platte have been converted to other land uses, primarily agriculture, which is facilitated by reduced water levels (Krapu et al. 1982). Macroinvertebrates are also influenced by hydrology changes. The location of earthworms is a result of soil temperature and wetness (Nagel and Harding 1987). Earthworms in soils with high water tables are more accessible to cranes because oxygen deprivation drives them to the surface.

The loss and potential degradation of habitat in the Platte River Valley has serious implications for the future of the sandhill crane. Crowding makes cranes susceptible to storms, disease, and other hazards (Frith 1974, Currier et al. 1985).

Considering the importance of lowland grasslands to cranes, relatively few studies have been conducted on factors influencing field selection. Research has focused on the composition of habitats needed and preference in field use, but quantification of within field characteristics affecting crane use has been limited. The goal of this study was to identify and quantify local scale variables influencing crane selection of lowland grasslands in the Platte River Valley. Because sandhill cranes are known to use marshes and other wetlands along migration routes (Frith 1974, Krapu 1983, Iverson et al. 1987, and Meine and Archibald 1996), I predicted cranes would be attracted to fields with standing water for drinking, preening, and social bonding. Crane abundance should be inversely related to depth to ground water because invertebrates are potentially more accessible and abundant in areas with higher ground water tables (Nagel and Harding 1987; J.A. Savidge and T.F. Seibert, University of Nebraska-Lincoln, unpublished data). Eastern greater sandhill cranes used fields with visual obstruction measures < 18 cm at Jasper-Pulaski (Lovvorn and Kirkpatrick 1982). Thus, I predicted cranes would be attracted to fields with low vegetation structure possibly due to decreased predation, increased mobility, better probing conditions, and increased access to invertebrates. Since cranes have been shown to be sensitive to disturbance (Norling et al. 1992), they should prefer larger fields. Lastly, I wanted to determine if grassland management, specifically, grazing and haying affected crane use.

An understanding of habitat parameters essential to sandhill cranes is particularly important because of habitat changes over the past century that threaten crane use of the Platte River Valley. Information on factors affecting crane use of the remaining lowland grasslands will aid grassland managers and help in habitat restoration efforts.

STUDY AREA

Originating from snowmelt in the Rocky Mountains of Colorado, the Platte River flows east through Nebraska until it merges with the Missouri River on the eastern border of the state. The Platte River Valley is covered by alluvial deposits overlaying thick layers of sand and gravel that contain a major aquifer (Krapu 1981). The river floodplain is characterized by forest, shrub, and sandbar vegetation with prairies and cultivated fields on the river terraces (Krapu 1981).

An estimated 97% of the land in the Platte River Valley is privately owned. Agriculture accounts for 53% (30,409 ha) of the land, while 23% (13,607 ha) is grassland,

and 7% (4,010 ha) is alfalfa (Krapu 1981). The rest of the area is either river habitat, which is mostly wooded, commercial or residential developments, or roads.

This study was conducted during spring 1996 and 1997 in primary staging area 1 (Krapu 1981), which extends from Grand Island to Kearney, Nebraska (Figure 2). Two-thirds of the mid-continent population of sandhill cranes stage along this 72-km stretch of river (Currier et al. 1985, Grooms 1992). Several conservation reserves have been established within primary staging area 1 that are managed primarily for cranes. My study sites, 44 in 1996 and 49 in 1997, were on several of these reserves as well as on private land. Sites were located within 5 km north and south of the Platte River since over 90% of the cranes occur within this distance of the main channel (Krapu 1981). Precipitation for spring 1996 and 1997 was significantly below normal, except for February 1997 which was average (NOAA 1996 and 1997, National Climatic Data Center, Grand Island, Nebraska, USA).

Lowland grasslands, including wet meadows and hayfields, were my primary focus. Wet meadows include grazed or hayed grasslands with ribbons of wetland species in intermittent relic channel areas (Krapu 1981). Dominant species on mesic sites include sedges (*Carex* spp.), bulrushes (*Sciurpus* spp.), spikesedge (*Eleocharis* spp.), switch grass (*Panicum virgatum*), and prairie cordgrass (*Spartina pectinata*). On xeric sites, little barley (*Hordeum pusillum*), blue grama (*Bouteloua gracilis*), Japanese brome (*Bromus japonicus*), and downy brome (*Bromus tectorum*) are most common. Historically, bison (*bison bison*) and fire were major disturbances on these grasslands, but today farmers control most of the land. The majority of grasslands are managed with haying and/or cattle grazing.

METHODS

Habitat sampling

Potential study sites were identified from maps delineating lowland grasslands within the study area. Permission from landowners was a large determinant of sites chosen. Transect sampling was used to obtain environmental data. The number of transects and sampling points on each transect were proportional to the size and shape of each site. I sampled 50 points per field in 1996 and 40 points per field in 1997. To increase my sample size for tall-idle fields, 5 lowland grassland sites were added in 1997. In 1996, my vegetation measurements at each sample point included visual obstruction, which is a combination of vegetation height and density (Robel et al. 1970); litter depth (defined as the amount of dead-decomposing vegetation on the ground); and percentages of cover, live, wood, forb, and grass using a Daubenmire frame (Daubenmire 1959). However, percent cover and grass were inappropriately measured in 1996 and not included in the analyses. Based on preliminary analysis of the 1996 data and apparent correlations between several of my independent variables, I focused on quantifying percent cover, visual obstruction, and litter depth in 1997.

I used soil augers to drill temporary wells to quantify relative water table depth during the study. The total number of wells drilled depended on the sites' topography; 3 wells were installed in a relatively flat site whereas a rolling site had 6. I used 3.2 cm PVC pipe for wells, which were installed to a maximum depth of 152 cm (roughly 5 ft). PVC caps were placed on both ends of the pipe with holes or slits in the top to allow for changes in barometric pressure (D.O. Carlson, U.S. Fish and Wildlife Service, personal communication). The bottom 61 cm of each well was cut with horizontal slits to allow water to flow in and out of the well. Holes should be made in the bottom of each well to assure no residual water remains if the water table drops below the level of the bottom of the well. I installed the wells during April 1996 and read them using an electronic measuring device (Henzey 1991) between 1-6 May and 7-15 June. Since wells were only drilled to a maximum depth of 152 cm, many of them were dry during the second sampling and henceforth those data were not used. In 1997, wells were read between 11-13 March. I read wells in the shortest time possible to minimize changes in water level from extraneous events including rainfall and changes in river stage. Readings were taken when permanent water table recorders indicated stable conditions.

In 1996, I used a digital soil moisture probe (Model 200, Aquaterr Instruments, Fremont, California, USA) to quantify relative moisture levels in the study sites. Ten readings (in fields with 3 wells) or 5 readings (in fields with 6 wells) were taken around each well for a total of 30 readings per field. This method was not continued in 1997 because of high variability between readings.

In 1996 and 1997, I flew once during the staging season and took photographs of study sites through the porthole in the bottom of the plane. Amount of standing water on fields was quantified using the software package NIH Image (National Institute of Health). Image was also used to determine the size of each study site from 1995 aerial photos.

Identifying field boundaries for my study sites was difficult because adjacent lands were often under similar management practices. I used fence rows and land ownership as field boundaries since landowners often hayed or grazed their fields at different times of the year and/or stocked them at different densities.

Crane censuses

I flew bi-weekly flights in a fixed-wing Cessna aircraft from late February to mid-April. Fifteen aerial censuses were conducted in each year with an additional 13 drive surveys in 1997. Flight initiation was alternated between airports in Grand Island and Kearney and between the north and south side of the channel. I flew 4 transects during each census, 2 north and 2 south of the main channel, covering a total width of 10 km. The plane was flown at 305 m to maximize visibility and minimize disturbance to cranes (T.F. Seibert, University of Nebraska-Lincoln, personal communication). Numbers and locations of cranes were recorded on 1995 aerial photos.

To increase crane observations and better account for their variability in field use, I supplemented aerial censuses with bi-weekly drive surveys in 1997. Drive surveys focused on my study sites, whereas, I recorded all fields used within 5 km of the main channel during aerial surveys. The starting point of each drive survey was rotated. Drive and flight surveys were conducted between 1000-1600 hrs, when crane use of lowland grasslands is greatest.

I also conducted ground surveys in 1997 to identify if any of the study sites served as secondary roost sites, fields cranes congregate on before heading out to feed in the morning or before coming into the river at night. These sites are usually lowland grasslands within 0.8 km of the channel (Wheeler and Lewis 1972). Ground surveys were conducted before 0900 and after 1700 hrs. I censused every study site at least twice to determine if they served as secondary roost sites and increased efforts during the height of the migration when opportunities for seeing cranes is optimum.

Data analyses

Estimates of birds for 1996 and 1997 were divided into an early and late period, for possible temporal affects, and also combined for the entire season. Early period for 1996 and 1997 represented from the start of crane migration until just before the height in mid-March. Late period was from mid-March until mid-April when most cranes have left. Analyses included only crane data collected from aerial and drive surveys for my study sites. The range of mean square errors was narrow (2.86-4.43), and thus I combined drive and flight data for that year. Years were not combined due to different methodology and environmental conditions.

Outliers in the data set were identified using diagnostics in Proc Logistic (SAS Institute Inc. 1990). Secondary roost sites that were influential observations ($n \leq 2$) were removed from analyses because cranes typically did not use these fields in the daytime.

A few large crane observations created high variability in my estimates causing overdispersion in the data. Thus, several different statistical techniques were employed. I initially tried proportion of crane use as my dependent variable, using the Logit model, to overcome the problem with overdispersion (Proc Genmod with logit link; SAS Institute Inc. 1990). The proportion of use was determined by dividing the total number of times a site was censused by the number of times cranes were observed on a study site. This accounted for the frequency of crane use of study sites but not their abundance. Thus, I tried multinomial categorical analysis with the proportional odds model because it allowed grouping of cranes into categories of high, medium, and low use (Proc Logistic; SAS Institute Inc. 1990). Insufficient sample sizes prohibited use of this model. A categorical approach (Proc GLM; SAS Institute Inc. 1990) was also attempted. This approach accounted for crane numbers and provided meaningful results, but delineating cut-off points for the categories was difficult.

Final analyses involved simple linear and multiple regression to examine the relationships between crane use and environmental variables (Proc GLM; SAS Institute Inc. 1990). Regression analyses provided similar results to the categorical GLM analyses and Logit model. A standard log plus one transformation was used on the count data (Zar 1974). Crane counts were the average number of cranes censused on a study site for a given period. Environmental variables for the multiple regression analyses were entered into the model based on importance from simple linear regression analyses for the respective years. Independent variables with a Pearson correlation coefficient ≥ 0.7 were not included in the same model.

I used independent *t*-tests to compare water table depth, field size, visual obstruction, and amount of standing water between grazed and hayed fields. Chi-squared analyses were used to analyze crane use of grazed vs hayed fields. Untransformed crane counts and total area for each management type were used to calculate expected crane distributions. A 3:1 ratio existed between area of grazed fields vs hayed fields. Significance was set at $P \leq 0.05$ for all analyses.

RESULTS

Cranes were present (≥ 1 crane observed on a study site during a census) on 36%

($n = 16$) of the study sites during 1996, whereas in 1997, using a combination of drive and aerial surveys, 75% of the study sites ($n = 37$) had cranes present (Appendix A). Twenty percent and 32% of sites had cranes during the early and late periods in 1996 and 53% and 75% had cranes in 1997, respectively. The largest crane estimate, 11,300, was recorded on a grazed study site with a field size of 106.6 ha.

Of lowland grasslands used during diurnal hours, cranes preferred grazed over hayed fields in 1996 and 1997 for the entire season ($X^2_1 = 1341$, $P \leq 0.001$; $X^2_1 = 1793$, $P \leq 0.001$, respectively). The average number of cranes counted for the entire 1996 season was 5,386 on 1,126 ha of grazed land while 211 cranes were on 367 ha of hayed land. For 1997, 8,273 cranes were on grazed land while 471 were on hayed land. The largest crane estimate on a single occasion for a grazed study site in 1996 was 9,800 and only 1,700 for a hayed site even though both sites were 65 ha. There was no significant difference in visual obstruction, field size, or depth to ground between grazed and hayed fields for both years. In 1996, amount of standing water was higher on grazed than on hayed fields ($t_{28} = 2.75$, $P = 0.01$).

Approximately 10 study sites were identified as secondary roost sites. Diurnal use of these fields did occur, but use increased during crepuscular hours. Six of these sites were hayed and 4 grazed, but all secondary roost sites were adjacent to the river indicating field location was more important than management type.

Habitat variables

Vegetation-- The range of litter depth measurements was greater in 1997 than 1996 (Table 1 and 2), possibly due to the tall, idle fields added in 1997. However, simple linear regression indicated litter depth did not significantly influence crane use of lowland grasslands in either year. There was no difference in means for visual obstruction measures for 1996 vs 1997 ($t_{89} = 1.99$, $P = 0.24$), but there was greater variability in visual obstruction measures in 1997. Visual obstruction was not related to crane numbers during 1996 (Table 1), but in 1997, with the inclusion of the 5 taller fields, visual obstruction was negatively related to crane numbers in the late and entire periods ($P \leq 0.001$; Table 2, Figure 3). In 1997, percent cover was positively related to crane numbers in lowland grasslands in the early period ($P = 0.05$; Table 2). Percent live vegetation, measured in 1996, also was positively related to crane use of study sites in the early period ($P = 0.05$; Table 1). Additional vegetation measures sampled in 1996 (percentages of litter, forb, bare, and wood) did not influence crane use.

Water-- In 1996, one field had a large amount of water (18.6 ha) due to an ice jam causing flooding. With this field included in our simple linear regression analyses, amount of standing water influenced cranes in the early period ($P = 0.004$). When omitted, standing water was not significant (Table 1). In 1997, crane numbers were positively related to the amount of standing water throughout all periods (Table 2, Figure 4). Though wells were read in different months, water table depths were similar for the two years (Pearson correlation = 0.90). Depth to the water table influenced crane numbers in all periods for 1996 and 1997 (Table 1 and 2). As depth to the water table within a site increased, crane use decreased (Figure 5). Percent moisture was positively related to crane use for all periods in 1996 (Table 1). There was a significant negative relationship between depth to the water table and amount of standing water on fields in 1996

($P = 0.005$) and 1997 ($P < 0.001$). The relationship was still significant in 1996 when the outlier for standing water was removed ($P = 0.027$).

Field size-- Study sites ranged from 2.6-132.6 ha, and field size was positively related to crane numbers in lowland grasslands in both 1996 and 1997 (Table 1 and 2).

Multiple regression model

Multiple regression models explained 0.30-0.59 of the variation in crane numbers on lowland grasslands for 1996 and 1997, respectively. When the outlying field for standing water was removed, depth to the water table was the only environmental variable retained in the models in 1996 (Table 3).

Early period results for 1997 identified a significant interaction between water and cover. The interaction was an artifact of 3 non-representative fields exerting excessive influence. The interaction of water and cover was not significant for late and entire periods. Additionally field size and standing water were correlated in 1997. Since censuses indicated cranes concentrated around standing water, I included standing water in multiple regression analyses rather than field size. Variables retained in the 1997 models included depth to water table, standing water, and visual obstruction (Table 4).

DISCUSSION

Depth to the water table was significant throughout the 1996 period and explained up to 40% of the variability in crane usage of lowland grassland study sites. Up to 26% of the variability in crane use of these habitats could be explained by depth to the water table in the 1997 analyses. The greatest numbers of cranes were recorded on fields with shallow water tables. Fields with water tables >100 cm had little crane use.

Water table depth influences the microhabitat within lowland grasslands and thus affects cranes. Greater numbers of soil invertebrates are reported in areas with water tables between 40-80 cm (Davis and Vohs 1993*b*, and Nagel and Harding 1987). These water tables provide adequate moisture levels for organisms including earthworms (*Lumbricidae*) and beetle larvae (*Coleoptera*), which constitute a major proportion of invertebrates consumed by cranes (Reinecke and Krapu 1986, Nagel and Harding 1987, Davis and Vohs 1993*b*). Additionally, shallow water tables, <40 cm, may drive organisms including earthworms to the surface making them more available (Nagel and Harding 1987). Shallow water tables may also allow easier probing for invertebrates. Invertebrate availability is important because they help balance the diet of cranes by adding certain amino acids and calcium that are deficient in corn (Krapu 1981).

Though standing water was not significant in 1996 it was significant in 1997, with greater numbers of cranes on fields with more water. Of the 19 fields in 1996 with standing water, all except the one with 18.6 ha had < 2 ha. The lack of significance in 1996 could have been a result of the lack of variation in standing water on fields and limited crane observations. Twenty-five fields had standing water present in 1997, and there were no outliers. Two factors may have contributed to the greater distribution of water on lowland grasslands during 1997. Below normal precipitation was recorded in the area for the 1996 period, while precipitation was average for February 1997. Furthermore, a hydrologic link exists between the river and adjacent habitats (Hurr 1981, Wesche et al. 1994). River flows for February, March, and April at Kearney and Grand Island were significantly higher in 1997 than in 1996 ($P \leq 0.013$).

I found a significant negative relationship in both years between ground water and surface water, indicating as depth to the water table increases amount of standing water on a field decreases. Cranes key in on standing water, which is important for maintenance and also social activities including pair bonding (Iverson et al. 1987, Tacha 1988). Sections with wetlands in the North Platte River Valley had 4 times greater use than sections without (Iverson et al. 1987). In North Dakota cranes typically sought fresh water, fens and dugouts, during midday (Krapu 1983). Cranes may save time and energy by selecting fields with standing water instead of traveling to the river for water.

Based on the simple linear regression analyses, field size also positively influenced crane use of lowland grasslands. However, amount of standing water and field size were correlated in 1997; as field size increased, the amount of standing water within a site increased. When field size was substituted for amount of standing water in the 1997 multiple regression, similar R squares were obtained. It is difficult to separate the relative importance of each. I consistently observed cranes concentrated around standing water in fields, but since cranes are gregarious during the staging season, they may prefer larger fields in general. Research on common cranes (*Grus grus*) has indicated subordinate cranes may avoid dominant cranes by staying in lower quality feeding areas (Bautista et al. 1995). However, larger fields may allow dominant and subordinate cranes to forage together without interference. Identifying fields based on fence lines and land ownership was somewhat arbitrary; the composition of habitats around our study sites may better reflect crane selection.

Cranes prefer vegetation lower than 25 cm in pastures, hayfields, and other grasslands on staging areas in Indiana (Lovvorn and Kirkpatrick 1982). In 1996, our tallest field had a visual obstruction measure of 24.8 cm. We had 6 fields in 1997 with visual obstruction measures ≥25 cm and a negative relationship between crane numbers and visual obstruction was found. Cranes did not use study sites where visual obstruction measures were greater than 30 cm. Tall-dense vegetation may impair foraging opportunities and mobility (Lovvorn and Kirkpatrick 1982) and may serve as cover for potential predators. During inclimate weather, though, cranes were observed using fields with taller vegetation possibly as thermal cover.

Our heaviest used study sites for both years were pastures. Though no difference was found in most environmental variables between grazed and hayed fields, considerable variation existed for all measures in grazed fields. Amount of standing water, though, was significantly different in 1996 with more water occurring on grazed fields. Fields that have shallow water tables are wetter making haying practices difficult, and thus they are usually grazed. All of my study sites with water tables <30 cm were managed with grazing. Previous research has indicated that of native grasslands used, 94% are grazed fields (Krapu 1981). Pastures that contain temporary or semipermanent palustrine wetlands and are adjacent to active channels provide the best habitat (Tacha et al. 1994). Grazing helps keep vegetation stature down, and it was not unusual to see invertebrates, including beetles and earthworms, associated with cow patties. Additionally the wetter conditions, in general, may encourage greater invertebrate diversity and availability. Many pastures have sloughs with open water and adjacent upland areas within them. Pastures that lack standing water typically have stock ponds that cranes also use.

With 80% of the entire sandhill crane population staging in Nebraska, sandhill cranes are particularly vulnerable to changes in their habitat. Because of reduced flows and subsequent changes in the channel, suitable sandhill crane roosting habitat has drastically declined (Faanes and LeValley 1993). With thousands of waterfowl now using the river valley, including Canada geese (*Branta canadensis* sp.) and snow geese (*Chen caerulescens*), and the possibility of improved harvesting techniques for agricultural crops, the availability of waste grain may also become limiting.

Cranes tend to exploit field interiors (McIvor and Conover 1994), but as the staging season progressed, cranes shifted to the edges of fields (T.L. VerCauteren, unpublished data). These shifts were most prevalent in agricultural fields. The general explanation is that cranes become acclimated to disturbances. However, I noticed that cranes near habitat edges were very alert and would typically run or fly from disturbances including people and cars on nearby roads. I also noticed cranes using corn fields further and further from the river, up to 13 km south of the channel and approximately 8 km north (as far as Highway 30), as the staging season progressed. This movement may have been a result of food depletion. A good distribution of feeding sites may be crucial in areas with high concentrations of cranes allowing dominant and subordinate cranes to meet their nutritional requirements. Cranes typically concentrate their activities within 5 km of the main channel (Krapu 1981), and this extended perpendicular movement away from the channel may be energetically expensive.

Perhaps the most common habitat component missing from crane staging areas in Nebraska is wet meadows (Tacha et al. 1994). These habitats are essential for daily crane use, but they may also provide future roosting sites. Along the North Platte where the river does not provide suitable roost sites due to vegetation encroachment, cranes will use wet meadows for primary roost sites (Iverson et al. 1987).

Research has indicated groundwater levels in wet meadows directly respond to alterations in river stage (Hurr 1981, Wesche et al. 1994). Adequate river flows that encourage standing water on grasslands, shallow water tables, and a good moisture regime are essential to protect these grassland habitats.

MANAGEMENT RECOMMENDATIONS

Adequate flows in the Platte River are needed to encourage standing water on adjacent grasslands and to maintain open roosting habitats. In spring of 1997, flows at Kearney and Grand Island averaged 2000+ cfs. These flows allowed cranes to select for greater amounts of standing water and may suggest a minimum for flows needed. With a loss of 75% of lowland grasslands within 5.6 km of the channel (Currier et al. 1985), maintenance and restoration of these habitats is essential. Sandhill crane fidelity to certain fields may reinforce the need to restore and maintain existing grassland habitats. Length of the staging season in the Platte River Valley should be monitored to track potential changes in resources.

Only the widest channels with sufficient adjacent wet meadow habitats are being occupied by cranes, the rest have been abandoned (Faanes and LeValley 1993). An eastward shift in sandhill crane use of the Big Bend is possibly related to vegetation encroachment in the upper reaches and habitat management in the lower reaches (Faanes and LeValley 1993). Tree clearing efforts initiated in 1982 correspond with a 5-fold increase in sandhill cranes roosting in this reach between 1984-1989 (Faanes and LeValley 1993).

A variety of management practices should be incorporated in the Platte River Valley that encourage not only cranes, but also the other native flora and fauna. Current management practices of haying, grazing, and burning help keep vegetation stature low and set back succession, thus benefitting cranes. However, constant haying, grazing, and burning may affect organic matter which can impact invertebrate populations (Edwards and Bohlen 1996, Curry 1998). Historically, chaotic events helped shape and alter the landscape encouraging diversity. Managers should rotate management practices on fields to encourage a variety of habitat conditions within the landscape. Constant management techniques, with the same intensities, may encourage monocultures, dominated by a few species. Adaptive management, whereby management efforts are monitored and changes made as necessary would serve to encourage native diversity. However, with 97% of the land privately owned in Nebraska, a collaborative effort between all stakeholders is essential.

LITERATURE CITED

Alonso, J.C., J.A. Alonso, and L.M. Bautista. 1994. Carrying capacity of staging areas and facultative migration extension in common cranes. Journal of Applied Ecology 31:212-222.

______, ______, ______, and R. Munoz-Pulido. 1995. Patch use in cranes: a field test of optimal foraging predictions. Animal Behavior 49:1367-1379.

Bautista, L.M., J.C. Alonso, and J.A. Alonso. 1995. A field test of ideal free distribution in flock-feeding common cranes. Journal of Animal Ecology 64:747-757.

Boise, C.M. 1976. Breeding biology of the Lesser Sandhill Crane *Grus canadensis canadensis* (L.) on the Yukon-Kuskokwim Delta, Alaska. Thesis, University of Alaska, Fairbanks, Alaska, USA.

Currier, P.J., G.R. Lingle, and J.G. VanDerwalker. 1985. Migratory bird habitat on the Platte and North Platte Rivers in Nebraska. The High Pressure Press, Marquette, Nebraska, USA.

Curry, J.P. 1998. Factors affecting earthworm abundance in soils. Pages 37-64 *in* C.A. Edwards, editor. Earthworm ecology. Soil and Water Conservation Society, Ankeny, Iowa, USA.

Daubenmire, R. 1959. A canopy-coverage method of vegetational analysis. Northwest Science 33:43-63.

Davis, C.A., and P.A. Vohs. 1993*a*. Role of macroinvertebrates in spring diet and habitat use of sandhill cranes. Transactions of the Nebraska Academy of Sciences XX:81-86.

______, and ______. 1993*b*. Availability of earthworms and scarab beetles to sandhill cranes in native grasslands along the Platte River. Prairie Naturalist 25:199-212.

Edwards, C.A., and P.J. Bohlen. 1996. The influence of environmental factors on earthworms. Pages 134-154 *in* C.A. Edwards and P.J. Bohlen, editors. Biology and ecology of earthworms. Third edition. Chapman & Hall, New York, New York, USA.

Eschner, T.R., R.F. Hadley, and K.D. Crowley. 1981. Hydrologic and morphologic changes in channels of the Platte River basin: a historical perspective. Geological Survey Open-file Report 81-1125.

Faanes, C.A., and M.J. LeValley. 1993. Is the distribution of Sandhill Cranes on the Platte River changing? Great Plains Research 3:297-304.

Folk, M.J., and T. C. Tacha. 1990. Sandhill crane roost site characteristics in the North Platte River Valley. Journal of Wildlife Management 54:480-488.

Frith, C.R. 1974. The ecology of the Platte River as related to Sandhill Cranes and other waterfowl in south central Nebraska. Thesis, Kearney State College, Kearney, Nebraska, USA.

Gerard, B.M. 1966. Factors affecting earthworms in pastures. Journal of Animal Ecology 34:235-252.

Grooms, S. 1992. The cry of the sandhill crane. North Word Press, Minocqua, Wisconsin, USA.

Henzey, R.J. 1991. A simple, inexpensive device for measuring shallow groundwater levels. Journal of Soil and Water Conservation 46:304-306.

Hoffman, R. 1976. Field use by Sandhill Cranes in southern Michigan. Pages 35-43 *in* J.C. Lewis, editor. Proceedings of the 1975 International Crane Workshop, Stillwater, Oklahoma, USA.

Hurr, T. 1981. Groundwater hydrology of the Mormon Island Crane Meadows wildlife area, near Grand Island, Hall County, Nebraska. U.S. Geological Survey Open-file Report 81-1109.

Iverson, G.C., P.A. Vohs, and T.C. Tacha. 1987. Habitat use by mid-continent sandhill cranes during spring migration. Journal of Wildlife Management 51:448-458.

James, E. 1823. Account of an expedition from Pittsburgh to the Rocky mountains. University Microfilms, Ann Arbor, Michigan, USA.

Johnsgard, P.A. 1983. Cranes of the World. Indiana University Press, Bloomington, Indiana, USA.

______. 1991. Crane music: a natural history of American cranes. Smithsonian Institution Press, Washington and London.

Johnson, W.C. 1994. Woodland expansion in the Platte River, Nebraska: patterns and causes. Ecological Monographs 64:45-84.

Klukas, R.W., and L.N. Locke. 1970. An outbreak of fowl cholera in Everglades National Park. Journal of Wildlife Diseases 6:77-79.

Krapu, G.L. 1981. The Platte River ecology study. U.S. Fish and Wildlife Service, Northern Prairie Wildlife Research Center, Jamestown, North Dakota, USA.

______. 1983. Use of staging areas by sandhill cranes in the mid-continent region of North America. Pages 451-462 *in* J.C. Lewis, editor. Proceedings of the 1983 International Crane Workshop, Bharatpur, India.

______, K.J. Reinecke, and C.R. Frith. 1982. Sandhill cranes and the Platte River. Transactions of the North American Wildlife Natural Resource Conference 47:542-552.

______, D.E. Facey, E.K. Fritzell, and D.H. Johnson. 1984. Habitat use by migrant Sandhill Cranes in Nebraska. Journal of Wildlife Management 48:407-417.

______, B. Gehring, D.E. Facey, and M.I. Meyer. 1985. A resource inventory of sandhill crane staging areas in Nebraska. Pages 364-370 *in* J.C. Lewis, editor. Proceedings of the International 1985 Crane Workshop, Grand Island, Nebraska, USA.

Leigh, E.G. Jr. 1981. The average lifetime of a population in a varying environment. Journal Theoretical Biology 90:213-239.

Lewis, J.C. 1977. Sandhill crane *Grus canadensis*. Pages 5-43 *in* G.C. Sanderson, editor. Management of migratory birds in North America, International Association Fish Wildlife Agencies, Washington, D.C., USA.

Lovvorn, J.R., and C.M. Kirkpatrick. 1982. Field use by staging Eastern Greater Sandhill Cranes. Journal of Wildlife Management 46:99-108.

McIvor, D.E., and M.R. Conover. 1994. Habitat preference and diurnal use among Greater Sandhill Cranes. Great Basin Naturalist 54:329-334.

Meine, C.D., and G.W. Archibald, Editors. 1996. The cranes: Status survey and conservation action plan. IUCN, Gland, Switzerland, and Cambridge, United Kingdom. 294pp. Northern Prairie Wildlife Research Center Home Page. Http://www/npwrc.usgs.gov/resource/distr/birds/cranes.htm (Version 02Mar98).

Melvin, S.M., and S.A. Temple. 1982. Migration ecology of Sandhill Cranes: a review. Pages 73-87 *in* J.C. Lewis, editor. Proceedings of the 1981 International Crane Workshop, Tavernier, Florida, USA.

______, and ______. 1983. Fall migration and mortality of Interlake, Manitoba, Sandhill Cranes in North Dakota. Journal of Wildlife Management 47:805-817.

Nagel, H.G., and R. Harding. 1987. Effects of water table depth and soil factors on invertebrate populations. Prairie Naturalist 19:251-258.

Norling, B.S, S.H. Anderson, and W.A. Hubert. 1990. The influence of water depth, unobstructed area, and disturbance features on selection of roost sites by sandhill cranes along Platte River, Nebraska. U.S. Fish and Wildlife Service, Wyoming Cooperative Fish and Wildlife Research Unit, Laramie, Wyoming, USA.

______, ______, and ______. 1992. Roost sites used by sandhill cranes staging along the Platte River Nebraska. Great Basin Naturalist 52:253-261.

Reinecke, K.J., and G.L. Krapu. 1979. Spring food habits of sandhill cranes in Nebraska. Pages 13-20 *in* J.C. Lewis, editor. Proceedings of the 1978 International Crane Workshop. Rockport, Texas, USA.

______, and ______. 1986. Feeding ecology of sandhill cranes during spring migration in Nebraska. Journal of Wildlife Management 50:71-79.

Robel, R.J., J.N. Briggs, A.D. Dayton, and L.C. Hulbert. 1970. Relationships between visual obstruction measurements and weight of grassland vegetation. Journal of Range Management 23:295-297.

Safina, C. 1993. Population trends, habitat utilization, and outlook for the future of the Sandhill Crane in North America: A review and synthesis. Bird Populations 1:1-27.

SAS Institute Inc. 1990. SAS/STAT user's guide, vol. 1 & 2. Version 6, 4th ed. SAS Statistical Institute, Cary, North Carolina, USA.

Sidle, J.G., E.D. Miller, and P.J. Currier. 1989. Changing habitats in the Platte River Valley of Nebraska. Prairie Naturalist 21:91-104.

Soine, P.J. 1982. Roost habitat selection by Sandhill Cranes in central North Dakota. Pages 88-94 *in* J. C. Lewis, editor. Proceedings of the 1981 International Crane Workshop, Tavernier, Florida, USA.

Tacha, T.C. 1981. Behavior and taxonomy of Sandhill Cranes from mid-continental North America. Dissertation, Oklahoma State University, Stillwater, Oklahoma, USA.

______. 1984. Preflight behavior of Sandhill Cranes. Wilson Bulletin 96:471-477.

______. 1988. Social organization of Sandhill Cranes from mid-continental North America. Wildlife Monographs 99:1-37.

______, D.E. Haley, and P.A. Vohs. 1989. Age of sexual maturity in Sandhill Cranes from mid-continental North America. Journal of Wildlife Management 53:43-46.

______, S.A. Nesbitt, and ______. 1992. Sandhill crane. The birds of North America. 31:1-19.

______, ______, and ______. 1994. Sandhill Crane. Pages 76-94 *in* T.C. Tacha and C.E. Braun, editors. Migratory Shore and Upland Game Bird Management in North America. International Association Fish and Wildlife Agencies, Washington, D.C., USA.

______, and P.A. Vohs. 1984. Some population parameters of Sandhill Cranes from mid-continental North America. Journal of Wildlife Management 48:89-98.

______, ______, and G.C. Iverson. 1984. Migration routes of sandhill cranes from mid-continental North America. Journal of Wildlife Management 48:1028-1033.

______, ______, and ______. 1987. Time and energy budgets of Sandhill Cranes from mid-continental North America. Journal of Wildlife Management 51:440-448.

Tiner, R.W. Jr. 1984. Wetlands of the United States: current status and recent trends. National Wetlands Inventory, U.S. Department of the Interior.

VanDerwalker, J.G. 1983. Preservation of crane habitat on the Platte River, Nebraska. Pages 425-437 *in* J.C. Lewis, editor. Proceedings of the 1983 International Crane Workshop, Bharatpur, India.

Walkinshaw, L.H. 1981. The Sandhill Cranes. Pages 151-162. *in* J.C. Lewis and H. Masatomi, editors. Crane Research Around the World, International Crane Foundation, Baraboo, Wisconsin, USA.

Ward, P. 1972. The function of communal roosts: relevance of mixed roosts. Ibis 114:531-536.

Warren, G.K. 1858. Explorations in Nebraska. Annual Report of the Secretary of War. Serial No. 975.

Wesche, T.A., Q.D. Skinner, and R.J. Henzey. 1994. Platte River Wetland Hydrology Study. U.S. Bureau of Reclamation, Mills, Wyoming, USA.

Wheeler, R.H., and J.C. Lewis. 1972. Trapping techniques for sandhill crane studies in the Platte River Valley. U.S. Bureau of Sport Fisheries and Wildlife, Resource Publication 107.

Williams, G.P. 1978. The case of the shrinking channels-the North Platte and Platte Rivers in Nebraska. Geological Survey Circular 781.

Windingstad, R.M. 1988. Nonhunting mortality in Sandhill Cranes. Journal of Wildlife Management 52:260-263.

Winker, K., D.W. Warner, and A.R. Weisbrod. 1992. Migration of woodland birds at a fragmented inland stopover site. Wilson Bulletin 104:580-598.

Zar, J.H. 1974. Data transformations. Pages 182-189 *in* W.E. McElroy and C.P. Swanson, editors. Prentice-Hall, Englewood Cliffs, New Jersey, USA.

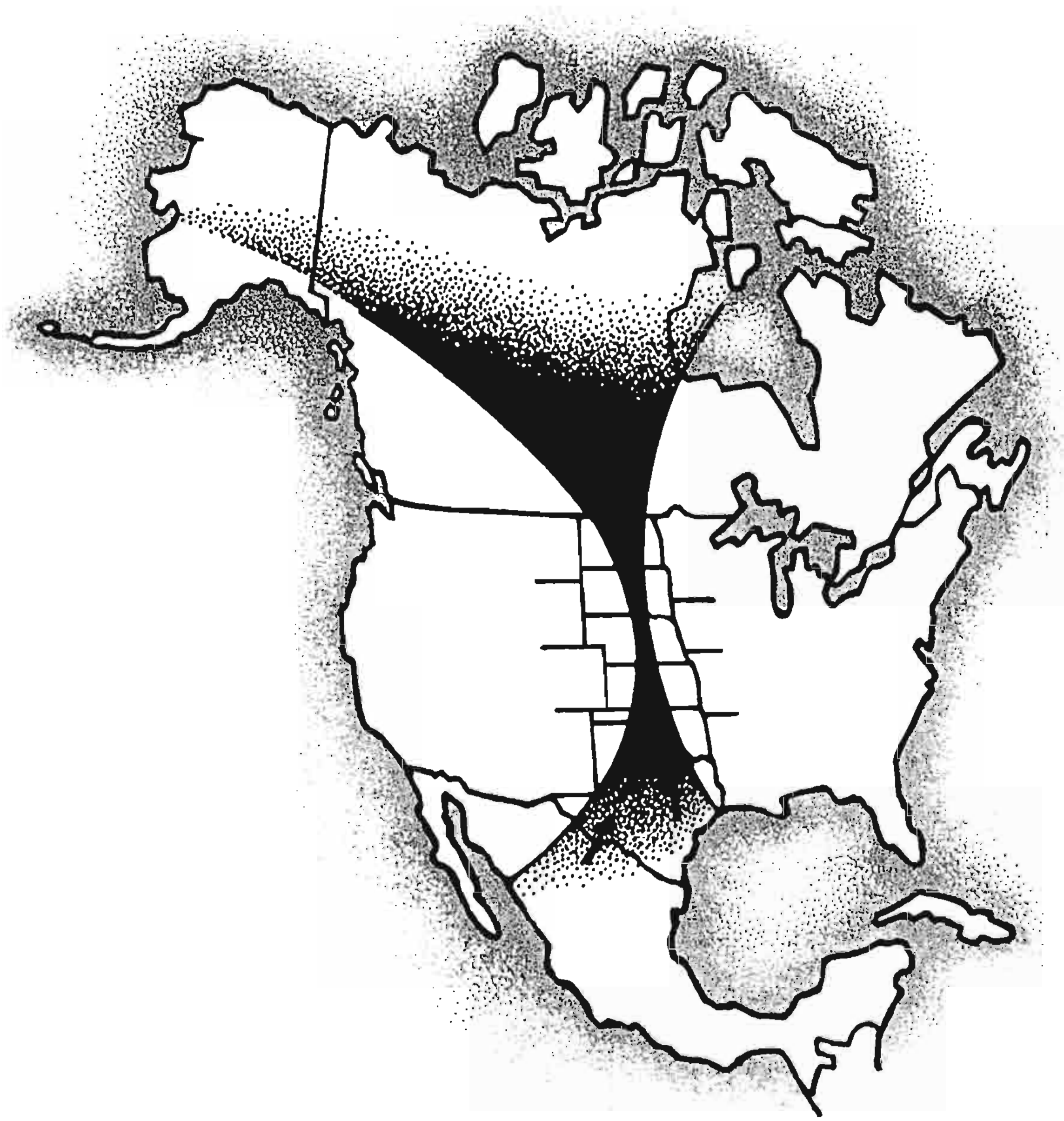

Figure 1. The Central Flyway linking wintering, staging, and breeding habitat of the mid-continent population of sandhill cranes.

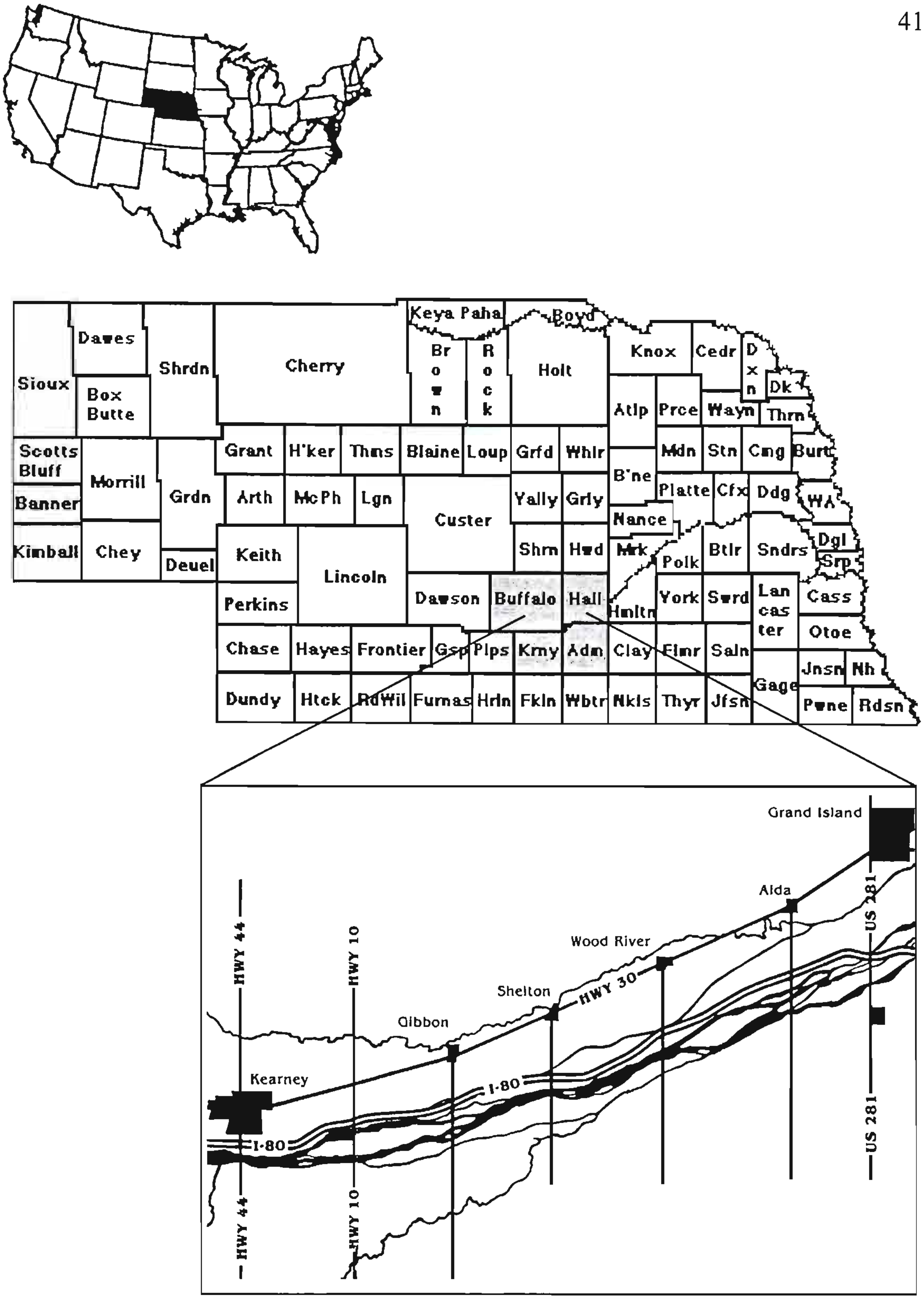

Figure 2. Primary staging area 1 from Grand Island to Kearney, Nebraska.

Table 1. R^2 and individual coefficients from linear regressions of environmental variables against numbers of cranes for early, late and entire seasons of 1996 for the Platte River Valley, Nebraska. Bolded R^2 values identify variables retained in multiple regression models.

			Early		Late		Entire	
Environmental Variable	$\bar{x}$	(Range)[a]	coef	R^2	coef	R^2	coef	R^2
Standing Water	0.25	(0.0-1.9 ha)	0.45	0.01	0.78	0.02	0.58	0.01
Visual Obstruction	7.50	(0.07-24.8 cm)	0.05	0.02	-0.01	0.00	-0.02	0.00
Water Table Depth	85.60	(12.93-168.25 cm)	-0.04	**0.30*****	-0.05	**0.37*****	-0.05	**0.40*****
Percent Moisture	83.99	(46.23-95.60 %)	0.08	0.10*	0.11	0.12*	0.11	0.14**
Field Size	34.58	(2.6-132.6 ha)	0.03	0.19**	0.04	0.19**	0.03	0.19**
Litter Depth	0.50	(0.272-0.957 cm)	-0.41	0.00	0.90	0.00	0.76	0.00
Percent Litter	17.87	(6.62-40.84 %)	-0.08	0.06	-0.04	0.01	-0.04	0.01
Percent Live	4.68	(0.24-14.10 %)	-0.16	0.09*	-0.10	0.02	-0.13	0.04
Percent Wood	0.06	(0.0-1.40 %)	0.77	0.01	0.01	0.00	0.11	0.00
Percent Forb	3.50	(0.0-15.34 %)	0.07	0.02	0.08	0.01	0.09	0.02
Percent Bare	6.65	(0.37-22.46 %)	-0.04	0.00	0.05	0.00	0.06	0.01

* $P \le 0.05$, ** $P \le 0.01$, *** $P \le 0.001$.

[a] Does not include outliers removed from statistical analyses.

Table 2. R^2 and individual coefficients from linear regressions of environmental variables against numbers of cranes for early, late and entire seasons of 1997 for the Platte River Valley, Nebraska. Bolded R^2 values identify variables retained in multiple regression models.

			Early		Late		Entire	
Environmental Variable	$\bar{x}$	(Range)[a]	coef	R^2	coef	R^2	coef	R^2
Standing Water	0.70	(0.0-6.07 ha)	1.02	**0.24*****	1.01	**0.21*****	0.99	**0.21*****
Visual Obstruction	9.85	(1.0-56 cm)	-0.05	**0.05**	-0.08	**0.15****	-0.07	**0.13****
Water Table Depth	63.99	(13.32-147.05 cm)	-0.04	**0.26*****	-0.04	**0.21*****	-0.03	**0.22*****
Field Size	34.79	(2.6-132.6 ha)	0.04	0.28***	0.04	0.31***	0.04	0.32***
Litter Depth	0.46	(0.017-1.81 cm)	-2.05	0.05	-2.16	0.05	-1.89	0.04
Percent Cover	73.12	(33.9-90.27 %)	0.06	0.08*	0.05	0.05	0.04	0.04

* $P \leq 0.05$, ** $P \leq 0.01$, *** $P \leq 0.001$.

[a] Does not include outliers removed from statistical analyses.

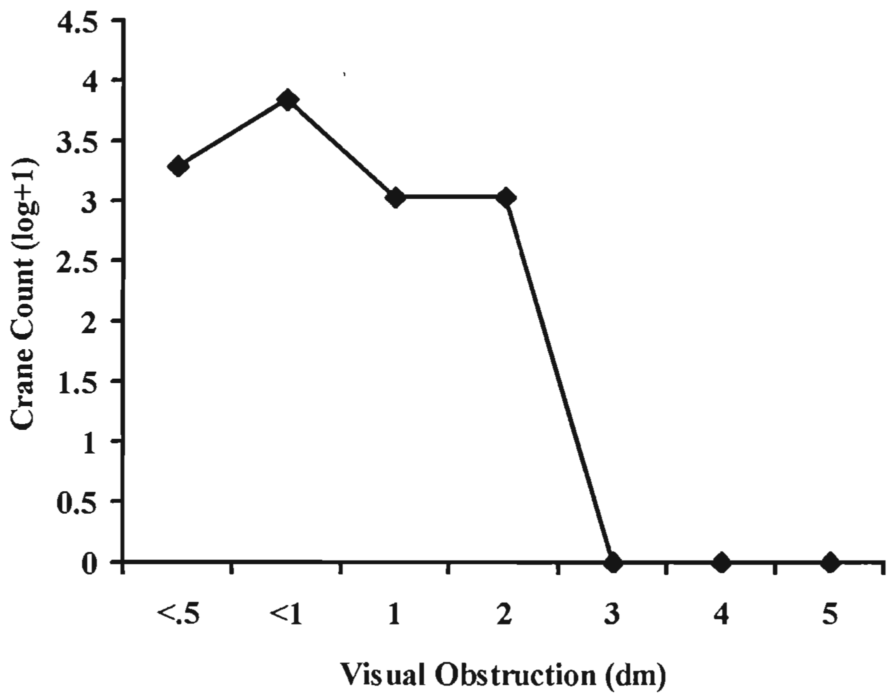

Figure 3. Average crane abundance during 19 February - 17 April 1997 at various visual obstruction readings for our study sites in the Platte River Valley, Nebraska.

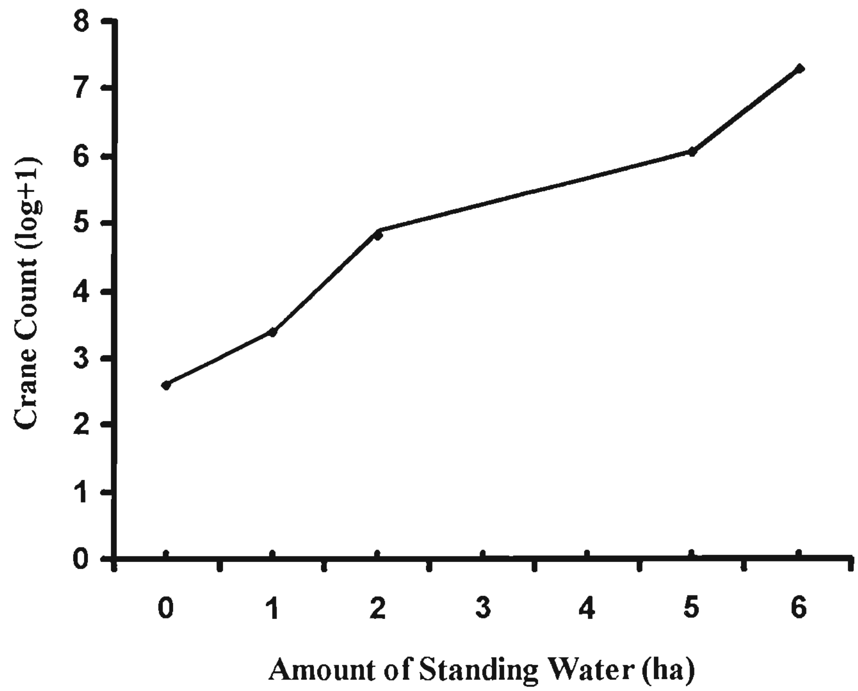

Figure 4. Average crane abundance for 19 February - 17April 1997 at various amounts of standing water on study sites in the Platte River Valley, Nebraska. There were no study sites with 3 and 4 ha of standing water.

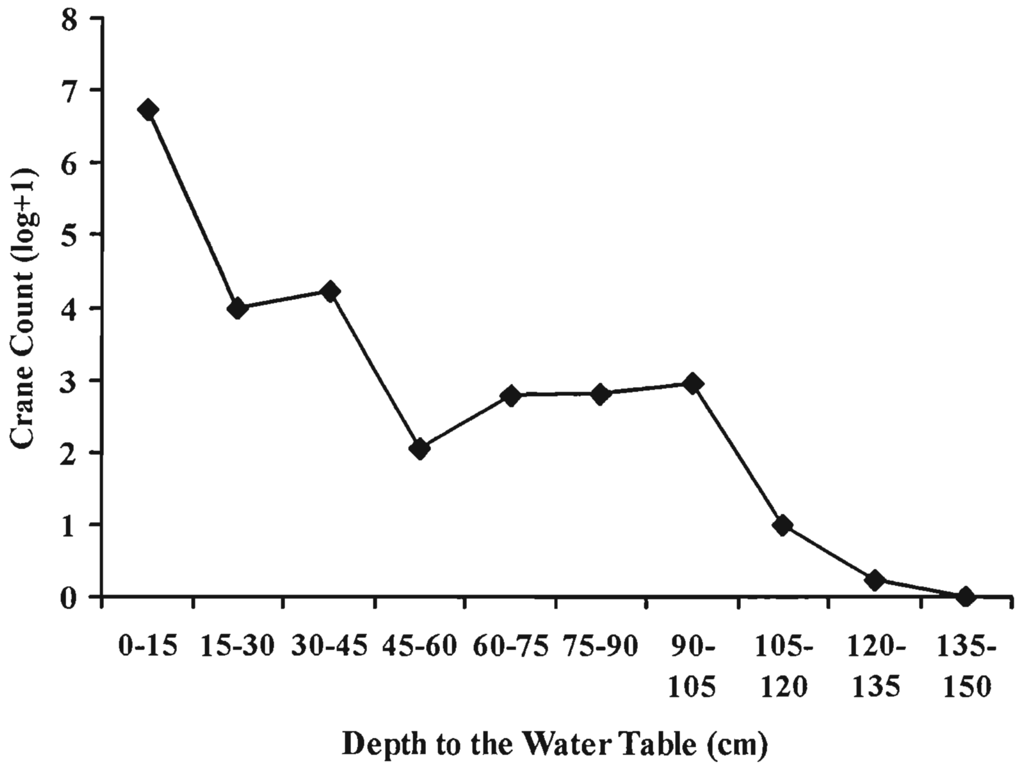

Figure 5. Average crane abundance for 19 February - 17 April 1997 at various water table depths on study sites in the Platte River Valley, Nebraska.

Table 3. Multiple regression model identifying environmental variables that were the best predictors of crane use of lowland grasslands in the Platte RiverValley, Nebraska 1996.

Season	R^2	*df*	*F*	*P*	coef	Significant Variables
Early	0.30	42	17.61	< 0.001	-0.04	Water Table Depth***
Late	0.37	42	23.98	< 0.001	-0.05	Water Table Depth***
Entire	0.40	42	27.03	< 0.001	-0.05	Water Table Depth***

*** $P \leq 0.001$.

Table 4. Multiple regression model identifying environmental variables that were the best predictors of crane use of lowland grasslands in the Platte River Valley, Nebraska 1997.

Season	R^2	*df*	*F*	*P*	coef	Significant Variables
Early	0.47	46	12.90	< 0.001	-0.03	Water Table Depth***
					0.63	Standing Water**
					-0.07	Visual Obstruction**
Late	0.59	45	20.36	< 0.001	-0.03	Water table Depth***
					0.65	Standing Water***
					-0.11	Visual Obstruction***
Entire	0.58	45	19.20	< 0.001	-0.03	Water table Depth***
					0.64	Standing Water***
					-0.10	Visual Obstruction***

** $P \leq 0.01$, *** $P \leq 0.001$.

Appendix A. Total number of sandhill cranes censused in the Platte River Valley, Nebraska during flight and drive surveys for 1996 and 1997.

Date	Time	Aerial Census[a]	Drive Census[a]	Study Area Total[b]
1996				
2/19/96	1215	1050		1750
2/23/96	1330	11510		16270
3/1/96	1330	100		22194
3/4/96	1330	1930		7935
3/6/96	1030	2300		11870
3/8/96	1330	1100		53840
3/13/96	1330	20065		71610
3/19/96	1330	4300		56312
3/20/96	1030	8615		150957
3/21/96	1330	15400		237700
3/26/96	1330	3260		65657
3/28/96	1330	1500		68634
4/2/96	1040	15200		153462
4/3/96	1350	904		41657
4/11/96	1045	1287		50880
1997				
2/19/97	1500		500	
2/22/97	1330	0		11298
2/26/97	1315	0		5380
2/27/97	1040	0		8992
3/3/97	1000		2083	
3/6/97	1330	3150		43709

Appendix A. continued

Date	Time	Aerial Census[a]	Drive Census[a]	Study Area Total[b]
3/7/97	1000		13963	
3/8/97	1200	9100		40710
3/10/97	1000		23668	
3/11/97	1300	18550		67880
3/14/97	1000		9390	
3/16/97	1040	140		31010
3/18/97	1000		6215	
3/19/97	1000	10450		138022
3/20/97	1030	22915		133050
3/21/97	1000		14651	
3/24/97	1000		39552	
3/25/97	1300	15168		107347
3/27/97	1215	20840		180142
3/28/97	1000		7038	
4/2/97	1000		1726	
4/3/97	1000		1767	
4/5/97	1000		18555	
4/8/97	1000	653		33037
4/13/97	1215	65		4620
4/14/97	1000		2221	
4/15/97	1230	1175		24088
4/17/97	1000	1325		16289

[a] Estimated total number of cranes censused on lowland grassland study sites.
[b] Estimated total number of cranes censused within entire study area (Grand Island to Kearney, Nebraska).

Appendix B. Blizzard of 1996

During the height of the migration in spring 1996, when thousands of cranes were concentrated in the Platte River Valley, a blizzard occurred on 24 March. Cranes were feeding in cornfields when the storm hit at 1600 hrs (personal observation). With the heavy winds and snow, it was difficult for cranes to maneuver back to the river. Most, though, were able to return to the security of their primary roost sites.

Temperatures dropped during the night and the river began to freeze causing ice to slam into the legs of roosting cranes. Cranes were forced to leave the river and fly into winds that exceeded 64 km/hr producing wind chills in excess of -22°C (-40°F). Wind sheer from the storm slammed cranes into the ground causing severe injury and death. Cranes could not see and some collided with power lines, billboards, fences, trees, and houses.

Temperatures the next day averaged 6.6°C (12°F). Some cranes were iced over, unable to fly and feed. These conditions made them vulnerable to predation.

We collected crane carcasses from the storm and conducted necropsys at the University of Nebraska Veterinary and Biomedical Sciences Clinic. Necropsys indicated many cranes died from trauma to their head and/or body.

It is estimated that 2000-5000 cranes died directly or indirectly from the blizzard (G. Lingle, Platte River Whooping Crane Maintenance Trust, personal communication). Concentrating cranes into less habitat increases their vulnerability to stochastic events. Spring storms, like the blizzard of 1996, are not uncommon in the Platte River Valley.