ASSESSING SPATIAL PATTERNS OF GREATER SANDHILL CRANE NESTING HABITAT USING GIS AND REMOTE SENSING

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This is to certify that I have examined this bound copy of a master's thesis by

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and have found that it is complete and satisfactory in all respects,
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examining committee have been made.

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PREFACE

This research attempted to characterize greater sandhill crane nesting habitat at a landscape level. I assumed that a working landscape model could be used to identify and determine the extent of potential nesting habitat in northwestern Minnesota. Combining a GIS with a digital map of plant communities derived from satellite data provided a means for characterizing potential nesting habitat according to landscape features. During the course of developing the GIS model, my ability to describe nest sites depended on available data and feasible modeling techniques. The emphasis of my thesis is to demonstrate how conditions and assumptions concerning data and modeling approaches can affect the interpretations of an analysis.

I begin by recounting the generation of the data layers, the formulation of the modeling approach, and the results of the Landsat classification and GIS model. The discussion section details the conditions and subsequent assumptions of the data and modeling approach and analyzes how these affected the results of the model. In conclusion, I summarize the fundamental issues of the modeling approach and make recommendations for future studies.

ABSTRACT

The goal of this research was to develop a descriptive GIS model to identify potential nesting habitat of greater sandhill cranes in northwestern Minnesota. To accomplish this goal, three objectives were met. The necessary data layers for the model, including a vegetation map classified from Landsat TM data, were produced. Twenty-two known nest sites were characterized with a raster-based GIS. Using the descriptive model, potential nesting habitat within a test area was identified to verify the applicability of the model to known locations of 10 additional nest sites.

The modeling approach involved 5 fundamental steps: generating the data layers, describing nest sites, testing for discrepancies between the observed and expected distributions of nest sites, generating the model, and assessing the model with additional nest sites. Using the vegetation map derived from the satellite classification, the study area was divided into potentially suitable and unsuitable nesting vegetation. Six additional habitat variables associated with 22 nest sites were measured with a raster GIS. Each of the 6 variables was divided into 3 or 4 zones of influence which represented different levels of suitability for nesting cranes. Chi square analyses were conducted to quantify the importance of each habitat feature. Based on the results from the chi square tests, potential nesting vegetation was categorized as optimal, sub-optimal, marginal, or unsuitable habitat for nesting according to specific combinations of variables. The model was projected onto a test area, and results were used to verify the applicability of the model to known locations of 10 additional nest sites.

Results of the model throughout the study area indicated that some pairs nested in sub-optimal and marginal areas despite the apparent availability of optimal habitat. The absence of nesting pairs in optimal habitat may be accounted for by conditions and assumptions inherent in the data and modeling approach, unanswered questions concerning the behavior of nesting cranes, the uncertainty that all nest sites in the study area were known, and the inability to model or detect certain landscape features and local parameters. A fundamental outcome derived from the nesting habitat model was

an understanding of the assumptions and limitations that are inherent in such modeling approaches.

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INTRODUCTION

Historically greater sandhill cranes (*Grus canadensis tabida*) commonly nested in wetlands south and west of Minnesota's band of deciduous forest (Roberts 1932). Hunting, loss of habitat and the drought of the 1930's reduced the state population to less than 25 pairs by the mid 1940's (Johnson 1976a, Walkinshaw 1949). Today two recovering populations in the northwest corner and central region of the state exist. Although the most recent estimate of the northwestern population was between 760-1160 pairs (Tacha and Tacha 1985), the sandhill crane is listed as a special concern species in Minnesota because wetlands are vulnerable to fragmentation and drainage (Coffin and Pfannmuller 1988).

Cranes typically nest in shallow emergent wetlands that are relatively isolated from human disturbances. Nesting marshes are commonly saturated or seasonally to permanently flooded (Armbruster 1987), but in dry years cranes may nest in dry marshes. While cranes often forage in crop lands and pastures (Hoffman 1976; Johnson 1976b; Bennett 1978; Henderson 1978a, 1978b, 1979), nest sites are generally isolated from frequent human disturbances. Distances from active nests to regular human activities vary considerably depending upon the degree of development in the area and the density of the local crane population (Johnson 1976b, Bennett 1978, Carlisle 1981, Hoffman 1983).

Within the Great Lakes region, cranes are known to nest in cattails, bulrush and phragmites (Walkinshaw 1965, Howard 1977, Melvin 1990, DiMatteo 1991, Provost 1991), sedge marshes, and sphagnum bogs (Walkinshaw 1978, Taylor 1976, Roth 1984, Urbanek 1988, Melvin 1990). Usually, tall, dense vegetation such as phragmites (Johnson 1976b), cattails (Walkinshaw 1965), and occasionally shrubs (Walkinshaw 1978, Carlisle 1981) conceal nest sites. However, marshes with 50% or greater shrub cover are generally avoided by nesting pairs (DiMatteo 1990).

Recent surveys in northwestern Minnesota (DiMatteo 1991, Maxson 1991, Provost 1991) have analyzed local habitat variables associated with crane nests, but little research has been conducted to characterize landscape features that influence the distribution of nest sites. Many studies have applied remote sensing technologies and geographic information systems to assess wildlife habitat on a regional scale. Satellite data has been digitally classified to map wetlands (Hodgson et al. 1987) and upland habitats (Lyon 1983, Ormsby and Lunetta 1987, Miller 1990), and GIS has been used to identify (Lyon 1983), monitor (Hodgson et al. 1988), and characterize habitats (Scepan et al. 1987, Stoms et al. 1990, Gagliuso 1991). Techniques such as GAP analysis have been developed to identify important areas for biodiversity (Davis et al. 1990) and species richness (Scott et al. 1987, Miller et al. 1989). Studies have documented, however, that the ability to model wildlife habitat depends on a number of conditions concerning data, modeling techniques, and sensitivity analyses (Lyon 1983, Miller et al. 1989, Stoms et al. 1990).

Goal and objectives

Combining a GIS with a digital map of plant communities derived from satellite data provides a means for characterizing potential nesting habitat according to landscape features. The goal of this research was to develop a descriptive GIS model to identify potential nesting habitat of sandhill cranes in northwestern Minnesota. To accomplish this goal, three objectives were met. The necessary data layers for the model, including a vegetation map classified from Landsat TM data, were produced. Twenty-two known nest sites were characterized with a raster-based GIS. Using the descriptive model, potential nesting habitat within a test area was identified to verify the applicability of the model to known locations of 10 additional nest sites.

Study area

The study area was comprised of four townships in northwestern Minnesota which were located in the transitional zone between the northern forest region to the east of Bemis Ridge and prairie and Aspen parkland to the west. Plant communities were comprised of gradients from open sedge fens and meadows to willow swamps and aspen stands. Large conifer stands were primarily to the east in the northern forest region. Much of the region has been affected by extensive drainage systems or fires (Aaseng 1991). The Landsat classification estimated that the extent of agricultural land ranged between 35% to 60% in the townships. No towns were present within the four townships, but the distribution of farmsteads and residences varied throughout the area. Paved roads were uncommon; most roads were either gravel or dirt.

METHODS

A raster-based GIS (Star and Estes 1990) was used as the framework for the model. All the data layers were formatted as 30-m wide, square pixels to be compatible with the original spatial resolution of the Landsat TM data. Consequently, nest sites and building locations were generalized to 30-m cells and all distance measurements were calculated in 30-m intervals.

Generating data layers

Landsat TM data were classified to obtain a synoptic coverage of plant communities important to the nesting biology of cranes. The nine target information classes were derived from the classification system of the Minnesota Natural Heritage Program and included emergent wetlands, sedge fens, shrub fens, shrub swamps, deciduous forests, coniferous forests, agricultural land, disturbed grasslands, and open water. Emergent wetlands, sedge fens,and shrub fens were considered potentially suitable nesting vegetation, while shrub swamps, deciduous forests, and coniferous forests were categorized as woody vegetation unsuitable for nesting. Classes which were categorized as potential nesting vegetation contained shallow wetlands primarily composed of cattails, bulrush, phragmites, sedge, and/or scattered shrubs (Appendix A), all of which are commonly used by nesting cranes in the Great Lakes region (Walkinshaw 1965, Howard 1977, Urbanek 1988, Melvin 1990, DiMatteo 1991, Provost 1991).

Only a single scene from September, 1987 was available for this project. Landsat data were geometrically rectified to UTM zone 15 and classified using a hybrid approach (Campbell 1987, Lillesand and Kiefer 1987). Two unsupervised passes using TM bands 2, 3, 4, and 5 were performed to separate large areas of agricultural land and open water from other cover types. During each pass the classifier automatically generated statistics for 20 spectral classes. Classes which corresponded to agricultural land and water were removed from further consideration and stored in a separate GIS file.

The remaining areas were classified using a supervised approach. Training sites were used to generate statistics for each desired information class (Campbell 1987, Lillesand and Kiefer 1987). Means and standard deviations were calculated for all but the thermal TM band. Each training site had to consist of at least 30 pixels and was rejected if the standard deviation of any band was too high. Standard deviations greater than 1.5 were accepted only if training sites were difficult to acquire for a particular information class. A series of six supervised classifications were conducted to distinguish nine information classes. Results from all the passes were combined, and a low pass filter was run to smooth the classes.

An accuracy assessment was performed using reference polygons that represented overall class proportions (Campbell 1987). UTM coordinates of the center of each polygon were measured, and classes of the corresponding pixel plus the 8 adjacent pixels were recorded. The 8 adjacent pixels were considered to eliminate possible skewed results from isolated pixels. To summarize the accuracy assessment, an error matrix was compiled and errors of omission and commission and the percent of correctly classified pixels were calculated (Campbell 1987).

Digital Line Graph files of road networks were converted to raster format (Star and Estes 1990) and updated according to field notes. The road files contained paved highways, light duty gravel roads that were easily drivable during a wet spring, and unimproved dirt roads which were not easily passable in wet conditions. Building locations plotted on USGS 7.5 minute topographic maps were confirmed during field surveys and later digitized. Aerial and subsequent ground surveys of the study area were conducted during the nesting season to locate active crane nests within the study area. Nest sites were plotted on topographic maps and digitized as 30-m cells.

Describing nest sites

The vegetation map of each township was divided into potentially suitable and unsuitable nesting vegetation. Six additional habitat features associated with the 22 nest sites were measured using a raster GIS (Appendix B). Distances from each nest site to the nearest paved highway, light duty road, unimproved road, building, and mapped agricultural land were calculated. While several of the nest sites were directly adjacent to agricultural land, in each case, undisturbed vegetation was present in all other directions. None of the nest sites was located in small pockets of vegetation surrounded by possible disturbances or in narrow bands of vegetation jutting into an agricultural field or separating an agricultural field from a road or building. Consequently, cranes were assumed to select sites near agricultural land only if an area of undisturbed vegetation was wide enough to buffer disturbances.

With this in mind, a procedure was developed to measure the width of the undisturbed vegetation associated with a nest site. All pixels labeled as agriculture and within an unacceptable distance from buildings or roads were combined into a disturbance class. A series of concentric rings at 30-m intervals was generated from all edges of the disturbed class into the remaining undisturbed areas. Using the 30-m intervals, the width of the undisturbed buffer was calculated. Henceforth, this habitat variable will be referred to as the width of the undisturbed buffer.

The six measured variables were divided into three or four zones of influence representing different degrees of suitability for nesting pairs. Distances delineating the zones of influence were selected using calculations from the 22 nest sites, observations of other nests in the region not included in the GIS, and intuitive reasoning. The zones of influence were labeled 0, 1, 2, and 3. Zero zones were assumed to represent unacceptable levels of human disturbance. For all variables, zones 1, 2, and 3 indicated increasingly desirable regions (Table 1).

The width of an unsuitable zone associated with a road or building was estimated according to the nearest distance to a known nest. If all known nests were far

Table 1: The zones of influence for the six habitat variables.

VARIABLE	ZONES OF INFLUENCE (in meters)			
	0	1	2	3
Width of Undisturbed Buffer	0-180	181-360	>360	
Distance to Highway	0-390	391-780	781-1590	>1590
Distance to Light Duty Road	0-90	91-180	181-600	>600
Distance to Unimproved Road	0-30	31-90	91-180	>180
Distance to Buildings	0-390	390-780	781-1200	>1200
Distance to Agricultural Land	0	>600	120-600	1-120

from a considered variable, a conservative minimum acceptable distance was estimated to prevent eliminating too much area as potential nesting habitat. Beyond a certain distance, disturbances were assumed to have no impact on nesting cranes. These distances were selected to ensure that most of the 22 known nest sites were located in optimal zones. Familiarity with the study area acquired during field surveys was used to reasonably estimate appropriate distances. A similar method was used to estimate zones of influence associated with the width of an undisturbed buffer.

Two variables were needed to demonstrate positive and negative aspects associated with proximity to agricultural lands. Because cranes often forage in cultivated fields and pastures, distance to agricultural land indicated that close proximity to agriculture may be beneficial. Width of the undisturbed buffer, which excluded agricultural land and unacceptable distances to roads and buildings, demonstrated that human activities in agricultural fields may inhibit cranes from nesting nearby if the adjacent section of undisturbed vegetation was too narrow.

Statistical analysis

Chi square analyses were calculated to determine whether discrepancies existed between the observed and expected distributions of crane nests in relation to the width of the undisturbed buffer, distance to nearest building, distance to agricultural land, and distance to nearest road. For each variable, the expected distribution of nests was based on the proportions of potentially suitable nesting vegetation within each zone of influence.

Preliminary chi square analyses were performed separately on distances to nearest paved highway, light duty road, and unimproved road. Results indicated that none of the three road types by themselves strongly influenced the distribution of crane nests. However, because these three variables were not independent, the network of the three road types was suspected of influencing the selection of nest sites by breeding pairs. To run a chi square analysis on the influence of the road network, three GIS files each containing zones of influence from different road types were combined into a single file. Each pixel in the new file was assigned to one zone of influence (0, 1, 2, or 3) which equaled that pixel's lowest zone of influence from any of the three road types.

Generating the model

Width of an undisturbed buffer, distance to roads, and distance to buildings were used to categorize potentially suitable nesting vegetation as potentially optimal, sub-optimal, marginal, or unsuitable habitat for nesting. These four categories strictly represent an ordinal relationship and are not meant to confer any additional information. If a pixel was within the zero zone of any of the three variables, it was classified as an unsuitable disturbance. Excluding the zero zones, eighteen combinations of zones of influence were possible. For each of these combinations, the level of optimization was determined by the significance of the variables and by assumptions about crane behavior.

All locations unaffected by roads and buildings were considered potentially optimal habitat. Sites in wide undisturbed areas, within zone 3 from roads but within zone 2 from buildings were also regarded as optimal because the presence of buildings did not significantly hinder nesting pairs. Potentially sub-optimal habitat was characterized as wide undisturbed regions within zones 1 and 2 from roads and/or zone 1 from buildings, or as narrow bands of undisturbed vegetation within zone 3 from roads and zone 2 from buildings. Narrow bands of undisturbed land within zones 1 or 2 from roads and/or zone 1 from buildings were categorized as potentially marginal habitat. Distance to roads refers to zones of influence associated with the entire road network that were generated for the chi square analysis.

Testing the model

Using the descriptive model, potential nesting habitat was identified and classified in a test area to verify the applicability of the model to known locations of 10 additional nest sites. At 5 of these nests, cranes were seen incubating eggs, but the status of the other nests remained undetermined because no cranes or traces of eggs were observed at the nest sites. While no evidence was found that a nest had been used, a pair obviously invested time and energy into building the nest. Furthermore, all of the 10 nest sites were located in similar habitat, and 4 of the 5 nests with undetermined status were found in areas isolated from human disturbance. For these reasons, no distinction was made between active nests and those of undetermined status.

RESULTS

Accuracy assessment of satellite classification

Although the accuracy assessment estimated that 81% of the satellite image was correctly classified, errors of omission and commission were high for some of the information classes (Table 2). Errors of omission for disturbed grass, shrub fen, shrub swamp, and deciduous forest were 47, 38, 39, and 30%, resulting in class accuracies of 53, 62, 61, and 70%, respectively. However, 82% of the pixels omitted from shrub fen were classified as sedge fen, both of which were considered potential nesting vegetation. Errors of commission for sedge fen, shrub fen, disturbed grass, and shrub swamp were 36, 46, 61, and 37%, respectively. Approximately 60% of the pixels misclassified as sedge fen corresponded to shrub fens, 82% of the pixels incorrectly labeled as disturbed grass were from agricultural land, and 66% of the pixels misclassified as shrub swamp were deciduous forest. Of the pixels misclassified as shrub fen, 38% were shrub swamp and 31% were agriculture. The errors of omission and commission for the remaining classes were under 15% (Table 3).

Chi square analysis

The results of the chi square tests indicated that the width of an undisturbed buffer and distance to nearest road significantly affected the distribution of the 22 known nest sites. However, distance to buildings and distance to agriculture were not significant. The p-values corresponding to the width of an undisturbed buffer, distance to roads, distance to buildings, and distance to agriculture were 0.005, 0.025, 0.146, and 0.647, respectively (Table 4).

Table 2: Errors of omission and commission and the percent of correctly classified pixels for each class and for the entire image.

CLASS	ERRORS OF OMISSION	ERRORS OF COMMISSION	CORRECT CLASSIFICATION
Emergent Wetland	0/45=0	7/52=0.14	45/45=1.0
Sedge Fen	5/90=0.06	47/132=0.36	5/90=0.94
Shrub Fen	34/90=0.38	48/140=0.46	56/90=0.62
Shrub Swamp	32/81=0.39	29/78=0.37	49/81=0.61
Deciduous Forest	27/90=0.3	9/72=0.12	63/90=0.7
Coniferous Forest	4/63=0.06	0/59=0	59/63=0.94
Agriculture	64/450=0.14	9/395=0.02	386/450=0.86
Disturbed Grass	21/45=0.47	38/62=0.61	24/45=0.53
Water	0/36=0	0/36=0	36/36=1.0
OVERALL	187/990=0.19	187/990=0.19	803/990=0.81

Table 3: Error matrix summarizing specific errors of omission (by row) and commission (by column) for the nine information classes, where A = emergent wetlands, B = sedge fens, C = shrub fens, D = shrub swamp, E = deciduous forest, F = coniferous forest, G = agricultural land, H = disturbed grass, and I = water.

Reference				Satelitte Classification						
Data	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**Total**
A	**45**	0	0	0	0	0	0	0	0	**45**
B	0	**85**	3	0	0	0	0	2	0	**90**
C	4	28	**56**	1	0	0	0	1	0	**90**
D	0	5	18	**49**	5	0	0	4	0	**81**
E	0	0	8	19	**63**	0	0	0	0	**90**
F	1	0	0	3	0	**59**	0	0	0	**63**
G	2	6	15	6	4	0	**386**	31	0	**450**
H	0	8	4	0	0	0	9	**24**	0	**45**
I	0	0	0	0	0	0	0	0	**36**	**36**
Total	**52**	**132**	**104**	**78**	**72**	**59**	**395**	**62**	**36**	**990**

Table 4: Results of the chi square analyses, where % of PSNV = the percent of potentially suitable nesting vegetation within the zones of influence for each variable.

Variables Zones of Influence	% of PSNV	Observed # Nests	Expected # Nests	X^2	P- Value
Width of Undisturbed Buffer				10.424	0.0054
0	19.39	0	4.2658		
1	12.76	0	2.8072		
2	67.85	22	14.927		
Distance to Roads				9.3239	0.0253
0	10.52	0	2.3144		
1	13.56	1	2.9832		
2	33.80	5	7.4360		
3	42.12	16	9.2664		
Distance to Buildings				5.3852	0.1457
0	5.40	0	1.1880		
1	16.88	4	3.7378		
2	25.71	2	5.6562		
3	52.01	16	11.4420		
Distance to Agriculture				0.8717	0.6467
1	3.81	0	0.8380		
2	47.94	11	10.5470		
3	48.25	11	10.6150		

Results of the model

Potentially suitable nesting vegetation was categorized as potentially optimal, sub-optimal, marginal, or unsuitable habitat for nesting. Of the 22 nest sites used to develop the model, 13 were in optimal habitat and 9 were in sub-optimal habitat. In the test area, 6 nest sites were in optimal habitat, 1 was in sub-optimal habitat, and 3 were in marginal habitat (Table 5). The area used to develop the model was comprised of 19.8% potentially suitable nesting vegetation, 59.6% agriculture, and 20.6% vegetation unsuitable for nesting. The composition of the test area was 28.4% potentially suitable nesting vegetation, 38.3% agriculture, and 33.3% vegetation unsuitable for nesting. Vegetation that was unsuitable for nesting included disturbed grass, shrub swamp, deciduous forest, and coniferous forest.

Table 5: Distribution of nest sites and potentially suitable nesting vegetation, where % PSNV = percent of potentially suitable nesting vegetation.

HABITAT	DEVELOPMENT AREA		TEST AREA	
	% of PSNV	# Nests	% of PSNV	# Nests
Optimal Habitat	33.3	13	40.0	6
Suboptimal Habitat	38.4	9	26.2	1
Marginal Habitat	8.9	0	9.4	3
Unsuitable Disturbance	19.4	0	24.4	0

DISCUSSION

Data layers

The objective of classifying Landsat data was to acquire a synoptic digital map of nine information classes over a large area. Difficulties with the classification occurred because of the natural heterogeneity of the plant communities and common vegetation gradients. The spatial complexity of the region and the poor relationship between target classes and single-date spectral data resulted in important limitations in the vegetation map.

Because the mapped classes represented heterogeneous plant communities and lacked a high level of spatial detail, small wetland basins and other small stands of vegetation were not delineated. Also, distinctions between classes were not always accurate. Errors of omission and commission estimated the levels of overlap between different mapped information classes. While confusion existed between sedge fens and shrub fens, the model was unaffected because both classes were considered as potential nesting vegetation. In some locations, however, vegetation which was unsuitable for nesting was misclassified as sedge fen or shrub fen, resulting in an overestimation of potentially suitable nesting vegetation.

Physical boundaries between vegetation classes were not precisely and accurately delineated. As a result, communities were not mapped as finite, discreet units. Neither the size nor the shape of plant communities was definitive on the cover type map, and therefore, the area and width of a particular community could not be accurately measured. Without distinct boundaries, habitat could not be reliably labeled as edge or interior and the composition of plant communities within a given area could not be characterized precisely.

Problems with the satellite classification resulted in fundamental assumptions about the vegetation classes. Only areas classified as emergent wetlands, sedge fens, and shrub fens were assumed to consist of substantial stands of potentially suitable nesting vegetation. These three classes provided the best available indication of the presence of wetlands. Accurate, independent information on wetland locations was not available. State files were highly generalized and the National Wetlands Inventory data were not yet completed for the study area. In addition, all classes except open water were known to contain sites with screening vegetation that could conceal a nest site from a road, building, or agricultural field. Disturbed grass, which was not considered heavily managed, was assumed to have no adverse impact on cranes. Finally, all agricultural land was presumed to exhibit the same degree of human disturbance and to provide equal foraging opportunities for cranes.

Assumptions about the frequencies and levels of human disturbances were also implicit in the data. All buildings were assumed to exhibit equal levels of disturbance for cranes. Similarly, all roads of a particular class were speculated to have the same level of disturbance based on the expected frequency and type of use during wet conditions. Thus, the final assessment of nesting habitat may have included more areas as potentially suitable than if marginal roads had been deemed to be dry and easily passable.

Describing nest sites

Modeling techniques used to describe nest sites were based on previously discussed conditions and assumptions about the data and modeling approach and on assumptions about the behavior of nesting pairs. The idea that the width of an undisturbed buffer influenced nesting pairs arose because none of the observed nest sites were isolated in small pockets or narrow bands of undisturbed vegetation and because areas of undisturbed vegetation were somewhat amorphous. The zones of influence associated with each variable were based on assumptions about how cranes responded to human disturbances and about the levels of disturbance associated with the buildings and roads within the study area.

Feasible modeling techniques were also determined by raster data limitations.

Interpreting spatial patterns in the vegetation map was difficult because the small cell size of the map resulted in high spatial texture. Problems also occurred because the raster data were formatted as square pixels. All distance measurements were assumed to be in equal increments although the diagonal was longer than the side of a pixel. Locations of point data, such as nest sites or building locations, were generalized to 30-m blocks, which also affected the accuracy of distance calculations.

Statistical Analysis

Both the width of the undisturbed buffer and distance to roads significantly influenced the observed distribution of 22 nest sites. These results partially support the HSI model developed by Armbruster (1987) who claimed that the size of a disturbance-free area and proximity to roads influenced where sandhill cranes nested. Armbruster (1987) used a 100-m buffer from all existing and proposed roadways, but encouraged potential users of the HSI model to modify the width of the zone of influence around roadways if deemed appropriate. The zones of influence associated with the 3 types of roads within the study area were adjusted to account for different levels of use under wet conditions.

The size of an area could not be reliably calculated from the vegetation map. Areas of undisturbed vegetation were somewhat amorphous because neither the size nor the shape of plant communities were definitively mapped. Consequently, areal estimations depended on the connectivity of pixels from vegetation boundaries that were not always accurate or precise. The width of an undisturbed buffer was used to eliminate small, isolated pockets and narrow bands of undisturbed vegetation from further consideration as potential nesting habitat.

Although distance to buildings was not significant, this variable was included as a minor component in the model because of patterns observed in the study area, the inability to account for a combination of variables with the chi square analysis, and reports in the literature. A visual comparison of the observed and expected distributions of nests showed that pairs tended to select farther distances from buildings than what was expected. Furthermore, all the nest sites that were within zone 1 from a building were also within 480 m of a road in the opposite direction. The presence of roads, the distribution of potentially suitable nesting vegetation, or a combination of factors may have prevented pairs from nesting farther from the building. Additional variables that were excluded from the model may have also influenced nesting pairs. While all information classes were assumed to contain screening vegetation, tall, dense vegetation was not found everywhere in the study area. Pairs may have nested closer to buildings where screening vegetation was ample.

Reports in the literature suggest that cranes tend to avoid nesting near buildings. In areas which were fairly undeveloped, cranes were far from any human disturbance (Carlisle 1981). However, distances from nest sites to regular human activities varied considerably depending on the development in the area and the density of the local crane population. In Wisconsin, Hoffman (1983) observed that the distance from nest sites to buildings decreased as the crane population increased.

According to the chi square analysis, distance to agriculture was also not significant. This supports Halbeisen's (1980) thesis which reported no indication that pairs were selecting nest sites based on proximity to agricultural fields. This result, however, does not indicate that proximity to agriculture is never important. In regions where farms are not as interspersed with undisturbed land, cranes may tend to select areas that are closer to agricultural fields.

Testing the model

Results of the model throughout the study area indicated that some pairs nested in sub-optimal and marginal areas despite the apparent availability of optimal habitat. The absence of nesting pairs in optimal habitat may be accounted for by a number of plausible explanations. Obviously, conditions and assumptions inherent in the data and modeling approach may not always hold true. Areas classified as emergent wetlands, sedge fens, or shrub fens, for example, were shown not to be entirely composed of suitable nesting vegetation.

The model was also predicated on assumptions about crane behavior derived from the literature. Cranes nest in relatively open, shallow wetlands that typically contain screening vegetation such as tall emergents or scattered shrubs (Roberts 1932, Walkinshaw 1965, Johnson 1976b, Carlisle 1981, Provost 1991). Consequently, the model considered only those information classes which were assumed to contain relatively open, shallow wetlands with screening vegetation as potentially suitable nesting vegetation. The size of the wetland was not deemed important in the model because nesting marshes may range from small, isolated wetlands within a larger complex of undisturbed plant communities to large, homogeneous marshes (Howard 1977, Bennett 1978). Historically, cranes have nested in expansive, isolated areas (Walkinshaw 1949), and therefore, wider undisturbed areas were considered more desirable than smaller or narrower patches of undisturbed vegetation. Furthermore, the proximity of a nest site to regular human activities has been considered to be a function of the availability of quality habitat, the density of the local crane population, and the levels of human development (Bennett 1978, Hoffman 1983). The likelihood of finding nesting pairs was presumed to increase as the distance to human disturbances increased. These generalized assumptions about crane behavior may not apply to all nesting pairs.

Additional questions about the behavior of breeding cranes may provide plausible explanations for why some pairs did not nest in potentially optimal areas. Nesting cranes are territorial (Johnsgard 1983). Established pairs may have prevented others from nesting within their vicinity despite the availability of optimal habitat. When young pairs first attempt to nest, they do not always select good nesting sites. Typically cranes begin nesting at three years of age but often do not successfully rear young until they are about seven or eight years old (Tacha et al. 1989). While first time breeders may not select prime habitat, established pairs usually return to the same nesting marsh in subsequent years (Walkinshaw 1949). Optimal habitat that did not contain a nest during the surveys may have been used by cranes in the past. When pairs currently

CONCLUSION

Results of the model indicated that some pairs nested in sub-optimal and marginal areas despite the apparent availability of optimal habitat. The absence of nesting pairs in optimal habitat may be accounted for by conditions and assumptions inherent in the data and modeling approach, unanswered questions concerning the behavior of nesting cranes, the uncertainty that all nest sites in the study area were known, and the inability to model or detect certain landscape features and local parameters. These explanations reflect fundamental issues and problems associated with assessing spatial patterns of wildlife habitat using a GIS and a satellite classification.

Several important issues are inherent in any attempt to digitally classify satellite data. Appropriate information classes must be defined *a priori* classifying a satellite image. Target classes should be discreet and succinctly defined and should not represent an ecological gradient that cannot be adequately delineated. Before synoptic classifications are attempted, tests should be run to determine whether desired information types are attainable. In heterogeneous areas, the spatial complexity of the vegetation may be too great to map single communities. Also, if desired information classes are not spectrally unique, the classifier will not adequately discriminate among classes. Rather than training the classifier on inappropriate classes, either the target information groups should be redefined so that they correspond to distinct spectral properties or other sources of data should be acquired to map the study area. Multitemporal classifications, which require two or more satellite images, would likely improve the capability of identifying the spectral responses of information classes.

Conditions and assumptions implicit in the available data and modeling approach are fundamental to assessing spatial patterns of wildlife habitat. Recognizing assumptions about the data is important because the feasibility of different modeling techniques can be limited by data which are either generalized, unreliable, or unavailable. Assumptions about the biology and behavior of the target species can also

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APPENDICES

Appendix A: Descriptions of the nine information classes mapped from the satellite image.

Emergent Wetland	Emergent vegetation primarily including cattails (*Typha* spp.), bulrush (*Scripus* spp.), phragmites, and sedges (*Carex* spp.).
Sedge Fen	Open fields of sedges and/or grasses with small scattered shrubs (primarily *Salix* spp.). Shrubs were generally less than 1.5 m tall and covered a minor portion (<30%) of the community. Areas labeled as sedge fen may also contain small, scattered basins of emergent vegetation.
Shrub Fen	Mixture of grasses, sedge, and small (<1.5 m tall) shrubs (primarily *Salix* spp.) that cover 30-50% of the area. This class was quite heterogeneous with some areas being considerably more open than others. Small scattered emergent wetlands may also be found in this class.
Shrub Swamp	Taller (>1.5 m), denser shrubs that typically enclosed between 50-70% of the stand. Small trees may also be present.
Deciduous Forest	Taller, older trees with less canopy dominated by shrubs.
Coniferous Forest	Primarily treed but also included some areas dominated by coniferous shrubs.
Agriculture	A combination of cultivated fields, hay fields, CRP land, pasture, and miscellaneous disturbed areas such as farmsteads.
Disturbed Grass	A combination of grasslands, old fields, meadows, and some agricultural areas which were primarily CRP plots, hay fields, and pastures.
Open Water	

Appendix B: Habitat measurements calculated in meters with a raster GIS from the 22 known nest sites, where NEST ID = nest identification number, BUFFER = width of undisturbed buffer, HWY = distance to nearest highway, LD RD = distance to nearest light duty road, UN RD = distance to nearest unimproved road, BDG = distance to nearest building, and AGRIC = distance to agriculture.

NEST ID	BUFFER	HWY	LD RD	UN RD	BDG	AGRIC
14	930	3900	2040	450	1830	30
15	630	3030	1560	90	1020	30
16	1410	4410	2490	690	2430	420
17	1620	1380	1530	2130	1710	600
18	690	2220	720	450	600	270
22	510	2610	1140	330	660	360
52	1410	4200	1810	420	1770	90
53	690	2370	870	480	420	120
54	690	3150	2910	1140	2820	120
55	1620	2460	1440	240	990	270
56	1230	990	780	1620	1320	600
24	1050	3330	1500	330	1410	60
25	510	1140	660	480	690	30
26	1290	2670	1710	1110	1650	330
27	1290	3300	1140	1710	1620	120
28	390	4840	210	1170	1230	90
29	1290	2400	2370	1350	1770	210
30	690	2220	2790	510	1440	120

NEST ID	BUFFER	HWY	LD RD	UN RD	BDG	AGRIC
48	750	5760	930	1470	1470	120
49	1290	3240	1560	1110	1230	510
50	510	3090	1740	150	1500	180
51	870	1890	2940	210	1380	240
MEAN	970.9	2936.4	1583.6	801.8	1407.3	223.6
STD. DEV.	388.8	1181.5	764.9	584.9	568.5	178.5
MEDIAN	900.0	2220.0	930.0	330.0	1020.0	90.0