Crane Habitat Evaluation Using GIS and Remote Sensing

Abstract

The objective of this research was to develop a descriptive GIS model to identify potential nesting habitat of greater sandhill cranes in northwestern Minnesota. The modeling approach involved five fundamental steps: generating data layers, describing nest sites, testing for discrepancies between observed and expected distributions of nest sites, generating the model, and assessing the model. Results indicated that some crane 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 pertinent landscape features and local variables.

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 1930s reduced the state population to less than 25 pairs by the mid-1940s (Walkinshaw, 1949; Johnson, 1976a). 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 and 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). Although cranes often forage in crop lands and pastures (Hoffman, 1976; Johnson, 1976b; Bennett, 1978; Henderson, 1978; Henderson, 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 (Typha spp.), bulrush (Scirpus spp.), phragmites (Phragmites spp.) (Walkinshaw, 1965; Howard, 1977; Melvin *et al.*, 1990; Provost, 1991), sedge (Carex spp.) marshes, and sphagnum (Sphagnum spp.) bogs (Taylor, 1976; Walkinshaw, 1978; Roth, 1984; Urbanek *et al.*, 1988; Melvin *et al.*, 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 percent or greater shrub cover are generally avoided by nesting pairs (J. J. DiMatteo, personal communication, 1990).

Recent surveys in northwestern Minnesota (DiMatteo, 1991; Provost, 1991; S. J. Maxson, personal communication, 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 (GIS) to assess wildlife habitat on a regional scale. Satellite data have been digitally classified to map wetlands (Hodgson *et al.*, 1987) and upland habitats (Lyon, 1983; Ormsby and Lunetta, 1987; Miller and Conroy, 1990), and GIS has been used to identify (Lyon, 1983), monitor (Hodgson *et al.*, 1988), and characterize (Scepan *et al.*, 1987; Stoms *et al.*, 1990; Gagliuso, 1991) habitats. 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). However, the ability to model wildlife habitat depends on conditions concerning data, modeling techniques, and sensitivity analyses (Lyon, 1983; Miller *et al.*, 1989; Stoms *et al.*, 1990).

Using GIS technology along 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 greater sandhill cranes in northwestern Minnesota. The objectives of the project were (1) to produce necessary data layers for the model, including a vegetation map classified from Landsat Thematic Mapper (TM) data; (2) to characterize 22 known nest sites using a raster-based GIS; and (3) to verify the applicability of the model to known locations of ten additional nest sites within a separate test area.

Study Area

The study area encompassed four townships in northwestern Minnesota that are located in the transitional zone between the northern forest region to the east, and prairie and aspen parkland to the west. Twenty-two known nest sites in Espelie and Veldt townships in Marshall county were used to develop the model, while ten known nest sites in Poplar Grove and Golden Valley townships in Roseau county were used to

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test the model (Figure 1). Plant communities are comprised of gradients from open sedge fens and meadows to willow (Salix spp.) swamps and aspen (Populus spp.) stands. Much of the region has been affected by extensive drainage systems or by fires (N. Aaseng, personal communication, 1991). The Landsat classification discussed below estimated that the extent of agricultural land ranged between 35 percent and 60 percent in the townships. No towns are located within the four townships, but the distribution of farmsteads and residences varies throughout the area. Paved roads are uncommon; most roads are either gravel or dirt.

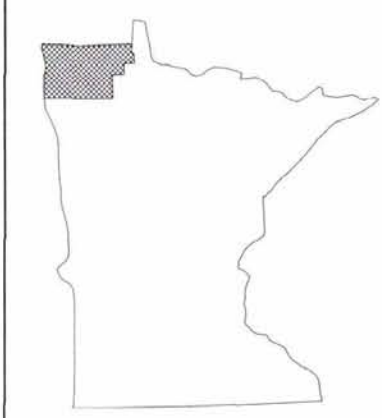

Figure 1. Location of study area in northwestern Minnesota. The map shows the counties that contain the four townships used to develop and test the nesting habitat model.

Methods

Generating Data Layers

A raster-based GIS using 30-m grid cells (compatible with the spatial resolution of Landsat TM data) was used as the framework for the model. Image analysis was conducted using ERDAS, and GIS modeling work was implemented using the EPPL7 package. Four primary data layers were generated and compiled for the GIS model, including vegetation, road networks, building locations, and nest site locations.

Landsat TM data were classified to develop a synoptic coverage of plant communities important to nesting biology of cranes. Nine target information classes were derived from the classification system of the Minnesota Natural Heritage Program (N. Aaseng, personal communication, 1991) 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 (PSNV), while shrub swamps, deciduous forests, and coniferous forests were categorized as woody vegetation unsuitable for nesting. Classes that were categorized as potential nesting vegetation contained shallow wetlands primarily composed of cattails, bulrush, phragmites, sedge, and/or scattered shrubs, all of which are commonly used by nesting cranes in the Great Lakes region.

Funding constraints allowed only a single date of imagery to be procured for the study; the scene provided to the project was imaged in 23 September 1987. Landsat data were geometrically rectified to the Universal Transverse Mercator (UTM) projection Zone 15 and then classified using a hybrid approach that combined supervised and unsupervised classifiers. Data were rectified prior to classification to allow ancillary data to be combined with the Landsat data for purposes of pre-classification image segmentation. Nearest neighbor resampling was used to minimize the effects of resampling on pixel spectral values.

The hybrid classification exercise consisted of two phases; an unsupervised phase and a supervised phase. First, two unsupervised passes were performed to separate large areas of agricultural land and open water from other cover types. During each of the two unsupervised passes, 20 spectral classes were generated. Those classes corresponding to known agricultural land and water were masked and stored in a separate GIS file. The end result of the two-tiered unsupervised classification was a site mask ("on-site") covering non-agricultural, non-water areas.

The on-site mask, which included approximately 80 percent of the image area, was then classified in a second phase using a supervised approach. Training sites selected from field surveys and aerial photos were used to generate statistics for each desired information class. A six-level hierarchical set of supervised classifications was conducted to distinguish the information classes. Initial supervised passes separated spectral portions of the satellite image that corresponded to groups of information classes or to minor components of an information class. Subsequent (supervised) passes, each covering different spectral portions or segments of the satellite image, were conducted to distinguish each information class.

Image segments were defined as information classes that were determined to be correctly classified. In practice, those areas correctly classified during each supervised pass were segmented and removed from further consideration (classification), and remaining areas were reclassified. A total of six iterations or classifications resulted in six classified image segments that were then mosaicked along with the agricultural land and water segments from the unsupervised classifications. A 3 by 3 low pass filter was applied to the image in order to remove small, infrequently occurring pixel clusters.

An accuracy assessment was performed using reference polygons that represented overall class proportions. All of the reference polygons were the same size, so the number of reference pixels selected for each class was proportional to the area of each class in the classified image. UTM coordinates of the center of each polygon were determined, and classes of the corresponding pixel plus the eight adjacent pixels were recorded. To summarize the results of the accuracy assessment, an error matrix was compiled and errors of omission and commission and the percent of correctly classified pixels were calculated.

U.S. Geological Survey (USGS) Digital Line Graph files of road networks in the study area were converted to raster format 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 that 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.

Active crane nests were located during May and June of 1990 and 1991 by flushing incubating adults during helicopter surveys of the study area. Although the nest surveys postdated the Landsat image date by four years, the cover classes of interest are a comparatively persistent landscape feature, and actual nest sites are normally used repeatedly over a several year period of time. While entire townships were covered, surveys were concentrated in emergent wetlands and open sedge marshes. When a nest was found, flagging was dropped from the helicopter within the nesting marsh and out to the nearest road or trail to mark the site for future ground surveys. A few days after an aerial survey, nests were located on the ground. Nest sites were plotted on 1:24,000-scale topographic maps and digitized as single 30-m cells.

Describing Nest Sites

The second step in the modeling approach was to describe known nest sites in Espelie and Veldt townships. The vegetation map of each township was divided into potentially suitable and unsuitable nesting vegetation or cover (Figure 2); then six additional habitat features associated with the 22 nest sites were measured using a raster GIS. These variables included distance to nearest paved highway, light duty road, unimproved road, building, mapped agricultural land, and a variable we term "width of undisturbed buffer."

Although several nests were directly adjacent to agricultural land, in each case undisturbed vegetation was present in all other directions. No nest was located in small pockets of vegetation 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 wide enough to buffer disturbances existed in another direction. With this in mind, a procedure was developed to measure the width of 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 (Figure 2). A series of concentric buffers 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 undisturbed buffer was calculated.

The six measured habitat variables were divided into zones of influence representing different degrees of suitability for nesting cranes. 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. Zones of influence were labeled 0, 1, 2, and 3. For all variables, zone 0 was assumed to represent unacceptable levels of human disturbance, and zones 1, 2, and 3 were considered to indicate increasing levels of desirability (Table 1).

The width of an unsuitable zone associated with a road (Figure 3) or building was estimated according to the nearest distance to a known nest. If all known nests were far 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 (Figure 3) 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.

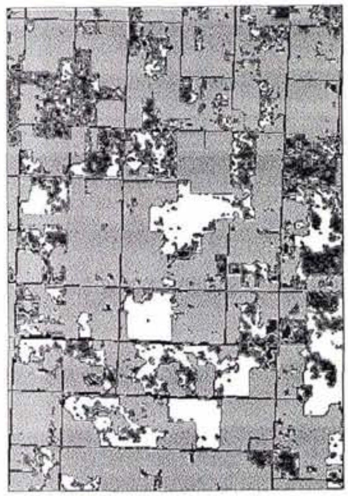

Figure 2. Map of Espelie Township and environs showing three classes of unsuitable habitat. White areas shown on the map correspond to areas of suitable nesting cover. Shaded areas show three types or classes of unsuitable nesting habitat. Agriculture and unsuitable cover classes are combined with unsuitable disturbance classes to define the extent of the unsuitable area. Unsuitable disturbance type and distance categories are listed in Table 1.

TABLE 1. ZONES OF INFLUENCE ASSOCIATED WITH SIX SELECTED HABITAT VARIABLES. NOTE THAT ZONES 1, 2, AND 3 INDICATE INCREASING LEVELS OF DESIRABILITY AS A NESTING CONDITION.

Habitat Variable	Zones of Influence (m) 0	1	2	3
Width of undisturbed buffer	0-180	181-360	>360	
Distance to highway	0-390	391-780	781-1,590	>1,590
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	391-780	781-1,200	>1,200
Distance to agricultural land	0	>600	121-600	1-120

Statistical Analysis

A series of chi-square analyses were conducted to determine whether discrepancies existed between the observed and expected distributions of crane nests. Preliminary chi-square analyses, which were performed separately on distances to nearest paved highway, light duty road, and unimproved road, 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 three road types was suspected of influencing 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 cell in the new file was assigned to one zone of influence (0, 1, 2, or 3) that equaled that cell's lowest zone of influence from any of the three road types. Chi-square tests were then completed

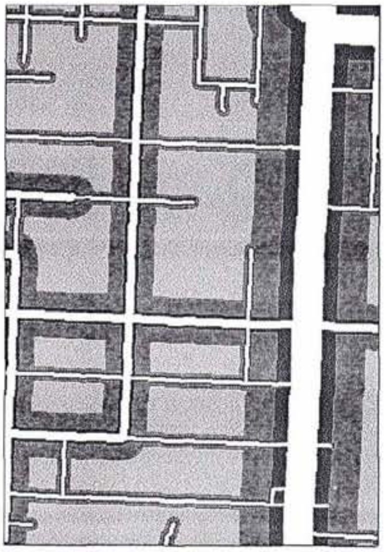

Figure 3. Zones of Influence associated with classes of roads. Four classes of disturbance are determined using distance categories from each of the road types. Each level of disturbance is shown by shaded buffers; the width of each buffer zone reflects distance categories listed in Table 1.

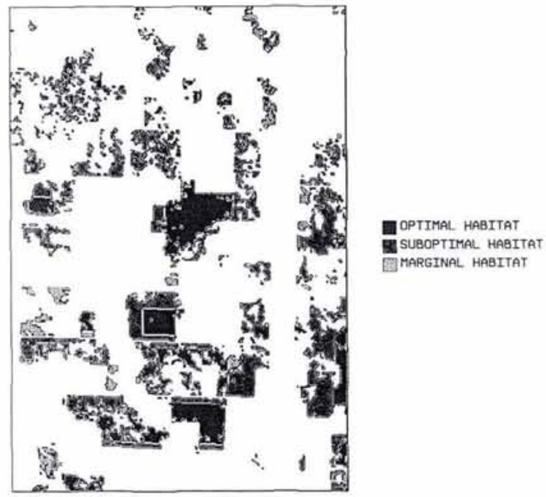

Figure 4. Map of ordinal habitat suitability classes. All shaded areas on the map correspond to areas of suitable nesting vegetation. Width of undisturbed buffer and distances to disturbances (roads and buildings) were used to define the three classes of habitat suitability. Note that the shaded areas in this figure are those areas shown in white on Figure 2.

for width of undisturbed buffer, distance to nearest road, distance to nearest building, and distance to agricultural land. For each variable, the expected distribution of nests was based on the proportions of potentially suitable nesting vegetation within each zone of influence.

Generating and Testing the Model

Based on the chi-square analyses, width of undisturbed buffer, distance to roads, and distance to buildings were used to categorize potentially suitable nesting vegetation as potentially optimal, suboptimal, marginal, or unsuitable habitat for nesting (Figure 4). These four categories of suitability represent an ordinal relationship and are not meant to convey any additional information. If a cell was within zone 0 of any of the three habitat variables, it was classified as an unsuitable habitat. Excluding the zero zones, 18 combinations of zones of influence associated with the three habitat variables were possible (Table 2). For each of these combinations, the level of optimization was determined by the significance levels of the habitat variables, which were based on the chi-square tests, and by assumptions about crane behavior, which were derived from the literature.

Sandhill cranes were assumed to nest in larger, undisturbed areas of emergent wetland, sedge, and shrub fen and to select sites that were farther from human disturbances. More significant habitat variables and more desirable zones of influence were given greater consideration when assigning levels of optimization (see Figure 4). 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 suboptimal 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 (Table 2). Note that distance to roads refers to zones of influence associated with the combined road network generated for the chi-square analysis.

Using the model, potential sandhill crane nesting habitat was identified and classified in a test area (Poplar Grove and

Table 2. Levels of Optimization Associated with Combinations of Significant Habitat Variables. Tabled Values Are Zone of Influence Numbers from Table 1.

Width of undisturbed buffer	Distance to roads	Distance to buildings	Potential habitat class
1	1	1	Marginal
1	1	2	Marginal
1	1	3	Marginal
1	2	1	Marginal
1	2	2	Marginal
1	2	3	Marginal
1	3	1	Marginal
1	3	2	Sub-optimal
1	3	3	Optimal
2	1	1	Sub-optimal
2	1	2	Sub-optimal
2	1	3	Sub-optimal
2	2	1	Sub-optimal
2	2	2	Sub-optimal
2	2	3	Sub-optimal
2	3	1	Sub-optimal
2	3	2	Optimal
2	3	3	Optimal

Golden Valley townships) in order to verify the applicability of the model to known locations of ten additional nest sites.

Results

Although the accuracy assessment estimated that 81 percent of the satellite image was correctly classified, errors of omission and commission were high for some of the information classes. Errors of omission were highest for disturbed grass, shrub fen, shrub swamp, and deciduous forest, resulting in class accuracies of 53 percent, 62 percent, 61 percent, and 70 percent, respectively (Table 3). However, 82 percent of the cells omitted from shrub fen were classified as sedge fen (Table 4), both of which were considered potential nesting vegetation. Errors of commission were highest for sedge fen, shrub fen, disturbed grass, and shrub swamp (Table 3). Approximately 60 percent of the pixels misclassified as sedge fen corresponded to shrub fens, 82 percent of the pixels incorrectly labeled as disturbed grass were from agricultural land, and 66 percent of the pixels misclassified as shrub swamp were deciduous forest. Of the pixels misclassified as shrub fen, 38 percent were shrub swamp and 31 percent were agriculture (Table 4). The errors of omission and commission for the remaining classes were under 15 percent.

The chi-square tests indicated that 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 (Table 5).

Table 3. Errors of Omission and Commission and Percent Correctly Classified for Nine Target Information Classes Derived from a Hybrid Classification of Landsat TM Data.

Class	Errors of Omission N	%	Errors of Commission N	%	Correct Classification N	%
Emergent wetland*	0/45	0	7/52	14	45/45	100
Sedge fen*	5/90	6	47/132	36	5/90	94
Shrub fen*	34/90	38	48/140	46	56/90	62
Shrub swamp	32/81	39	29/78	37	49/81	61
Deciduous forest	27/90	30	9/72	12	63/90	70
Coniferous forest	4/63	60	0/59	0	59/63	94
Agriculture	64/450	14	9/395	2	386/450	86
Disturbed grass	21/45	47	38/62	61	24/45	53
Water	0/36	0	0/36	0	36/36	100
OVERALL	187/990	19	187/990	19	803/990	81

*Denotes classes identified as potentially suitable nesting vegetation.

Table 4. Error Matrix Summarizing Specific Errors of Omission (by Row) and Commission (by Column) for the Nine Information Classes. EW = Emergent Wetlands, SE = Sedge Fens, SF = Shrub Fens, SS = Shrub Swamp, DF = Deciduous Forest, CF = Coniferous Forest, AG = Agricultural Land, DG = Disturbed Grass, and WA = Water.

Reference Data	Satellite Classification EW	SE	SF	SS	DF	CF	AG	DG	WA	Total
EW	45	0	0	0	0	0	0	0	0	45
SE	0	85	3	0	0	0	0	2	0	90
SF	4	28	56	1	0	0	0	1	0	90
SS	0	5	18	49	5	0	0	4	0	81
DF	0	0	8	19	63	0	0	0	0	90
CF	1	0	0	3	0	59	0	0	0	63
AG	2	6	15	6	4	0	386	31	0	450
DG	0	8	4	0	0	0	9	24	0	45
WA	0	0	0	0	0	0	0	0	36	36
Total	52	132	104	78	72	59	395	62	36	990

Table 5. Results of the Chi-Square Analyses which Tested for Discrepancies between Observed and Expected Distributions of Crane Nests in Relation to Four Habitat Variables. PSNV = Potentially Suitable Nesting Vegetation.

Habitat Variables Zones of Influence	% of PSNV	Observed # Nests	Expected # Nests	χ^2	P
Width of undisturbed buffer				10.424	0.0054
0	19.39	0	4.2658		
1	12.76	0	2.8072		
2	67.85	22	14.9270		
Distance to roads				9.324	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				5.385	0.1457
0	5.4	0	1.1880		
1	16.88	4	3.7378		
2	25.71	2	5.6562		
3	52.01	16	11.4420		
Distance to agriculture				0.872	0.6467
1	3.81	0	0.8380		
2	47.94	11	10.5470		
3	48.25	11	10.6150		

Table 6. Model Results of the Distribution of Crane Nest Sites and Potentially Suitable Nesting Vegetation. PSNV = Potentially Suitable Nesting Vegetation.

Habitat Class	Development Area % PSNV	# Nests	Test Area % PSNV	# Nests
Optimal	33.3	13	40.0	6
Sub-optimal	38.4	9	26.2	1
Marginal	8.9	0	9.4	3
Unsuitable	19.4	0	24.4	0

All of the 22 nest sites used to develop the model were in potentially optimal or suboptimal habitat, while the ten nests used to test the model were in potentially optimal, suboptimal, or marginal habitat (Table 6). The area used to develop the model was comprised of 19.8 percent potentially suitable nesting vegetation, 59.6 percent agriculture, and 20.6 percent vegetation unsuitable for nesting. The composition of the test area was 28.4 percent potentially suitable nesting vegetation, 38.3 percent agriculture, and 33.3 percent vegetation unsuitable for nesting.

Discussion

Data Layers

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

Because mapped information 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 mapped information 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 in this case because both of these classes were considered potential nesting vegetation. Only a small percentage (approximately 2 percent) of sedge fens and shrub fens was misclassified as unsuitable nesting vegetation. In some locations, however, vegetation unsuitable for nesting was misclassified as sedge fen or shrub fen, resulting in an overestimation of potentially suitable nesting vegetation.

Problems with the satellite classification necessitated fundamental assumptions about the mapped information classes. Only areas classified as emergent wetlands, sedge fens, and shrub fens were assumed to consist of substantial stands of potentially suitable nesting vegetation (Figure 2). These three information classes provided the best available indication of the presence of wetlands. Accurate, independent information on wetland locations was not available. In addition, all mapped information 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 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 road class were speculated to have the same level of disturbance (see Figure 3) 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 cranes. The idea that 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. Therefore, simply estimating area would not differentiate between large, continuous sections of undisturbed vegetation and narrow bands or peninsulas of undisturbed vegetation that extend from a larger area. Zones of influence associated with each habitat variable were based on assumptions about how cranes responded to human disturbances and about levels of disturbance associated with buildings and roads (Figure 3) within the study area.

Note that the low-pass filter applied to the classified image had already eliminated low-frequency, very small, isolated pockets of vegetation that were considered unsuitable as nesting sites. These small pockets also could not be verified as to cover type. The width of undisturbed buffer variable would have eliminated these small pockets from consideration as suitable nesting sites; the low-pass filter was applied as a pre-processing routine primarily because these pockets could not be verified as to cover class at the scale and resolution of the study.

Statistical Analysis

Both the width of undisturbed buffer and distance to roads were significantly related to the observed distribution of 22 nest sites. These results partially support the Habitat Suitability Index (HSI) model developed by Armbruster (1987) who claimed that 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. Zones of influence associated with the three types of roads within the study area were adjusted to account for different levels and types of use under wet conditions. Frequencies of traffic were considered highest for paved highways, intermediate for light duty roads, and lowest for unimproved roads. Consequently, assigned zones of influence were widest for paved highways, intermediate for light duty roads, and narrowest for unimproved roads.

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 significantly related to the observed distribution of 22 nest sites, this variable was included as a minor component in the model because of limitations with modeling techniques and reports in the literature. A visual comparison of observed and expected distributions of nests showed that pairs tended to select distances farther from buildings than what was expected. Furthermore, all four nest sites within zone 1 from a building were also within 480 m of a road in the opposite direction. Thus, presence of roads, 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. Although 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.

The literature suggests that sandhill cranes tend to avoid nesting near buildings. In Alberta, Canada, crane nests ranged between 2.3 to 8.5 km from any human disturbance (Carlisle, 1981). However, distances from nest sites to regular human activities varied considerably, depending on development in the area and 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.

In this study, distance to agricultural land was not significantly related to the observed distribution of 22 nest sites. This supports Halbeisen (1980), who 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 less interspersed with undisturbed land, cranes may tend to select areas that are closer to agricultural fields.

Testing the Model

The model indicated that some pairs nested in potentially suboptimal and marginal areas despite the apparent availability of optimal habitat. Our most basic working assumption is that cranes will select the most optimal habitat available. The apparent absence of nesting pairs in optimal habitat may be accounted for by a number of plausible explanations. 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. Wetland size 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 availability of quality habitat, density of the local crane population, and levels of human development (Bennett, 1978; Hoffman, 1983). The likelihood of finding nesting pairs was presumed to increase as the distance from 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 may 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). Thirdly, established pairs usually return to the same nesting marsh in subsequent years (Walkinshaw, 1949). Optimal habitat that did not contain a nest during our surveys may have been used by cranes in the past. When pairs currently nesting in the study area established their territories, other pairs may have been present in the currently unused optimal areas. These explanations are purely hypothetical because no data about the history of nesting pairs within the study area were available. Additionally, some nest sites may have been undetected during aerial surveys of the study area.

Limitations of the model may have also affected the described distribution of nest sites. Potentially optimal habitat was selected according to features in the landscape and not accounting for local variability, such as water levels and specific information about vegetation. Incorporating data on local variability would potentially alter the status of some areas.

Furthermore, other landscape variables could not be reliably measured with the available raster data. For example, cranes were suspected of selecting against wetlands which were isolated from agricultural land and other foraging habitat by large forested stands. Although chicks are precocial, they do not fledge for approximately 60 days (Walkinshaw, 1949). Large stands of dense forest may be too difficult for young to cross and may restrict movement of a brood. Because plant communities were not mapped as finite, discrete units, the width of forested stands could not be accurately measured, and, consequently, wetlands that were isolated by large forested stands were not identified.

Conclusion

Results of the model indicated that some sandhill crane pairs nested in potentially suboptimal 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 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 and with using a GIS and a satellite classification. Limited information on the biology and behavior of cranes in the study area reflect an elemental limitation inherent in biological investigations.

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 influence both model development and assessment. Consequently, conditions and assumptions inherent in the data and generation of the model should be explicitly stated and considered when interpreting subsequent results of the model. To reduce difficulties associated with interpreting results, long term studies and monitoring programs are needed to address questions about behavior of the target species.

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