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Impacts of Invasive Plants on Sandhill Crane (*Grus canadensis*) Roosting Habitat

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Invasive plants continue to spread in riparian ecosystems, causing both ecological and economic damage. This research investigated the impacts of common reed, purple loosestrife, riparian shrubland, and riparian woodlands on the quality and quantity of sandhill crane roosting habitat in the central Platte River, Nebraska, using a discrete choice model. A more detailed investigation of the impacts of common reed on sandhill crane roosting habitat was performed by forecasting a spread or contraction of this invasive plant. The discrete choice model indicates that riparian woodlands had the largest negative impact on sandhill crane roosting habitat. The forecasting results predict that a contraction of common reed could increase sandhill crane habitat availability by 50%, whereas an expansion could reduce the availability by as much as 250%. This suggests that if the distribution of common reed continues to expand in the central Platte River the availability of sandhill crane roosting habitat would likely be greatly reduced.
Nomenclature: Common reed, *Phragmites australis* (Cav.) Trin. ex Steud.; purple loosestrife, *Lythrum salicaria* L.
Key words: Discrete choice model, GIS, central Platte River, forecast habitat impacts.

The Platte River watershed is a threatened ecosystem of international ecological importance (National Research Council 2004). In Nebraska, the central Platte River is a unique and critical habitat for migratory waterfowl and each spring serves as a staging area for more than 500,000 sandhill cranes (*Grus canadensis*). Quality roosting and foraging habitat are required for sandhill cranes to survive migration and reproduce (Krapu et al. 1985). Yet, this habitat has been dramatically altered over the past century. Decreased water levels, stemming from the development of reservoirs (Williams 1978) and increased use of irrigation for agricultural production, along with reduced hydrological variance resulting from reservoir operation, have resulted in reduced scouring and shifting of alluvium within the channel (Frith 1974) which, among other things, has contributed to significant woodland expansion along the Platte (Johnson 1994). Anthropogenic disturbances such as these often contribute to the spread of invasive plants, especially common reed [*Phragmites australis* (Cav.) Trin. ex Steud.; Hudon et al. 2005] and purple loosestrife (*Lythrum salicaria* L.; Stanley et al. 2005). Both purple loosestrife and common reed have been identified as invasive plants of concern in the central Platte River ecosystem (Currier and Davis 2000); however, the environmental impacts of common reed have received far less attention than those of purple loosestrife. Although both plants are dealt with in this research, the primary focus is on common reed which, at the time of the study, was a species of special concern to wildlife management agencies in Nebraska.

Common reed is a prolific invasive plant of particular concern in the Platte River ecosystem. Based on the invasive species assessment protocol developed by Randall et al. (2008), common reed was found to have a highly significant impact on native plant and animal species and it is believed that the increasing distribution of common reed may reduce the quality and availability of sandhill crane habitat. Common reed is a tall perennial hydrophilic grass species found primarily in wetland and riparian environments (Chambers et al. 1999). It can reach heights of 4 m (13 ft) and is rapidly increasing in distribution and abundance in many places in the United States (Fell et al. 1998). Common reed spreads by rhizomes and stolons and often forms dense monotypic communities (Marks et al. 1994). Both native and nonnative forms of common reed have been identified in the United States, and the nonnative genotype has become a prolific invasive species. An expansion of common reed in eastern tidal wetlands of the United States has been followed by noticeable changes

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Interpretive Summary

This research demonstrates the suitability of discrete choice modeling for quantifying the impacts of invasive plants on sandhill crane roosting habitat. Moreover, this research successfully applied a discrete choice model to forecast the implications that a spread (unsuccessful management) or contraction (successful management) of the invasive plant common reed (*Phragmites australis*) could have on the distribution and abundance of sandhill crane roosting habitat. The methods presented in this research could easily be adopted to provide managers with useful information that aids in the management of invasive plants for the benefit of native species' habitat.

For example, managers could use the modeling and forecasting methods developed in this project to quantify the degree to which invasive species impact native species' habitat, prioritize the location of invasive plant management, and forecast which invasive species are most likely to impact native species. In addition, the discrete choice model forecasting methods described in this research allow the user to quantify the change in abundance and distribution of native species habitat as a result of invasive species spread or contraction. As the availability of digital land cover data grows and knowledge of invasive species' impacts expands, discrete choice modeling and forecasting simulations based on discrete choice models could be instrumental in aiding a field practitioner's management of invasive plants.

to the invaded ecosystems, with direct and indirect impacts on neighboring species abundance and composition (Chambers et al. 1999).

Where common reed is the dominant species, plant species richness generally decreases, potentially having a negative impact on native wildlife. For example, Benoit and Askins (1999) found that an infestation of common reed led to a reduction in the number of bird species present in Connecticut's tidal wetlands. Moreover, they found that large wading birds were often excluded from invaded wetlands. Similarly, Meyer et al. (2010) found that common reed limited the habitat availability of marsh-nesting birds on Lake Erie. Hudon et al. (2005) found that the spread and establishment of common reed in riparian ecosystems is highly dependent on hydrological factors. Changes in hydrology in the Platte River have likely contributed to the expansion of common reed, and as a result could have a negative impact on sandhill crane roosting habitat. Research has examined a wide variety of physical characteristics and has identified those associated with suitable sandhill crane roosting sites (Davis 2003; Folk and Tacha 1990; Norling et al. 1992), such as unobstructed views (Folk and Tacha 1990; Norling et al. 1992). Such obstructions include plants greater than 1 m in height.

A variety of methods have been developed to determine how wildlife species respond to changes in habitat. Wildlife resource selection models, for example, are often used to assess how individuals within a species use or avoid specific habitat. The discrete choice model, rooted in human-choice behavior economic utility theory (Ben-Akiva and Lerman 1985), has been adapted to wildlife resource selection studies in order to provide information related to species habitat preferences (Cooper and Millspaugh 1999; McCracken et al. 1998; McDonald et al. 2001). Discrete choice modeling also provides managers with a tool for forecasting the impacts of alternative management actions (Cooper and Millspaugh 1999). However, discrete choice modeling has rarely been used to forecast the impacts of a change in distribution of invasive plants on native wildlife habitat.

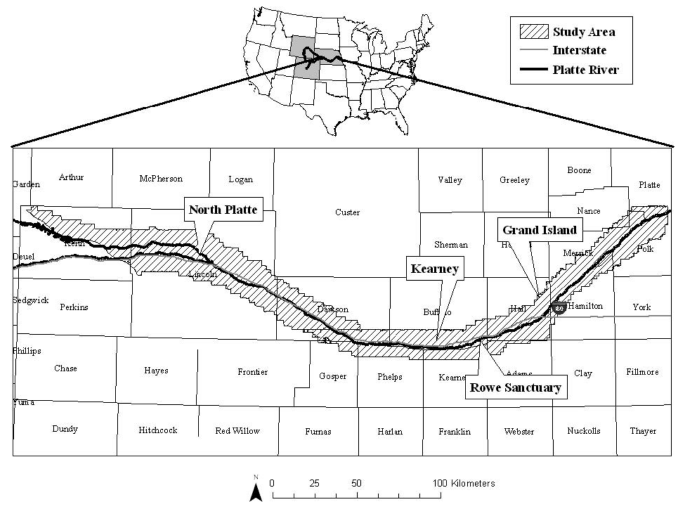

Figure 1. The portion of the central Platte River, Nebraska used in this study.

Riparian ecosystems such as the Platte River are biologically rich (Dodds et al. 2004), but also often contain vectors for the invasion and spread of nonindigenous species. The central Platte River, Nebraska (Figure 1), has been heavily invaded by invasive plants, which may impact the quality of sandhill crane roosting habitat. The objectives of this research were to evaluate discrete choice modeling as a means to (1) assess the impacts different types of invasive plants may have on the quality and distribution of sandhill crane roosting habitat and (2) forecast the potential impacts of an expansion or contraction of common reed on sandhill crane roosting habitat.

Materials and Methods

Study Area. The study area for this project was the central Platte River in Nebraska between the towns of North Platte and Grand Island (Figure 1). This area has been designated a priority ecosystem by the U.S. Geological Survey. This designation stems from its use as a vital staging area for migratory water birds along the Central Flyway. In addition to the approximately 500,000 sandhill cranes that annually use the river (Benning and Johnson 1987; National Research Council 2004), the central Platte also provides habitat for four species covered under the Endangered Species Act: whooping crane (*Grus americana*)

Table 1. Data sources.

Data	Provider	Date
Land cover data set (2004–2005)	J. Brei and A. A. Bishop, U.S. Fish and Wildlife Service, unpublished report	Fall 2004 and fall 2005
Sandhill crane roosting observations	Kinzel et al. 2001	Spring 2005
Landsat 5 imagery	U.S. Geological Survey EROS Data Center Earth Explorer http://edcsns17.cr.usgs.gov/EarthExplorer/	Spring and fall 2005
U.S. Geological Survey water gage data	U.S. Geological Survey water data	Spring and fall 2005

piping plover (*Chardrius melodus*), least tern (*Sterna antillarum*), and pallid sturgeon (*Scaphirhynchus albus*) (National Research Council 2004).

Geospatial Data. The research was founded upon a 2005 digital land cover data set and ancillary data that identified crane roosting sites (Table 1). The 2005 land cover data, developed by the Great Plains Geographic Information Systems (GIS) Partnership, was classified from aerial imagery flown September 5, 2004; August 25, 2004; and August 25 to September 1, 2005 with 1-m spatial resolution (J. Brei and A. A. Bishop, unpublished data). The reported overall accuracy of the classification was 82.7%. The 2005 land cover data were resampled to a 10-m resolution to reduce the size of files for subsequent analyses. A digital map portraying sandhill crane roosting sites was developed by the U.S. Geological Survey using an analysis of aerial infrared videography obtained in March 2005 (Kinzel et al. 2001).

Data Processing. The U.S. Geological Survey sandhill crane roost observation data and the 2005 land cover data set were collected at different times of the year; therefore, the land cover data were adjusted to reflect conditions in the spring. U.S. Geological Survey water gage data were downloaded to confirm and document these differences (Table 2). Platte River water flows are typically higher during the spring when the sandhill crane data set was collected. In order to adjust for the difference in water levels between the data collection dates, six Landsat-5 Thematic Mapper images (band 4) were used (three fall and three spring) to create a binary water and nonwater mask for the fall and spring. Subsequently, the difference between the fall and spring water masks was calculated. The output image was then resampled to a 10-m spatial resolution. The 2005 land cover data were adjusted based on the water mask. All areas highlighted by the water mask subtraction that were not classified as active river channel in the original land cover data set were reclassified to active river channel. This adjusted the fall water levels in the original land cover to more closely represent the spring water levels present at the time of the sandhill crane roost site data collection.

Discrete Choice Modeling. Discrete choice modeling was used to assess the possible influence of land cover on sandhill crane roosting habitat selection. The predictor variables considered are summarized in Table 3. The choice of predictor variables used in this study was based on the findings of previous research (Folk and Tacha 1990; Norling et al. 1992) and the expert opinion of U.S. Fish and Wildlife Service (USFWS) biologists. All predictor variables were measured within a GIS, based on the adjusted 2005 land cover data set.

The area of land cover within 50 m of an observation was defined as the habitat patch required for suitable roosting sites to occur based on previous research findings that sandhill cranes prefer to be a maximum of 50 m from river banks (Norling et al. 1992). Three habitat patch categories were tested; early successional river, active river channel, and unvegetated sandbars (Figure 2a), all of which have been shown to impact sandhill crane roosting habitat (Folk and Tacha 1990; Norling et al. 1992). The habitat patch variables were calculated by totaling the area of each

Table 2. U.S. Geological Survey water gage data near Grand Island, NE, and Landsat image information.

Gage site number	Date (2005)	Discharge avg. (cms)	Gage height avg. (m)	Landsat image no.	Path	Row
6770500	9/5	4.98	0.27	LT50290322005251EDC00	29	32
6770500	8/30	5.18	0.27	LT50300322005242EDC00	30	32
6770500	9/8	3.74	0.26	LT50290312005251EDC00	29	31
6770500	3/16	13.56	0.26	LT50290322005075EDC00	29	32
6770500	4/24	12.03	0.31	LT50300322005114EDC01	30	32
6770500	3/16	13.56	0.32	LT50290312005075EDC00	29	31
6770500	3/25	21.2	0.34	Crane data		

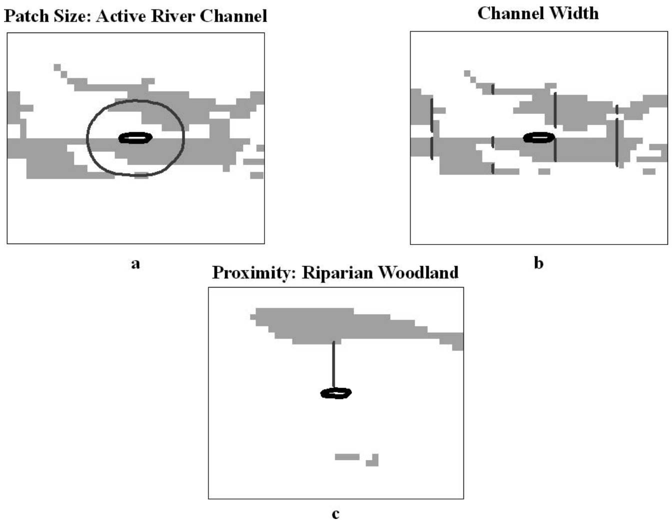

Figure 2. Methods used to calculate the predictor variables, with the black polygon in each diagram representing a sandhill crane roost site. (a) An example of patch size calculation with the circle representing the area used to calculate habitat patch size of the active river channel. (b) An example of the north-to-south parallel lines used to estimate the width of the active river channel. (c) An example of a proximity calculation with the line representing the minimum distance to riparian woodland.

category, using a moving window with a 50-m radius. An estimate for the area of wet meadow was also calculated using a similar method. However, a 500-m radius was used as suggested by USFWS biologists familiar with the area.

This study estimated the wetted width of the river channel as an indicator of the potential distance to shore (Figure 2b). Distance to shore has been found to have a significant impact on sandhill crane roost site suitability (Fold and Tacha 1990). Calculating the width of a braided river channel, such as the Platte, is complex. To estimate wetted width, a series of parallel north-to-south lines were digitized across the study area at 100-m intervals. The lines were then clipped based on the active river channel in the adjusted 2005 land cover data set. All lines were manually checked to insure that they overlaid an east-to-west portion of the river channel. Those lines falling on areas of the river other than east-to-west portions were deleted. The remaining lines were converted to points, after calculating the length of the active river channel falling under each line. An inverse distance weighted function was applied to the points to develop a continuous grid, estimating the wetted width of the active river channel across the study area. The maximum estimated wetted width was calculated for each observation.

Finally, several proximity variables were calculated using the minimum Euclidean distance between an observation and land cover (Figure 2c). These variables were consistent with other efforts (Folk and Tacha 1990); however, they were established at a finer level of detail. For example, the 2005 land cover data set allowed plants to be separated into the two species under consideration, common reed and purple loosestrife.

Fitting the Discrete Choice Model. The binary logit form of the discrete choice model, implemented using SPSS statistical software,[1] was used to fit and estimate the predictor variables, and to predict the probability of occurrence of sandhill crane roosting sites. In wildlife resource selection studies, the discrete choice model is usually applied as the multinomial logit form by developing a "choice set" of all possible resources available to an individual at a given time and place (see Copper and Millspaugh 1999), assuming that the characteristics of the site selected by an individual represented preferred suitable habitat and that the characteristics of multiple nonselected alternative sites are less suitable. Nonselected sites, or the "choice set," are generally identified as all the alternative sites an individual could have traveled to from its original selected location within a given time period. Sandhill cranes, however, are capable of traveling great distances, as demonstrated during their migration. Therefore, the entire extent of the study area within the Platte River channel was used in this study. Since this study area contained both selected or nonselected sites, the multinomial logit form of the discrete choice model was reduced to the binary logit linear form:

$$U_h = b_1 x_1 + b_2 x_2 + \ldots + b_p x_p + e_r \qquad [1]$$

where U_h is the probability of occurrence, b_p is an estimable parameter determining the attributes contribution, x_p is the value of a predictor variable at a location, e_r is an error term.

A total of 1,370 sites where cranes were observed to be present were used. Another 1,700 sites were selected at random in areas where cranes were assumed to be absent based on the results of the aerial infrared survey data. It was assumed that if the infrared sensor could not detect the presence of cranes during the survey that they were absent from the area. The absent data set was limited to areas within the channel of the river (i.e., within 1.6 km [1 mile] of the centerline of the river), and could not be located within 20 m of an observed sandhill crane roost site in order to avoid spatial autocorrelation.

The completed database was randomly subset into halves, with an equal number of presence and absence indicators in each. Half of the data were used to fit the model, and the other half were reserved exclusively for validating the predictions. This technique is commonly applied to insure that data used to validate models are not also used to create the model. Ideally, a second data set collected independently of the data used to construct the model would be used for validating the results. However, a

Table 3. List of predictor variable used to fit the discrete choice model.

Proximity to	Patch size (m^2 within 50 m)	Patch size (m^2 within 500 m)	River channel
Common reed	Active river channel	Wet meadow	Wetted width
Purple loosestrife	Early successional river		
Riparian shrubland	Unvegetated sandbar		
Riparian woodland			
Unvegetated sandbar			
Minor roads			
Major roads			
Rural developments			
Urban areas			
Early successional river			
Bridges			
Active river channel			

second independently collected data set was not available for this project.

The Wald test statistic was used to evaluate the statistical significance of the model coefficients, and a log-likelihood test comparing the null model (empty model) to the final selected model was used to evaluate the statistical significance of model fit. If the Wald test statistic indicated a coefficient was significant based on a z test statistic, it was included in the model. To determine the final "best" model a number of plausible alternative models were manually built following methods outlined by Johnson and Omland (2004). The final "best" model was then selected based on a goodness-of-fit statistic using the Akaike Information Criterion (AIC). The choice of plausible models was based on the findings of prior research (Davis 2003; Folk and Tacha 1990; Norling et al. 1992). Collinearity among variables in the final model was examined through an asymptotic correlation matrix.

The best fit model was applied to the 2005 land cover data set using the ESRI ArcInfo 9.3 raster calculator,[2] creating a continuous grid of the probability (0 to 99%) of sandhill crane roost site occurrence for the entire study area. Results were assessed by overlaying the validation data set on the probability grid. All values greater than or equal to 70% probability were considered suitable sandhill crane roost sites and all values less than 70% probability were considered unsuitable.

Scenarios. A subset of the study area (Figure 3), adjacent to the Audubon Society's Rowe Sanctuary (see Figure 1), was selected to explore scenarios of contraction or expansion of the geographic range of common reed within the central Platte River. Rowe Sanctuary is a hub of sandhill crane activity during spring migration. Although several invasive plants are present in the central Platte River, at the time of this study common reed was an invasive plant of emerging and special concern as indicated by its recent placement on Nebraska's noxious weed list. It was, therefore, the focus for the forecasting simulations.

Contraction of common reed was simulated by removing a uniform 10-m buffer from the edge of each patch of existing common reed. This process was repeated at 10-m intervals to 80 m. After each of the scenario iterations, the hectares of sandhill crane roosting habitat were calculated using the discrete choice model, with all values greater than or equal to 70% probability being considered suitable habitat. The change in area of sandhill crane habitat was recorded after each interval. The change in percentage of sandhill crane roosting habitat was then calculated for each interval of the simulation.

Simulation of common reed expansion followed a similar process. The expansion was simulated by adding a uniform 10-m buffer to the edge of each patch of common reed. The areas in which common reed could expand were limited to unvegetated sandbars and early successional river, creating a conservative estimate. This process was repeated at 10-m intervals to a limit of 80 m. After each of the iterations, the area of sandhill crane roosting habitat was calculated using the discrete choice model, with all values greater than or equal to 70% probability being considered suitable habitat. The change in area of sandhill crane habitat was recorded after each interval. The change in percentage of sandhill crane roosting habitat was then calculated for each interval of the simulations (Figure 4).

Results and Discussion

Discrete Choice Modeling. Discrete choice modeling indicated that proximity to major roads, minor roads, rural developments, purple loosestrife, riparian woodland, riparian shrubland, river channel, early successional river, and sandbars all had a significant impact on the probability of sandhill crane roosting occurrence (Table 4). Additionally, unvegetated sandbar, river channel, and wet meadow

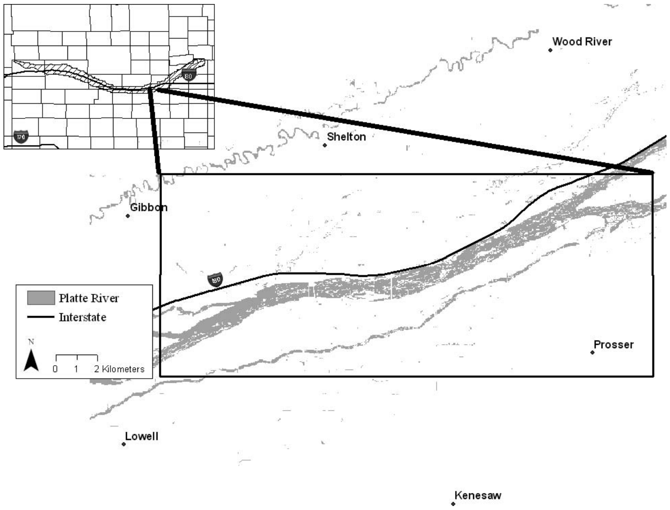

Figure 3. The study area for the simulated expansion and contraction of common reed (see "Invasive Scenarios"). The portion of the Platte River, Nebraska, immediately south of Interstate 80 within the black rectangular box was used for the forecasting simulations.

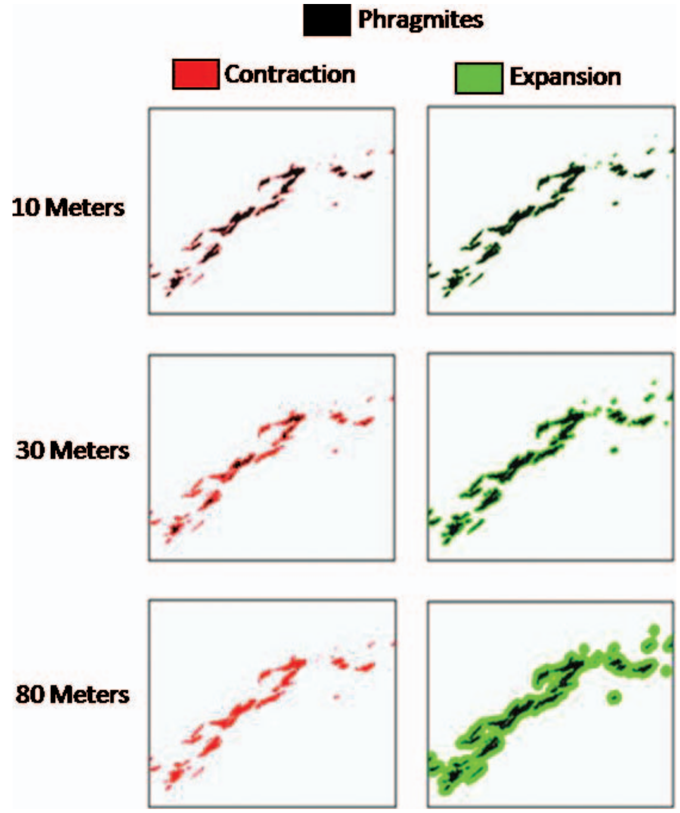

Figure 4. Simulated contraction (left, in red) and expansion (right, in green) of common reed at the invasive scenarios study area, near Audubon's Rowe Sanctuary along the Platte River. The black polygons represent the current extent of common reed, and colors show contraction or expansion by 10, 30, and 80 m yr^{-1}. A color version of this figure is available in the online journal.

patch sizes were also significant. The log-likelihood of the null model equaled 1,834 (all coefficients equal to zero), whereas the log-likelihood of the final model equaled 524. The log-likelihood ratio test for the final model, as compared to the null model equaled 1,310, which is chi-square distributed ($df = 12$, $P < 0.001$) indicating a highly significant model. The AIC score of the final selected model was 549.9; this was the lowest AIC score of all models tested.

The modeling results indicate that different kinds of vegetation have varying levels of impact on the likelihood of sandhill crane occurrence; however, the probability of occurrence of cranes increased with distance from all types of vegetation tested. The model indicated that the probability of sandhill crane occurrence increased the most with distance from riparian shrubland. A recent study found that the invasive shrub saltcedar (*Tamarix* sp.) was found frequently in the western portion of the Platte River in Nebraska (Hoffman et al. 2008). If the distribution of salt cedar continues to expand in the central Platte River, the results of this study suggest that the availability of sandhill crane roosting habitat would decline significantly. There was also a strong decline in the likelihood of sandhill crane occurrence as distance from the active river channel and unvegetated sandbars increased. This reinforces the suggestion that as the distribution of invasive plants increases, the quantity and quality of sandhill crane roosting habitat would decline. Such observations may be helpful to natural resources managers seeking to control invasives in order to increase the availability of sandhill crane roosting habitat.

The accuracy of the model prediction was 88.4%. The user's accuracy (errors of commission) for suitable roosting sites (presence) was 73.9% and the user's accuracy for unsuitable roosting sites (absence) was 98.3%. The producer's accuracy (errors of omission) for suitable roosting sites and unsuitable roosting sites scored 96.8 and 84.7% respectively. User accuracy is the probability that an area predicted as suitable habitat would actually serve as suitable roosting habitat in the field, whereas the producer accuracy is the probability that an area of known roosting habitat is correctly identified as suitable roosting habitat. The results of the accuracy assessment indicate that the model performed well in predicting the occurrence of sandhill crane roosting within the study area. As depicted in the map (Figure 5), wider river channels had a higher probability of roosting occurrence, and the narrower channels had a lower probability of roosting occurrence. The model also successfully predicted a lower probability of roost site occurrence as the river approached major roads. Although the results are promising, the discrete choice model would likely be improved by incorporating

Table 4. Output for the final discrete choice model for sandhill crane roost sites.

Variables	Coefficient	SE	Wald	df	P	Odds ratio
Proximity to						
Major roads	0.0005	< 0.01	12.405	1	< 0.01	1.001
Minor roads	0.0012	< 0.01	11.875	1	< 0.01	1.001
Rural developments	0.0013	< 0.01	11.621	1	< 0.01	1.001
Purple loosestrife	0.002	< 0.01	32.512	1	< 0.01	1.000
Riparian woodland	0.006	< 0.01	47.460	1	< 0.01	1.006
Riparian shrubland	0.008	< 0.01	22.414	1	< 0.01	1.008
River channel	−0.008	< 0.01	10.295	1	0.09	0.992
Early successional river	−0.004	< 0.01	36.855	1	< 0.01	0.996
Unvegetated sandbars	−0.004	< 0.01	3.381	1	0.07	0.996
Patch size						
Unvegetated sandbar	0.0002	< 0.01	5.768	1	< 0.01	1.000
River channel	0.0007	< 0.01	77.157	1	< 0.01	1.001
Wet meadow	0.00001	< 0.01	37.337	1	< 0.01	0.999

additional years of observations and a validation data set collected independently of the data used to fit the model. Furthermore, field measurements for predictor variables taken at the time of sandhill crane roosting observations could reduce the possibility of errors arising from the temporal difference between the 2005 land cover data and the sandhill crane roost site observations.

Invasive Scenarios. Under conditions of maximum contraction, the model forecast that the area of sandhill crane roosting habitat would increase by 55% (Figure 6). There was an initial spike in the percentage of increase of available roosting habitat; however, the increasing availability of habitat began to plateau by the 30-m buffer distance. As the area of common reed expanded to the maximum forecasted distance the area of sandhill crane roosting habitat decreased by 250%. The common reed expansion simulation illustrates a precipitous drop in the availability of sandhill crane roosting habitat as the simulated expansion of common reed increases. This forecast predicts that even a slight expansion of common reed could drastically reduce the occurrence of roost site

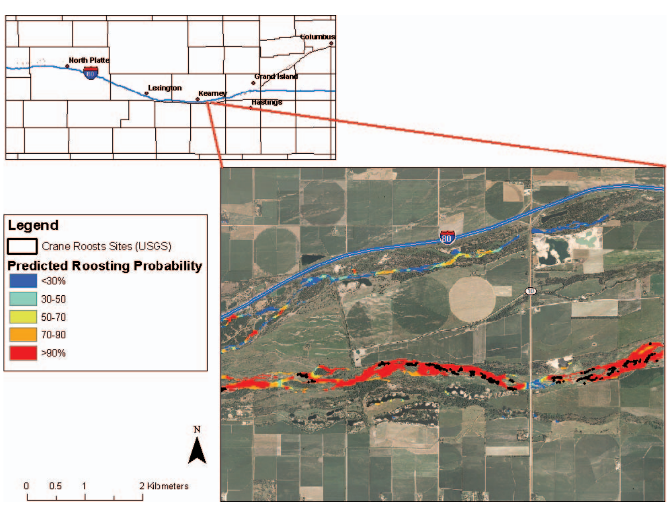

Figure 5. Predicted roosting probability for sandhill cranes derived from the final discrete choice model. Black polygons indicate crane roost sites used to validate the performance of the model. A color version of this figure is available in the online journal.

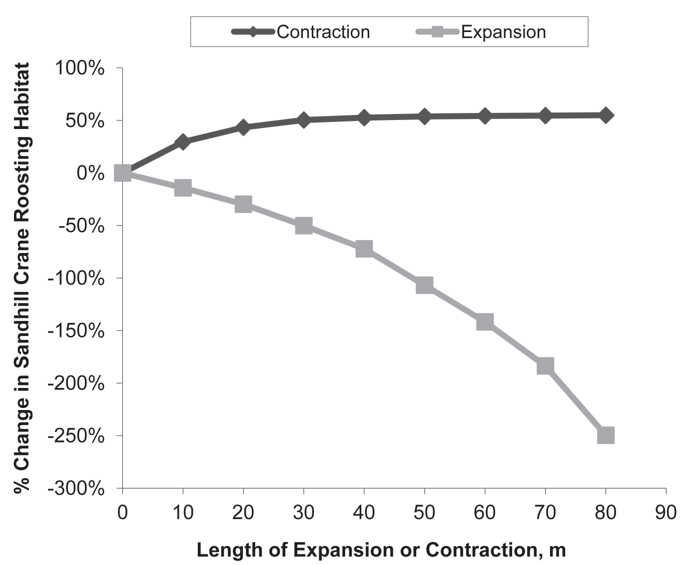

Figure 6. Results of the common reed expansion and contraction simulations showing the impact on sandhill crane habitat as a percentage of change in area. The grey line represents the percentage of change in area under an expansion of common reed, and the black line represents the percentage of change in area under a contraction of common reed.

habitat, whereas a reduction in the distribution and abundance may not significantly increase the availability of sandhill crane roosting habitat. Wilcox et al. (2003) found that nonnative common reed could expand exponentially within short time periods in Lake Erie, Ontario, Canada. If this trend occurs in the central Platte River, the results of the forecasting scenarios indicate that the availability of sandhill crane roosting habitat could be severely reduced.

Research has shown that the spread and establishment of common reed in riparian ecosystems is highly dependent on hydrological factors (Hudon et al. 2005). The forecasting simulations used in this study assumed a uniform rate of spread and did not account for variations in flow. More reliable forecasting simulations could likely be developed if the factors controlling common reed spread in the central Platte River were identified and incorporated into the simulation. Furthermore, developing methods to predict the likelihood that an invasive plant could spread in concert with models that identify suitable habitat for native species could aid in identifying areas to target control efforts.

These findings indicate that an increase in the distribution of common reed could have deleterious impacts on the availability of suitable sandhill crane roosting habitat in the central Platte River, Nebraska. This investigation found strong evidence that discrete choice modeling could be used for forecasting the implications that change in distribution of invasive plants may have on native fauna. Forecasting could be expanded to evaluate additional invasive plant species to help prioritize their management. Information generated by forecasting efforts could have direct impacts on management and policy for invasive plant control projects.

Sources of Materials

[1] SPSS statistical software, Chicago, IL.
[2] ESRI, Redlands, CA.

Acknowledgments

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