11-2011

Habitat Use and Abundance Patterns of Sandhill Cranes in the Central Platte River Valley, Nebraska, 2003–2010

Todd Joseph Buckley
University of Nebraska-Lincoln, tbuckley@huskers.unl.edu

HABITAT USE AND ABUNDANCE PATTERNS OF

SANDHILL CRANES IN THE

CENTRAL PLATTE RIVER VALLEY, NEBRASKA, 2003–2010

by

Todd Joseph Buckley

A THESIS

Presented to the Faculty of

The Graduate College at the University of Nebraska

In Partial Fulfillment of Requirements

For the Degree of Master of Science

Major: Natural Resource Sciences

Under the Supervision of Professors Felipe Chavez-Ramirez & Andrew J. Tyre

Lincoln, Nebraska

November 2011

HABITAT USE AND ABUNDANCE PATTERNS OF SANDHILL CRANES IN THE CENTRAL PLATTE RIVER VALLEY, NEBRASKA, 2003–2010

Todd Joseph Buckley, M.S.

University of Nebraska, 2011

Advisors: Felipe Chavez-Ramirez & Andrew J. Tyre

The Central Platte River Valley (CPRV) in Nebraska is an important spring stopover area for the midcontinent population of sandhill cranes (*Grus canadensis*). Alterations to crop rotation and loss of native habitat in the CPRV pose a risk to the future population. Personnel drove designated routes in the CPRV from 2003–2010 to record the presence of cranes in agricultural fields and estimate their abundance. I developed and evaluated models to predict habitat use and flock sizes of cranes. Alfalfa was predicted to receive the highest use followed by corn, soybeans, winter wheat, grassland, and shrubland. Flock size followed a similar pattern. Use of all habitats and flock size increased as field area increased. Flock size increased as distance from development increased in all habitats. The distance cranes traveled from roosting habitat on the Platte River to agricultural fields increased as the stopover period progressed. My results suggest diverse crop rotations in large fields far from development but near roosting habitat are the most beneficial stopover habitat conditions for cranes in the CPRV. However, variation in the distance travelled to fields suggests roosting habitat might be limiting the overall spatial distribution of cranes. Understanding the use of the Platte River by cranes is critical for future management decisions of roosting habitat. Personnel conducted aerial surveys in the CPRV from 2004–2010 to determine the presence of cranes in segments of the Platte River and estimate roost sizes. I developed

and evaluated models to predict roosting habitat use and roost sizes. Segments of the Platte River not adjacent to development, wider than 150 meters, and free of tall woody vegetation on river banks received the highest use and contained the largest roosts. The results of my entire study suggest management in the CPRV for cranes should be focused west of Kearney, Nebraska, due to the potential for roosting habitat expansion and the characteristics of surrounding agricultural fields.

DEDICATION

I dedicate this work to my late grandfather Albert Andera. His love of the outdoors and willingness to share it with me during my childhood led me down this road.

ACKNOWLEDGEMENTS

I would like to thank The Crane Trust for their financial support throughout the duration of this study. I am especially indebted to all the past staff members and volunteers of The Crane Trust that devoted their time and energy to collect the enormous data set I analyzed. I would like to thank my co-advisor Dr. Felipe Chavez-Ramirez for taking a chance on me as his student. Felipe gave me the opportunity to succeed when others had written me off as lost cause in this field. I thank my other co-advisor Dr. Andrew Tyre for the analytical expertise he provided. Drew's patience and willingness to teach someone like me the skills necessary to complete this study were limitless. I also thank the sole member of my graduate committee, Dr. Larkin Powell. Larkin's viewpoint regarding the relationship between conservation and profitable agricultural production was greatly appreciated. Scott Groepper served as a confidant during the good times and the bad and was a great person to share office spaces with. Finally and most importantly, I thank my parents, Thomas and Kathryn Buckley. I have no idea where I would be without their love and support. It is always nice to know that I have a place I can hang my hat the next time I need to figure my life out.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: MORNING HABITAT USE AND ABUNDANCE PATTERNS OF SANDHILL CRANES IN THE CENTRAL PLATTE RIVER VALLEY, NEBRASKA, 2003–2010.

Abstract**:** The Central Platte River Valley (CPRV) in Nebraska is an important spring stopover area for the midcontinent population of sandhill cranes (*Grus canadensis*). Alterations to crop rotation and loss of native habitat in the CPRV pose a risk to the future population. Having the ability to predict areas of agricultural land most likely to meet the nutrient requirements of cranes would be useful data for managers to have. I developed a contemporary habitat inventory of my study area to demonstrate relative habitat availability in the CPRV. I also developed predictive models to evaluate habitat use and abundance patterns exhibited by cranes in the CPRV from 2003–2010. All model covariates were based on remotely sensed landscape and environmental data collected during the same time period. Corn was the most available habitat type all years while alfalfa was one of least available habitats. Development and timber occurred in the highest proportions in the eastern part of the study area, while the highest proportions of alfalfa and winter wheat were occurred in the western part of the study area. Remaining grasslands appear to occur in the highest proportion in middle of the study area. Alfalfa received the highest use by cranes followed by corn, soybeans, winter wheat, grassland, and shrubland. Flock size followed a similar pattern. Use of all habitats and flock size increased as field area increased. Flock size increased as distance from development increased in all habitats. The distance cranes traveled from roosting habitat on the Platte River to agricultural fields increased as the stopover period progressed. My results suggest diverse crop rotations in large fields far from development but near roosting

habitat are the most beneficial stopover habitat conditions for cranes in the CPRV. Roosting habitat might be limiting the overall spatial distribution of cranes because agricultural land west of Kearney, Nebraska should be receiving more use by greater numbers of cranes, based upon the landscape characteristics. Expansion of roosting habitat for cranes on the Platte River in this area might increase the accessibility of surrounding agricultural land.

Key words: abundance, Bayesian Information Criterion, Central Platte River Valley, habitat use, mixed model analysis, Nebraska, sandhill crane

Abbreviations: AIC = Akaike's Information Criterion, AR–1 = First Order Auto-Regressive Model Structure, AUC = Area Under the Receiver Operating Characteristic Curve, AWDN = Automated Weather Data Network, BIC = Bayesian Information Criterion, C = Degrees Celsius, cfs = Cubic Feet Per Second, CPRV = Central Platte River Valley, GLMM = Generalized Linear Mixed Model, HPRCC = High Plains Regional Climate Center, kph = Kilometers Per Hour, LMM = Linear Mixed Model, NASS = National Agriculture Statistics Service, NRCS = Natural Resources Conservation Service, NPRV = North Platte River Valley, PFS = Predicted Flock Size, PPU = Predicted Probability of Use, ROC = Receiver Operating Characteristic Curve, USDA = United States Department of Agriculture, USFWS = United States Fish and Wildlife Service, USGS = United States Geological Survey, *w* =Model Weight

INTRODUCTION

Ecosystems can change slowly through natural processes or rapidly in the aftermath of a natural disaster. Ecosystem changes due to human activities commonly occur at higher rates than natural processes and the effects of such activities often have as much of an impact on an ecosystem as a natural disaster (Antrop 1998, 2000). When management strategies for wildlife are not adjusted to account for changes within ecosystems, the species being managed can be negatively impacted by decreased productivity (Blewett and Marzluff 2005, Shake et al. 2011), increased habitat degradation (Gubanyi et al. 2008, Hygnstrom et al. 2011), or overharvest (Gilliland et al. 2009, Powell et al. 2011). Proper management of migratory bird species is especially difficult, because populations can be influenced by habitat conditions throughout their migration corridor (Newton 2006). Habitat conditions at stopover areas within a migration corridor are particularly important because birds use these areas to condition their bodies prior to migration and reproduction (Alerstam and Hedenstrom 1998).

Stopover habitats in Nebraska are an example of extremely altered ecosystems used annually by migratory birds, especially Arctic nesting species (Krapu et al. 1995, Jorgensen et al. 2008). The Central Platte River Valley (CPRV) in south-central Nebraska and the North Platte River Valley (NPRV) in west-central Nebraska are particularly important spring stopover areas for the midcontinent population of sandhill cranes (*Grus canadensis*; hereafter, cranes). Cranes stopping in the CPRV and NPRV have access to food resources near roosting and resting areas, which results in minimal energy expenditure and high lipid accumulation rates (Krapu et al. 1985, Tacha et al. 1987). Lipid reserves acquired in spring are known to affect subsequent breeding success for many Arctic nesting species (Ankney and MacInnes 1978, Ebbinge and Spaans 1995, Alisauskas 2002).

Breeding success has allowed cranes to remain at or above regulatory thresholds to sustain harvest since the 1980's, despite continued alteration and degradation of stopover habitat in Nebraska (Kruse et al. 2010). However, there is a growing concern that some subpopulations of cranes are storing less fat today than in previous decades which put the population at risk for future declines (Krapu et al. 2005). Research has identified potential mechanisms for declines in lipid storage, but focus is often on stopover habitats outside roosting areas that are primarily in private ownership and management rather than roosting areas managers have more control over (Reinecke and Krapu 1986, Krapu et al. 2004, Pearse et al. 2010, Sherfy et al. 2011).

The availability of suitable roosting habitat is known to limit the spatial distribution of cranes in the NPRV and CPRV, and subsequently the habitats they can use to acquire energy reserves (Krapu et al. 1982). Upstream water diversions and dams have reduced annual river flows which have resulted in the expansion of undesired woody vegetation in formerly open channels of the North Platte and Platte Rivers (USFWS 1981, Sidle et al. 1989, Currier 1997). Changes in roosting habitat have caused a distinct west to east shift of cranes into areas formerly receiving little use during their spring stopover period (Krapu 1987, Faanes and LeValley 1993).

Today, most cranes have been forced into the few remaining suitable roosting areas on the Platte River receiving regular removal of undesired vegetation (Kinzel et al. 2006). Distributing cranes more evenly along the Platte River to reduce crowding on roosting areas has been suggested, because of the potential negative impacts on the MCP such as competition for food resources, natural disasters, and disease (USFWS 1981, Currier 1991). By combining the trends of increasing cranes numbers and decreasing roost areas, there is likely higher intraspecific competition for resources because group sizes have become too large in some areas of the CPRV.

Optimal group size theory predicts the most beneficial group size is reached when individual fitness is maximized (Higashi and Yamamura 1993). Cranes are known to join flocks already on the ground rather than land in an unoccupied area, which could be related to foraging efficiency and risk of predation (Pulliam 1976, Caraco 1979, Lovvorn and Kirkpatrick 1982b, Sparling and Krapu 1994). For cranes in Nebraska, flock size is most likely impacting foraging efficiency because overall predation risk is low (Lingle and Krapu 1986, Windingstad 1988). Therefore, increased competition for resources due to large flocks could be the potential mechanism for lower nutrient reserves in cranes.

One potential solution to attaining optimal group sizes would be to expand roosting areas on the Platte River by removing woody vegetation. Roost expansion has been recommended many times (USFWS 1981, Davis 2003, Pearse et al. 2010), but roost maintenance is a more common practice because large scale clearing projects are often cost prohibitive, time consuming, and require long term commitment of future maintenance (Currier 1991).

Roost maintenance also presents challenges for managers because access to the river with heavy equipment is limited due to the nesting season of the endangered interior least tern (*Sterna antillarum athalassos*) and piping plover (*Charadrius melodus*) and river freeze up (Sidle and Faanes 1997). Due to the challenges associated with management of crane habitat, having the ability to predict areas of agricultural land adjacent to the river most likely to meet the nutrient requirements for the largest number of cranes would be useful data for managers to have when river management opportunities are limited or river clearing projects are proposed.

The purpose of the study was to develop predictive models with the ability to estimate crane habitat use patterns and flock sizes based on current agricultural practices adjacent to the river. The models I developed could maximize return from investments for both river maintenance and clearing projects by demonstrating the likelihood cranes would distribute into available habitats and how many cranes these habitats could support. My specific objectives were to: 1.) provide a contemporary assessment of the habitats available to cranes in the CPRV, 2.) develop and evaluate models predicting how the probability of habitat use by cranes is influenced by landscape and environmental factors, and 3.) develop and evaluate models predicting how the flock size of cranes is influenced by landscape and environmental factors.

METHODS

Study Area

This study was conducted in the CPRV of south-central Nebraska and included portions of Adams, Buffalo, Hall, Hamilton, Kearney, Merrick, and Phelps counties (Figure 1–1). This region is commonly referred to in the crane literature as bridge segments 1–11. The study area encompassed approximately 34,870 hectares within a six kilometer buffer of the Platte River main channel (Table 1–1). Outside the main channels of the Platte River lays an agricultural landscape dominated by row and forage crop production and livestock grazing.

The primary row crops produced are corn (*Zea mays*) and soybeans (*Glycine max*), and to a lesser extent winter wheat (*Triticum aestivum*) and sorghum (*Sorghum bicolor*). The primary forage crop produced is alfalfa (*Medicago sativa*). Grasslands used for livestock grazing and hay production are composed of big bluestem (*Andropogon gerardii*), Indiangrass (*Sorghastrum nutans*), switchgrass (*Panicum *virgatum*), and sedges (*Carex spp.*). The main channels of the Platte River are dominated by cottonwood (*Populus deltoides*), Eastern red cedar (*Juniperus virginiana*), willows (*Salix spp.*), red mulberry (*Morus rubra*), and common reed (*Phragmites australis*) (USFWS 1981, Currier et al. 1985, USDA-NRCS 2011).

Road-based Crane Surveys

Personnel sampled 2,425 observation fields weekly, as weather conditions allowed, from late February to mid-April, 2003–2010. Personnel conducted crane surveys on 255 kilometers of maintained roads between Chapman and Overton, Nebraska (Figure 1–1). Road-based surveys were used during my study because problems typically associated with road surveys, such as species detection and route coverage, were minimized (Ekman 1981, Peterjohn et al. 1995). The relatively flat topography in the CPRV allowed for high visibility of a conspicuous avian species, which often gathers in large flocks during the spring stopover period (Currier et al. 1985, Johnson et al. 2001).

Personnel drove a total of five transects parallel to the main channel Platte River weekly. Two transects were positioned north of the main channel and three transects were positioned south of the main channel. Transect placement in this configuration was selected due to logistical issues, such as funding, personnel, and low densities of cranes north of the Platte River west of Kearney, Nebraska (Craig Davis, Oklahoma State University, personal communication). Transects paralleling the Platte River also provided a unique survey method for cranes in the CPRV compared to previous work (Davis 2001, Davis 2003, Krapu et al. 2005, Pearse et al. 2010, Anteau et al. 2011). Personnel drove all transects east to west beginning at 0800 hrs CST to maximize observations of cranes after they leave roosting areas (Sparling and Krapu 1994).

Surveys were conducted on weekdays to reduce the potential impact that increased traffic and human disturbance by weekend bird watchers might have on crane behavior (Burger and Gochfeld 2001, Thomas et al. 2003, Griffith et al. 2010, Tarr et al. 2010). Personnel stopped periodically to search for cranes within 800 meters of the road with binoculars (Krapu et al. 2005, Pearse et al. 2010). All new personnel were trained prior to data collection to locate cranes and estimate flock size by using methods similar to Burger and Gochfeld (2001). Individual cranes were counted in flocks less than 50 and multipliers were used to estimate the size of larger flocks. Crane locations were recorded using unique alphanumeric codes for each observation field.

Database Management

I obtained digital orthophotos from the United States Department of Agriculture's (USDA) Natural Resources Conservation Service's (NRCS) Geospatial Data Gateway for Adams, Buffalo, Hall, Hamilton, Kearney, Merrick, and Phelps counties from 2003–2010 (USDA-NRCS 2010). I digitized 800 meters surrounding each transect into observation fields using ArcMap 9.3 (ESRI 2008). I divided observation fields by using any physical barrier identifiable in orthophotos that separated one field from another including; property fences, wind breaks, maintained roads, driveways, streams, and irrigation or drainage ditches. I also subdivided observation fields by habitat types cranes could choose from within a field. The subdivision of a field by habitat type is justified because of crop rotation within a field and the various agricultural uses of pivot corners on field margins. I calculated field area for all observations fields and most (70%) were less than 20 hectares in size.

I derived habitat types from 30 meter resolution land cover maps for the state of Nebraska produced by USDA's National Agriculture Statistics Service (NASS) (NASS 2002–2009). I used crop years 2002–2009 to derive 2003–2010 habitats because the previous years' crop residue was still present during the survey period. I reclassified all land cover maps in ArcGIS to reduce the total number of habitat types from 16 to 8 (Table 1–2).

The reclassified land cover categories were chosen to correspond with the major row crop and non-row crop habitats in the study area, as well as those commonly described in other assessments of habitat use by cranes in Nebraska (Krapu et al. 1984, Iverson et al. 1987, Sparling and Krapu 1994, Davis 2003). Reclassification was necessary to account for heterogeneity in non-row crop habitats and to simplify the analyses. Correct classifications for row crops on USDA maps, such as corn, soybeans, and wheat, have exceeded 95% in agricultural landscapes similar to my study area (Luman and Tweddale 2008, Johnson and Mueller 2010).

I confirmed reclassification of non-row crop habitats, such as alfalfa, grassland, shrubland, timber, and development, by referencing orthophotos taken during the same time period. Land classified as alfalfa was confirmed by identifying mowing patterns within a field or hay bales stacked near field borders. Classification of grassland was confirmed by the absence of woody vegetation in pastures or hay fields. Land reclassified as shrubland was occupied by woody vegetation on less than 50% of its total area, while land reclassified as timber was occupied by woody vegetation on greater than 50% of its total area was. Reclassification of land with development was confirmed by the presence of residential housing, commercial buildings, farmsteads, or feed lots.

Timber and development were subsequently excluded from the analysis due to no detection of cranes on these non-row crop habitats during my study.

In addition to habitat reclassifications from 2003–2010, distance from development, and distance from riverine roosting habitat (hereafter, roosting habitat) were calculated in ArcGIS 9.3 (ESRI 2008). All distance calculations were in kilometers. I used the Proximity extension in the Analysis Toolbox to calculate distance from development. The extension calculates the distance from the center point of an observation field to the nearest observation field reclassified as development. Nearly 95% of my observation fields were less than one kilometer from development.

I also used the Proximity extension in the Analysis Toolbox to calculate distance from roosting habitat. All calculations were based on the shortest distance from the center point of an observation field to segments of the Platte River classified as a Category 1 roosting habitat (Table 1–3, *see Chapter 2*). Most (90%) observation fields in my study were less than six kilometers from roosting habitat classified as Category 1.

I obtained weather measurements for all survey dates from the High Plains Regional Climate Center's (HPRCC) Automated Weather Data Network (AWDN) stations near Grand Island, Shelton, and Kearney (HPRCC 2003–2010). I selected these stations due to their proximity to the survey area. The specific weather measurements I obtained from each station were temperature and wind speed at 0800 hrs CST, which coincides with the time all road-based crane surveys began. I chose temperature, reported in degrees Celsius (C), and wind speed, reported in kilometers per hour (kph), over other available weather measurements, due to their demonstrated importance in effecting eastern sandhill crane foraging behavior (Lovvorn and Kirkpatrick 1982a). I averaged all weather measurements among the three ADWN stations, due to their close proximity to one another and their centralized location relative to my entire survey area.

I obtained river flow data, reported in cubic feet per second (cfs), from United States Geological Survey (USGS) Nebraska Water Science Center for all ground survey dates (USGS 2003–2010). I selected the Platte River gauge stations at Grand Island, Kearney, and Overton because these were the only gauge stations within my survey area. I applied river flow to each observation field nearest gauge station, because I wanted to account for any effects pulses of river flow could have on habitat use or flock size of cranes in the CPRV.

Model Development

I developed models to predict habitat use and flock size of cranes in the CPRV by using the described landscape and environmental metrics as fixed effects in my analysis. I included the landscape metric, habitat, in all models due to previous research reporting cranes in the CPRV appear to demonstrate habitat preferences (Sparling and Krapu 1994, Davis 2003, Krapu et al. 2005). I also included a temporal variable, Julian date and the quadratic of Julian date, in all models to account for any within season variation cranes might be exhibiting during the stopover period (Reinecke and Krapu 1986, Pearse et al. 2010). The effect of environmental metrics on crane habitat use patterns in the CPRV is largely unknown, so I added these metrics to my models as weather variables (temperature and wind speed), river flow, or all environmental metrics.

I also developed interaction models to include in my final model set. The interaction models I developed using landscape metrics included; habitat*field area, habitat*distance from development, habitat*distance from roosting habitat. The interaction models I developed using landscape metrics and temporal variables included; field area*date, distance from development*date, and distance from roosting habitat*date. I did not develop any interaction models among weather variables (temperature and wind speed) or weather and river flow.

The models I developed did not include a spatial or temporal auto correlation structure. However, I did test for both spatial and temporal auto correlation post hoc. I tested for spatial auto correlation by plotting model residuals on variograms. I tested for temporal auto correlation by assessing the correlation of model residuals at various time lags to identify potential violations of independence (Zuur et al. 2009).

Habitat Use Analysis

I used R 2.11.1to fit generalized linear mixed models (GLMM) to the 249 models I developed and ran all models on a binomial distribution (R Development Core Team 2008). I used GLMMs to estimate the effects model covariates have on the predicted probability of use (PPU) of habitats in the CPRV. I selected GLMMs because they allow for nested data structures, repeated measures within a fixed survey area, and correlation between observations (Zuur et al. 2009).

Mixed effects modeling techniques were also selected because I wanted to incorporate a random intercept in all models. I used the temporal variable, year, as a random effect to allow the model intercept to vary by year and to account for yearly variation in model covariates. To ensure model convergence, I normalized the following covariates; field area, distance from development, distance from roosting habitat, temperature, wind speed, river flow, Julian date, and the quadratic of Julian date. I also calculated descriptive statistics for the model covariates and the availability of all habitats by bridge segment and year.

I evaluated all models by using Bayesian Information Criteria (BIC) (Schwarz 1978). I used BIC rather than Akaike's Information Criteria (AIC) due to my large sample size (n = 106,416; Akaike 1974). Akaike's Information Criteria tends to give more model weight (w) to the most parameterized models compared to simpler models given that increased parameterization typically improves model goodness of fit. Bayesian Information Criteria is able to overcome this drawback of AIC, because the penalty term used in BIC is a function of both the number of model parameters and the number of observations rather than just a function of the number of model parameters.

I selected models from my model set based on criteria commonly used in AIC model selection (Burnham and Anderson 2002). Models not selected carried model weights of evidence less than 0.01. Models carrying weights greater than 0.01, as well as the global and null models are still reported for covariate structure comparison. I selected one model as the best model to report coefficient estimates. The best model had a ΔBIC value less than two and a model weight of evidence greater than 0.1 (Burnham and Anderson 2002).

I also tested a models' ability to correctly identify crane presence-absence by using a discrimination method known as Receiver Operating Characteristic (ROC) curve. The area under the ROC curve (AUC) measures the discriminatory power of a model with values ranging from 0.5–1.0 (Pearce and Ferrier. 2000). I considered AUC values of 0.5 are no better than random, while AUC values greater than 0.5 provided adequate discriminatory power (Hosmer and Lemeshow 2000).

I used R 2.11.1 to calculate AUC values for each selected model using the original dataset and a predicted dataset (R Development Core Team. 2008). All AUC values I report are derived from a predicted dataset. I created the predicted dataset using a K-fold cross validation technique to randomly partition the original dataset into ten subsamples (Kohavi 1995). Nine subsamples of original data were used as training data in the covariate structure of the selected model to predict the remaining ten percent of data. I repeated the process ten times and combined the ten predicted subsets to create a final predicted dataset for each model.

Flock Size Analysis

I used R 2.11.1 to fit linear mixed models (LMM) to the same 249 models I developed and ran all models on a normal distribution (R Development Core Team 2008). I used LMMs to estimate the effects covariates have on predicted flock size (PFS) of cranes in the CPRV. I $\log_{10}$ transformed the crane count data (n = 10,466) to normalize the variance. I applied a data transformation to account for the large distribution of flock sizes observed in the field and for estimation errors of flock size by personnel.

I evaluated models using BIC and selected models based on ΔBIC values and weights of evidence (Schwarz 1978, Burnham and Anderson 2002). I selected one model as the best model to report coefficient estimates. The best model had a ΔBIC value less than two and a model weight of evidence greater than 0.1 (Burnham and Anderson 2002). Models carrying weights greater than 0.01, as well as the global and null models are reported for covariate structure comparison. I used the root mean squared error (RMSE) technique to validate all selected models meeting selection criteria (Mayer and Butler

1993). I also calculated descriptive statistics for the model covariates and the proportion crane observations by habitat and year.

RESULTS

Habitat Availability

Corn was the most available row crop habitat type all years and was planted on the majority ($\bar{x}$ = 57%) of the survey area (Table 1–4, Figure 1–2). Soybeans were the next most available row crop and occupied 8–16% ($\bar{x}$ = 13%) of the survey area. Winter wheat was the least available row crop all years and occupied less than one percent of the survey area in 2003 to as high as three percent in 2007 ($\bar{x}$ = 2%). Grasslands were the most available non-row crop, occupying 17–19% ($\bar{x}$ = 18%) of the survey area, while shrublands occupied less than one percent of the survey area in all years. Yearly alfalfa production varied the most among non-row crops and ranged from less than one percent of the survey area in 2007, to as much as six percent in 2004 ($\bar{x}$ = 3%). Development consistently stayed near five percent and timber occupied less than one percent of the survey area in all years.

Current habitat proportions by bridge segment are representative of previous survey years (Table 1–5, Figure 1–2; *2010*). The highest proportion of development and timber occur in the eastern part of the survey area, while the highest proportions of alfalfa and winter wheat are produced in the western part of the survey area. Remaining habitat types appear to exhibit a more uniform distribution across the survey area with minor variations by bridge segment, such as the high proportion of grassland in the center of the survey area.

Habitat Use

The results of my analysis and subsequent model fit assessment for the selected models are shown in Table 1–6. Model 233, with approximately 72% of the weight of evidence, was selected for reporting the effects of covariate on predicted probabilities of use (PPU; Table 1–7). Plots representing PPU as a function of specific covariates assume all other landscape and environmental covariates are fixed at their mean value (Table 1–8). Plots representing PPU as a response to a covariate with a temporal effect use independent Julian date values for the early (Q1), mid ($\bar{x}$), and late (Q3) stopover periods.

The AUC value calculated for Model 233 demonstrates adequate model fit to represent patterns present within the data (Table 1–6). Variograms of Model 233 residuals suggest little evidence of spatial autocorrelation. Weak evidence of temporal auto correlation between surveys within a year might be present in the first time lag ($r^2 < 0.40$). If temporal auto correlation is influencing my results, the coefficient estimates I report might have smaller standard errors and smaller confidence intervals. Model 233 might benefit from incorporating a first order auto-regressive model structure (AR–1). However, my coefficient estimates and confidence intervals are sufficient for the purpose of illustrating larger patterns present in the data.

The PPU and average habitat availability varied by habitat type (Figure 1–3, Table 1–7). Alfalfa was one of the least available habitats but had the highest PPU. Corn was the most available habitat all years and PPU was lower than alfalfa but not significantly different ($p > 0.05$). The PPU of soybean and winter wheat fields are similar and significantly less ($p < 0.001$) than alfalfa and corn. Soybeans had a similar PPU and average availability, while the PPU of winter wheat was higher than its average availability. The PPU of soybean and winter wheat fields both differed from grassland and shrubland, which have the lowest PPU among habitats relative to alfalfa and corn ($p < 0.001$). Comparatively, the PPU of grasslands and shrublands are similar despite variation in their vegetation structures. The PPU of grasslands was low relative to its availability while shrubland PPU was higher than its availability.

The effect of distance travelled to fields from roosting habitat varied during the stopover period (Table 1–7). Early in the stopover period before cranes numbers peak, PPU generally decreased as distance from roosting habitat increased (Figure 1–4). The PPU of alfalfa decreased the least as distance from roosting habitat increased. The PPU of corn was greater than alfalfa at distances less than four kilometers from the roosting habitat. The PPU of soybeans was also greater than alfalfa at distances less than one kilometer from roosting habitat. The PPU of soybean and winter wheat fields decreased similarly beyond six kilometers, but soybean field PPU was greater when fields were closer than six kilometers from roosting habitat. Grassland and shrubland PPU decreased the most relative to all other habitats with negligible use beyond six kilometers.

During the middle of the stopover period, when crane numbers peak, PPU estimates were larger than early season estimates as distances travelled to fields from roosting habitat increased (Figure 1–5). Alfalfa was the only habitat where PPU increased with increasing distances from roosting habitat. The PPU of corn decreased but was remained greater than alfalfa at distances less than four kilometers from the roosting habitat. Similarly, the PPU of soybeans also decreased but was greater than alfalfa at distances less than one kilometer from roosting habitat. The PPU of winter wheat PPU decreased the least among row crop habitats, but the PPU of soybeans was greater at distances less than six kilometers from roosting habitat. The PPU of both grassland and shrubland habitat decreased with increasing distance from roosting habitat and were the lowest among all habitat types.

The effect distance travelled from roosting habitat had on PPU varied the most among habitats late in the stopover period, after crane numbers have peaked (Figure 1–6). The PPU of alfalfa increased the most as the distance from roosting habitat increased, but at distances less than four kilometers the PPU of alfalfa was less than the PPU of corn. The PPU of corn and winter wheat increased similarly, but the PPU of corn remained higher than winter wheat at all distances from roosting habitat. The PPU of soybeans remained relatively constant with respect to distance from roosting habitat, but PPU estimates were higher than winter wheat at distances less than six kilometers from roosting habitat. The PPU of grassland and shrubland decreased with increasing distances from roosting habitat, similar to the pattern exhibited during the middle of the stopover period.

The effect of field area was positive for all habitat types (Table 1–7). Similar patterns of PPU with regard to field area were exhibited by cranes during the entire stopover period, so only mid-season estimates were plotted (Figure 1–7). The PPU of soybeans, winter wheat, and grassland exhibit similar positive relationships with field area. The PPU of alfalfa fields varied the most among all habitats, with fields larger than 17 hectares having the highest PPU and fields smaller than two hectares having the lowest PPU. The PPU of corn was highest among all habitats except alfalfa fields larger than 17 hectares. Little evidence of a relationship appears to exist for field area and shrublands.

The effect of distance from development was negative for all habitat types (Table 1–7). Throughout the stopover period the PPU of all habitat types decreased in a similar pattern as development distance increased (Figure 1–8). The PPU of alfalfa and corn were the highest among all habitats. Soybeans and winter wheat had the next highest PPU, while grassland and shrubland had the lowest. The PPU of all habitats more than two kilometers from development decreased less than the PPU of habitats closer than one kilometer from development.

The effect of wind speed was negative for all habitat types (Table 1–7). Similar patterns of PPU as a response to wind speed were exhibited by cranes in all habitat types throughout the stopover period (Figure 1–9). The PPU for all habitats decreased the least when wind speeds were greater than 20 kilometers per hour. The PPU of alfalfa and corn were nearly identical and the highest among all habitats. Soybeans and winter wheat had the next highest PPU, while grassland and shrubland had the lowest.

Crane Observations

The distribution of crane flock observations by habitat and year are summarized in Table 1–9. Observations of cranes in row crop habitats were dominated by corn fields, which accounted for 59–74% of the total observations yearly. Soybean fields accounted for 7–15% of the yearly observations, while winter wheat ranged from less than one percent in 2005 to as high as four percent of the total observations in 2007. Non-row crop habitats typically accounted for 20% of the total observations yearly. Observations in non-row crop habitats were primarily in grasslands, which made up approximately 15% of the total. Shrublands consistently accounted for less than one percent of the yearly observations, while alfalfa ranged from less than one percent in 2007 to as high as ten percent of the total observations in 2004.

Flock Size

Estimates of flock sizes in the field ranged from 1–11,000 cranes ($\bar{x}$ = 243). The results of my analysis and subsequent model fit assessment for the selected models are reported in Table 1–10. Model 35, with approximately 98% of the weight of evidence, was selected reporting the effects of covariates on predicted flock size (PFS; Table 1–11). The RMSE value for Model 35 demonstrates adequate model fit to represent patterns present within the data (Table 1–10).

Variograms of Model 35 residuals suggest little evidence of spatial autocorrelation. Testing of Model 35 residuals suggest weak evidence of temporal auto correlation ($r^2 < 0.28$). Incorporating an AR–1 correlation structure might result in coefficient estimates with larger standard errors, but current estimates are sufficient for illustrating patterns present in the data. Plots representing PFS as a function of specific covariates assume all other landscape and environmental covariates are fixed at their mean value (Table 1–12). Plots representing PFS as a response to a covariate with a temporal effect use independent Julian date values for the early (Q1), mid ($\bar{x}$), and late (Q3) stopover periods.

Predicted flock size estimates from the best model varied by habitat type (Figure 1–10, Table 1–11). Estimates from the best model are consistent with field estimates of flock size because most (80%) flocks were estimated to be made up of 200 cranes or less. However, flocks estimated to be larger than 1,000 cranes (4%) were observed in the field as well. Corn fields had the highest PFS of any row crop habitat followed by soybeans and winter wheat. Alfalfa had the highest PFS among non-row crop habitats followed by grassland and shrubland. The PFS in alfalfa was higher than both soybeans and winter wheat but not corn. Grassland and shrubland accounted for the lowest PFS among all habitats.

The effect of distance travelled to fields from roosting habitat varied during the stopover period (Table 1–11). Early in the stopover period, a decrease in PFS occurred in all habitats as distance from roosting habitat increased (Figure 1–11). Predicted flock size decreased at the highest rate in corn and alfalfa fields, whose starting estimates were highest among all habitats. Soybeans, winter wheat, and grasslands demonstrated similar patterns of decrease in PFS as distance from the river increased. Shrubland PFS decreased at the slowest rate among all habitats, but PFS estimates are nearly half that of corn at similar distances from the river.

During the middle of the stopover period, when total crane numbers in CPRV peak, starting PFS estimates were smaller than early season estimates (Figure 1–12). Predicted flock size decreased in a similar manner in all habitats as distance from roosting habitat increased. The negative relationship was not as defined as earlier, but general patterns were similar. Predicted flock size in corn and alfalfa decreased at the highest rate, but were the highest starting estimates among all habitats. Soybeans, winter wheat, and grasslands showed nearly identical decreases in PFS as distance from roosting habitat increased. Predicted flock size in shrubland was influenced the least by increasing distance from the river among all habitats.

Late in the stopover period, PFS estimates nearest to roosting habitat were the smallest among all seasonal estimates (Figure 1–13). Unlike earlier time periods, PFS estimates for all habitats increased as distance from roosting habitat increased. All habitats demonstrated similar patterns, but corn had the highest PFS estimate among all habitat types followed by alfalfa, soybeans, winter wheat, grasslands, and shrubland.

The effect of field area was positive for all habitat types and did not vary seasonally (Table 1–11). Corn had the largest PFS among all habitats of similar field sizes (Figure1–14). Predicted flock size in alfalfa fields followed a similar pattern as corn fields of a similar size but was less. The increase in PFS for soybeans, winter wheat, and grasslands with regard to field area were nearly identical. Predicted flock size in shrubland had the smallest starting value, increased at the slowest rate, and was nearly half that of corn and alfalfa of similar field sizes.

The effect of distance from development was positive for all habitat types (Table 1–11). Similar patterns of PFS as a response to development distance were exhibited by cranes in all habitat types throughout the stopover period. Predicted flock size estimates as a response of development distance were the largest among all landscape metrics (Figure 1–15). The PFS of alfalfa and corn were the highest among all habitats at all distances from development. Predicted flock size estimates in soybeans, winter wheat, and grasslands were similar as development distance increased. Shrubland PFS estimates were the smallest among all habitats regardless of distance from development and increased at the slowest rate.

DICUSSION

Habitat Availability Assessment

Increased soybean production has been implicated as a potential cause for reduced corn hectares and declining waste corn in the CPRV (Krapu et al. 2004). My results indicate contemporary estimates of corn hectares within the CPRV are consistent with historic habitat inventories and have remained more stable than often reported. My results also suggest alfalfa production adjacent to the Platte River and grasslands outside the river bottom have experienced the greatest decline in availability since research was initiated (USFWS 1981). Variation in the availability of habitat types, especially grasslands and alfalfa, appears to exist between eastern and western CPRV, and demonstrates the adaptability of cranes to exploit a wide range of habitats in Nebraska.

Corn has been Nebraska's primary commodity crop for over a century; however, soybean hectares in production statewide did not surpass alfalfa or sorghum until the late 1970's, and wheat in the mid 1980's (Hiller et al. 2009). The counties making up the CPRV do follow the general statewide trend of soybean hectares surpassing other commodity crops, but soybeans did not surpass these crops until 1984 and the area in production remained relatively low until 1997 (NASS 2010). Since the late 1990's, soybean production has likely replaced some of the crop land formerly devoted to corn production in CPRV (NASS 2010), but a complete conversion of these hectares to soybeans is unlikely due to expiring Conservation Reserve Program (CRP) contracts and early CRP termination options offered by the USDA in 1995 and 1996 (Roberts and Lubowski 2007).

Historic surveys of crane habitat in the eastern CPRV also support my assessment that the area in corn production has changed less than recently suggested while alfalfa production and grasslands have continued to decline. When river bottom habitat and roosting areas in the CPRV are excluded and recognized as separate habitat complexes, my contemporary habitat availability estimates are comparable with past habitat inventories (Krapu et al. 1984, Currier et al. 1985, Davis 2003).

In the late 1970's, the eastern CPRV study area (50,864 ha) outside the river bottom, used by Krapu et al. (1984), was largely in corn production (60%) followed by grasslands (26%) and alfalfa hay (8%) for cattle production row crops, and development and timber (6%). Over 95% of the area planted to row crops was devoted specifically to corn production in their study area (Krapu et al. 1984). Currier et al. (1985) reported similar proportions of corn (55%) and timber and development (6%) in the eastern CPRV (258, 376 ha) during the 1980's, while grassland (21%) and alfalfa (6%) hectares declined and production of other row crops increased (11%).

Past habitat inventories in the western CPRV are also consistent with my results demonstrating variation in the availability of habitats compared to the eastern CPRV. The western CPRV demonstrates the general pattern of declining alfalfa hectares and the stability of corn production since research was initiated (Krapu et al. 1984). Krapu et al. (1984) reported corn was grown on a large proportion (45%) of their western CPRV study area (21,845 ha) outside the river bottom and was followed by grasslands (24%), alfalfa hay (22%), and development and timber (9%). A later habitat inventory of the western CPRV (108,919 ha) by Currier et al. (1985) reported similar corn (44%), grassland (26%), and timber and development (6%) proportions, while alfalfa (15%) decreased in response to an increase in production of other row crops (9%).

The stability of grasslands and higher proportion of land devoted to alfalfa in the western CPRV might be influenced by local cattle production, which has the potential to increase the demand for supplemental forage crops used during winter (Vanzant and Cochran 1994). But much like the eastern CPRV, alfalfa appears to be the habitat type most affected by production of other commodity crops such as winter wheat and soybeans. In general, lower production of forage crops might also be attributed to historically high grain commodity prices or increased availability of alternative forage supplements, such as corn distillers grains (Klopfenstein et al. 2008, NASS 2010).

Variation in the availability of habitat types also exists between the entire CPRV and the NPRV stopover area. The use of the NPRV not only demonstrates the adaptability of cranes to exploit a wide range of stopover conditions, but also the ability of large blocks of native habitats to provide high energy foods (Davis and Vohs 1993, Ballard and Thompson 2000). Krapu et al. (1984) reported the NPRV study area (15,640 ha), excluding river bottom habitat, was 47% grasslands, 33% row crops, 13% alfalfa hay, and 7% development and timber. The NPRV study area (26,000 ha) reported by Iverson et al. (1987) was 44% grassland, 27% corn, 19% development and timber, 9% alfalfa, and 1% wetlands. A more extensive habitat inventory of NPRV (106,202 ha), conducted by Currier et al. (1985), reported slightly different habitat proportions; however, grasslands (59%) remained dominant followed by corn (18%), development and timber (10%), alfalfa hay (9%), and other row crops (4%).

My assessment that alfalfa production has declined while corn availability has remained stable is further supported by a more recent habitat inventory encompassing the entire CPRV. In the late 1990's, the study area (77,400 ha) reported by Davis (2003), was mostly corn (60%) followed by grassland (27%), alfalfa (5%), soybeans (5%), shrubland (1%), winter wheat (< 1%), and development (< 1%). Contrary to my results, Davis (2003) reported a larger proportion of grasslands, which is likely due to the placement of his survey area near wet meadow habitat bordering the Platte River. Wet meadows are commonly used as loafing areas by cranes and Davis (2003) likely wanted afternoon sampling efforts to coincide with the highest use of these habitats during the day (Sparling and Krapu 1994).

More recently, Pearse et al. (2010) reported corn occupied 29–39% ($\bar{x}$ = 33%) of the total land cover in 3.7 kilometer buffer around the main channel of the Platte River (114,100 ha), which would signify over a 20% decline from the late 1970's. The seemingly significant decline in corn hectares is likely due to a large proportion of their study area being classified as river bottom habitat. In general, locations bordering the Platte River main channel receive uses other than row crop production due to the high water table and frequent flood events (Hurr 1981, Currier et al. 1985). In my study, the average distance from the Platte River main channel to grasslands (1.9 km) was less than the distance to corn fields (2.4 km). Additionally, lowland grassland and wet meadow habitat bordering the Platte River in central Nebraska have been restored or protected through easements since the 1970's by conservation organizations such as the National Audubon Society (Strom 1987), the Nature Conservancy (Vanderwalker 1987), and the Crane Trust (Currier 1991).

Habitat Use

Habitat type and location have been demonstrated to influence the distribution of cranes in the CPRV (Krapu et al. 1982, Pearse et al. 2010, Anteau et al. 2011). My results demonstrate habitat use by cranes is not only influenced by habitat type and location, but also extends to other landscape and environmental factors. Crane habitat use has been previously addressed by applying various calculation methods to quantify habitat preferences (Iverson et al. 1987, Sparling and Krapu 1994, Davis 2003, Krapu et al. 2005). Individual habitats were considered preferred by cranes if observed habitat use exceeded its availability and vice versa (Neu et al. 1974, Byers et al. 1984). The modeling techniques I used provide an unbiased estimate that a field will be used by cranes based upon site characteristics and availability within the survey area while allowing for temporal variability.

The consequence of not accounting for the non-random use or availability of other habitats is that one habitat type might have different reported preferences in the same area (Aebischer et al. 1993). Iverson et al. (1987) reported alfalfa and corn use exceeded availability in the NPRV while grasslands did not. In the CPRV, Sparling and Krapu (1994) and Davis (2003) reported use of alfalfa and grasslands exceeded their availability. Conversely, use of corn did not exceed availability despite the majority of crane observations occurring in corn fields (Sparling and Krapu 1994, Davis 2003). More recently, Krapu et al. (2005) reported corn was used more often than expected in their survey area. Davis' (2003) also reported soybeans were used in proportion to availability; whereas Krapu et al. (2005) reported soybeans were used less than expected.

My best model predicts corn and alfalfa receive the highest use among all habitats in the CPRV. The use high predicted use of corn is likely related to previous work showing waste corn accounts for over 90% of a crane's diet in Nebraska (Reinecke and Krapu 1986). The use high predicted use of alfalfa is likely related to previous work showing the remainder of a crane's diet is supplemented with alternative food resources, such as invertebrates and other plant material, to compensate for the low levels of protein, fat, and amino acids in corn (Reinecke and Krapu 1986, Davis and Vohs 1993, Petrie et al. 1998).

Soybeans, winter wheat, grasslands, and shrubland were all predicted to receive lower use than alfalfa and corn; however, my results do not suggest these habitats are low quality areas. Lower predicted use of these habitats is potentially related to the small proportion of a crane's diet allocated to supplementing waste corn. Time budgets of foraging activity demonstrate cranes spend as much time supplementing their diet as they do foraging for waste corn, which highlights the importance of supplemental food resources (Reinecke and Krapu 1986).

The predicted habitat use estimates for soybeans and winter wheat suggest these habitats potentially provide a portion of supplemental food resources when alfalfa fields and grasslands are absent from the landscape or present in low proportions. Alfalfa fields and grassland areas are a known source of invertebrate food resources for cranes (Reinecke and Krapu 1986, Davis and Vohs 1993), while soybeans and winter wheat have not been reported in the diet of harvested cranes (Krapu et al. 2004). Grasslands have also been reported to serve as important areas for midday loafing and pair formation (Iverson et al. 1987, Tacha 1988). Therefore, when grasslands are present in low proportions, soybean and winter wheat fields might serve as alternative areas for these behaviors.

The importance of waste corn in a crane's diet is demonstrated by my best model, which predicted the late season use of corn fields increased as distance from suitable roosting habitat increased. The model developed by Anteau et al. (2011) did not detect any seasonal difference in distance traveled to corn compared to my best model, but both models support the notion that corn resources closest to suitable roosting areas receive greater pressure by cranes attempting to reduce energy expenditure. Pearse et al. (2010)

suggested cranes likely stop using a corn field when waste corn is reduced below a certain threshold. However, there might be different thresholds for waste corn throughout the stopover period resulting in cranes seeking other food resources closer to the river rather than flying to corn fields further away. Other habitats close to the river, such as soybeans and winter wheat, potentially provide similar energy as further away corn fields which might explain the predicted use estimates calculated for these habitats.

The best model also detected a seasonal pattern in the distance traveled from suitable roosting areas to fields outside the river. Previous research has reported cranes in the CPRV were observed at varying distances from the river throughout the stopover period, but no associations with specific habitats were provided (Sparling and Krapu 1994, Pearse et al. 2010). My results show cranes travel further from roosting areas to use alfalfa fields compared to other habitats and do so earlier in the stopover period. This pattern might indicate supplemental food resources become limited earlier in the stopover period than grain resources. Therefore, by further increasing the foraging time cranes allocate to acquiring supplemental foods cranes might be adversely impacting their physiological condition. Alternatively, my model also shows a late season increase in the distance travelled to winter wheat fields. Invertebrates present in cattle manure might provide an additional foraging opportunity for cranes in winter wheat fields when invertebrate resources in alfalfa fields are reduced, because winter wheat is commonly grazed by cattle in early spring to stimulate winter wheat growth and increase subsequent grain yields (Redmon et al. 1995).

Habitat use by cranes in the CPRV is influenced by field area and distance from development, in addition to habitat type and location of habitats with regard to roosting areas. The best model predicts cranes are more likely to use larger fields throughout the stopover period regardless of habitat type. Fields larger than 20 hectares made up only a small proportion (0.30) of the survey area, which suggests cranes might put more foraging pressure on larger fields. However, higher predicted use of larger fields does not suggest smaller fields do not provide sufficient food resources. Anteau et al (2011) reported use of corn fields larger than 16.2 hectares ($\bar{x}$ = 39.4 ha) in the CPRV was not influenced by waste grain density despite the availability of waste grain being influenced by post harvest treatment (Reinecke and Krapu 1986, Sherfy et al. 2011).

Food resources in the CPRV, especially waste corn, have been demonstrated to vary widely from year to year and even field to field (Reinecke and Krapu 1986, Krapu et al. 2004, Sherfy et al. 2011). Yearly variation and among field variation of waste corn potentially influenced my estimate of the effect of distance from development, which predicted cranes are more likely to use fields closer to development. My reported estimate of the effect of distance from development either means the model did not fully capture the effect of distance from development because most (95%) observation fields were close to development, or cranes are not negatively influenced by development as reported for other avian species (Chace and Walsh 2004).

Throughout the study, cranes were commonly observed feeding near farmsteads and feed lots, as well as near fence lines, farm lanes, and maintained roads. The willingness of cranes to be near potential disturbances and edge habitats might be related to variation in forage density within a field. Forage density is often measured in the middle a field to remove edge effects (van Groenigen et al. 2003, Anteau et al. 2011, Sherfy et al. 2011). Grain harvested on field edges is typically drier than in the middle of a field, and lower grain moisture has been shown to increase waste corn (Baldassarre et al. 1983). Sherfy et al. (2011) reported little variation in corn density between crane arrival and departure when corn density measurements were restricted to more than 20 meters from field edges, which suggest field edges might be an important source of waste grain for cranes and current estimates of corn density in the CPRV have potentially been underestimated.

Finally, wind speed was the only measured environmental variable to influence habitat use by cranes. The model predicted use of all habitats decreased as wind speeds increased suggesting in high winds cranes likely limit activity to conserve energy. However, the model might not have fully captured the effect of wind speed because most wind speed measurements (81%) were less than 20 kilometers per hour and sampling occurred in the morning. Greater sandhill cranes staging in Indiana are reported to remain on roosts longer and use fields closer to roosting areas during high winds (Lovvorn and Kirkpatrick 1982a). Similarly, cranes in the CPRV have been shown to remain on the roost longer during periods of inclement weather such as heavy precipitation and fog (Norling et al. 1992b).

Flock Size

Model estimated crane flock sizes are representative of field observations as well as previous research showing crane flocks in the CPRV are typically smaller than 200 individuals (Faanes and Frank 1982, Sparling and Krapu 1994, Burger and Gochfeld 2001). My results show cranes in the CPRV aggregate in different flock sizes depending on the characteristics of the location such as habitat type, distance from roosting habitat, field area, and distance from development. Similar to greater sandhill cranes staging in

Indiana, high proportions of crane observations occurred in grasslands, corn, and soybean fields during my study (Lovvorn and Kirpatrick 1982a).

Predicted flock size differed among habitats, with the largest flocks predicted to occur in corn fields followed by alfalfa, soybeans, winter wheat, grassland, and shrubland. Lorenz and Chavez-Ramirez (2008) reported that grasslands supported the largest crane flocks followed by corn and alfalfa. Lorenz and Chavez-Ramirez (2008) also observed larger crane flocks in all habitats compared to my model predicted estimates of flock size, which suggests my estimates of flock size might be too conservative for some habitats or the model was not able to fully capture the effect grasslands have on flock size.

In addition to habitat type, the best model also detected crane flock size in the CPRV is influenced by distance from roosting habitat and field area which has not been previously described. Cranes exhibited seasonal variation in predicted flock size with regard to distance from roosting habitat. Early in the stopover period the largest crane flocks are predicted to occur closest to roosting habitat, which potentially means food resources closest to the river receive the greatest pressure early in the stopover period. During the middle of the stopover period when crane numbers peak in the CPRV, predicted flock sizes in all habitats were smaller than earlier but still decreased as distance from roosting habitat increased. Late in the stopover period, crane flock sizes were smallest among all time periods but were predicted to increase with increasing distance from roosting habitat. The late season pattern suggests high energy expenditures for cranes might be occurring due to either increased distance traveled to food resources or by increased search time for food resources near roosting areas.

Flocks size was also predicted to increase in larger fields and fields further from development, but no seasonal variation was detected by the best model for either variable. Crane behavior potentially affected my reported estimates of predicted flock size in relation to these variables. Burger and Gochfeld (2001) repoted that crane behavior changed in the presence of vehicle disturbance and other human activity. Cranes less than 100 meters from disturbance often stop foraging and fly to another area of the field or leave completely (Burger and Gochfeld 2001). Larger fields would allow for greater distances from disturbance, but only a limited number of fields larger than 30 hectares and more than one kilometer from development in the CPRV exist. Therefore, fields meeting these criteria deserve protection from future development, because they likely serve as important refuge areas for large numbers of cranes during the middle of the day.

MANAGEMENT IMPLICATIONS

Wildlife managers in the CPRV need to alter their current management strategy if the midcontinent population of cranes continues to increase. Under current management in the CPRV, my data shows cranes travel further in larger flocks to agricultural fields as the stopover period progresses, suggesting food resources close to river might become depleted as crane numbers peak. Cranes have been observed up to 20 kilometers from the Platte River (G.L. Krapu, USGS, unpublished data), but energy expenditure and assimilation of resources at different distances is unknown. Certain subpopulations of cranes, particularly in the eastern stopover area from Grand Island to Kearney, Nebraska (*see* Krapu et al. 2011), might be demonstrating this pattern more than cranes west of Kearney, Nebraska due to greater number of cranes roosting in the east (Pearse et al. 2010).

If managers want to minimize the potential negative impacts greater travel distance to fields have on energy storage for certain subpopulations, roost expansion should be focused in the western stopover area while maintaining current roosting conditions in east (Currier et al. 1985, Currier and Ziewitz 1987). In the western portion of the study area most of the crane observations were limited to fields near maintained river segments, which suggests further expansion of western river segments would likely distribute cranes over more of the landscape not currently being used. With the proper management of roosting areas, my data also suggests large numbers of cranes could use habitats in the western stopover area because fields are generally larger, further from development, and alfalfa is produced on a greater proportion of the landscape compared to the east.

FUTURE RESEARCH

Future research should focus on the aspects of crane foraging ecology that have allowed the midcontinent crane population to continue to grow, despite research continually reporting less food is available to cranes today compared to when research was initiated in the late 1970's (Krapu et al. 2004, Pearse et al. 2010, Anteau et al. 2011, Sherfy et al. 2011). No research to date has specifically quantified the diet or behavior of cranes using soybean and winter wheat fields, which were commonly used habitats during my study. Soybeans and winter wheat shoots are potential sources of protein and fat that are lacking in waste corn (Petrie et al. 1998), and these crops are typically grown in no-till or minimum tillage row crop systems which have been shown to increase invertebrate populations over time (Kladivko 2001).

Finally, waste corn resources in the CPRV should be investigated further. Future estimates of waste corn density in the CPRV should include field borders. Including field borders will likely improve the accuracy of waste corn density estimates within a field and allow for comparison between edge and interior locations. In addition to waste corn densities changing with post-harvest management and livestock grazing (Krapu et al. 1986, Anteau et al. 2011, Sherfy et al. 2011), the impact resident wildlife species have on waste corn resources should be investigated. Species such as, white-tailed deer (*Odocoileus virginianus*) and wild turkeys (*Meleagris gallopavo*) put additional pressure on waste corn resources close to the river before cranes and snow geese (*Chen caerulescens*) arrive in the CPRV in spring. Conservative estimates of white-tailed deer densities in the CPRV range from 8–12 deer/km^2, and wild turkey densities are estimated to vary seasonally from 4–12 turkeys/ km^2 in the spring and fall (Kit Hams, Nebraska Game and Parks Commission, personal communication).

LITERATURE CITED

Aebischer, N.J., P.A. Robertson, and R.E. Kenward. 1993. Compositional analysis of habitat use from animal radio-tracking data. Ecology 74: 1313-1325.

Akaike, H. 1974. A new look at the statistical model identification. IEEE Transactions on Automatic Control 19: 716-723.

Alerstam, T., and A. Hedenstrom. 1998. The development of bird migration theory. Journal of Avian Biology 29: 343-369.

Alisauskas, R.T. 2002. Arctic climate, spring nutrition, and recruitment of midcontinent lesser snow geese. Journal of Wildlife Management 66: 181-193.

Ankney, C.D., and C.D. MacInnes. 1978. Nutrient reserves and the reproductive performance of female lesser snow geese. Auk 95: 459-471.

Anteau, M.J., M.H. Sherfy, and A.A. Bishop. 2011. Location and agricultural practices influence spring use of harvested cornfields by cranes and geese in Nebraska. Journal of Wildlife Management 75: in press.

Antrop, M. 1998. Landscape change: Plan or chaos? Landscape and Urban Planning 41: 155-161.

Antrop, M. 2000. Background concepts for integrated landscape analysis. Agriculture, Ecosystems, and the Environment 77: 17-28.

Baldassarre, G.A, R.J. Whyte, E.E. Quinlan, and E.G. Bolen. 1983. Dynamics and quality of waste corn available to postbreeding waterfowl in Texas. Wildlife Society Bulletin 11: 25-31.

Ballard, B.M., and J.E. Thompson. 2000. Winter diets of sandhill cranes from central and coastal Texas. The Wilson Bulletin 112: 263-268.

Blewett, C.M., and J.M. Marzluff. 2005. Effects of urban sprawl on snags and the abundance and productivity of cavity-nesting birds. Condor 107: 678-693.

Burger, J., and M. Gochfeld. 2001. Effect of human presence on foraging behavior of sandhill cranes (*Grus canadensis*) in Nebraska. Bird Behavior 14: 81-87.

Burnham, K.P., and D.R. Anderson. 2002. Model selection and multimodel inference. Springer. New York, New York, USA.

Byers, C.R., R.K. Steinhorst, and P.R. Krausman. 1984. Clarification of a technique for analysis of utilization-availability data. Journal of Wildlife Management 48: 1050-1053.

Caraco, T. 1979. Time budgeting and group size: a theory. Ecology 60: 611-617.

Chace, J.F., and J.J. Walsh. 2004. Urban effects on native avifauna: a review. Landscape and Urban Planning 74: 46-69.

Currier, P.J. 1997. Woody vegetation expansion and continuing declines in open channel habitat on the Platte River in Nebraska. Proceedings of the North American Crane Workshop 7: 141-152.

Currier, P.J. 1991. Reclamation of crane roosting habitat on the Platte River and restoration of riverine wetlands. Proceedings of the 1987 International Crane Workshop: 403-407.

Currier, P.J., and J.W. Ziewitz. 1987. Application of a sandhill crane model to the management of habitat along the Platte River. Proceedings of the 1985 Crane Workshop: 315-325.

Currier, P.J., G.R. Lingle, and J.G. VanDerwalker. 1985. Migratory bird habitat on the Platte and North Platte Rivers in Nebraska. The Platte River Whooping Crane Critical Habitat Maintenance Trust, Grand Island, Nebraska, USA.

Davis, C.A. 2001. Nocturnal roost site selection and diurnal habitat use by sandhill cranes during spring in central Nebraska. Proceedings North American Crane Workshop 8: 48-56.

Davis, C.A. 2003. Habitat use and migration patterns of sandhill cranes along the Platte River, 1998-2001. Great Plains Research 13: 199-216.

Davis, C.A., and P.A. Vohs. 1993. Role of macroinvertebrates in spring diet and habitat use of sandhill cranes. Transactions of the Nebraska Academy of Sciences 10: 81-86.

Ebbinge, B.S, and B. Spaans. 1995. The importance of body reserves accumulated in spring staging areas in the temperate zone for breeding in dark-bellied brent geese *Branta b. bernicla* in the High Arctic. Journal of Avian Biology 26: 105-113.

Eckman, J. 1981. Problems of unequal observability. Pages 230-234 *in* Estimating the numbers of terrestrial birds (C.J. Ralph and J.M. Scott, Eds.). Studies in Avian Biology 6.

Environmental Systems Research Institute, Inc. 2008. ArcMap. Version 9.3. Redlands, CA.

Faanes, C.A., and A.M. Frank. 1982. Characteristics of diurnal sandhill crane flocks in the Platte River Valley, Nebraska. Proceedings of the 1981 Crane Workshop: 22-26.

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: 480-486.

Gilliland, S.G., G.H. Gilchrist, R.F. Rockwell, G.J. Robertson, J-P. L. Savard, F. Merkel, and A. Mosbech. 2009. Evaluating the sustainability of harvest among northern common eiders *Somateria mollissima borealis* in Greenland and Canada. Wildlife Biology 15: 24-36.

Griffith, E.H., J.R. Sauer, and J.A. Royle. 2010. Traffic effects on bird counts on North American Breeding Bird Survey routes. Auk 127: 387-393.

Gubanyi, J.A., J.A. Savidge, S.E. Hygnstrom, K.C. VerCauteren, G.W. Garabrandt, and S.P. Korte. 2008. Deer impact on vegetation in natural areas in southeastern Nebraska. Natural Areas Journal 28: 121-129.

Hiller, T.L., L.A. Powell, T.D. McCoy, and J.J. Lusk. 2009. Long-term agricultural land-use trends in Nebraska, 1866-2007. Great Plains Research 19: 225-237.

Higashi, M., and N. Yamamura. 1993. What determines animal group size? Insider-outsider conflict and its resolution. American Naturalist 142: 553-563.

High Plains Regional Climate Center. 2003-2010. Climate Data Services. <http://www.hprcc.unl.edu/index.php>. Accessed 10 Nov 2010.

Hosmer Jr., D.W., and S. Lemeshow. 2000. Applied logistic regression. Second edition. Wiley. New York, New York, USA.

Hurr, R.T. 1981. Ground water hydrology of the Mormon Island Crane Meadows Wildlife Area, near Grand Island, Hall County, Nebraska. United States Geological Survey Open File Report 81-1109

Hygnstrom, S.E., K.C. VerCauteren, S.R. Groepper, G.W. Garabrandt, and J.A. Gubanyi. 2011. Effects of seasons and hunting on space use by female white-tailed deer in a developed landscape in southeastern Nebraska. Wildlife Society Bulletin: *In press*.

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.

Johnson, D.H., R.C. Drewien, and D.S. Benning. 2001. Counting cranes: how much effort is enough? Proceedings of the North American Crane Workshop 8: 203-210.

Johnson, D.M., and R. Mueller. 2010. The 2009 cropland data layer. Photogrammetric Engineering and Remote Sensing 76: 1201-1205.

Jorgensen, J.G., J.P. McCarty, and L.L. Wolfenbarger. 2008. Buff-breasted sandpiper density and numbers during migratory stopover in the Rainwater Basin, Nebraska. Condor 110: 63-69.

Kinzel, P. J., J. M. Nelson, R. S. Parker, and L. R. Davis. 2006. Spring census of mid-continent sandhill cranes using aerial infrared videography. Journal of Wildlife Management 70: 70-77.

Kladivko, E.J. 2001. Tillage systems and soil ecology. Soil and Tillage Research 61: 61-76.

Klopfenstein, T.J., G.E. Erickson, and V.R. Bremer. 2008. Board Invited Review: use of distillers by products in the beef cattle feeding industry. Journal of Animal Science 86: 1223-1231.

Kohavi, R. 1995. A study of cross-validation and bootstrap for accuracy estimation and model selection. The International Joint Conference on Artificial Intelligence: 1137-1145.

Krapu, G.L. 1987. Use of staging areas by sandhill cranes in the midcontinent region of North America. Proceedings of the 1983 International Crane Workshop: 451-462.

Krapu, G.L., D.A. Brandt, and R.R. Cox. 2005. Do Arctic-nesting geese compete with sandhill cranes for waste corn in the Central Platte River Valley, Nebraska. Proceedings North American Crane Workshop 9: 185-191.

Krapu, G.L., D.A. Brandt, and R.R. Cox. 2004. Less waste corn, more land in soybeans, and the switch of genetically modified crops: trends with important implications for wildlife management. Wildlife Society Bulletin 32: 127-136.

Krapu, G.L., D.A. Brandt, K.L. Jones, and D.H. Johnson. 2011. Geographic distribution of the mid-continent population of sandhill cranes and related management applications. Wildlife Monographs 175: 1-38.

Krapu, G.L., 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.

Krapu, G.L., G.C. Iverson, K.J. Reinecke, and C.M. Boise. 1985. Fat deposition and usage by Arctic-nesting sandhill cranes during spring. Auk 102: 362-368.

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

Krapu, G.L., K.J. Reinecke, D.G. Jorde, and S.G. Simpson. 1995. Spring-staging ecology of midcontinent greater white-fronted geese. Journal of Wildlife Management 59: 736-746.

Kruse, K.L., D.E. Sharp, and J.A. Dubovsky. 2010. Status and harvests of sandhill cranes: Mid-Continent, Rocky Mountain and Lower Colorado River Valley Populations. Administrative Report, U.S.Fish and Wildlife Service, Denver, Colorado. 11pp.

Lingle, G.R., and G.L. Krapu. 1986. Winter ecology of bald eagles in southcentral Nebraska. Prairie Naturalist 18: 65-78.

Lorenz, B., and F. Chavez-Ramirez. 2008. Distribution and dispersion patterns of sandhill crane flocks in the Platte River Valley. Proceedings of the North American Crane Workshop 10: 159.

Lovvorn, J. R., and C. M. Kirkpatrick. 1982a. Field use by staging eastern greater sandhill cranes. Journal of Wildlife Management 46: 99-108.

Lovvorn, J. R., and C. M. Kirkpatrick. 1982b. Recruitment and socially specific flocking tendencies of eastern sandhill cranes. Wilson Bulletin 94: 313-321.

Luman, D., and T. Tweddale. 2008. Assessment and potential of the 2007 USDA-NASS Cropland Data Layer for statewide annual land cover applications. Illinois Natural History Survey Technical Report 2008 (49).

Mayer, D.G., and D.G. Butler. 1993. Statistical validation. Ecological Modelling 68: 21-32.

National Agricultural Statistics Service. 2002-2009. Cropland Data Layer. <http://www.nass.usda.gov/research/Cropland/SARS1a.htm>. Accessed 11 Feb 2010.

National Agricultural Statistics Service. 2010. Data and Statistics. <http://www.nass.usda.gov/Data_and_Statistics>. Accessed 10 Apr 2011.

Neu, C.W., C.R. Byers, and J.M. Peek. 1974. A technique for analysis of utilization-availability data. Journal of Wildlife Management 38: 541-545.

Newton, I. 2006. Can conditions experienced during migration limit the population levels of birds? Journal of Ornithology 147: 146-166.

Norling, B.S., S.H. Anderson, and W.A. Hubert. 1992a. Roost sites used by sandhill cranes staging along the Platte River, Nebraska. Great Basin Naturalist 52: 253-261.

Norling, B.S., S.H. Anderson, and W.A. Hubert. 1992b. Temporal patterns of sandhill crane roost site use in the Platte River. Proceedings of the North American Crane Workshop 6: 106-113.

Pearce, J., and S. Ferrier. 2000. Evaluating the predictive performance of habitat models developed using logistic regression. Ecological Modelling 133: 225-245.

Pearse, A.T, G.L. Krapu, D.A. Brandt, and P.J. Kinzel. 2010. Changes in agriculture and abundance of snow geese affect carrying capacity of sandhill cranes in Nebraska. Journal of Wildlife Management 74: 479-488.

Peterjohn, B.G., J.R. Sauer, and C.S. Robbins. 1995. Population trends from the North American Breeding Bird Survey. Pages 3-39 *in* Ecology and management of Neotropical migratory birds (T.E. Martin and D.M. Finch, Eds.). Oxford University Press, New York.

Petrie, M.J, R.D. Drobney, and D.A. Graber. 1998. True metabolizable energy estimates of Canada goose foods. Journal of Wildlife Management 62: 1147-1152.

Pfeiffer, K., and P.J. Currier. 2005. An adaptive approach to channel management of the Platte River. Proceedings of the North American Crane Workshop 9: 151-154.

Powell, L.A., J.S. Taylor, J.J. Lusk, and T.W. Matthews. 2011. Adaptive harvest management and harvest mortality of greater prairie-chickens. Pages 329-339 *in* B.K. Sandercock, K. Martin, and G. Segelbacher (Editors). Ecology, conservation, and management of grouse. Studies in Avian Biology (39), University of California Press, Berkeley, California, USA.

Pulliam, H.R. 1976. The principle of optimal behavior and the theory of communities. Pages 311-332 *in* Perspectives in Ethology (P.H. Klopfer and P.P.G. Bateson, Eds.). Plenum Press, New York.

R Development Core Team. 2008. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Redmon, L.A., G.W. Horn, E.G. Krenzer, and D.J. Bernardo. 1994. A review of livestock grazing and wheat grain yield: boom or bust? Agronomy Journal 87: 137-147.

Reinecke, K. J., and G.L. Krapu. 1986. Feeding ecology of sandhill cranes during spring migration in Nebraska. Journal of Wildlife Management 50: 71-79.

Roberts, M.J., and R.N. Lubowski. 2007. Enduring impacts of land retirement policies: Evidence from the Conservation Reserve Program. Land Economics 83: 516-538.

Schwarz, G.E. 1978. Estimating the dimension of a model. Annals of Statistics 6: 461-464.

Shake, C.S., C.E. Moorman, and M.R. Burchell II. 2011. Cropland edge, forest succession, and landscape affect shrubland bird nest predation. Journal of Wildlife Management 75: 825-835.

Sherfy, M.H., M.J. Anteau, and A.A. Bishop. 2011. Agricultural practices and residual corn during spring crane and waterfowl migration in Nebraska. Journal of Wildlife Management 75: in press.

Sidle, J.G., and C.A. Faanes. 1997. Platte River ecosystem resources and management, with emphasis on the Big Bend reach in Nebraska. U.S. Fish and Wildlife Service, Grand Island, Nebraska. 261pages.

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.

Sparling, D. W., and G. L. Krapu. 1994. Communal roosting and foraging behavior of staging sandhill cranes. Wilson Bulletin 106: 62-77.

Strom, K.J. 1987. Lillian Annette Rowe Sanctuary-Managing migratory crane habitat on the Platte River, Nebraska. Proceedings of the 1985 Crane Workshop: 326-330.

Tacha, T.C. 1988. Social organization of sandhill cranes from midcontinental North America. Wildlife Monographs 99: 1-37.

Tacha, T.C., P.A. Vohs, and G.C. Iverson. 1987. Time and energy budgets of sandhill cranes from mid-continental North America. Journal of Wildlife Management 51: 440-448.

Tarr, N.M., T.R. Simons, and K.H. Pollock. 2010. An experimental assessment of vehicle disturbance effects on migratory shorebirds. Journal of Wildlife Management 74: 1776-1783.

Thomas, K., R.G. Kvitek, and C. Bretz. 2003. Effects of human activity on the foraging behavior of sanderlings (*Calidris alba*). Biological Conservation 109: 67-71.

United States Department of Agriculture – Natural Resources Conservation Service. 2010. Geospatial Data Gateway. <http://datagateway.nrcs.usda.gov>. Accessed 11 Feb 2010.

United States Department of Agriculture – Natural Resources Conservation Service. 2011. Plants Database. <http://plants.usda.gov>. Accessed 05 April 2011.

United States Fish and Wildlife Service. 1981. The Platte River ecology study. U.S. Fish and Wildlife Service, Jamestown, North Dakota. 187 pages.

United States Geological Survey. 2003-2010. Nebraska Water Science Center. <http://ne.water.usgs.gov/>. Accessed 10 Nov 2010.

van Groenigen, J.W., E.G. Burns, J.M. Eadie, W.R. Horwath, and C. van Kessel. 2003. Effects of foraging waterfowl in winter flooded rice fields on weed stress and residue decomposition. Agriculture, Ecosystems & Environment 95: 289-296.

Vanderwalker, J.G. 1987. Preservation of crane habitat on the Platte River, Nebraska. Proceedings of the 1983 International Crane Workshop: 425-437.

Vanzant, E.S., and R.C. Cochran. 1994. Performance and forage utilization by beef cattle receiving increasing amounts of alfalfa hay as a supplement to low quality, tallgrass prairie forage. Journal of Animal Science 72: 1059-1067.

Walkinshaw, G.P. 1956. Two visits to the Platte Rivers and their sandhill crane migration. Nebraska Bird Review 24: 18-21.

Windingstad, R. M. 1988. Non-hunting mortality in sandhill cranes. Journal of Wildlife Management 52: 260-263.

Zuur, A.F., E.N. Ieno, N.J. Walker, A.A. Saveliev, and G.M. Smith. 2009. Mixed effects models and extensions in ecology with R. Springer. New York, New York, USA.

Table 1–1. Description of Platte River bridge segments between Chapman and Overton, Nebraska.

Bridge Segment*	**Location**
1	Chapman to Highway 34
2	Highway 34 to Highway 281
3	Highway 281 to Alda
4	Alda to Wood River
5	Wood River to Shelton
6	Shelton to Gibbon
7	Gibbon to Highway 10
8	Highway 10 to Kearney
9	Kearney to Odessa
10	Odessa to Elm Creek
11	Elm Creek to Overton

* Bridge segments increase from east to west (adopted from Currier et al. 1985).

Table 1–2. NASS habitat classifications included in the final habitat classification scheme, 2003–2010.

Corn	**Soybeans**	**Winter Wheat**	**Alfalfa**	**Grassland***	**Shrubland***	**Timber***	**Development**
Corn	Soybeans	Winter Wheat	Alfalfa	Pasture/Grass	Pasture/Grass	Pasture/Grass	Urban/Developed
Sorghum	Winter Wheat and Soybean Double Crop	Other Small Grains		Fallow/Idle Cropland	Woodland	Woodland	
Millet				Other Hays	Wetlands	Wetlands	
				Clover/Wildflowers	Shrubland		
				Wetlands			

* Orthophotos referenced for proportion of woody vegetation occupying an observation field.

Table 1–3. Criteria used to classify 800 meter segments of the Platte River main channel from Chapman to Overton, Nebraska 2003–2010.

Category*	**Channel Width (m)**	**Category Description**
1	≥ 150	• Both banks free of tall woody vegetation ○ Both banks can have tall woody IF channel is greater than 200m • One bank is free of tall woody vegetation • One bank is free of tall woody vegetation AND segment does not contain an elevated island with vegetation
2	≥ 150	• Segment contains an elevated island with vegetation OR segment parallels a road • Both bank have tall woody vegetation AND channel is less than 200m • Both bank have woody vegetation AND segment contains an elevated island with vegetation OR segment parallels a road
3	100–150	• One bank is free of tall woody vegetation • One bank is free of tall woody vegetation AND segment does not contain an elevated island with vegetation
4	100–150	• Segment contains an elevated island with vegetation OR segment parallels a road • Both banks have tall woody vegetation • Both banks have tall woody vegetation AND segment contains an elevated island with vegetation OR segment parallels a road
5	< 100	• Any channel less than 100m

* River segments less than 400 meters from bridges and less than 200 meters from power lines were excluded from analysis.

Table 1–4. Proportions of each habitat type in the CPRV survey area (34,870 ha) from 2003–2010.

	Year								
Habitat	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	$\bar{x}$
Corn	0.5549	0.5305	0.5857	0.5339	0.5824	0.6228	0.5914	0.5847	0.5732
Grassland	0.1851	0.1741	0.1857	0.1920	0.1781	0.1761	0.1719	0.1724	0.1794
Soybeans	0.1406	0.1512	0.1115	0.1663	0.1368	0.0852	0.1254	0.1281	0.1306
Development	0.0514	0.0514	0.0514	0.0508	0.0508	0.0508	0.0508	0.0508	0.0510
Alfalfa	0.0432	0.0634	0.0328	0.0233	0.0028	0.0300	0.0307	0.0278	0.0317
Winter Wheat	0.0057	0.0102	0.0138	0.0144	0.0298	0.0159	0.0105	0.0169	0.0147
Timber	0.0129	0.0129	0.0129	0.0127	0.0127	0.0127	0.0127	0.0127	0.0128
Shrubland	0.0062	0.0062	0.0062	0.0065	0.0065	0.0065	0.0065	0.0065	0.0064

Table 1–5. Proportions of each habitat type by bridge segment in the 2010 CPRV survey area.

	Bridge Segment										
Habitat	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Corn	0.543	0.618	0.653	0.598	0.696	0.574	0.439	0.594	0.645	0.525	0.470
Grassland	0.164	0.123	0.110	0.211	0.194	0.183	0.358	0.175	0.087	0.081	0.254
Soybeans	0.203	0.123	0.110	0.085	0.033	0.143	0.103	0.161	0.073	0.225	0.129
Development	0.049	0.093	0.097	0.037	0.035	0.037	0.035	0.037	0.030	0.022	0.034
Alfalfa	0.008	0.016	0.014	0.016	0.018	0.035	0.036	< 0.001	0.040	0.101	0.096
Winter Wheat	0.007	0.012	< 0.001	0.008	0.005	0.011	0.011	0.026	0.119	0.035	< 0.001
Timber	0.023	0.010	0.017	0.023	0.004	0.017	0.009	0.002	0.004	0.002	0.009
Shrubland	0.003	0.005	< 0.001	0.021	0.015	< 0.001	0.008	0.006	0.002	0.009	0.008
Hectares	6309	4246	3832	2832	3784	2956	2558	2017	2328	1887	2122

Table 1–6. Results of habitat use analysis and model selection.

Model	k	Explanatory Variables*	ΔBIC	*w*	AUC
233	28	HAB*FA + HAB*DR + DR*JD + FA*JD + DD + TC + WSP	0.00	0.718	0.750
182	26	HAB*FA + HAB*DR + DR*JD + DD + TC + WSP	2.50	0.206	0.745
236	29	HAB*FA + HAB*DR + DR*JD + FA*JD + DD + PRF + TC + WSP	4.99	0.059	0.750
191	27	HAB*FA + HAB*DR + DR*JD + DD + PRF + TC + WSP	7.47	0.017	0.745
Global	36	HAB*FA + HAB*DR + HAB*DD + DR*JD + DD*JD + FA*JD + PRF + TC + WSP	40.30	0.000	–
Null	9	1	2871.22	0.000	–

Abbreviations of explanatory variables are as follows:
HAB = Habitat, FA = Field Area (ha), DR = Distance from Riverine Roosting Habitat (km), DD = Distance from Development (km), PRF = Platte River Flow (cfs), TC = Temperature (C), WSP = Wind Speed (kph), JD = Julian Date and Julian Date Quadratic, YR = Year.
* All models include the fixed effects, HAB and JD, and the random effect, YR.

Table 1–7. Coefficient estimates for Model 233.

Coefficient	**Estimate***	**SE**	**z value**	**Significance**
(Intercept)	-1.568	0.067	-23.39	$p < 0.001$
HAB – Corn	-0.018	0.056	-0.32	–
HAB – Soybeans	-0.371	0.064	-5.78	$p < 0.001$
HAB – Winter Wheat	-0.446	0.113	-3.96	$p < 0.001$
HAB –Grassland	-0.725	0.061	-11.9	$p < 0.001$
HAB – Shrubland	-0.937	0.175	-5.36	$p < 0.001$
FA	1.082	0.071	15.19	$p < 0.001$
DR	0.161	0.042	3.86	$p < 0.001$
DD	-0.319	0.016	-20.57	$p < 0.001$
TC	0.022	0.015	1.50	–
WSP	-0.117	0.012	-9.44	$p < 0.001$
JD	0.534	0.019	28.02	$p < 0.001$
JD^2	-0.811	0.018	-45.82	$p < 0.001$
FA*HAB – Corn	-0.580	0.072	-8.09	$p < 0.001$
FA*HAB – Soybeans	-0.734	0.076	-9.61	$p < 0.001$
FA*HAB – Winter Wheat	-0.693	0.112	-6.19	$p < 0.001$
FA*HAB –Grassland	-0.647	0.073	-8.87	$p < 0.001$
FA*HAB – Shrubland	-0.899	0.179	-5.01	$p < 0.001$
DR*HAB – Corn	-0.244	0.043	-5.65	$p < 0.001$
DR*HAB – Soybeans	-0.348	0.059	-5.88	$p < 0.001$
DR*HAB – Winter Wheat	-0.233	0.083	-2.83	$p < 0.05$
DR*HAB – Grassland	-0.481	0.051	-9.42	$p < 0.001$
DR*HAB – Shrubland	-0.721	0.240	-3.01	$p < 0.05$
DR*JD	0.289	0.021	13.95	$p < 0.001$
$DR*JD^2$	-0.079	0.019	-4.22	$p < 0.001$
FA*JD	0.063	0.013	4.98	$p < 0.001$
$FA*JD^2$	-0.024	0.013	-1.82	–
Random Effect	**Variance**	**SD**		
Year (Intercept)	0.012	0.109		

* Reported on log-odds scale
Abbreviations of explanatory variables are as follows:
HAB = Habitat, FA = Field Area (ha), DR = Distance from Riverine Roosting Habitat (km), DD = Distance from Development (km), PRF = Platte River Flow (cfs), TC = Temperature (C), WSP = Wind Speed (kph), JD = Julian Date.

Table 1–8. Descriptive statistics of covariates used for habitat use analysis.

Covariate	**Min.**	**Q1**	**Median**	$\bar{x}$	**Q3**	**Max.**
JD	54 (Feb. 23)	69 (Mar. 10)	81 (Mar. 22)	81 (Mar. 22)	92 (Apr. 2)	107 (Apr. 17)
FA	0.45	5.87	13.04	17.23	23.88	124.20
DR	0.19	1.79	3.05	3.63	4.61	18.10
DD	0.00	0.18	0.30	0.39	0.50	3.50
TC	-15.26	-1.41	2.54	1.77	5.94	15.84
WSP	1.92	7.60	11.04	15.14	21.57	46.14
PRF	0 (Ice)	548	780	906	1030	3790

Abbreviations of explanatory variables are as follows:
JD = Julian Date, FA = Field Area (ha), DR = Distance from Riverine Roosting Habitat (km),
DD = Distance from Development (km), PRF = Platte River Flow (cfs), TC = Temperature (C), WSP = Wind Speed (kph).

Table 1–9. Proportion of crane flocks observed in each habitat type in the CPRV, 2003–2010.

	Year								
Habitat	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	$\bar{x}$
Corn	0.6463	0.5908	0.7441	0.6482	0.6966	0.6891	0.6996	0.6595	**0.6718**
Grassland	0.1779	0.1364	0.1388	0.1407	0.1610	0.1591	0.1426	0.1509	**0.1509**
Soybeans	0.1141	0.1559	0.0669	0.1639	0.0918	0.0825	0.1011	0.1138	**0.1112**
Alfalfa	0.0564	0.1009	0.0443	0.0381	0.0055	0.0467	0.0498	0.0578	**0.0499**
Winter Wheat	0.0013	0.0125	0.0049	0.0075	0.0384	0.0182	0.0038	0.0121	**0.0123**
Shrubland	0.0040	0.0035	0.0010	0.0017	0.0068	0.0044	0.0030	0.0060	**0.0038**
Timber	–	–	–	–	–	–	–	–	–
Development	–	–	–	–	–	–	–	–	–
Flocks Observed	1490	1437	1016	1208	1460	1370	1325	1160	**10,466**

Table 1–10. Results of flock size analysis and model selection.

Model	k	Explanatory Variables*	ΔBIC	*w*	RMSE
35	14	DR*JD + FA + DD	0.00	0.983	0.639
33	13	DR*JD + FA	8.12	0.017	0.640
Global	36	HAB*FA + HAB*DR + HAB*DD + DR*JD + DD*JD + FA*JD + PRF + TC + WSP	248.59	0.000	–
Null	9	1	252.57	0.000	–

Abbreviations of explanatory variables are as follows:
HAB = Habitat, FA = Field Area (ha), DR = Distance from Riverine Roosting Habitat (km), DD = Distance from Development (km), PRF = Platte River Flow (cfs), TC = Temperature (C), WSP = Wind Speed (kph), JD = Julian Date and Julian Date Quadratic, YR = Year.
* All models include the fixed effects, HAB and JD, and the random effect, YR.

Table 1–11. Coefficient estimates for Model 35.

Coefficient	Estimate*	SE	t value
(Intercept)	1.979	0.039	50.61
HAB – Corn	0.029	0.029	0.99
HAB – Soybeans	-0.048	0.034	-1.41
HAB – Winter Wheat	-0.063	0.062	-1.02
HAB – Grassland	-0.072	0.033	-2.20
HAB – Shrubland	-0.254	0.103	-2.46
FA	0.086	0.007	12.81
DR	-0.014	0.009	-1.62
DD	0.033	0.007	5.06
JD	-0.189	0.007	-28.84
JD^2	-0.063	0.006	-11.29
DR*JD	0.052	0.006	8.08
$DR*JD^2$	-0.019	0.006	-3.17
Random Effect	**Variance**	**SD**	
Year (Intercept)	0.006	0.074	

* Reported on $\log_{10}$ scale
Abbreviations of explanatory variables are as follows:
HAB = Habitat, FA = Field Area (ha), DR = Distance from Riverine Roosting Habitat (km), DD = Distance from Development (km), JD = Julian Date.

Table 1–12. Descriptive statistics of covariates used for flock size analysis.

Covariate	Min.	Q1	Median	$\bar{x}$	Q3	Max.
JD	54 (Feb. 23)	76 (Mar. 17)	84 (Mar. 25)	84 (Mar. 25)	92 (Apr. 2)	107 (Apr. 17)
DR	0.22	1.69	2.76	3.48	4.23	17.98
FA	0.45	12.13	20.48	24.78	31.37	124.20
DD	0.00	0.20	0.28	0.34	0.42	2.86
TC	-13.63	-0.13	3.36	3.04	5.94	15.84
WSP	1.92	7.98	11.04	16.01	23.00	46.14
PRF	0	507	678	853	977	3790

Abbreviations of explanatory variables are as follows:
JD = Julian Date, FA = Field Area (ha), DR = Distance from Riverine Roosting Habitat (km),
DD = Distance from Development (km), PRF = Platte River Flow (cfs), TC = Temperature (C), WSP = Wind Speed (kph).

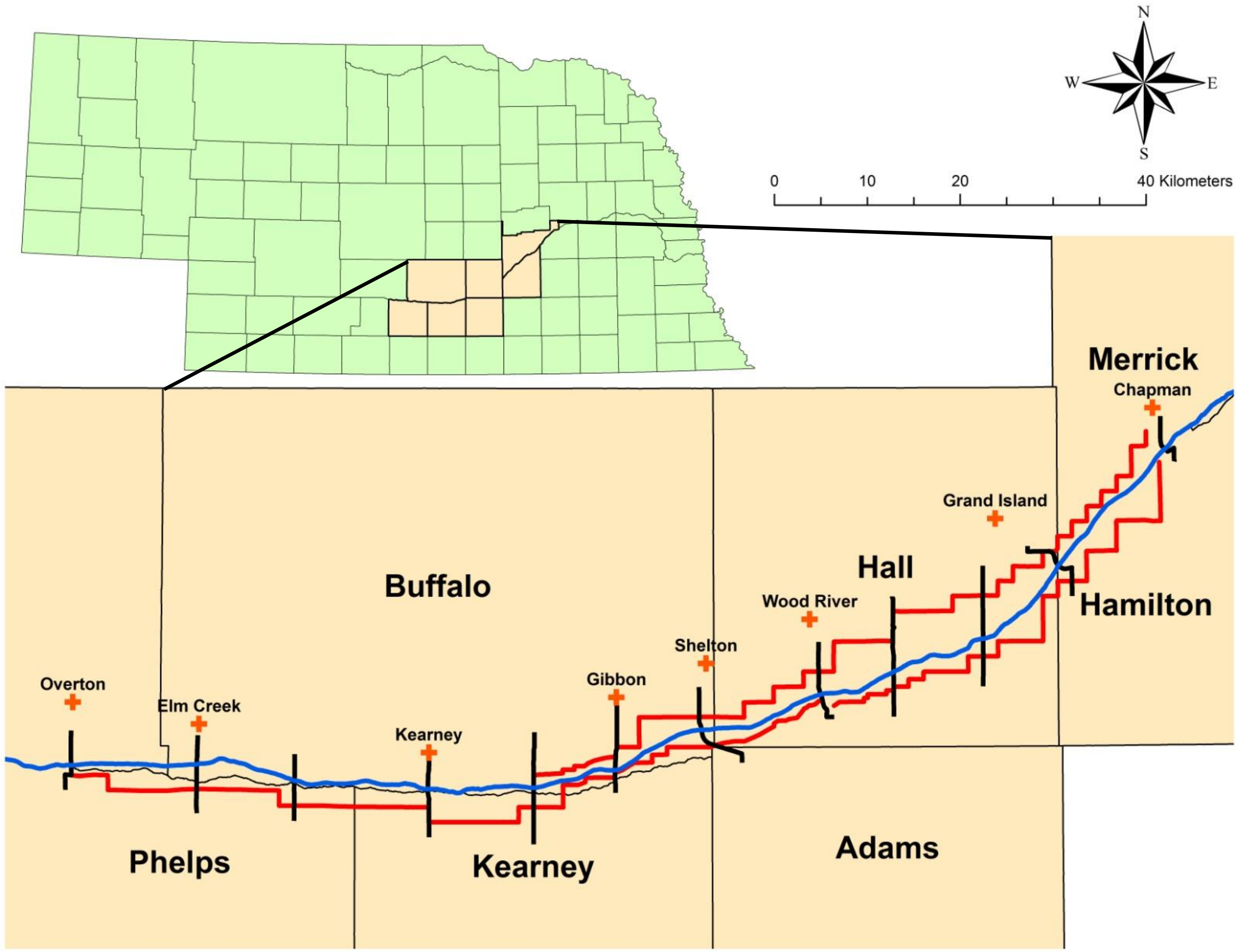

Figure 1–1. Ground survey routes (red lines) in the Central Platte River Valley, Nebraska study area, 2003–2010.

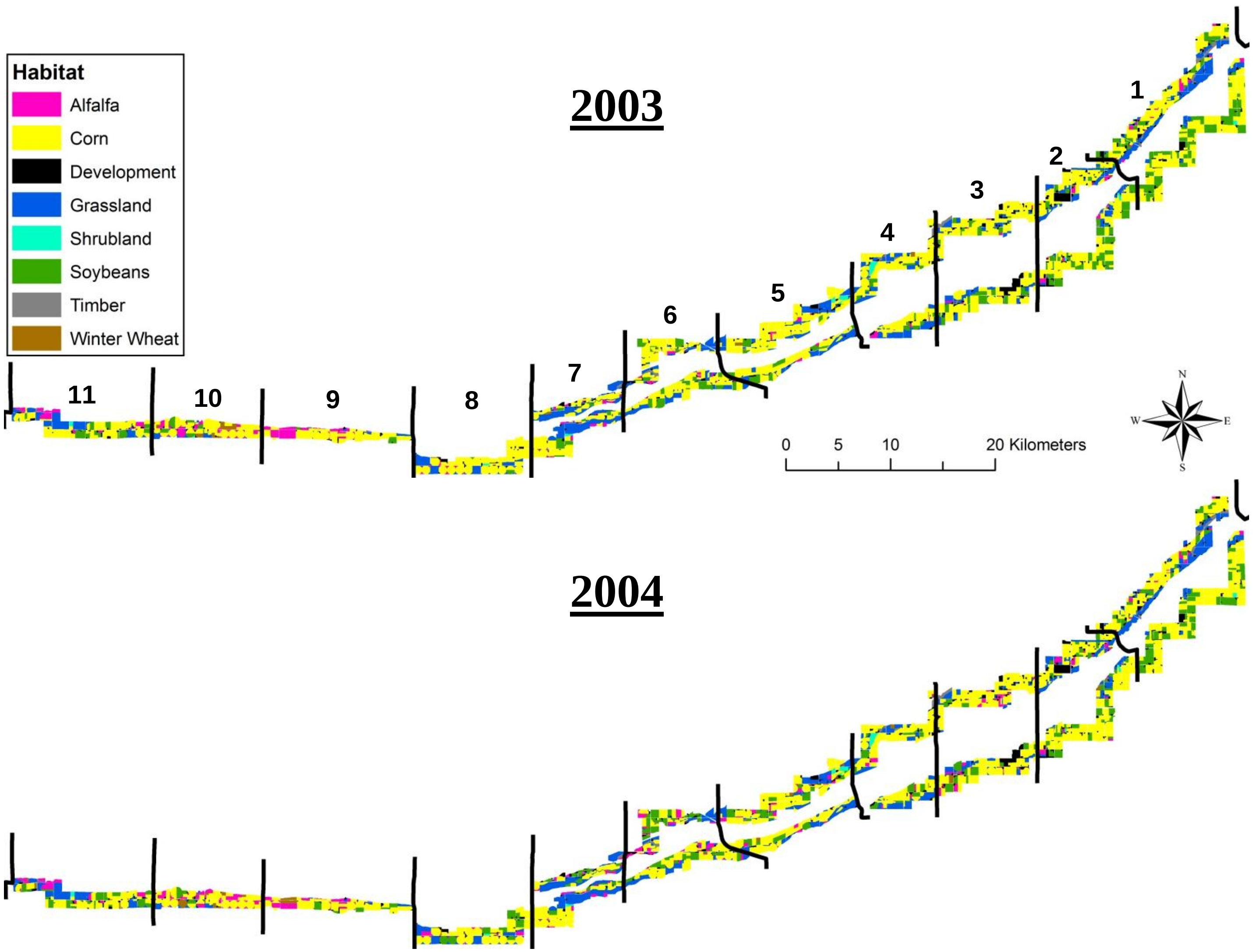

Figure 1–2. Habitat availability by bridge segment (black lines) in the Central Platte River Valley, Nebraska study area, 2003–2010.

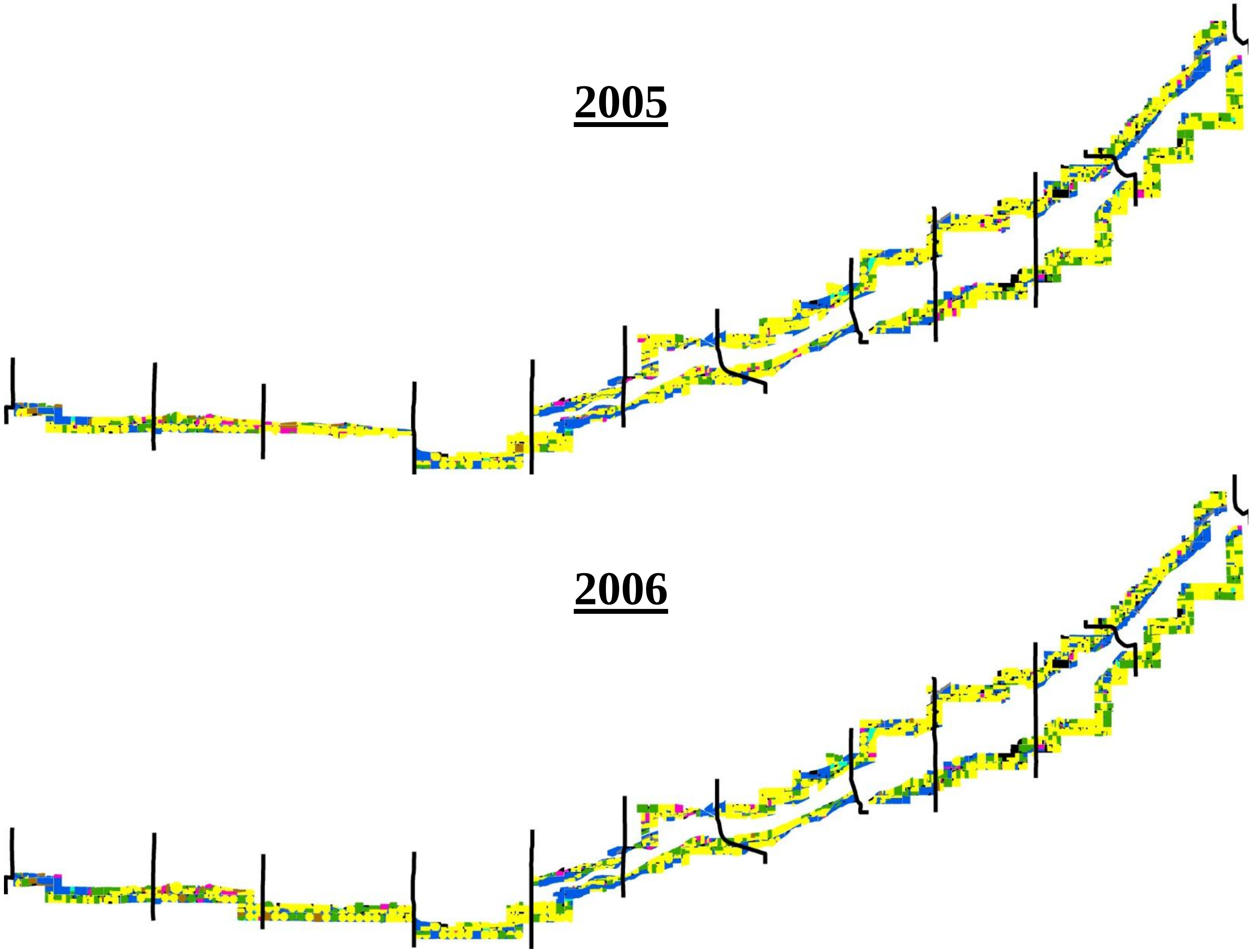

Figure 1–2 Continued.

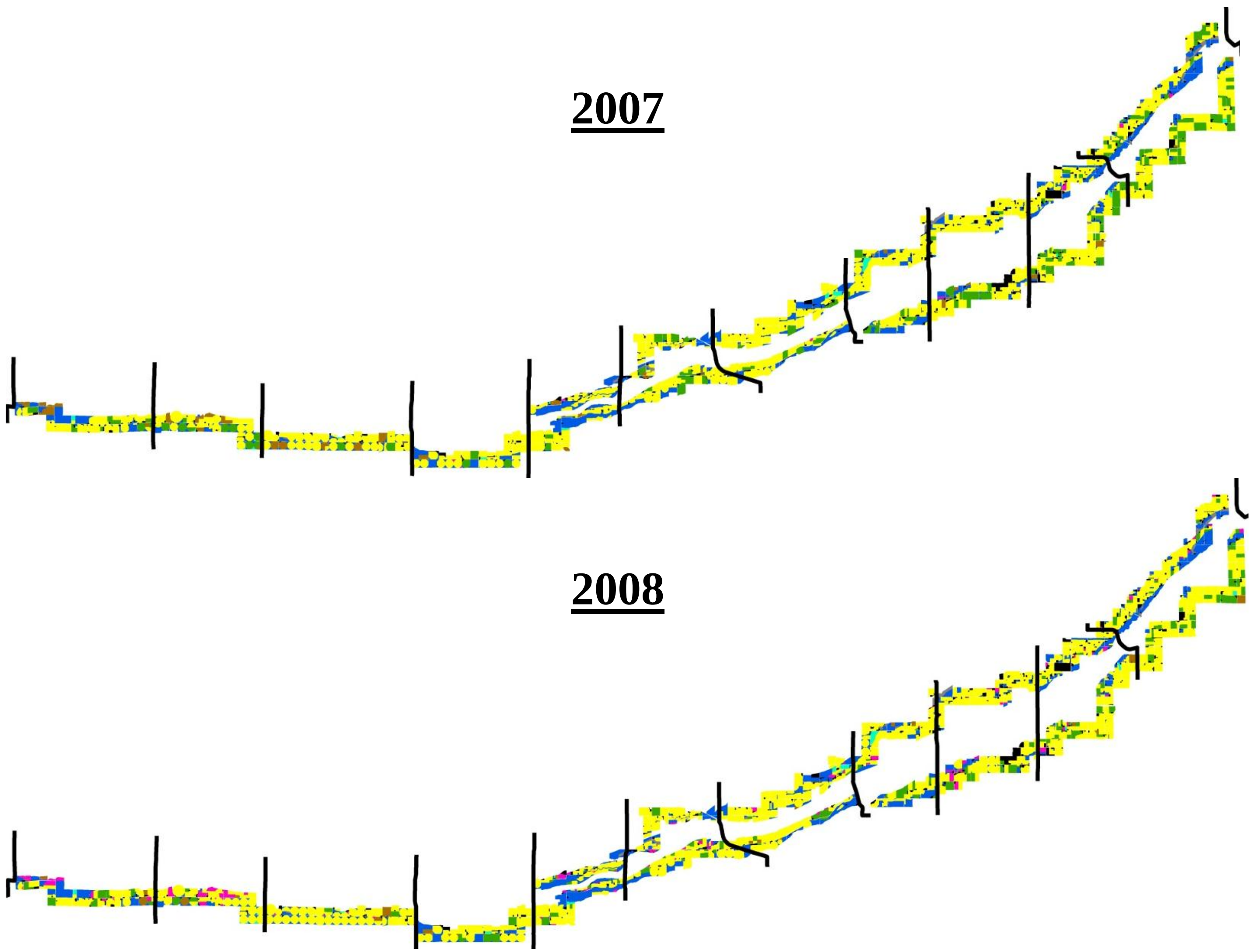

Figure 1–2 Continued.

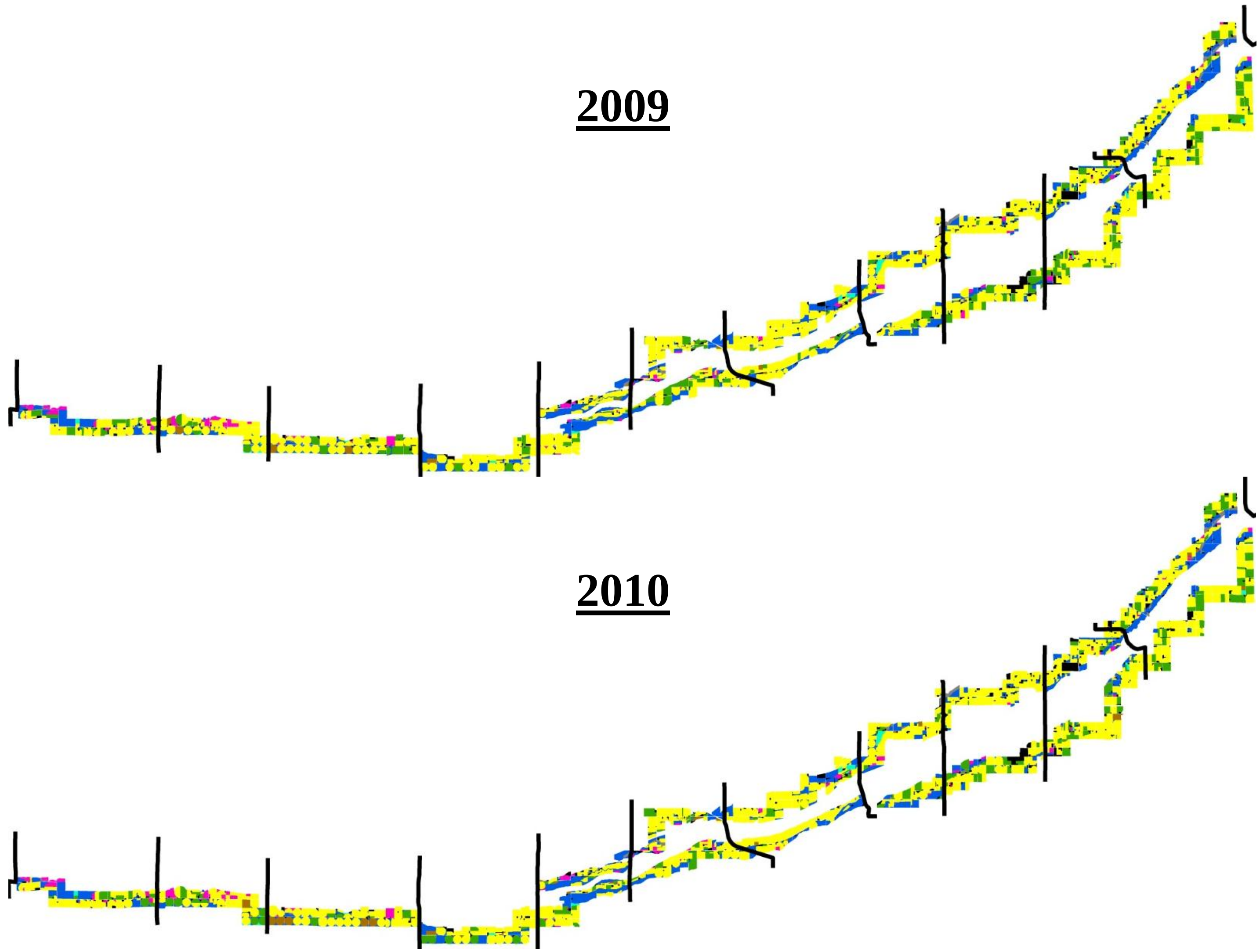

Figure 1–2 Continued.

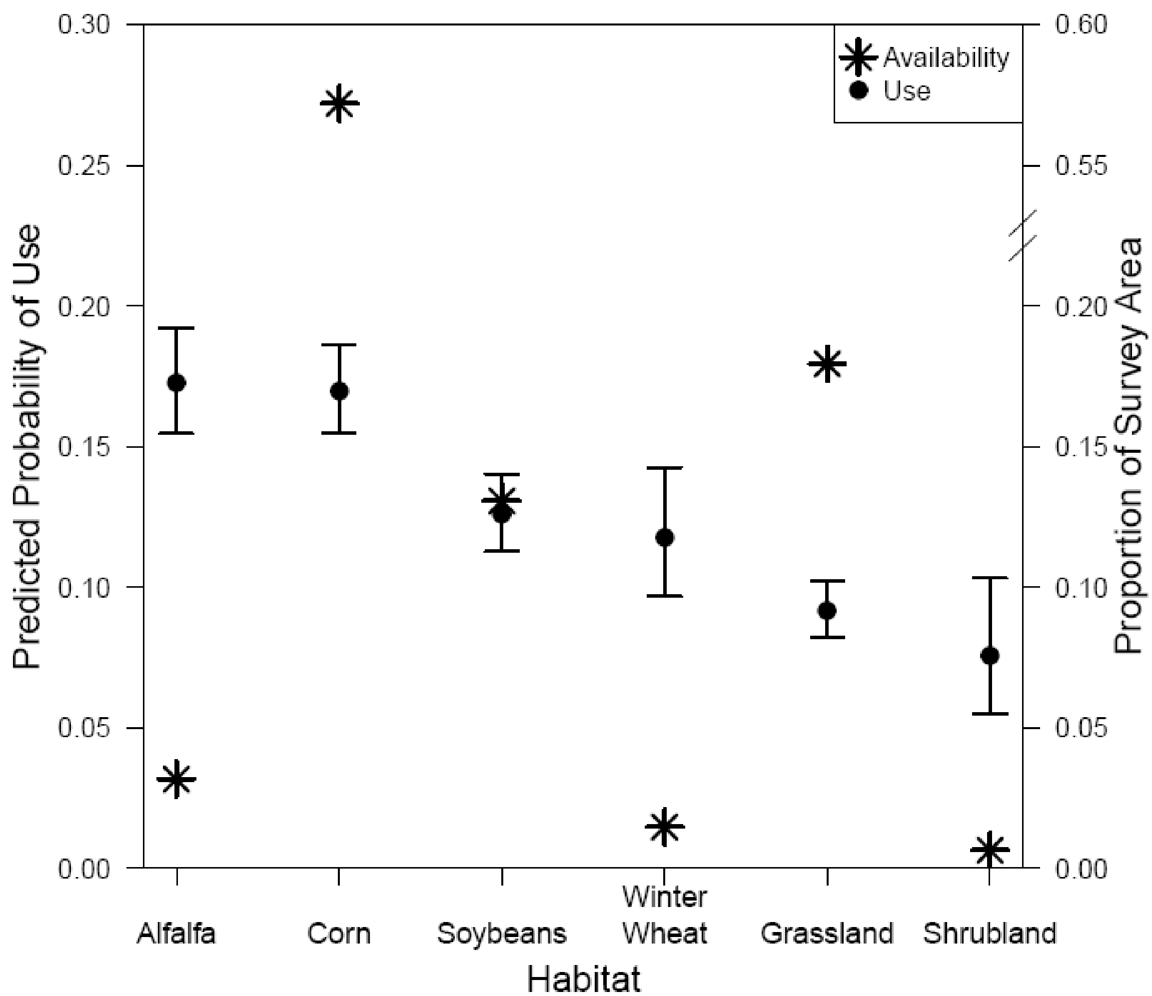

Figure 1–3. Model predicted habitat use (black circle ± SE) by sandhill cranes and the average availability of each habitat type (black star) in the CPRV survey area, 2003–2010.

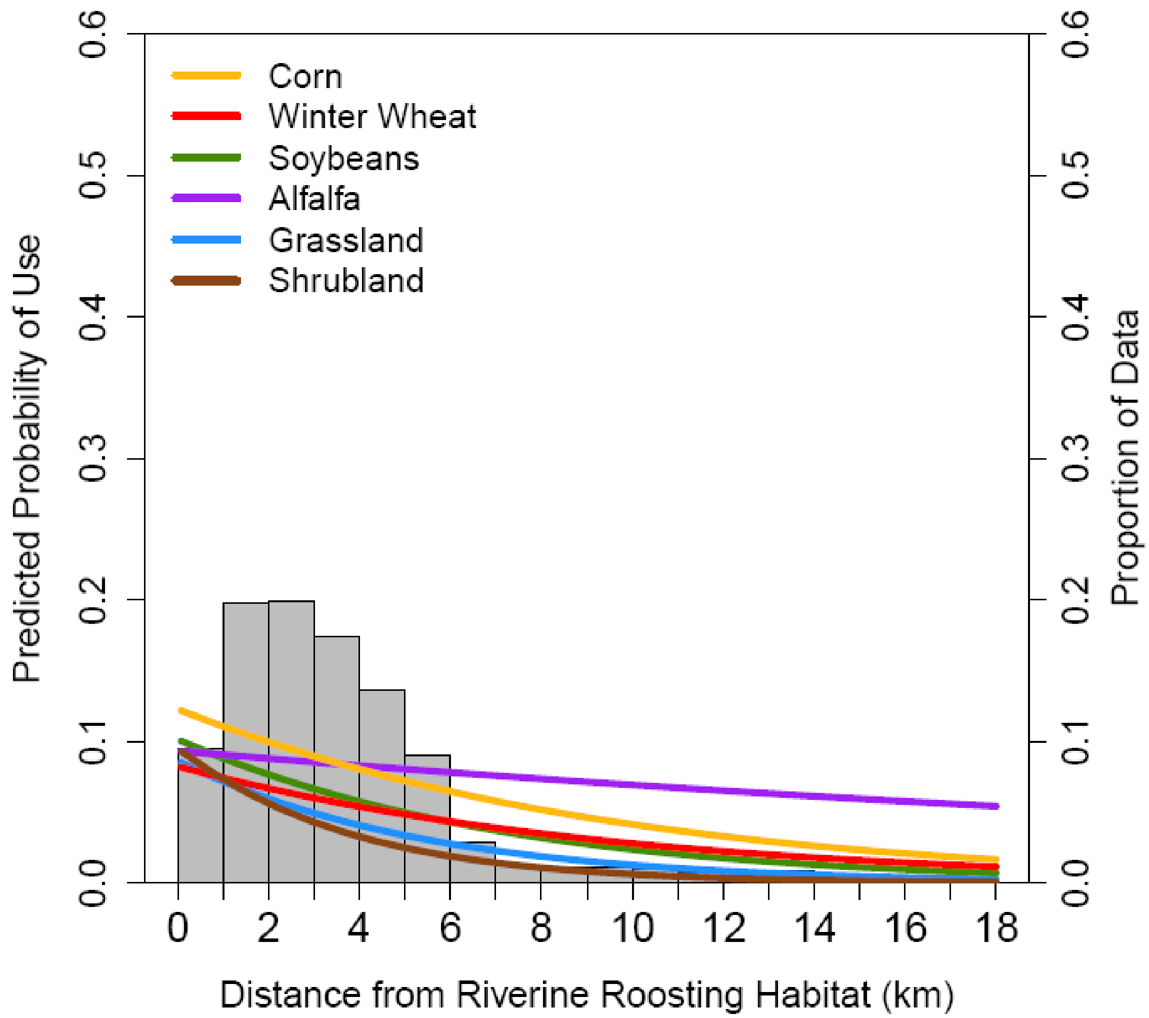

Figure 1–4. Model predicted early season habitat use at different distances from riverine roosting habitat exhibited by sandhill cranes in the CPRV, 2003–2010; bars represent the proportion of data in each distance from riverine roosting habitat category.

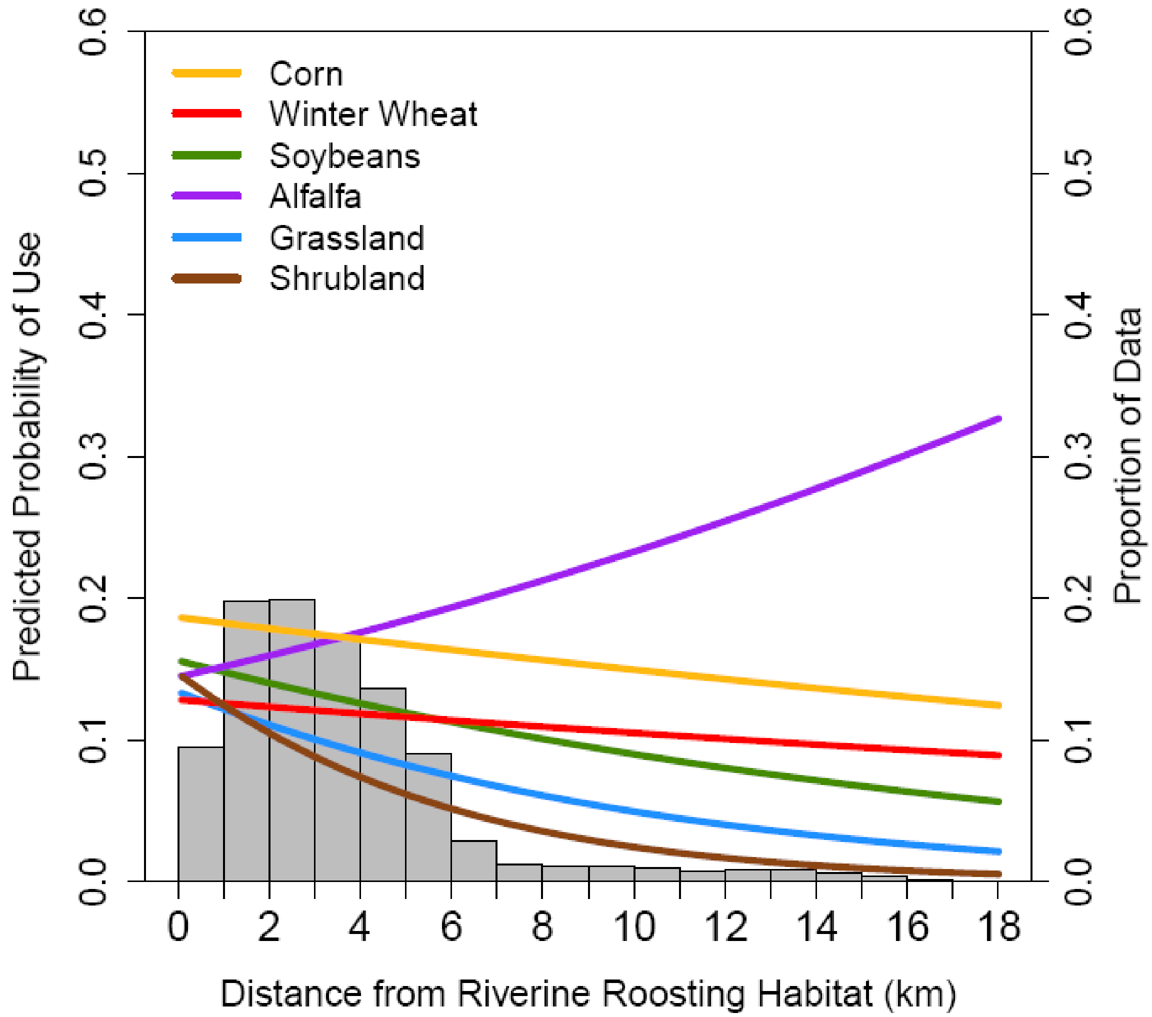

Figure 1–5. Model predicted mid-season habitat use at different distances from riverine roosting habitat exhibited by sandhill cranes in the CPRV, 2003–2010; bars represent the proportion of data in each distance from riverine roosting habitat category.

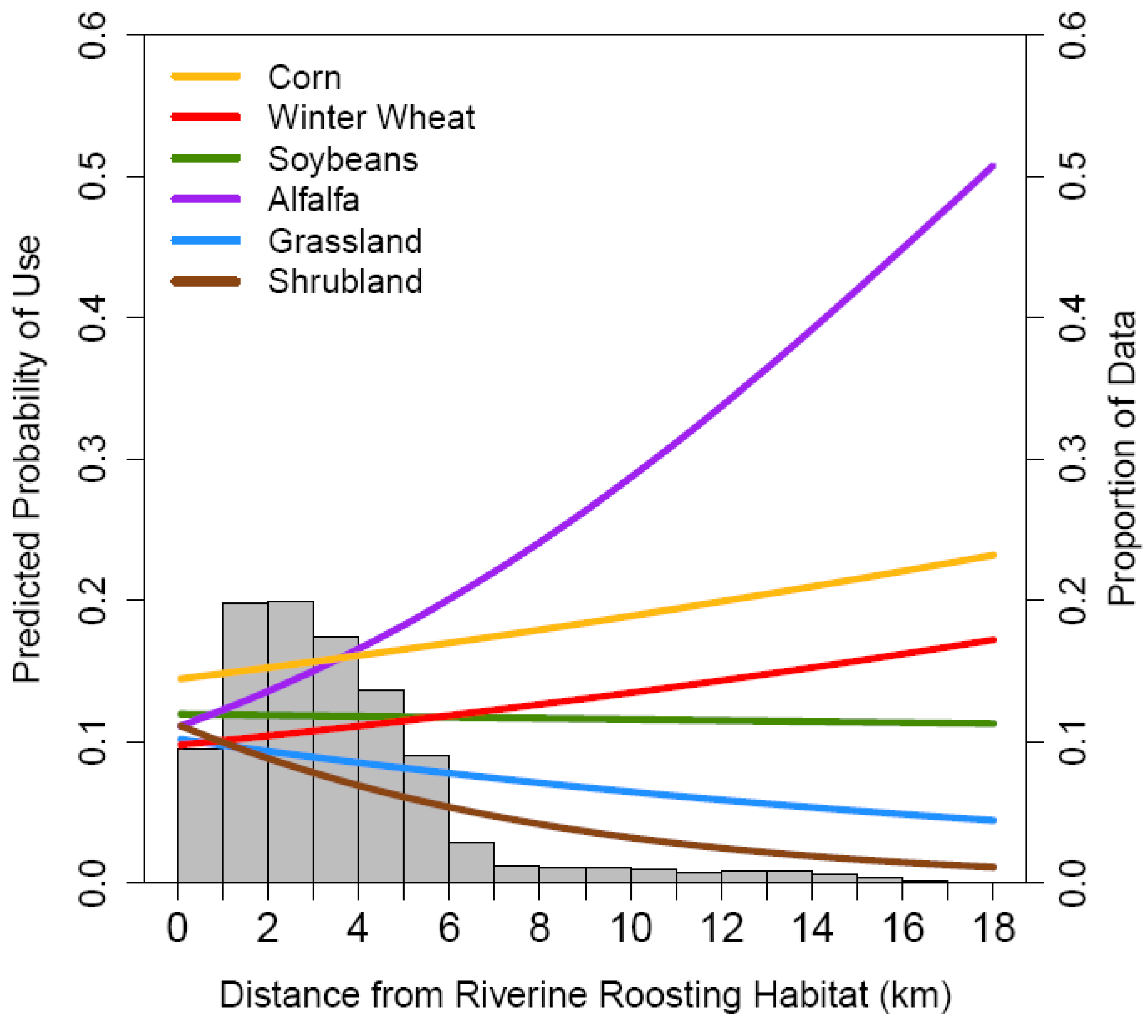

Figure 1–6. Model predicted late season habitat use at different distances from riverine roosting habitat exhibited by sandhill cranes in the CPRV, 2003–2010; bars represent the proportion of data in each distance from riverine roosting habitat category.

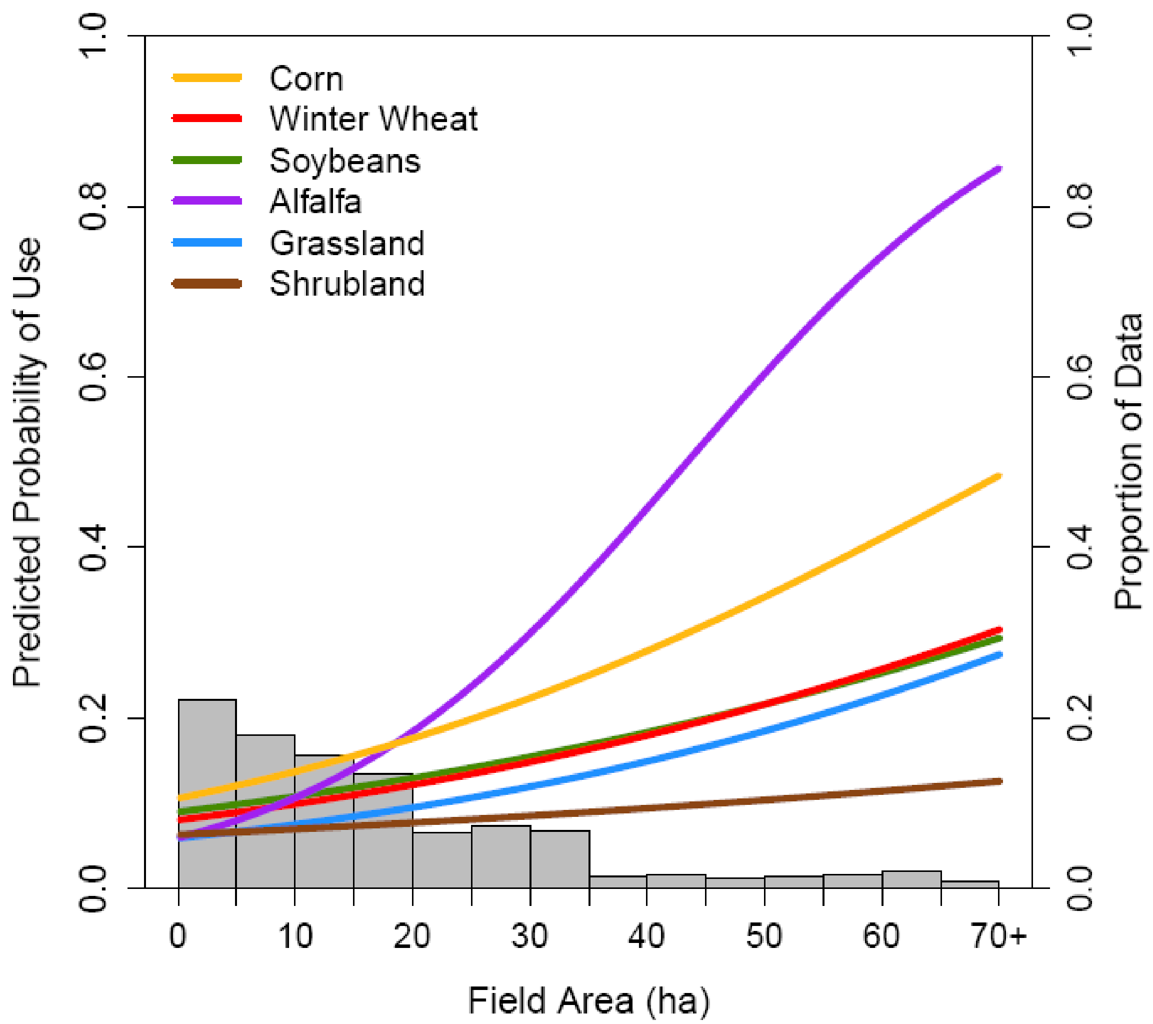

Figure 1–7. Model predicted mid season habitat use of different field sizes exhibited by sandhill cranes in the CPRV, 2003–2010; bars represent the proportion of data in each field area category.

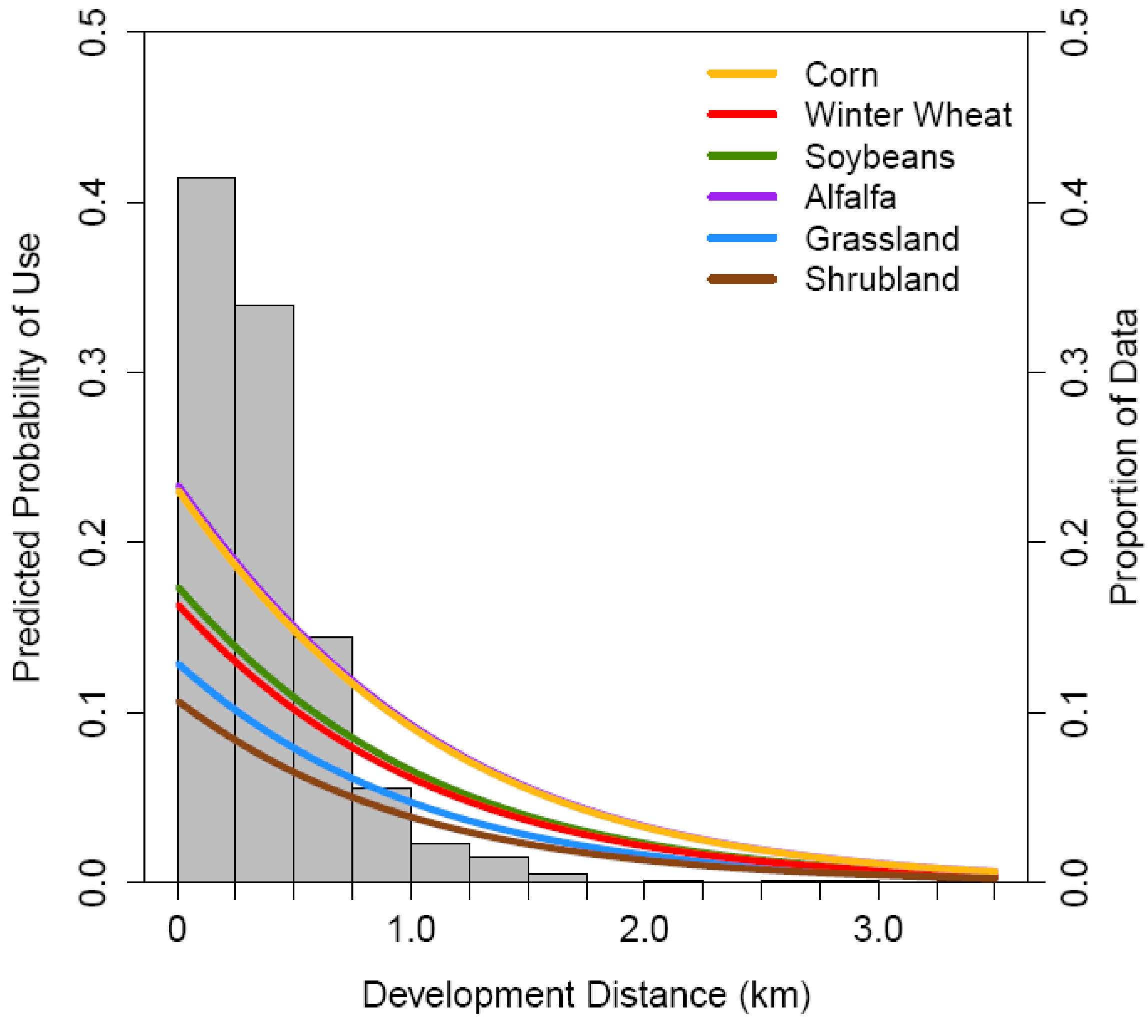

Figure 1–8. Model predicted habitat use at different distances from development exhibited by sandhill cranes in the CPRV, 2003–2010; bars represent the proportion of data in each development distance category.

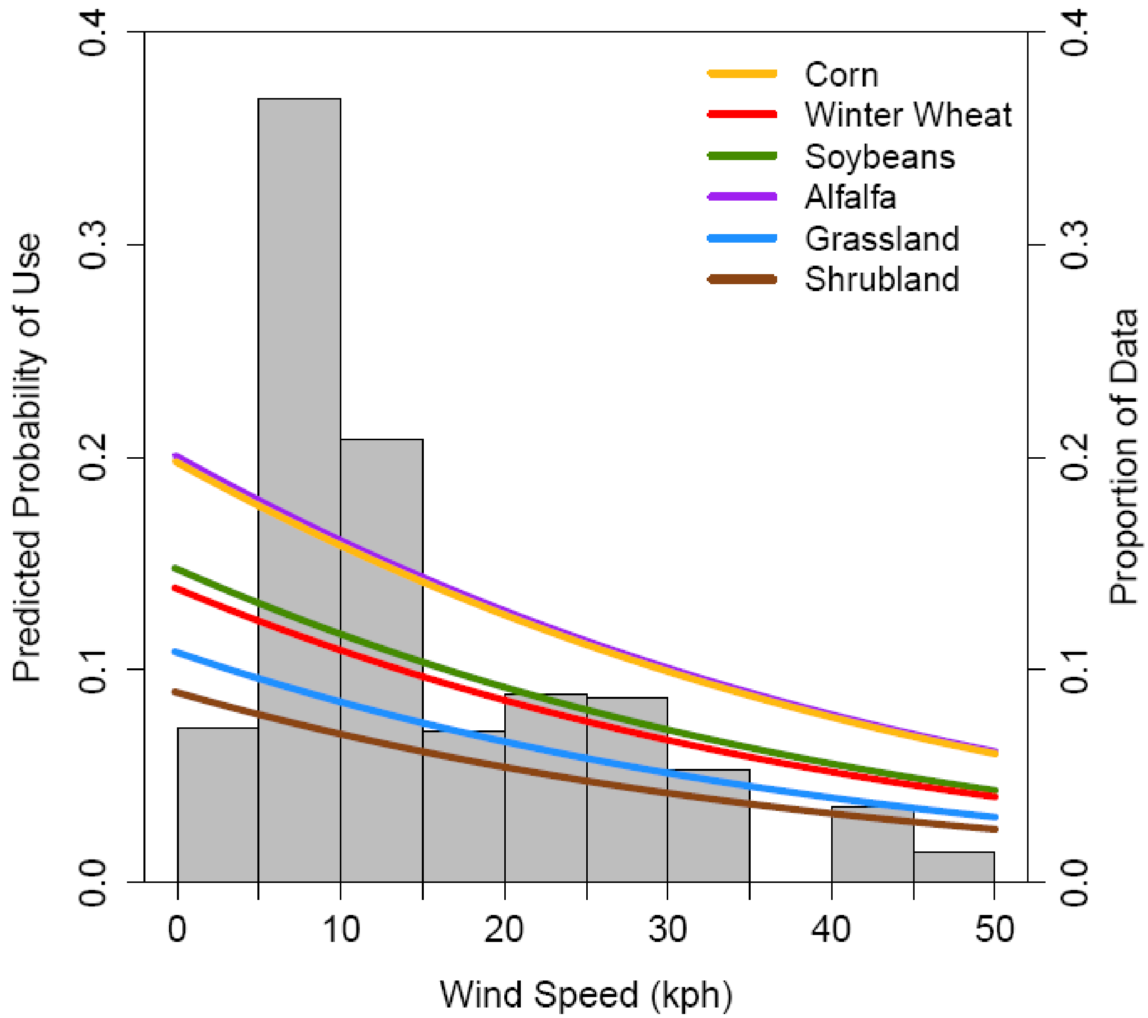

Figure 1–9. Model predicted habitat use at different wind speeds exhibited by sandhill cranes in the CPRV, 2003–2010; bars represent the proportion of data in each wind speed category.

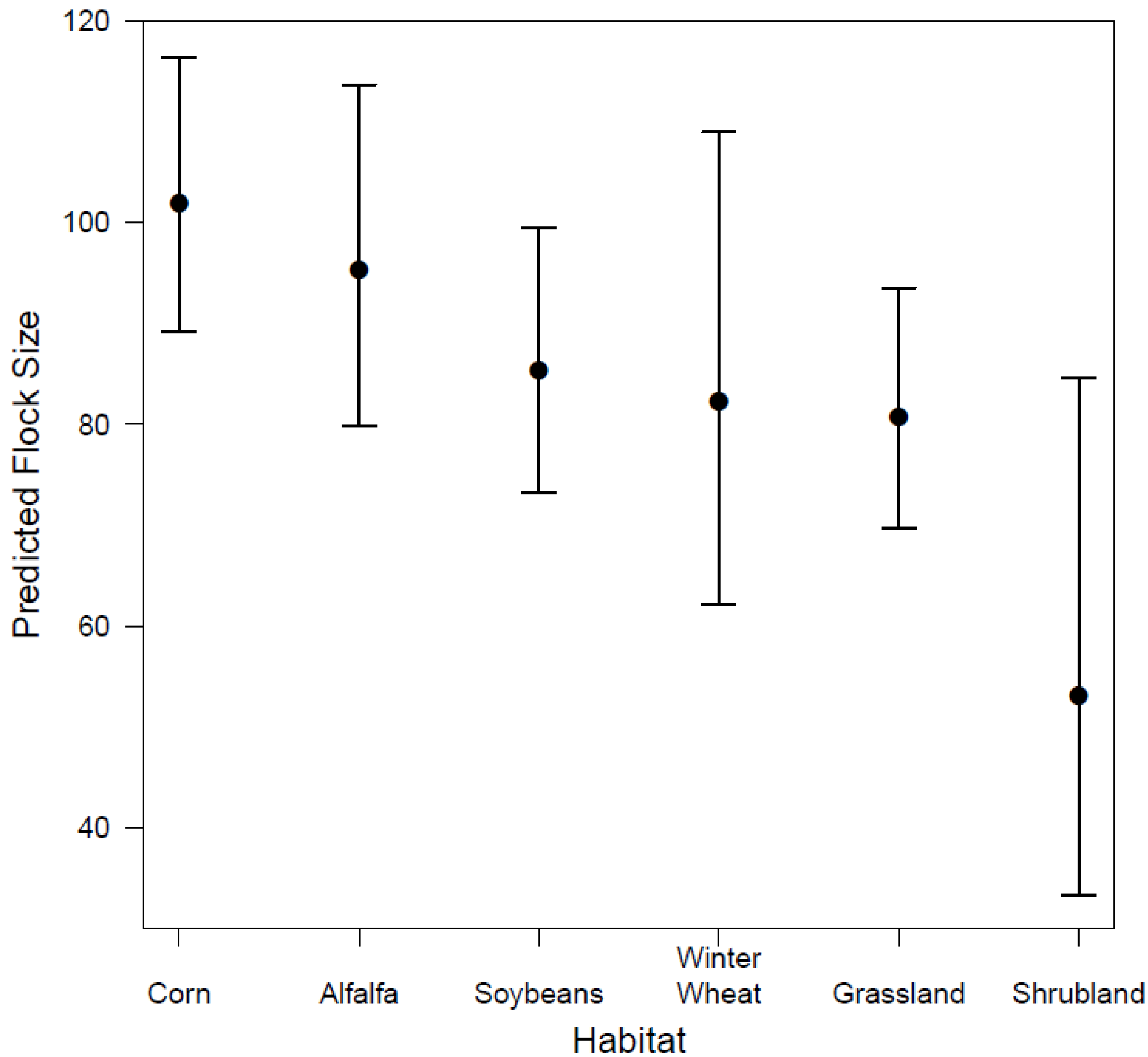

Figure 1–10. Model predicted flock size (black circle ± SE) in habitats used by sandhill cranes in the CPRV, 2003–2010.

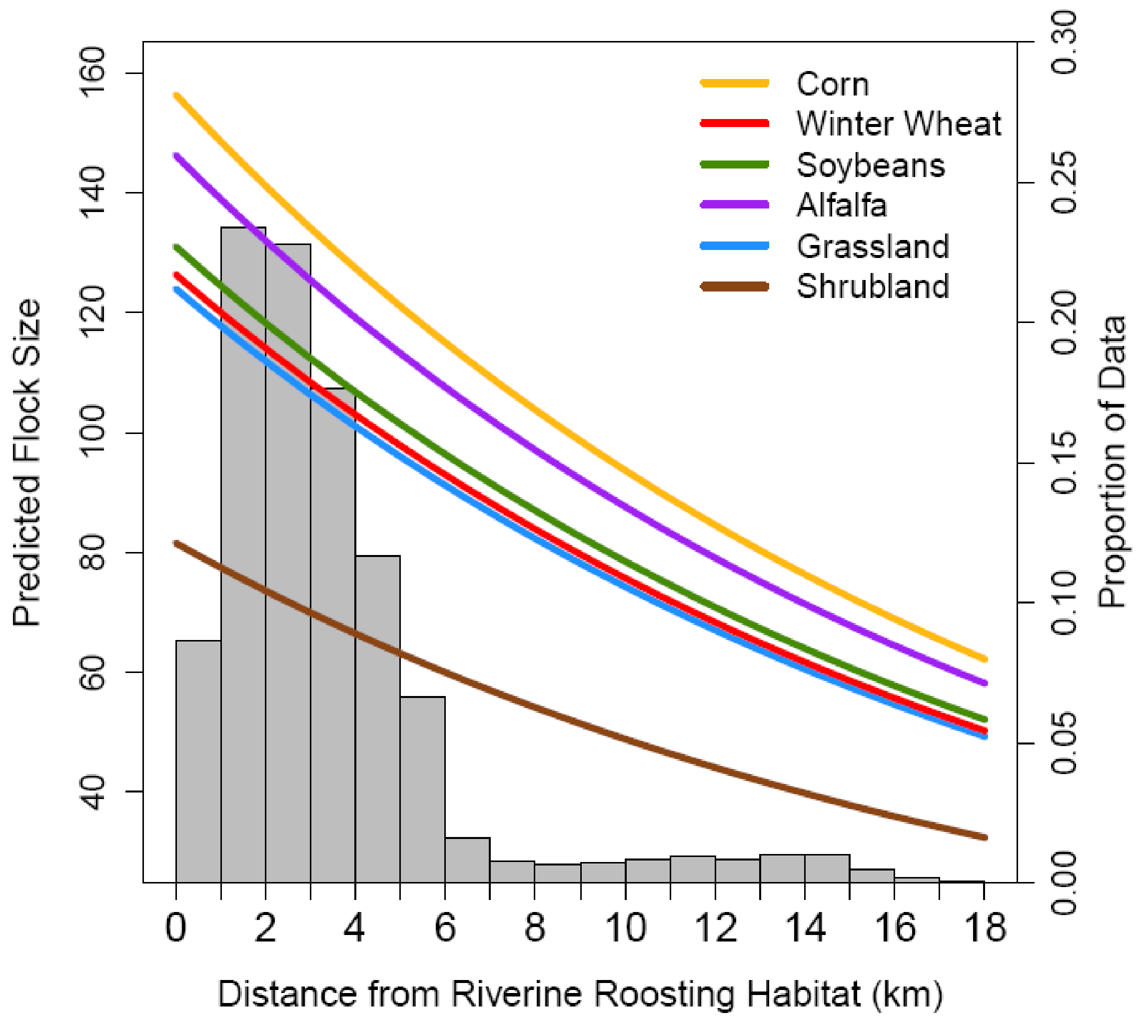

Figure 1–11. Model predicted early season flock size for habitats at different distances from riverine roosting habitat exhibited by sandhill cranes in the CPRV, 2003–2010; bars represent the proportion of data in each distance from riverine roosting habitat category.

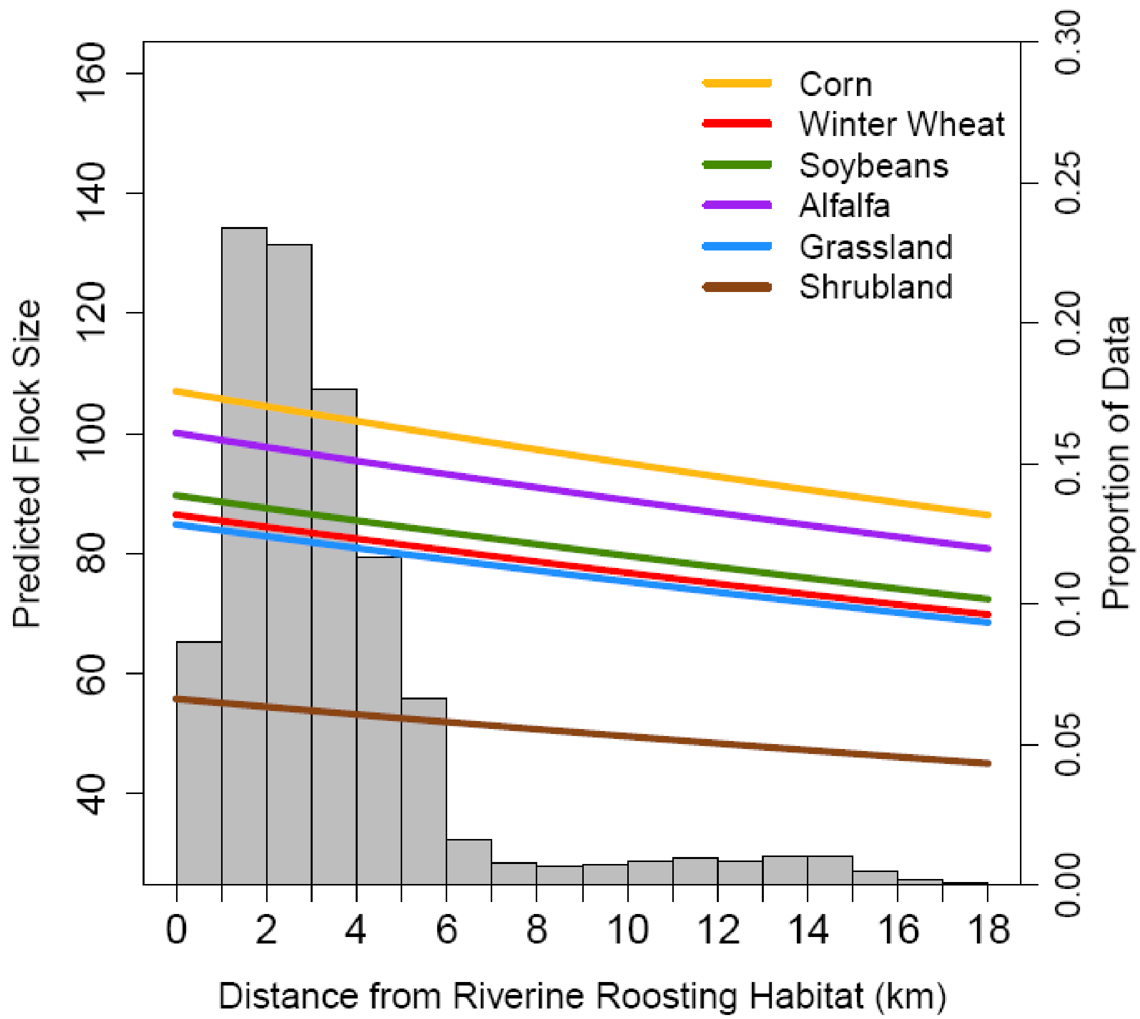

Figure 1–12. Model predicted mid-season flock size for habitats at different distances from riverine roosting habitat exhibited by sandhill cranes in the CPRV, 2003–2010; bars represent the proportion of data in each distance from riverine roosting habitat category.

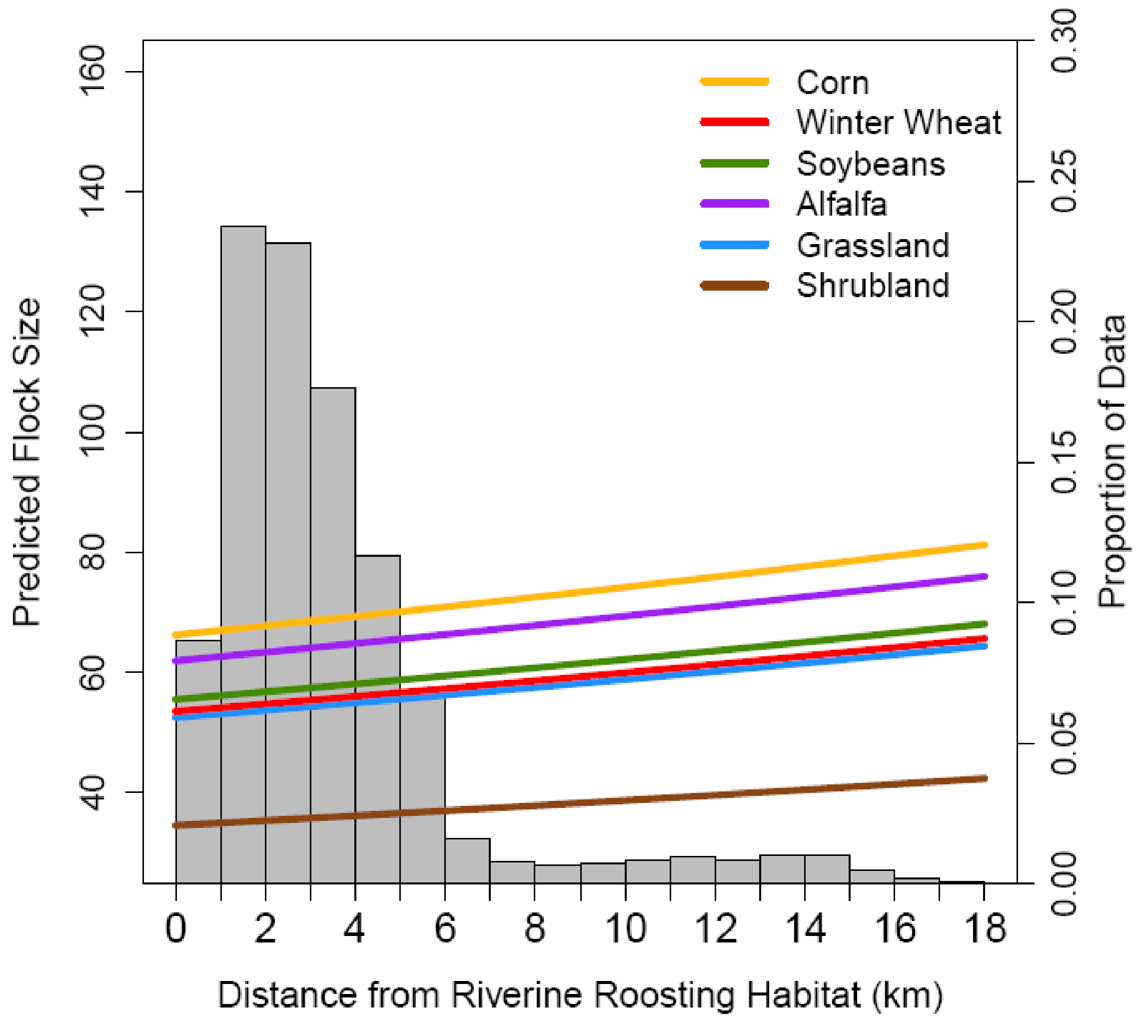

Figure 1–13. Model predicted late season flock size for habitats at different distances from riverine roosting habitat exhibited by sandhill cranes in the CPRV, 2003–2010; bars represent the proportion of data in each distance from riverine roosting habitat category.

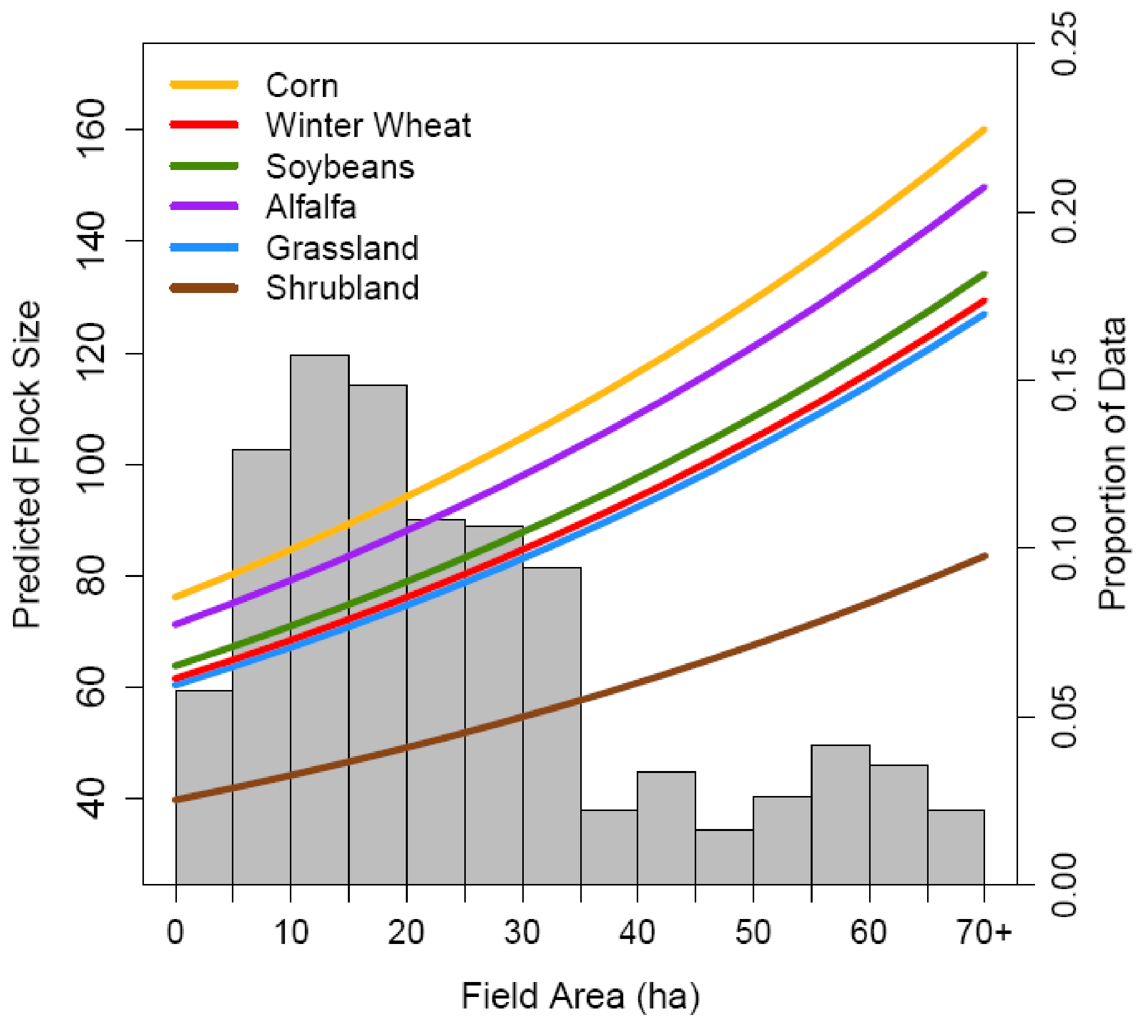

Figure 1–14. Model predicted flock sizes in habitats of different field sizes exhibited by sandhill cranes in the CPRV, 2003–2010; bars represent the proportion of data in each field area category.

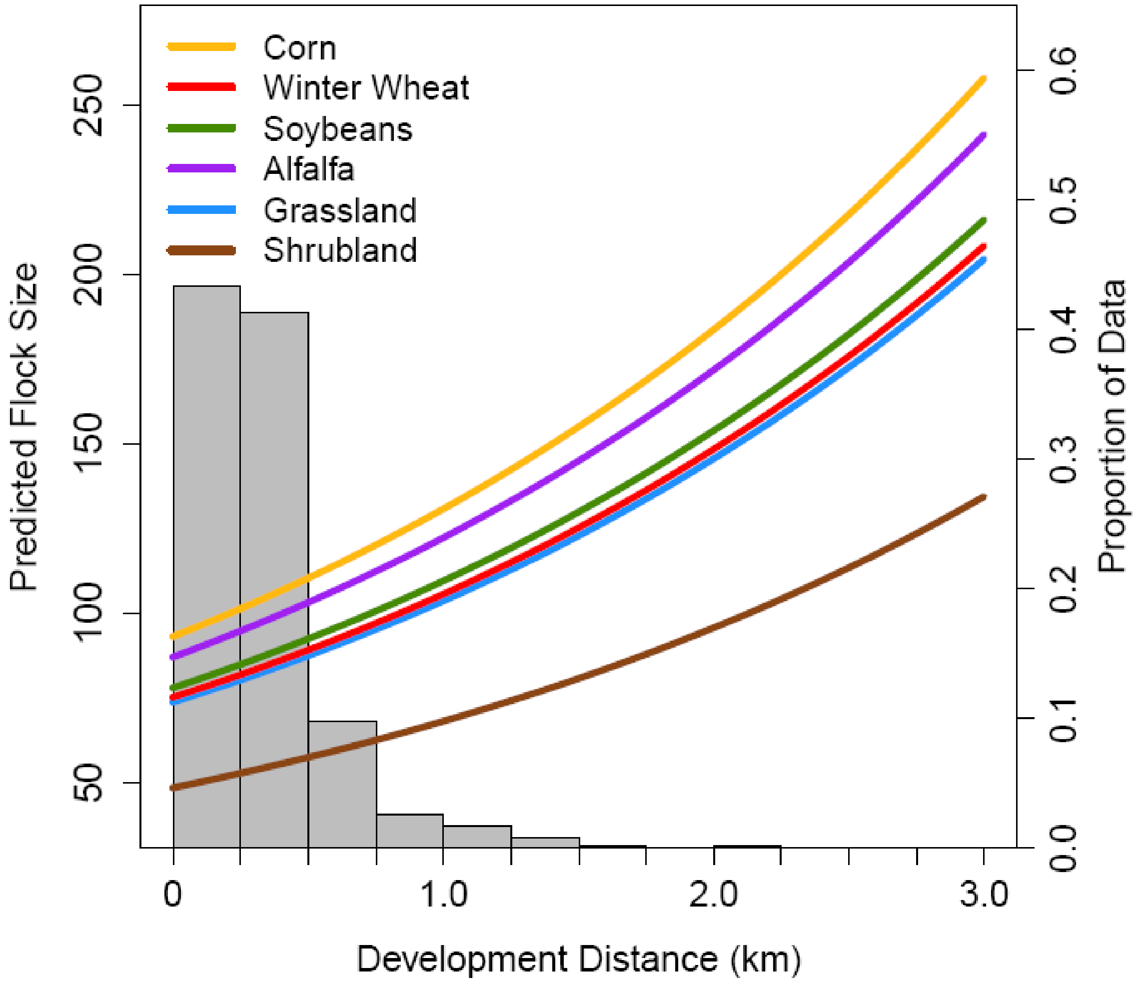

Figure 1–15. Model predicted flock sizes in habitats different distances from development exhibited by sandhill cranes in the CPRV, 2003–2010; bars represent the proportion of data in each development distance category.

CHAPTER 2: ROOSTING HABITAT USE AND ROOST SIZE OF SANDHILL CRANES IN THE CENTRAL PLATTE RIVER VALLEY, NEBRASKA, 2004–2010.

***Abstract*:** The Central Platte River Valley (CPRV) in Nebraska is an important spring stopover area for the midcontinent population of sandhill cranes (*Grus canadensis*). Most cranes roost in sections of the Platte River receiving regular maintenance and removal of woody vegetation. Understanding the use of the Platte River by cranes is critical for future management decisions of roosting habitat because crowding on these areas by a large number of cranes likely increases competition for food resources on nearby agricultural land. I developed a contemporary roosting habitat inventory of the Platte River between Chapman and Overton, Nebraska to demonstrate relative roosting habitat availability in this area. I also developed predictive models to evaluate roosting habitat use and roost size of cranes in the CPRV from 2004–2010. All model covariates were based on remotely sensed landscape and environmental data collected during the same time period. Roosting habitat conditions varied across the study area spatially and temporally. Roosting habitat used by the greatest number of cranes was confined to the center and eastern portions of the study area, while western portions received less overall use by fewer cranes. Roosting habitat availability followed the same pattern. My results suggest segments of the Platte River not adjacent to sources of disturbance, wider than 150 meters, and free of tall woody vegetation on river banks should receive the highest crane use and contain the largest roosts. Current roosting habitat availability and habitat use patterns suggest expansion of roosting habitat on the Platte River should focus on

land west of Kearney, Nebraska because there are fewer sources of disturbance, river morphology is favorable, and large numbers of cranes historically used this area.

Key words: Bayesian Information Criterion, Platte River, habitat use, mixed model analysis, Nebraska, roost size, sandhill crane

Abbreviations: AIC = Akaike's Information Criterion, AR-1 = First Order Auto-Regressive Model Structure, AUC = Area Under the Receiver Operating Characteristic Curve, AWDN = Automated Weather Data Network, BIC = Bayesian Information Criterion, C = Degrees Celsius, cfs = Cubic Feet Per Second, CPRV = Central Platte River Valley, GLMM = Generalized Linear Mixed Model, GPS = Global Positioning System, HPRCC = High Plains Regional Climate Center, kph = Kilometers Per Hour, LMM = Linear Mixed Model, NASS = National Agriculture Statistics Service, NRCS = Natural Resources Conservation Service, NPRV = North Platte River Valley, PFS = Predicted Flock Size, PPU = Predicted Probability of Use, ROC = Receiver Operating Characteristic Curve, USDA = United States Department of Agriculture, USFWS = United States Fish and Wildlife Service, USGS = United States Geological Survey, *w* = Model Weight

INTRODUCTION

The Central Platte River Valley (CPRV) in south-central Nebraska is an important spring stopover area for the midcontinent population of sandhill cranes (*Grus canadensis*; hereafter, cranes). Cranes in the CPRV expend little energy while accumulating lipid reserves because food resources are often near suitable roosting habitat (Krapu et al. 1985, Tacha et al. 1987). Important roosting habitat characteristics for cranes include shallow water with solid substrates, low visual obstruction, and low levels of human disturbance (Krapu et al. 1984, Folk and Tacha 1990). However, the availability of roosting habitat having these characteristics limits the distribution of cranes in the CPRV and limits the habitats they can use to acquire energy reserves (Krapu et al. 1982, *see Chapter 1*).

During the 1940's and 1950's major dam projects on the North Platte and South Platte Rivers were completed (Johnson 1994). During this time period, most cranes were concentrated in the western CPRV between Kearney and Lexington, Nebraska (Walkinshaw 1956). Upstream dams and increased diversion of water for irrigation soon reduced the annual flow of the Platte River (Johnson 1994). Flows associated with flood events were reduced as well, which resulted in fewer ice jams and less sediment deposition (Johnson 1994). The combination of ice jams scouring river bed sediments and the deposition of new sediments during flood events reduced the survival and recruitment rates of woody vegetation (Johnson et al. 1976). The reduction or absence of these natural forces lead to the expansion of woody vegetation within channels of the Platte River formerly used as roosting habitat (USFWS 1981, Sidle et al. 1989, Currier 1997).

By the 1980's, the western CPRV was largely abandoned by cranes because roosting habitat was reduced by as much as 90%, with only isolated segments between Overton and Kearney, Nebraska remaining (Sidle et al. 1989, Faanes and LeValley 1993). The loss of roosting habitat in the western CPRV lead to in a distinct west to east shift of cranes along the Platte River into areas of the eastern CPRV, between Kearney and Grand Island, Nebraska, that formerly received little use (Krapu 1987, Faanes and LeValley 1993).

The reduction of roosting habitat in the CPRV due to the loss of natural forces which previously maintained the Platte River was a cause for concern. Attempting to disperse cranes along the Platte River became a priority in order to avoid negative impacts on the population caused by increased competition for food resources, disease outbreaks, or natural disasters (USFWS 1981, Currier 1991). Roost expansion was suggested for the western CPRV because the Platte River in this area has the potential to support larger numbers of cranes due to upstream river morphology, lower disturbance levels, and adjacent foraging habitat composition (Currier and Ziewitz 1987). Maintenance of roosting areas in the eastern CPRV soon became a more common practice than roost expansion in the west due to the prohibitive costs of large scale clearing projects (Currier 1991). However, river maintenance in the eastern CPRV still presents challenges to managers.

Early maintenance of roosting habitat on the Platte River was limited to approximately 30 kilometers owned by the Crane Trust, the National Audubon Society, and The Nature Conservancy (Currier 1984, 1991). Increased landholdings by conservation organizations and the purchase of conservation easements on private lands supported with state and Federal funding lead to more opportunities for roosting habitat management. Currently, over 80 kilometers of the Platte River is being managed for the removal of annual vegetation and woody vegetation (Pfeiffer and Currier 2005). Despite the expansion of river maintenance throughout the CPRV, access to the Platte River with heavy equipment is still limited due to the nesting season of the endangered interior least tern (*Sterna antillarum athalassos*) and piping plover (*Charadrius melodus*) (Sidle and

Faanes 1997). High river flow, early frost, and freeze up also present obstacles managers must deal with in a limited time frame.

Managers are currently faced with limited budgets and limited time frames to complete maintenance projects over a larger area. Therefore, it would be beneficial to know where management efforts should be focused if time frames become more restricted in the future. The purpose of the study was to assess the current distribution of roosting habitat in the CPRV and evaluate how cranes are responding to current management on Platte River. My specific objectives were to: 1.) provide a contemporary assessment of roosting habitat conditions on the Platte River from Chapman to Overton, Nebraska, 2.) develop and evaluate models to predict how use of roosting habitat by cranes is influenced by river characteristics and environmental factors, and 3.) develop and evaluate models to predict how roost size is influenced by river characteristics and environmental factors.

METHODS

Study Area

The study was conducted along the Big Bend reach of the Platte River in Adams, Buffalo, Dawson, Hall, Hamilton, Kearney, Merrick, and Phelps counties in south-central Nebraska (Figure 2–1). Frequent flooding events and a high water table influence the vegetation communities in the CPRV (Hurr 1981, Currier et al. 1985). Vegetation within the main channels of the Platte River and hydrologically connected wetlands are dominated by sedges (*Carex spp.*), rushes (*Elocharis spp.*, *Juncus spp.*, and *Scirpus spp.*), and common reed (*Phragmites australis*). Islands and river banks of the Platte River are dominated by woody vegetation including; cottonwood (*Populus deltoides*), Eastern red cedar (*Juniperus virginiana*), red mulberry (*Morus rubra*), and willows (*Salix spp.*).

(Currier et al. 1985, USDA-NRCS 2011, USFWS 1981). Outside the main channels of the Platte River lays an agricultural landscape dominated by row and forage crop production and livestock grazing (USFWS 1981, Currier et al. 1985).

Aerial Survey

Personnel conducted aerial surveys over the Platte River from Chapman to Overton, Nebraska, 2004–2010. Aerial surveys were conducted weekly from late February to mid-April, as weather condition allowed. Aerial surveys began at the Chapman bridge one half hour before sunrise and ended at the Overton bridge approximately one hour later. The pilot of a small Cessna aircraft maintained an altitude of 200–250 meters while maintaining a ground speed of 110–130 kilometers per hour, as weather conditions allowed. The pilot maintained a flight path from Chapman to Overton, Nebraska by following the tree line bordering the south river bank of the Platte River. Personnel recorded the locations of all crane roosts using a Global Positioning System (GPS) and estimated the number of cranes roosting at each location. All new personnel were trained prior to data collection to use GPS equipment and estimate bird numbers by flying over the survey area and observing Canada geese (*Branta canadensis*) and snow geese (*Chen caerulescens*).

Database Management

I obtained digital orthophotos from the United States Department of Agriculture's (USDA) Natural Resources Conservation Service's (NRCS) Geospatial Data Gateway for Adams, Buffalo, Dawson, Hall, Hamilton, Kearney, Merrick, and Phelps counties (USDA-NRCS 2010). Similar to previous work, I digitized the Platte River from Chapman to Overton, Nebraska and divided it into 800 meter segments using ArcMap 9.3

(ESRI 2008, USFWS 1981). I classified each river segment into one of five roosting habitat categories (Table 2–2), based on reported crane roosting preferences in the CPRV (Krapu et al. 1984, Norling et al. 1992, Davis 2003). All river segments were classified yearly to account for changing river conditions and management activities identifiable in digital orthophotos (Pfeiffer and Currier 2005).

I obtained weather measurements from the High Plains Regional Climate Center's (HPRCC) Automated Weather Data Network (AWDN) stations near Grand Island, Shelton, and Kearney, Nebraska (HPRCC 2004–2010). I selected these weather stations due of their close proximity to the Platte River and the survey area. However, due to their close proximity to one another, all weather measurements were averaged among the three ADWN stations.

The specific weather measurements I obtained from each weather station included temperature, reported in degrees Celsius (C), and wind speed, reported in kilometers per hour (kph). All weather measurements were recorded at 1900 hrs CST the day before all aerial surveys. I selected 1900 hrs the day before all aerial surveys because the roost patterns observed during aerial surveys the next morning might be influenced by weather conditions the previous evening. This time period also coincides with the average sunset in the CPRV and the average time cranes arrive on river roosts (Norling et al. 1992).

I also obtained river flow data for the Platte River from the United States Geological Survey (USGS) Nebraska Water Science Center (USGS 2004–2010). I selected the Grand Island, Kearney, and Overton, Nebraska gauge stations for reporting the average daily river flow, reported in cubic feet per second (cfs). I applied river flow data from the nearest gauge station to each river segment for all aerial survey dates. I used river flow data from individual gauge stations rather than averaging river flow over all stations, because I wanted to account for any river flow pulses during my sampling period.

Model Development

I developed models to predict roosting habitat use and roost size of cranes in the CPRV by using the described landscape and environmental metrics as fixed effects in my analysis. I included the temporal variable, Julian date and quadratic of Julian date, in all models to account for within season variation of crane numbers throughout the stopover period in the CPRV (Reinecke and Krapu 1986, Pearse et al. 2010). I also developed models using the following interaction terms; category *river flow, and category*date. I did not develop any interaction models for the environmental covariates (temperature and wind speed).

The models I developed did not include a spatial or temporal auto correlation structure. However, I did test for both spatial and temporal auto correlation post hoc. I tested for spatial auto correlation by plotting model residuals on variograms. I tested for temporal auto correlation by assessing the correlation of model residuals at various time lags to identify potential violations of independence (Zuur et al. 2009).

Roosting Habitat Use Analysis

I used R 2.11.1 to fit generalized linear mixed models (GLMM) to the 28 models I developed and ran all model on a binomial distribution (R Development Core Team 2008). I used GLMMs to estimate the effect model covariates have on the predicted probability of use (PPU) of roosting habitats on the Platte River in the CPRV. Using a mixed effects modeling technique allowed for a random intercept to be included in all models. I selected year as the random intercept, because I wanted to account for any yearly variation in the effect of the covariates I measured. To ensure model convergence I normalized the following covariates; temperature, wind speed, river flow, Julian date, and the quadratic of Julian date. I also calculated descriptive statistics for all model covariates and the availability of roosting habitat by bridge segment and year.

I evaluated all models using Bayesian Information Criteria (BIC), rather than Akaike's Information Criteria (AIC) due to my large sample size (n = 9,212; Akaike 1974, Schwarz 1978). However, I selected models from my model set based on criteria commonly used in AIC model selection (Burnham and Anderson 2002). Models not selected carried model weights of evidence less than 0.01. Models carrying weights greater than 0.01, as well as the global and null models are still reported for covariate structure comparison. I selected one model as the best model to report coefficient estimates. The best model had a ΔBIC value less than two and a model weight greater than 0.1 (Burnham and Anderson 2002).

I tested the best models' ability to correctly identify crane presence-absence by using a discrimination method known as Area Under the receiver operating characteristic Curve (AUC) (Pearce and Ferrier. 2000). I calculated AUC values for the selected models in R 2.11.1 using a K-fold cross validated dataset (Kohavi 1995, R Development Core Team. 2008). I considered AUC values of 0.5 are no better than random, while AUC values greater than 0.5 provided adequate discriminatory power (Hosmer and Lemeshow 2000).

Roost Size Analysis

I used R 2.11.1 to fit linear mixed models (LMM) to the same 28 models I developed and ran all models on a normal distribution. I used LMMs to estimate the effects model covariates have on predicted flock size (PFS) of crane roosts in the CPRV (R Development Core Team 2008). I $\log_{10}$ transformed the roost count data (n = 1,664) to normalize the variance. I applied a data transformation to account for the large distribution of roost sizes observed during aerial surveys and for estimation errors of flock size by personnel.

I evaluated models using BIC and selected models based on ΔBIC values and weights of evidence (Schwarz 1978, Burnham and Anderson 2002). I selected one model as the best model to report coefficient estimates. The best model had a ΔBIC value less than two and a model weight of evidence greater than 0.1 (Burnham and Anderson 2002). Models carrying weights greater than 0.01, as well as the global and null models are reported for covariate structure comparison. I used the root mean squared error (RMSE) technique to validate all selected models meeting selection criteria (Mayer and Butler 1993). I also calculated descriptive statistics for the model covariates and the proportion crane observations by habitat and year.

RESULTS

Roosting Habitat Conditions

Roosting habitat conditions varied yearly on the 155 kilometers of the Platte River within the survey area (Table 2–3, Figure 2–2). More than 75% of the river in bridge segments 3, 4, and 7 was classified as Category 1 and 2 yearly. Category 1 and 2 habitats constituted 35–50% of the river in bridge segments 1, 2, 5, and 6 yearly. Bridge segments 8, 9, 10, and 11 contained the fewest kilometers of river classified as Category

1 and 2. However, the most recent estimates of roosting habitat conditions show bridge segments 8 and 10 have improved and now contain at least 35% Category 1 and 2. River conditions in bridge segment 11 have also improved recently, but bridge segment 9 contains no Category 1 and 2 roosting habitat.

Roosting Habitat Use

The results of my analysis and subsequent model fit assessment for the selected models are shown in Table 2–4. Model 6, with approximately 95% f the weight of evidence, was selected for reporting the effects of covariates on predicted probability of use (PPU; Table 2–5). The AUC value for Model 6 demonstrates adequate model fit to show patterns present within the data (Table 2–4). All plots representing PPU as a function of specific covariates assume all other covariates are fixed at their mean value (Table 2–6).

Variograms of Model 6 residuals suggest little evidence of spatial autocorrelation. Weak evidence of temporal auto correlation between surveys within a year might be present in the first time lag ($r^2 < 0.27$). If temporal auto correlation is influencing my results, Model 6 might benefit from incorporating a first order auto-regressive model structure (AR–1). Without the AR–1 structure the coefficient estimates I report might have smaller standard errors and smaller confidence intervals. However, my coefficient estimates and confidence intervals are sufficient for the purpose of illustrating larger patterns present in the data.

The proportion of crane flock observed in each river category is summarized in Table 2–7. On average, nearly 70% of the crane flocks were observed roosting on the Platte River in Category 1 and 2 habitats. Observations in Category 1 accounted for 35–

48% of the total yearly observations, while Category 2 accounted for 23–34%. The proportion of flocks roosting in Category 3 and 4 habitats was similar, but on average accounts for only 25% of the total. Category 5 habitats contained the lowest proportion of crane flocks yearly. The most recent aerial survey indicated 3% of the cranes or less were roosting in sections of the Platte River classified as Category 5 habitat.

The PPU varied by river category despite all river categories having similar average availabilities in the survey area (Table 2–5, Figure 2–3). River channel width was similar for Category 1 and 2, but different vegetation structures within the river channel and on islands resulted in a significantly lower ($p < 0.001$) PPU estimate in Category 2. However, the PPU of both Category 1 and 2 were higher than their average availability. River channel widths for Categories 3 and 4 were similar, but less than Categories 1 and 2, resulting in significantly lower ($p < 0.001$) PPU estimates than Category 1. Different vegetation structures within the river channel and on islands resulted in the PPU of Category 3 being higher than its average availability while the PPU of Category 4 was lower than its average availability. Category 5 included both the narrowest and most vegetated river channels among all categories, which resulted in a significantly lower ($p < 0.001$) PPU estimate and a lower predicted use relative to its average yearly availability.

The effect of temperature was positive for all habitat types with no detectable seasonal effect (Table 2–5). Varying patterns of PPU as a response to temperature were exhibited by roosting cranes in all river categories (Figure 2–4). The PPU of Categories 1–4 increased similarly over the range of temperatures cranes would be exposed to throughout the stopover period. The lowest PPU estimate among all river categories occurred in Category 5 and the response of PPU to temperature increased the least relative to all other river categories.

Roost Observations

The proportion of cranes counted in each bridge segment during the study is summarized in Table 2–8. Nearly 25% of the cranes counted yearly were using roosting habitat in bridge segment 3. Higher percentages (14–16%) of cranes also roosted on the Platte River in bridge segments 4, 5, and 7 yearly. Crane counts within bridge segments 2 and 6 were lower than adjacent bridge segments with the 8 year average remaining near 10%. Bridge segments 1, 8, 9, 10, and 11 had the lowest percentage of cranes annually and accounted for less than 10% of the total.

Roost Size

The results of my analysis and subsequent model fit assessment for the selected models are reported in Table 2–9. Model 4, with approximately 78% of the weight of evidence, was selected for reporting the effects of covariates on predicted flock size (PFS; Table 2–10). The RMSE resulting from cross validation demonstrates adequate model fit to show patterns present within the data (Table 2–9). Plots representing PFS as a function of specific covariates assume all other covariates are fixed at their mean value (Table 2–11). Variograms of Model 4 residuals suggest little evidence of spatial autocorrelation. Additional tests of Model 4 residuals suggest weak evidence of temporal auto correlation ($r^2 < 0.35$). Incorporating an AR–1 correlation structure might improve coefficient estimates, but current estimates are sufficient for illustrating patterns present in the data.

Predicted flock size estimates varied by river category (Table 2–10, Figure 2–4). Estimates of PFS from the best model are consistent with field estimates of roost size, because most (80%) crane roosts were estimated to be made up of 5,000 cranes or less. Category 1 had the highest PFS estimate among all river categories. Different within river channel and island vegetation structures in Categories 1 and 2 resulted in the PFS estimate for Category 2 to be reduced by more than half the estimate of Category 1. Predicted flock size estimates for Categories 3 and 4 were lower than Category 2; however, the reduction in PFS from Category 3–4 was less than the reduction from Category 1–2. The lowest PFS estimate among all river categories were in river segments classified as Category 5.

The effect of river flow was positive for all river categories with no detectable seasonal effect (Table 2–10). Predicted flock size estimates were the largest in Category 1 and increased the most as river flow increased (Figure 2–5). Category 2 PFS estimates were next highest, but the response of PFS to increasing river flow was not as strong as Category 1. Predicted flock size estimates in response to increased river flows were similar for Categories 3 and 4, but were lower than Category 2. Category 5 PFS estimates were the smallest among all river categories and increased the least as river flow increased.

DISCUSSION

Roosting Habitat Conditions

My results indicate roosting habitat conditions on the Platte River between Overton and Chapman, Nebraska vary yearly. Therefore, woody vegetation management in the study area appears to influence roosting habitat conditions. Expansion of woody vegetation management in the CPRV has improved roosting habitat conditions since the late 1990's and my contemporary roosting habitat inventory shows roosting habitat conditions are similar to when research was initiated (USFWS 1981).

Historic roosting habitat inventories of the Platte River support my assessment that roosting conditions in the CPRV are dynamic. In the late 1970's, 60% of the Platte River between Chapman and Overton, Nebraska was more than 150 meters wide, 26% was 100-150 meters wide, and 14% was less than 100 meters wide (USFWS 1981). However, in the late 1980's and early 1990's severe drought conditions resulted in substantial island development and woody vegetation expansion reducing the river channel area 25–35% (Currier 1997, Wilhite et al. 2005). By the mid 1990's roosting habitat conditions in the CPRV were severely degraded. Davis (2003) reported 25% of the Platte River between Chapman and Overton, Nebraska was more than 150 meters wide, while 12% of the river ranged from 100-150 meters wide, and 63% of the river was less than 100 meters wide.

Roosting Habitat Use

My results support the idea that roosting habitat use by cranes is influenced by river characteristics (Krapu et al. 1984, Folk and Tacha 1990, Norling et al. 1992, Davis 2003). Cranes in my study showed high affinity for river segments more than 150 meters wide, which is consistent with previous research in the CPRV (Krapu et al. 1984, Norling et al. 1992, Davis 2003). My results also show over 70% of cranes roosted in areas of the Platte River more than 150 meters wide. Krapu et al. (1984) reported the same proportion of cranes roosting in wide river segments during the late 1970's, when roosting habitat conditions were similar to my current inventory.

Research conducted in the 1980's and 1990's contrast with my results. During this time period, woody vegetation expanded in the CPRV which resulted in greater numbers of cranes roosting in limited areas of the Platte River that remained wider than 150 meters. Norling et al. (1992) reported 80% of the cranes roosted in river channels over 150 meters wide. Davis (2003) reported an even higher proportion (90%) of the cranes roosting in river segments more than 150 meters wide, when roost conditions were severely degraded during the height of the drought (Wilhite et al. 2005).

Roosting habitats receiving the highest use, such as Category 1, might be further enhanced by new migrants to the stopover area. New migrants might be using habitat conditions associated with Category 1 as a visual cue to determine the center of their activity range during the stopover period (Sparling and Krapu 1994). Cranes are known to exhibit high site fidelity within a single activity range once it is established. Cranes are also known to shift roosting locations daily; however, the average distance moved is typically less than two kilometers (USFWS 1981). Therefore, cranes establishing an activity range containing continuous Category 1 roosting habitat would have greater access to more food resources on adjacent agricultural land compared to cranes establishing an activity range containing an isolated roosting complex.

In addition to river characteristics, the best model identified roosting habitat use by cranes in the CPRV is influenced by temperature. The predicted use of all river categories increased as temperatures increased. The effect of temperature might not have been fully captured by the best model because most observations (92%) were recorded when temperatures were above freezing. My results might also be influenced by the low incidence of cranes roosting on the Platte River during periods of below freezing temperatures due to the limited availability of open water roosting habitat. Furthermore, use of alternative roosting sites during below freezing temperatures could be occurring because ice jams and flooding are known to temporarily reduce the availability of roosting habitat on the Platte River (Davis 2001).

Roost Observations

My results suggest a west to east shift in cranes, as noted by Faanes and LeValley (1993), might still be occurring within the CPRV because the abundance of cranes in western bridge segments with high proportions of suitable roosting habitat has decreased. During my study, 76% of cranes in the CPRV roosted in bridge segments 2–6. In the late 1970's, nearly 80% of the cranes in the CPRV roosted in bridge segments 2, 3, 4, 7, and 10 (USFWS 1981). During this time period, the USFWS (1981) reported similar percentages of cranes roosting in bridge segments 3-4 (33%) and segments 7 and 10 (30%).

My results show over 40% of the cranes roost in bridge segments 3–4, while bridge segments 7 (14%) and 10 (1%) roost less than half as many cranes. Kinzel et al (2006) also reports a decline in the abundance of cranes in bridge segment 7 despite annual maintenance of roosting habitat. The shift in cranes from bridge segments 7 and 10 to eastern bridge segments might be due to roosting habitat isolation. Very little continuous roosting habitat classified as Category 1 exists in bridge segment 10 or surrounding bridge segments (*see* Figure 2–2). Bridge segment 7 appears to be isolated as well due to large areas of lower category river areas in bridge segment 8 and portions of bridge segments 5 and 6 (*see* Figure 2–2).

Roost Size

My results support the idea that the number of cranes on a roosting area in the CPRV is influenced by river characteristics such as width and vegetation (Faanes and LeValley 1993, Davis 2003). In general, my results show that areas of the Platte River receiving the most intensive and the most frequent management of roosting areas will contain the highest abundance of cranes. However, management alone might not ensure large numbers of cranes will use a roosting area. For example, Category 2 roosting habitat has the second highest predicted use among all river categories while the predicted abundance of cranes, relative to Category 1, is reduced by more than half. Improvements to Category 2 roosting habitat, such as removal of tall vegetation from islands or reduction to island area, might facilitate roost sizes to increase in this category.

Alternatively, the differences in roost size for Category 1 and 2 roosting habitats might be due to social facilitation. Cranes roosting near each other have been shown to depart roosts at similar times and join existing flocks in agricultural fields (Sparling and Krapu 1994). Therefore, cranes departing agricultural fields late in the evening might be joining existing flocks of cranes that arrived to roosting areas earlier.

My results also support the need to manage for more continuous complexes of Category 1 roosting habitat in the CPRV. Roost size is predicted to increases in all river categories as river flow increases. However, roost size in Category 1 is predicted to increase the most as river flow increases relative to other categories. Increased river flow has also been shown to change the spatial distribution of roosts from nearly continuous flocks to isolated flocks (Kinzel et al. 2009). Increased water depth during higher river flows might be influencing distribution patterns, because cranes typically roost in water depths less than 35 centimeters while preferring depths less than 20 centimeters (Folk and Tacha 1990, Norling et al 1992, Kinzel et al. 2009). Category 1 roosting habitat likely remains within the optimal range of water depths longer compared to narrower river channels with more islands. Therefore, Category 1 roosting habitat would receive greater use by greater numbers of cranes if river flows were to remain high for an extended period of time during the spring, which would result in food resources near these roosting areas to become depleted earlier.

MANAGEMENT IMPLICATIONS

Maintenance of current roosting habitat should be focused on bridge segments 2-7. Maintaining roosting complexes containing Category 1 and 2 river segments is essential to ensure the density of cranes within these bridge segments does not increase further. Further increases in crane density has the potential to put further stress on the food resources near roosting areas and force cranes to forage further from the river earlier in the stopover period (*see Chapter 1*).

Efforts to improve roost conditions should be focused on bridge segments 10–11, because existing roosting habitat complexes exist and a high abundance of cranes used these segments historically (USFWS 1981). Bridge segments 8–9 also have high capacity for habitat improvement and the adjacent landscape provides high proportions of preferred foraging sites (*see Chapter 1*), but these bridge segments present additional challenges for managers to overcome. Extensive development along the Platte River in bridge segment 8 might reduce its value to cranes, since disturbance due to develop in this area is higher compared to western bridge segments (Currier 1991). The absence of Category 1 and 2 habitats in bridge segment 9 presents an initial challenge for managers, because there are no existing roosting habitat complexes to expand upon.

Large-scale river clearing in bridge segment 1 should not be expanded and river maintenance in bridge segment 1 should be limited to the areas closest to bridge segment 2. Bridge segment 1 contained some of the largest continuous areas of the Category 1 and 2 river segments, but received only 3% of the annual use, similar to other more western sites not containing as high of proportions of these roosting habitats. The adjacent landscape might be driving the limited use of bridge segment 1, because bridge segment 1 contained some of the lowest proportions of alfalfa and winter wheat (*see Chapter 1*).

Finally, near record high Platte River flows during 2010–2011 due to above normal precipitation and above normal snow pack in the Rocky Mountains likely scoured many islands free of vegetation. The presence of vegetated islands is likely driving the low abundance of cranes in Category 2 roosting habitat. Therefore, island management in Category 2 roosting habitat should be the primary focus of managers when river flows return to normal levels because if woody vegetation is not controlled, cottonwood and willow seedling establishment and expansion is rapid (Currier 1997).

LITERATURE CITED

Akaike, H. 1974. A new look at the statistical model identification. IEEE Transactions on Automatic Control 19: 716-723.

Burnham, K.P., and D.R. Anderson. 2002. Model selection and multimodel inference. Springer. New York, New York, USA.

Currier, P.J. 1984. Woody vegetation clearing on the Platte River aids restoration of sandhill crane roosting habitat (Nebraska). Restoration and Management Notes 2:38.

Currier, P.J. 1991. Reclamation of crane roosting habitat on the Platte River and restoration of riverine wetlands. Proceedings of the 1987 International Crane Workshop: 403-407.

Currier, P.J. 1997. Woody vegetation expansion and continuing declines in open channel habitat on the Platte River in Nebraska. Proceedings of the North American Crane Workshop 7: 141-152.

Currier, P.J., and J.W. Ziewitz. 1987. Application of a sandhill crane model to the management of habitat along the Platte River. Proceedings of the 1985 Crane Workshop: 315-325.

Currier, P.J., G.R. Lingle, and J.G. VanDerwalker. 1985. Migratory bird habitat on the Platte and North Platte Rivers in Nebraska. The Platte River Whooping Crane Critical Habitat Maintenance Trust, Grand Island, Nebraska, USA.

Davis, C.A. 2001. Nocturnal roost site selection and diurnal habitat use by sandhill cranes during spring in central Nebraska. Proceedings North American Crane Workshop 8: 48-56.

Davis, C.A. 2003. Habitat use and migration patterns of sandhill cranes along the Platte River, 1998-2001. Great Plains Research 13: 199-216.

Environmental Systems Research Institute, Inc. 2008. ArcMap. Version 9.3. Redlands, CA.

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: 480-486.

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

Johnson, W.C., R.L. Burgess, and W.R. Keammerer. 1976. Forest overstory vegetation and environment on the Missouri River floodplain in North Dakota. Ecological Monographs 46: 59-84.

High Plains Regional Climate Center. 2004-2010. Climate Data Services. <http://www.hprcc.unl.edu/index.php>. Accessed 10 Nov 2010.

Hurr, R.T. 1981. Ground water hydrology of the Mormon Island Crane Meadows Wildlife Area, near Grand Island, Hall County, Nebraska. United States Geological Survey Open File Report 81-1109

Kinzel, P.J., J.M. Nelson, and A.K. Heckman. 2009. Response of sandhill crane (Grus Canadensis) riverine roosting habitat to changes in stage and sandbar morphology. River Research and Applications 25: 135-152.

Kinzel, P. J., J. M. Nelson, R. S. Parker, and L. R. Davis. 2006. Spring census of mid-continent sandhill cranes using aerial infrared videography. Journal of Wildlife Management 70: 70-77.

Kohavi, R. 1995. A study of cross-validation and bootstrap for accuracy estimation and model selection. The International Joint Conference on Artificial Intelligence: 1137-1145.

Krapu, G.L. 1987. Use of staging areas by sandhill cranes in the midcontinent region of North America. Proceedings of the 1983 International Crane Workshop: 451-462.

Krapu, G.L., 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.

Krapu, G.L., G.C. Iverson, K.J. Reinecke, and C.M. Boise. 1985. Fat deposition and usage by Arctic-nesting sandhill cranes during spring. Auk 102: 362-368.

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

Mayer, D.G., and D.G. Butler. 1993. Statistical validation. Ecological Modelling 68: 21-32.

Norling, B.S., S.H. Anderson, and W.A. Hubert. 1992. Roost sites used by sandhill cranes staging along the Platte River, Nebraska. Great Basin Naturalist 52: 253-261.

Pearce, J., and S. Ferrier. 2000. Evaluating the predictive performance of habitat models developed using logistic regression. Ecological Modelling 133: 225-245.

Pearse, A.T, G.L. Krapu, D.A. Brandt, and P.J. Kinzel. 2010. Changes in agriculture and abundance of snow geese affect carrying capacity of sandhill cranes in Nebraska. Journal of Wildlife Management 74: 479-488.

Pfeiffer, K., and P.J. Currier. 2005. An adaptive approach to channel management of the Platte River. Proceedings of the North American Crane Workshop 9: 151-154.

R Development Core Team. 2008. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Reinecke, K. J., and G.L. Krapu. 1986. Feeding ecology of sandhill cranes during spring migration in Nebraska. Journal of Wildlife Management 50: 71-79.

Schwarz, G.E. 1978. Estimating the dimension of a model. Annals of Statistics 6: 461-464.

Sidle, J.G., and C.A. Faanes. 1997. Platte River ecosystem resources and management, with emphasis on the Big Bend reach in Nebraska. U.S. Fish and Wildlife Service, Grand Island, Nebraska. 261pages.

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.

Sparling, D. W., and G. L. Krapu. 1994. Communal roosting and foraging behavior of staging sandhill cranes. Wilson Bulletin 106: 62-77.

Tacha, T.C., P.A. Vohs, and G.C. Iverson. 1987. Time and energy budgets of sandhill cranes from mid-continental North America. Journal of Wildlife Management 51: 440-448.

United States Department of Agriculture – Natural Resources Conservation Service. 2011. Plants Database. <http://plants.usda.gov>. Accessed 05 April 2011.

United States Department of Agriculture – Natural Resources Conservation Service. 2010. Geospatial Data Gateway. <http://datagateway.nrcs.usda.gov>. Accessed 11 Feb 2010.

United States Fish and Wildlife Service. 1981. The Platte River ecology study. U.S. Fish and Wildlife Service, Jamestown, North Dakota. 187 pages.

United States Geological Survey. 2004-2010. Nebraska Water Science Center. <http://ne.water.usgs.gov/>. Accessed 10 Nov 2010.

Walkinshaw, G.P. 1956. Two visits to the Platte Rivers and their sandhill crane migration. Nebraska Bird Review 24: 18-21.

Wilhite, D.A., M.D. Svoboda, and M.J. Hayes. 2005. Monitoring Drought in the United States: Status and Trends. Pages 121-131 *in* V.K. Boken, A.P. Cracknell, and R.L. Heathcote (Eds.), Monitoring and Predicting Agricultural Drought: A Global Study. Oxford University Press, Inc. New York, New York USA.

Table 2–1. Description of Platte River bridge segments between Chapman and Overton, Nebraska.

Bridge Segment*	Location
1	Chapman to Highway 34
2	Highway 34 to Highway 281
3	Highway 281 to Alda
4	Alda to Wood River
5	Wood River to Shelton
6	Shelton to Gibbon
7	Gibbon to Highway 10
8	Highway 10 to Kearney
9	Kearney to Odessa
10	Odessa to Elm Creek
11	Elm Creek to Overton

* Bridge segments increase from east to west (adopted from Currier et al. 1985).

Table 2–2. Criteria used to classify 800 meter segments of the Platte River main channel from Chapman to Overton, Nebraska, 2004–2010.

Category*	**Channel Width (m)**	**Category Description**
1	≥ 150	• Both banks free of tall woody vegetation ○ Both banks can have tall woody IF channel is greater than 200m • One bank is free of tall woody vegetation • One bank is free of tall woody vegetation AND segment does not contain an elevated island with vegetation
2	≥ 150	• Segment contains an elevated island with vegetation OR segment parallels a road • Both bank have tall woody vegetation AND channel is less than 200m • Both bank have woody vegetation AND segment contains an elevated island with vegetation OR segment parallels a road
3	100–150	• One bank is free of tall woody vegetation • One bank is free of tall woody vegetation AND segment does not contain an elevated island with vegetation
4	100–150	• Segment contains an elevated island with vegetation OR segment parallels a road • Both banks have tall woody vegetation • Both banks have tall woody vegetation AND segment contains an elevated island with vegetation OR segment parallels a road
5	< 100	• Any channel less than 100m

* River segments less than 400 meters from bridges and less than 200 meters from power lines were excluded from analysis.

Table 2–3. Proportion of the Platte River in each category by bridge segment, 2004–2010.

		Bridge Segment											
Year	**Category**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	$\bar{x}$
2004	**1**	0.286	0.286	0.500	0.455	0.294	0.313	0.727	0.043	-	0.200	0.095	**0.255**
	2	0.321	0.238	0.429	0.364	0.235	0.313	0.273	0.130	-	0.067	-	**0.204**
	3	0.214	0.048	0.071	-	0.118	0.188	-	0.261	0.158	0.067	0.095	**0.128**
	4	0.107	0.190	-	0.182	0.176	0.063	-	0.304	0.632	0.467	0.190	**0.219**
	5	0.071	0.238	-	-	0.176	0.125	-	0.261	0.211	0.200	0.619	**0.194**
2005	**1**	0.357	0.286	0.571	0.455	0.176	0.188	0.455	-	-	0.200	0.095	**0.230**
	2	0.179	0.286	0.357	0.455	0.235	0.375	0.545	0.261	-	0.067	-	**0.224**
	3	0.143	0.048	0.071	-	0.059	0.063	-	0.087	0.211	0.133	-	**0.082**
	4	0.250	0.143	-	0.091	0.353	0.250	-	0.304	0.579	0.133	0.238	**0.235**
	5	0.071	0.238	-	-	0.176	0.125	-	0.348	0.211	0.467	0.667	**0.230**
2006	**1**	0.321	0.095	0.500	0.455	0.176	0.188	0.727	0.087	-	0.267	0.095	**0.230**
	2	0.286	0.429	0.357	0.455	0.235	0.375	0.273	0.174	-	-	-	**0.224**
	3	0.036	0.143	0.071	-	0.118	0.063	-	0.130	0.158	0.133	0.143	**0.097**
	4	0.286	0.095	0.071	0.091	0.353	0.188	-	0.261	0.632	0.133	0.095	**0.219**
	5	0.071	0.238	-	-	0.118	0.188	-	0.348	0.211	0.467	0.667	**0.230**
2007	**1**	0.143	0.095	0.429	0.545	0.176	0.250	0.545	-	-	0.133	0.095	**0.179**
	2	0.357	0.143	0.429	0.364	0.235	0.250	0.455	0.087	-	0.200	-	**0.209**
	3	0.071	0.381	0.071	-	0.176	0.188	-	0.043	0.158	0.067	0.143	**0.128**
	4	0.357	0.190	0.071	0.091	0.294	0.188	-	0.478	0.632	0.133	0.095	**0.260**
	5	0.071	0.190	-	-	0.118	0.125	-	0.391	0.211	0.467	0.667	**0.224**

Table 2–3 Continued.

		Bridge Segment											
Year	**Category**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	$\bar{x}$
2008	**1**	0.143	0.095	0.429	0.545	0.176	0.250	0.545	-	-	0.133	0.095	**0.179**
	2	0.357	0.143	0.429	0.364	0.235	0.250	0.455	0.087	-	0.200	-	**0.209**
	3	0.071	0.286	0.071	-	0.176	0.188	-	0.043	0.158	0.067	0.143	**0.117**
	4	0.357	0.286	0.071	0.091	0.294	0.188	-	0.478	0.632	0.133	0.095	**0.270**
	5	0.071	0.190	-	-	0.118	0.125	-	0.391	0.211	0.467	0.667	**0.224**
2009	**1**	0.214	0.143	0.571	0.545	0.176	0.125	1.000	0.043	-	0.333	0.143	**0.245**
	2	0.321	0.238	0.429	0.364	0.235	0.375	-	0.217	-	0.067	0.143	**0.219**
	3	0.036	0.286	-	-	0.235	0.250	-	0.087	0.105	0.067	0.143	**0.117**
	4	0.357	0.190	-	0.091	0.235	0.125	-	0.304	0.842	0.333	0.095	**0.260**
	5	0.071	0.143	-	-	0.118	0.125	-	0.348	0.053	0.200	0.476	**0.158**
2010	**1**	0.393	0.190	0.714	0.636	0.176	0.250	1.000	0.043	-	0.400	0.238	**0.316**
	2	0.321	0.190	0.286	0.273	0.235	0.313	-	0.304	-	-	0.048	**0.189**
	3	0.107	0.333	-	-	0.235	0.250	-	0.174	0.105	0.133	0.143	**0.148**
	4	0.143	0.143	-	0.091	0.235	0.063	-	0.261	0.842	0.400	0.143	**0.224**
	5	0.036	0.143	-	-	0.118	0.125	-	0.217	0.053	0.067	0.429	**0.122**
	Kilometers	22.22	15.04	11.34	8.91	13.77	12.36	8.91	18.02	15.39	12.06	16.98	**155.00**

Table 2–4. Results of roosting habitat use analysis and model selection.

Model	**k**	**Explanatory Variables***	**ΔBIC**	***w***	**AUC**
6	9	CAT + TC	0.00	0.947	0.768
8	10	CAT + TC + PRF	6.95	0.029	0.767
2	8	CAT	8.68	0.012	0.773
14	10	CAT + TC + WSP	8.94	0.011	0.766
Global	23	CAT*JD + CAT*PRF + TC + WSP + PRF	73.37	0.000	–
Null	4	1	948.01	0.000	–

Abbreviations of explanatory variables are as follows:
CAT = Category, PRF = Platte River Flow (cfs), TC = Temperature (C), WSP = Wind Speed (kph), JD = Julian Date and Julian Date Quadratic, YR = Year.
* All models include the fixed effect, JD, and the random effect, YR.

Table 2–5. Coefficient estimates for Model 6.

Coefficient	**Estimate***	**SE**	**z value**	**Significance**
(Intercept)	-0.206	0.197	-1.05	–
CAT – 2	-0.508	0.074	-6.85	$p < 0.001$
CAT – 3	-0.933	0.097	-9.66	$p < 0.001$
CAT – 4	-1.662	0.088	-18.97	$p < 0.001$
CAT – 5	-3.302	0.169	-19.53	$p < 0.001$
TC	0.165	0.039	4.24	$p < 0.001$
JD	0.441	0.043	10.25	$p < 0.001$
JD^2	-0.644	0.040	-16.08	$p < 0.001$
Random Effect	**Variance**	**SD**		
Year (Intercept)	0.250	0.500		

* Reported on log-odds scale
Abbreviations of explanatory variables are as follows:
CAT = Category, TC = Temperature (C), JD = Julian Date.

Table 2–6. Descriptive statistics of covariates used for roosting habitat use analysis.

Covariate	**Min.**	**Q1**	**Median**	$\bar{x}$	**Q3**	**Max.**
JD	55 (Feb. 24)	70 (Mar. 11)	84 (Mar. 25)	82 (Mar. 23)	95 (Apr. 5)	109 (Apr. 19)
TC	-7.34	3.26	8.54	8.77	15.02	20.48
WSP	5.89	10.94	14.02	16.40	19.18	34.10
PRF	0 (Ice)	547	794	892	1120	3540

Abbreviations of explanatory variables are as follows:
JD = Julian Date, PRF = Platte River Flow (cfs), TC = Temperature (C), WSP = Wind Speed (kph).

Table 2–7. Proportion of crane flocks observed in each category, 2004–2010.

	Year							
Category	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	$\bar{x}$
1	0.491	0.451	0.430	0.351	0.362	0.480	0.463	**0.433**
2	0.241	0.321	0.338	0.298	0.294	0.289	0.234	**0.288**
3	0.069	0.056	0.077	0.149	0.110	0.133	0.189	**0.112**
4	0.147	0.126	0.121	0.190	0.205	0.095	0.098	**0.140**
5	0.052	0.047	0.034	0.012	0.030	0.003	0.016	**0.028**
Flocks Observed	116	215	207	168	337	377	244	**1,664**

Table 2–8. Proportion of cranes counted in each bridge segment, 2004–2010.

	Year							
Bridge Segment	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	$\bar{x}$
1	0.013	0.016	0.062	0.024	0.022	0.072	0.024	**0.033**
2	0.100	0.140	0.165	0.102	0.092	0.102	0.076	**0.111**
3	0.178	0.271	0.253	0.194	0.224	0.259	0.319	**0.243**
4	0.141	0.150	0.171	0.177	0.194	0.164	0.162	**0.166**
5	0.189	0.096	0.166	0.161	0.152	0.116	0.100	**0.140**
6	0.179	0.133	0.081	0.088	0.082	0.064	0.091	**0.103**
7	0.112	0.128	0.064	0.154	0.187	0.160	0.176	**0.140**
8	0.058	0.033	0.020	0.044	0.035	0.032	0.033	**0.036**
9	0.018	0.017	0.017	0.025	0.007	0.006	0.003	**0.013**
10	0.010	0.014	0.000	0.032	0.005	0.024	0.016	**0.014**
11	–	0.003	> 0.001	–	–	–	> 0.001	**> 0.001**

Table 2–9. Results of roost size analysis and model selection.

Model	**k**	**Explanatory Variables***	**ΔBIC**	***w***	**RMSE**
4	9	CAT + PRF	0.00	0.782	0.626
2	8	CAT	2.59	0.214	0.630
Global	23	CAT*JD + CAT*PRF + TC + WSP + PRF	135.62	0.000	–
Null	4	1	416.63	0.000	–

Abbreviations of explanatory variables are as follows:
CAT = Category, PRF = Platte River Flow (cfs), TC = Temperature (C), WSP = Wind Speed (kph), JD = Julian Date and Julian Date Quadratic, YR = Year.
* All models include the fixed effects, JD, and the random effect, YR.

Table 2–10. Coefficient estimates for Model 4.

Coefficient	**Estimate***	**SE**	**t value**
(Intercept)	3.628	0.027	133.54
CAT – 2	-0.436	0.037	-11.79
CAT – 3	-0.695	0.051	-13.65
CAT – 4	-0.840	0.048	-17.52
CAT – 5	-1.382	0.102	-13.51
PRF	0.071	0.016	4.55
JD	-0.168	0.017	-9.87
JD^2	-0.221	0.013	-17.00
Random Effect	**Variance**	**SD**	
Year (Intercept)	0.000	0.000	

* Reported on $\log_{10}$ scale
Abbreviations of explanatory variables are as follows:
CAT = Category, PRF = Platte River Flow (cfs), JD = Julian Date.

Table 2–11. Descriptive statistics of covariates used for roost size analysis.

Covariate	Min.	Q1	Median	$\bar{x}$	Q3	Max.
JD	55 (Feb. 24)	78 (Mar. 19)	90 (Mar. 31)	87 (Mar. 28)	95 (Apr. 5)	109 (Apr. 19)
TC	-6.69	3.66	9.50	9.45	15.31	20.48
WSP	5.89	12.59	14.02	17.17	22.10	34.10
PRF	0 (Ice)	558	796	912	1150	3540

*Abbreviations of explanatory variables are as follows:
JD = Julian Date, PRF = Platte River Flow (cfs), TC = Temperature (C), WSP = Wind Speed (kph).

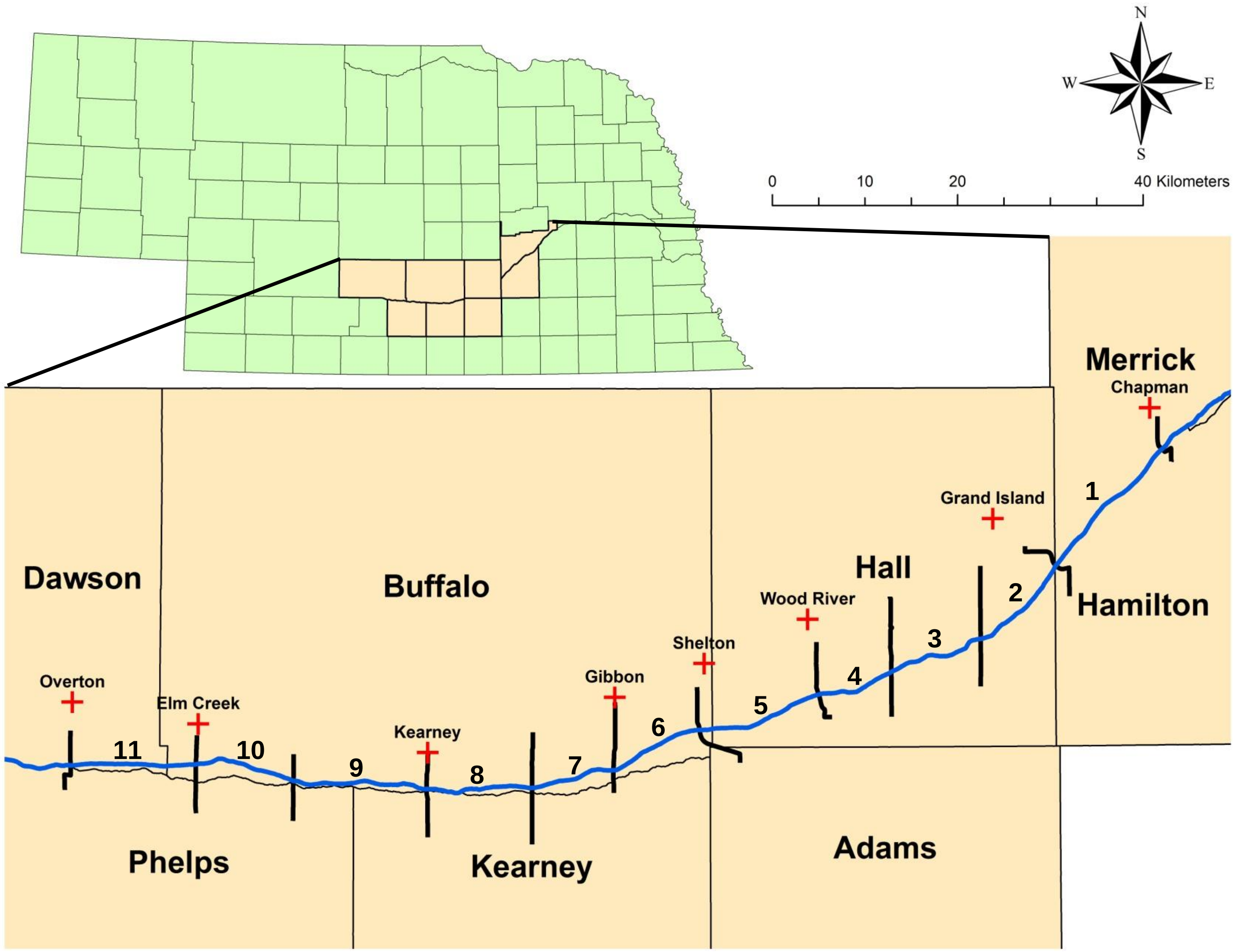

Figure 2–1. Sandhill crane roost survey area on the Platte River, Nebraska, 2004–2010; black lines represent bridge segment divisions.

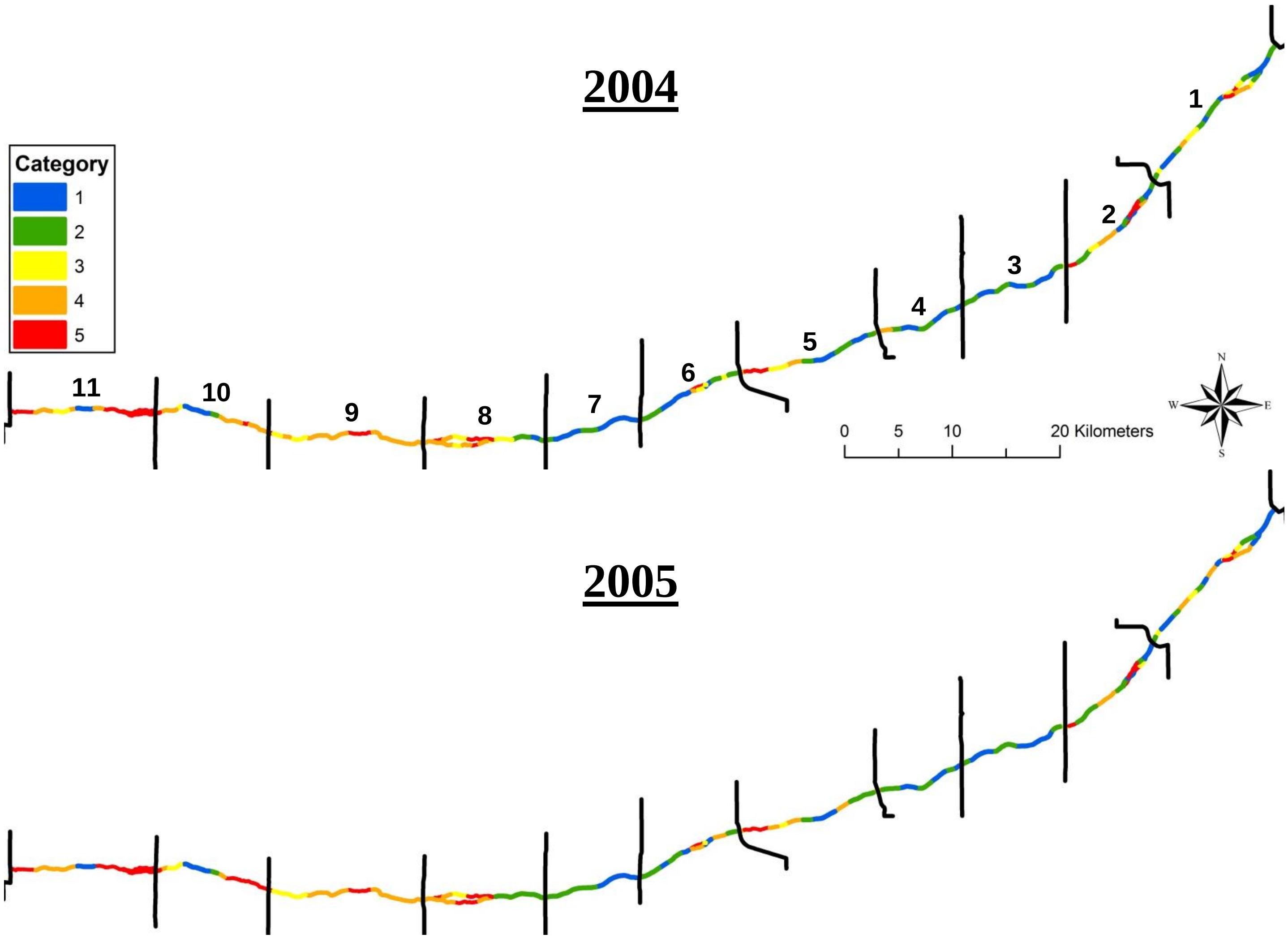

Figure 2–2. Roosting habitat availability by bridge segment (black lines) in the Central Platte River Valley, Nebraska, 2003–2010.

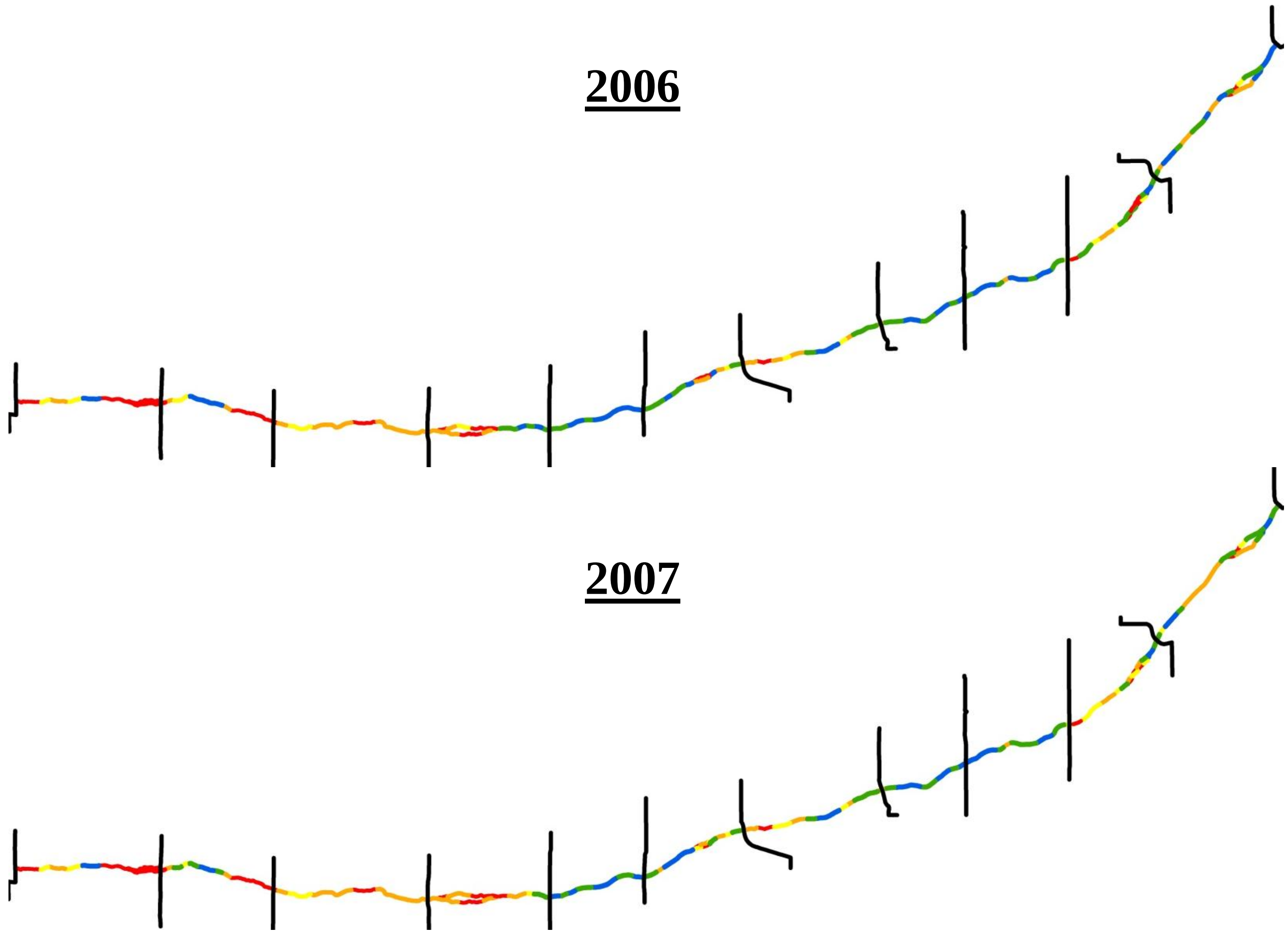

Figure 2–2 Continued.

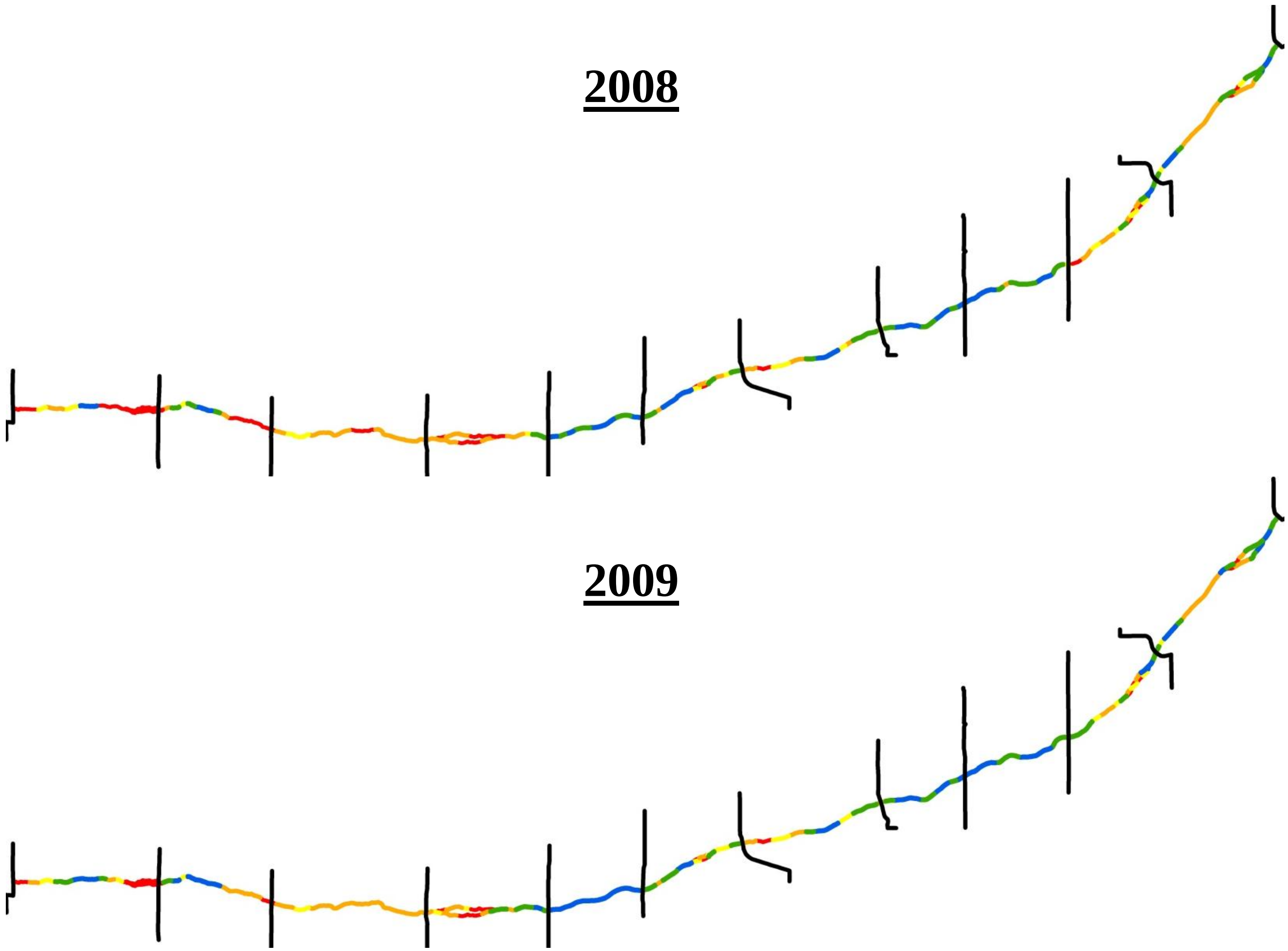

Figure 2–2 Continued.

2010

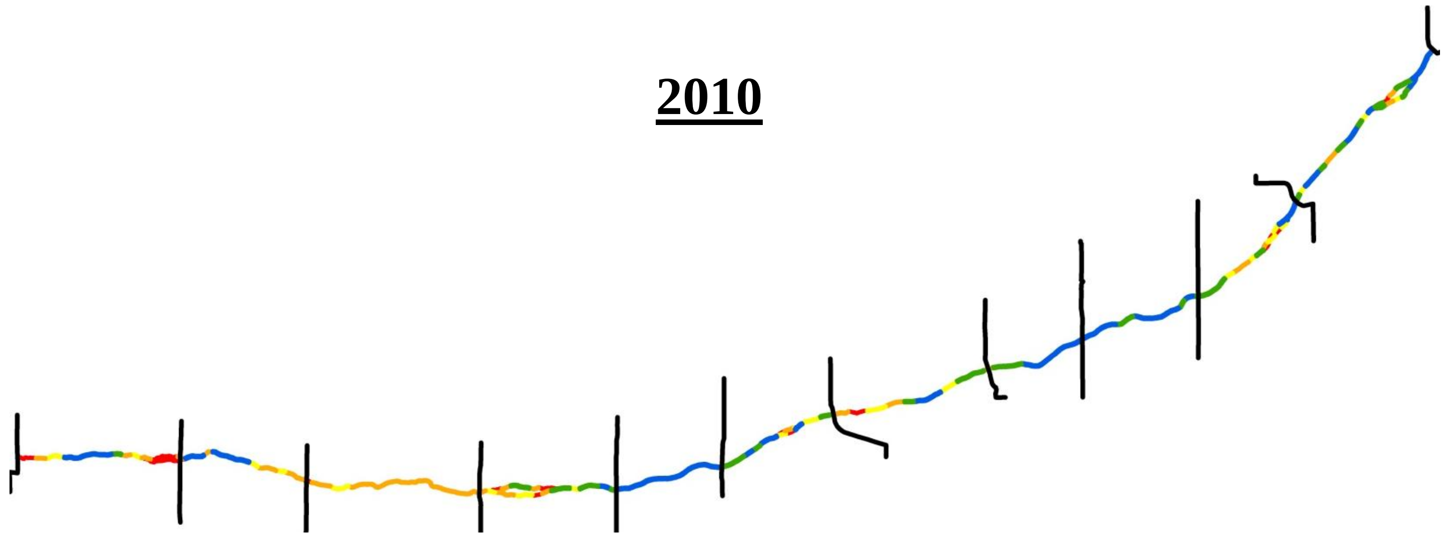

Figure 2–2 Continued.

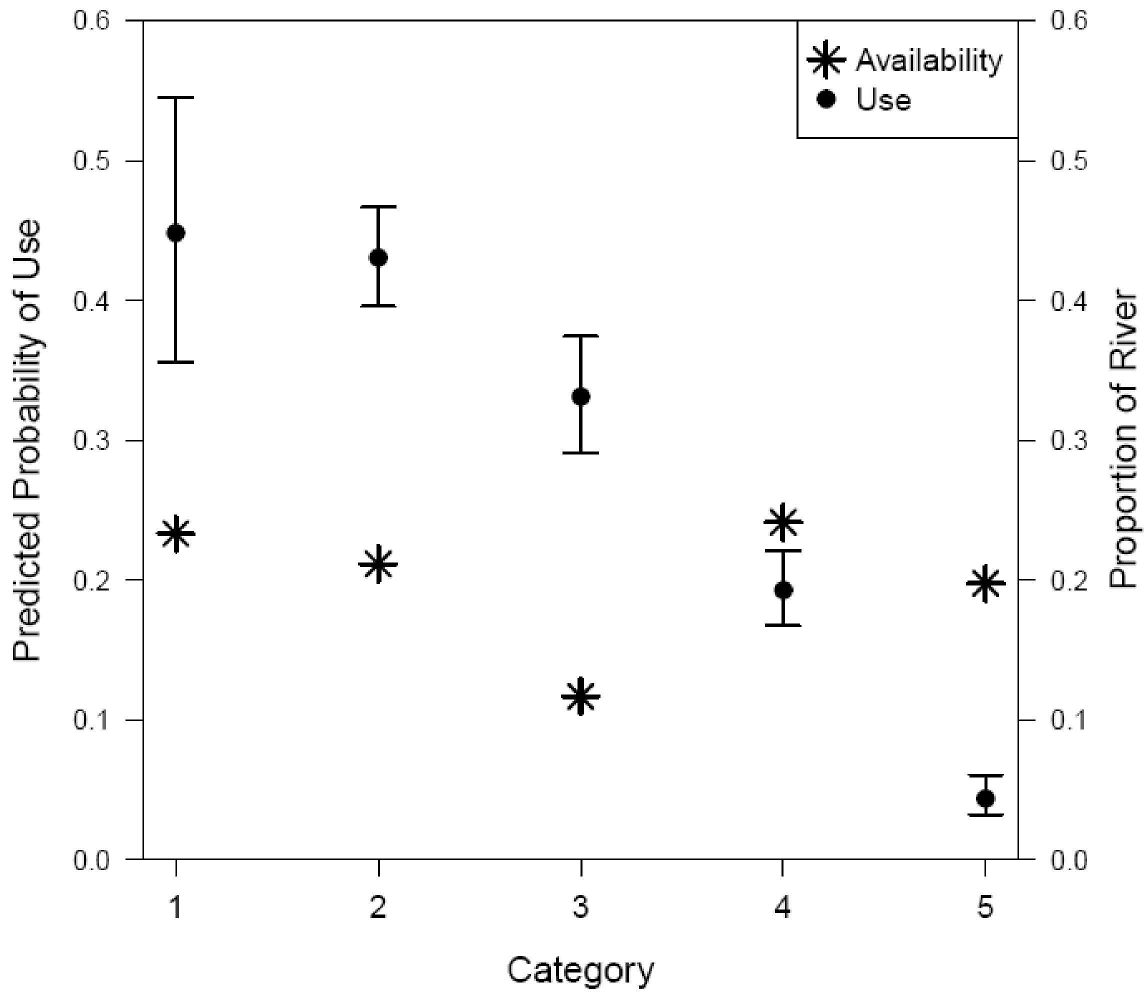

Figure 2–3. Model predicted roosting habitat use (black circle ± SE) by sandhill cranes and average availability (black star) of roosting habitat by category in the CPRV survey area, 2004–2010.

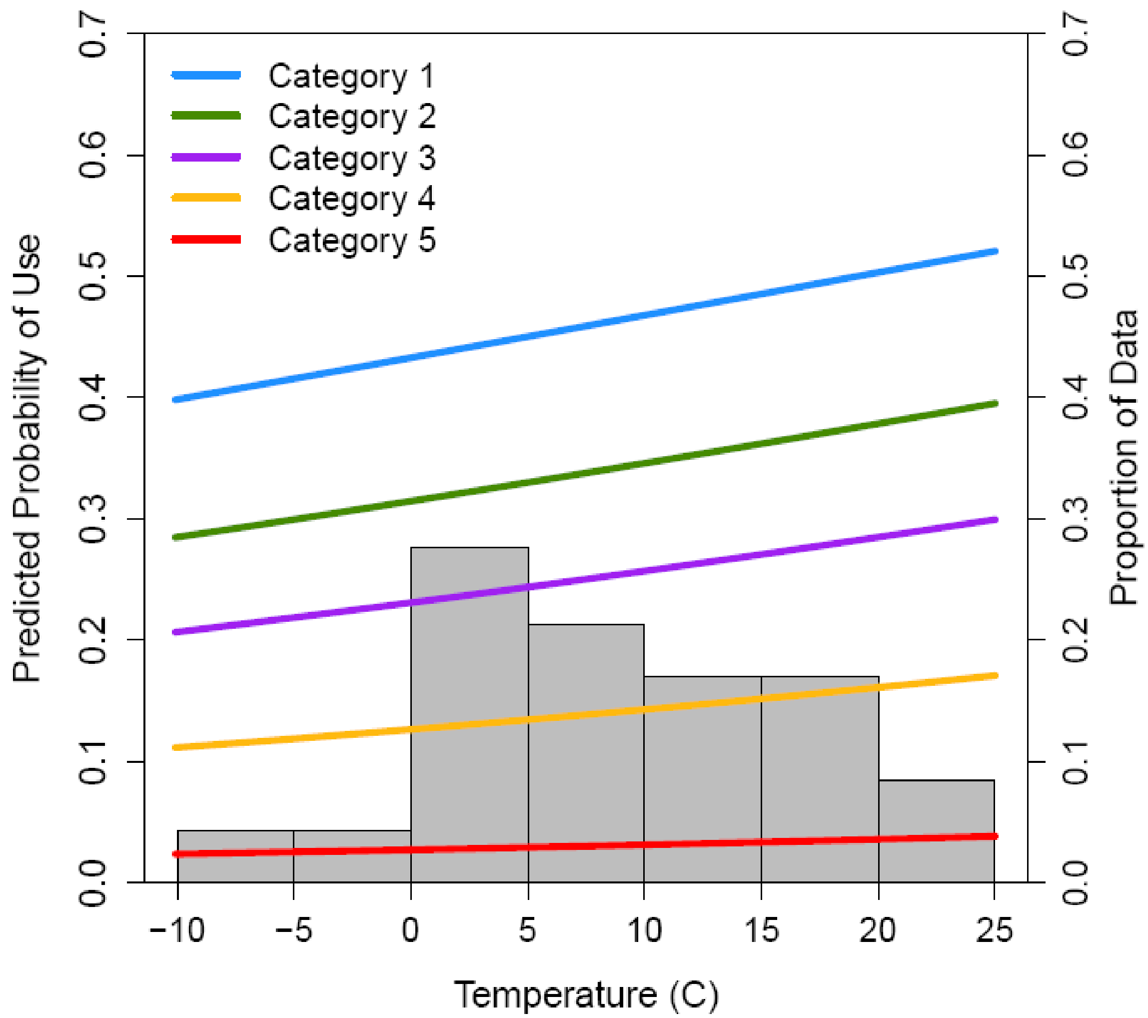

Figure 2–4. Model predicted use of river categories at different temperatures exhibited by sandhill cranes in the CPRV, 2004–2010; bars represent the proportion of data in each temperature class.

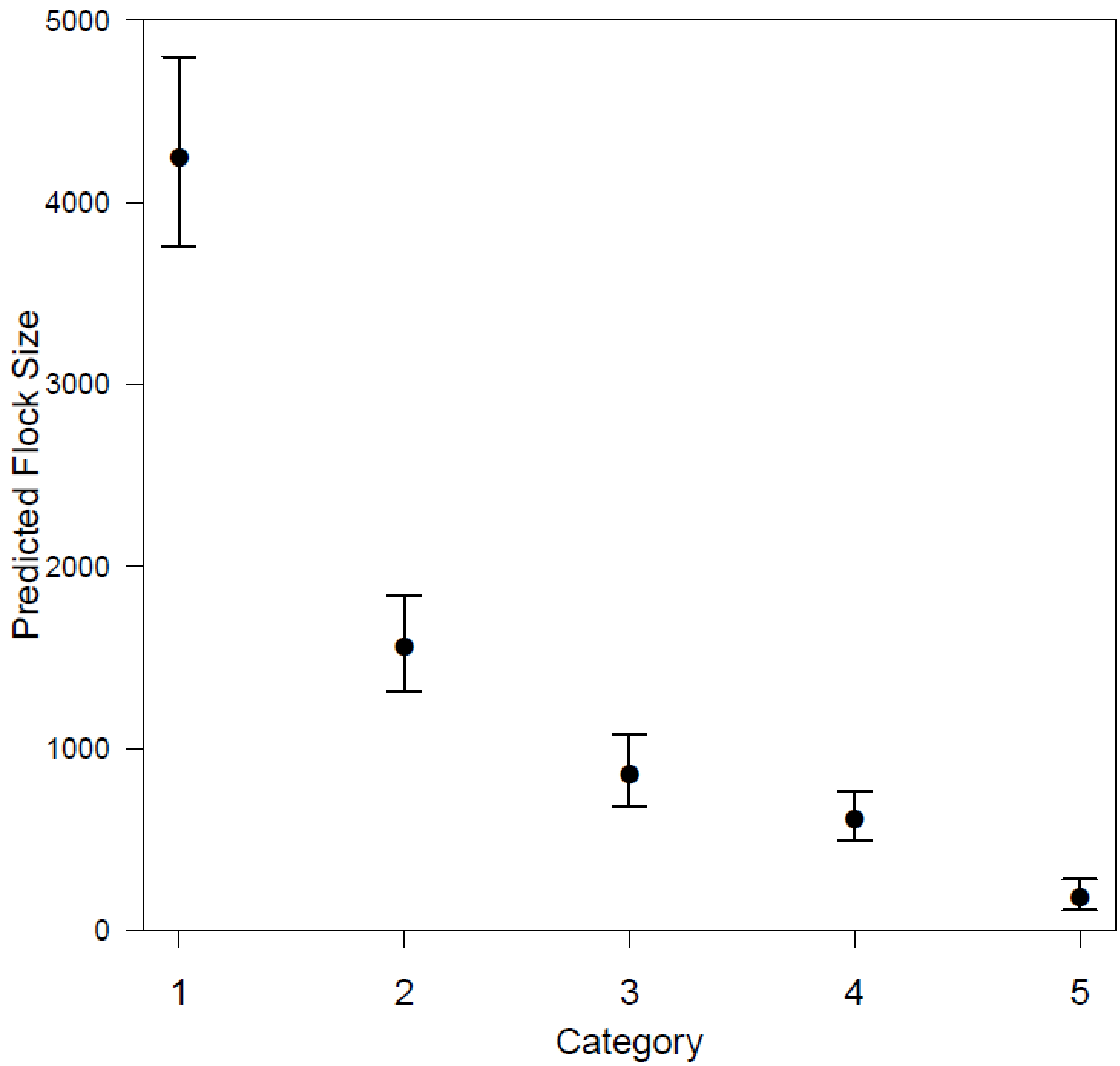

Figure 2–5. Model predicted flock size (black circle ± SE) for river categories used by sandhill cranes in the CPRV, 2004–2010.

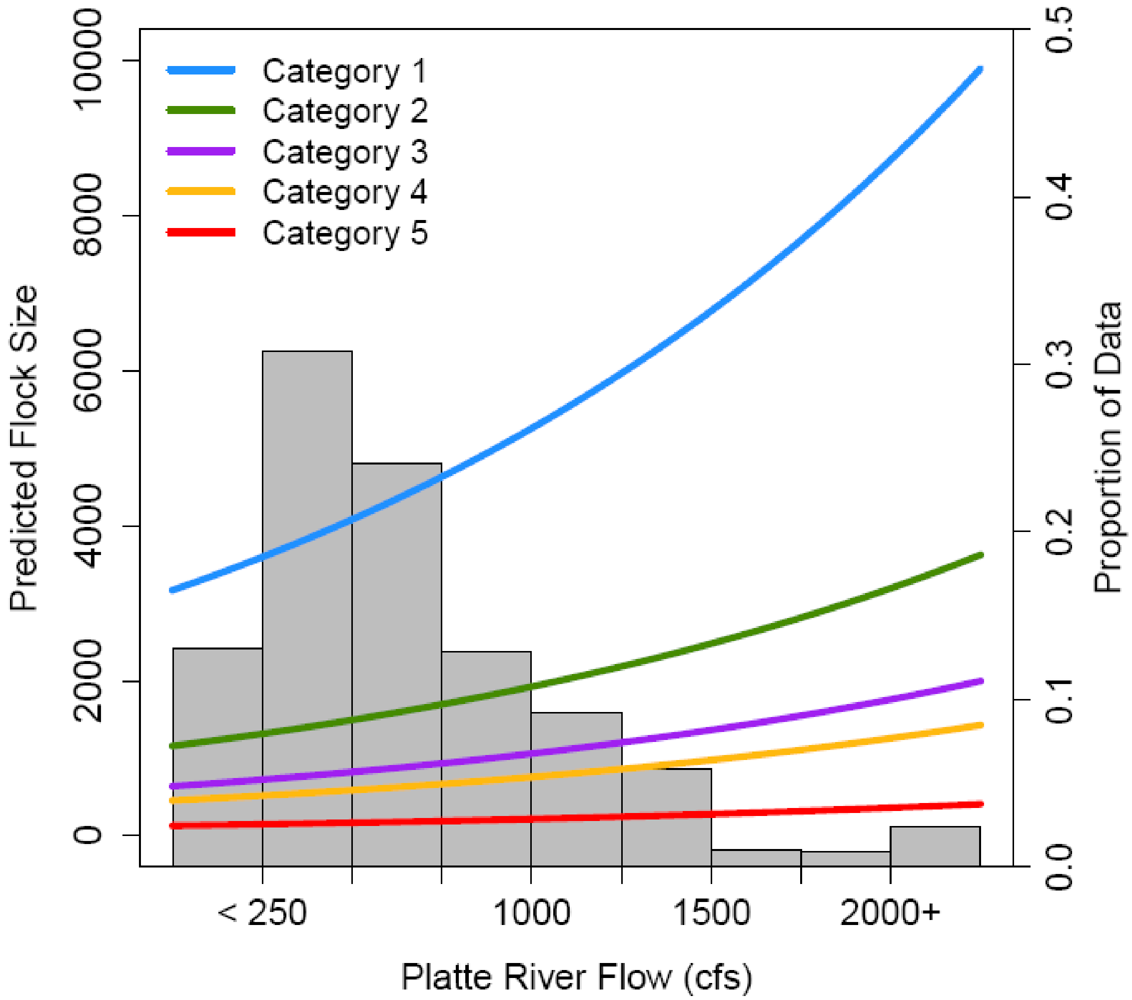

Figure 2–6. Model predicted flock sizes in river categories with different river flow exhibited by sandhill cranes in the CPRV, 2004–2010; bars represent the proportion of data in each Platte River flow class.