Remote Sensing Approach to Avian Conservation: A Greater Sandhill Crane Model

Final Report to Minnesota DNR, Nongame Wildlife Program
Contract M8110/#24

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December, 1991

EXECUTIVE SUMMARY

Goal and Objectives

The goal of this project was to develop a descriptive GIS model to identify potentially suitable nesting habitat of Greater Sandhill Cranes in northwestern Minnesota. Four primary objectives of the project were: (1) to produce a digital map of plant communities in the study area from Landsat-5 Thematic Mapper data to be used as a primary data layer in the GIS model, (2) to characterize the habitat of twenty-two known nest sites in Espelie and Veldt townships of Marshall County using the EPPL7 GIS software package, (3) to identify potentially suitable nesting habitat in Poplar Grove and Golden Valley townships of Roseau County using the descriptive model developed from the nest site characteristics studied in Espelie and Veldt, and (4) to compare the results of the model in Poplar Grove and Golden Valley to the locations of ten known nest sites.

Modeling Approach

A hybrid classification of Landsat data generated a cover type map with nine information classes. Extensive field surveys were used to update digital files of road networks and to confirm building locations which were digitized from USGS 7.5 minute topographic maps. Thirty-two known nest sites detected during helicopter surveys of the study area were plotted on USGS 7.5 minute topographic maps. UTM coordinates of each site were measured and transformed into point files.

Limitations and assumptions about the data layers, EPPL7, and the current knowledge of the breeding behavior of cranes were identified. Six habitat variables associated with twenty-two nest sites were measured with EPPL7, a raster GIS. Using these calculations, observations of other nests, and assumptions about crane behavior, each of the variables was divided into three or four zones of influence which represented different levels of suitability. Principle components and chi square analyses were conducted to quantify the importance of each habitat feature. Based on the results from the chi square analysis, potentially suitable nesting vegetation was categorized as optimal, suboptimal, marginal or unsuitable according to specific combinations of variables. The model was projected over the entire study area, and results were compared to ten additional nest sites.

Results

From the chi square tests, p-values corresponding to the width of the undisturbed area, distance to roads, distance to buildings, and distance to agricultural land were 0.005, 0.025, 0.146, and 0.647, respectively. Results of the model indicated that of the thirty-

two known active nest sites, nineteen were in optimal habitat, ten were in suboptimal habitat, and three were in marginal habitat.

Conclusions

Spatial and spectral variability of plant communities in Roseau and Marshall counties limited the detail of the cover type map that could be derived from a single Landsat scene. The lack of distinct spectral responses of the desired information classes was the primary barrier to more complete cover type mapping. Distinguishing among similar vegetative communities was difficult because of natural gradients which existed within and among communities. The resulting cover type map from the satellite data contained generalized plant communities that exhibited varying degrees of overlap.

A series of assumptions about the composition of mapped vegetation classes, the levels of disturbance imposed by buildings and different road types, and the current understanding of the nesting behavior of Greater Sandhill Cranes were fundamental to the model. The principle assumption was that potentially suitable nesting habitat was found only in areas classified as emergent wetlands, sedge fens/meadows, and shrub fens. Results from a chi square analysis indicated that the width of an undisturbed area and the proximity to roads both significantly affected where pairs nested, while the distance to buildings was somewhat influential. Habitat was characterized as potentially optimal, suboptimal, marginal, and unsuitable according to specific combinations of the zones of influence associated with these three variables. Suitability depended upon the degree of isolation from specific cultural features in the landscape and the estimated frequencies of human disturbances from roads and buildings that impacted a site.

The model indicated that some pairs nested in suspected marginal and suboptimal areas despite the availability of presumably optimal habitat. The absence of nesting pairs in optimal habitat may be accounted for by the inability to model or detect certain landscape features and local variables, the uncertainty that all nest sites in the study area were known, and the unanswered questions concerning the behavior of nesting pairs.

The primary outcome derived from this research was less a working nesting habitat model than an understanding of the assumptions and limitations that are inherent in such modeling procedures.

ACKNOWLEDGEMENTS

I would like to thank Carmen Converse and the Minnesota Natural Heritage Program for supporting the classification of the Landsat data. Norm Aaseng and Robert Dana provided knowledge of northwestern Minnesota and the information necessary for the classification. Special thanks go to Norm Aaseng for all his patience and dedication. Help was also received from Al Epp who provided additional data for the model.

This project would not have been possible without the technical skills of John Ladwig and Stephen Lime who successfully kept programs and machines working properly.

I would like to thank Francesca J. Cuthbert, J. L. David Smith, LLoyd P. Queen, and Stephen J. Maxson for serving as my advisors. Special appreciation goes to LLoyd Queen for his invaluable guidance and ideas about modeling with a GIS. I am especially indebted to Stephen Maxson who willingly shared his expertise and permitted me to accompany him during his field work. Without his help, I would not have had nest sites from which to build the model.

In addition, I would like to thank Gary Oehlert for offering his statistical expertise and Lauren Wemmer for helping me with the principle components analysis.

I express my gratitude to Lee Pfannmuller and the Nongame Wildlife Program for support from the Minnesota Nongame Wildlife Tax Checkoff. Additional funding was provided by the James W. Wilkie Fund for Natural History of the Bell Museum of Natural History and by the Grants-in-Aid of Research from Sigma Xi.

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December 1991

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INTRODUCTION

Prior to 1870, 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 from settlement practices, and the drought of the 1930's reduced the state population to less than twenty-five pairs by the mid 1940's (Walkinshaw, 1949; Johnson, 1976a). Today two recovering populations in the northwest corner and the 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 Greater 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. Within the Great Lakes region, cranes are known to nest in cattails, bulrush and phragmites (Walkinshaw, 1965a; Howard, 1977a, 1977b; Crete and Grewe, 1981; Melvin 1990; Maxson, 1990; Provost, 1991; DiMatteo, 1991), in sedge marshes (Roth, 1984; Urbanek, 1988), and in sphagnum bogs (Walkinshaw, 1965a, 1978; Taylor, 1976; Roth, 1984; Urbanek, 1988; Melvin, 1990). Usually, tall, dense vegetation such as phragmites (Johnson, 1976b), cattails (Walkinshaw, 1965a) and occasionally shrubs (Walkinshaw, 1950a, 1978; Carlisle, 1981) conceal nest sites. However, marshes with fifty percent or greater shrub cover are generally avoided by nesting pairs (DiMatteo, 1990).

Nesting marshes are commonly saturated or seasonally to permanently flooded (Armbruster, 1987) and may contain open water (Carlisle, 1981; Hoffman, 1983). Pairs build their nests above standing water which can be fifteen to thirty centimeters or deeper (Walkinshaw, 1949, 1950a; Carlisle, 1981; Tacha and Tacha, 1985; Urbanek, 1988). In dry years cranes may nest in marshes with no standing water. Because of the variation in vegetation types and water regimes, nests may be found in all palustrine wetlands lacking extensive tree or shrub canopies (Urbanek, 1988; Johnson, 1990).

Breeding territories consist of upland plant communities as well as nesting marshes and other wetlands (Drewien, 1973). After the first several days, broods will forage in small grain fields and cattle pastures if they are available (Bennett, 1978). Other potentially important foraging habitat includes hay fields, CRP plots, prairies, sedge meadows, and forested ridges (Walkinshaw, 1950a; Johnson, 1976b; Hoffman, 1976; Henderson, 1978a, 1978b, 1979; Carlisle, 1981).

Although cranes forage in crop lands and pastures, nest sites are generally isolated from frequent human disturbances. Distances from an active nest to regular human activities vary considerably depending upon the degree of development in the area and the density of the local crane population. In Alberta, Canada, nests range from 2.3 to 8.5

kilometers from human disturbances (Carlisle, 1981). But distances can be considerably shorter, such as averages of one kilometer in Morrison County, Minnesota (Johnson, 1976b) to under one kilometer in Jackson County, Michigan. Between 1970-1982 as the crane population expanded in Jackson County, the average distance between a nest site and various human disturbances decreased. By 1982, average distances from a road and the nearest residence declined twenty percent to 431 meters and twenty-six percent to 476 meters, respectively (Hoffman, 1983).

In northwestern Minnesota cranes may begin nesting by late April. With a thirty-one to thirty-two day incubation period, most eggs have hatched by early June, unless pairs renested (Walkinshaw, 1950b). Surveys are best conducted during the incubation period while adults are attentive to their nests (Walkinshaw, 1965b). Chicks are precocial so broods are not restricted to the nest or nesting marsh after the first several days (Walkinshaw, 1949). Because nest sites are relatively inaccessible and inconspicuous from the ground, aerial surveys have become the preferred method for surveying nesting marshes (Maxson, 1990). Generally, nests are found by flushing the incubating bird. Helicopters are commonly used for better maneuverability and hovering capabilities (Gluesing, 1974; Urbanek, 1988; Maxson, 1990).

Although selected study areas in northwestern Minnesota have been recently surveyed for crane nests (Maxson, 1990; Provost, 1991; DiMatteo, 1991), the extent of potentially suitable nesting habitat throughout this region has not been described. Combining a geographic information system (GIS) and a digital map of plant communities derived from satellite data may provide a useful means of identifying potentially suitable nesting habitat over a large area.

Habitat of various species has been mapped from satellite images (Lyon, 1983; Hodgson, 1987; Hill, 1987; Ormsby, 1987) and monitored and characterized with a GIS (Lyon, 1983; Scepan, 1987; Stenbach, 1987; Hodgson, 1988; Mead, 1988; Shaw, 1988). For example, Hodgson (1987) classified Landsat TM data to locate foraging habitat of wood storks in central Georgia. With a GIS, Hodgson (1988) monitored changes in the foraging habitat between wet and dry years and calculated the distance from the nesting colony to foraging areas. Nesting habitat of kestrels in Oregon has also been modeled using a classification of Landsat MSS data and a GIS (Lyons, 1983). Techniques such as GAP analysis have been developed to identify important areas for biodiversity and species richness (Scott et al., 1987; Davis et al., 1990).

Goals and Objectives

The goal of this project was to develop a descriptive GIS model to identify potentially suitable nesting habitat of Greater Sandhill Cranes in northwestern Minnesota. Four primary objectives of the project were: (1) to produce a digital map of plant communities in the study area from Landsat-5 Thematic Mapper data (to be used as a primary data layer in the GIS model), (2) to characterize the habitat of twenty-two known nest sites in Espelie and Veldt townships of Marshall County using the EPPL7 GIS software package, (3) to identify potentially suitable nesting habitat in Poplar Grove and Golden Valley townships of Roseau County using the descriptive model developed from the nest site characteristics studied in Espelie and Veldt, and (4) to compare the results of the model in Poplar Grove and Golden Valley to the locations of ten known nest sites.

Study Area

The study area was comprised of four townships, Espelie and Veldt in eastern Marshall county and Poplar Grove and Golden Valley in southeastern Roseau county. Most of this area is located within the transitional zone between the northern forest region to the east of Bemis Ridge and the prairie and Aspen parkland regions to the west. The plant communities comprise a gradient from open sedge fens and meadows to willow swamps. Much of the region has been affected by disturbance regimes. Extensive drainage systems have promoted the growth of shrubs in some areas, while fires have reduced the density and height of shrubs in other locations. Most of the aspen woods within the study area have been highly disturbed. Extensive conifer stands are primarily to the east in the northern forest region (Aaseng, 1991).

Estimates from the Landsat classification indicate that the percent of land converted to agricultural practices varies from approximately 60% in Espelie and Veldt townships, 40% in Golden Valley, to 35% in Poplar Grove. The primary crops are a mixture of small grains, but sunflowers and, to a lesser extent, corn are also cultivated. Cattle pastures, hay fields, and Conservation Reserve Program (CRP) plots are also present throughout the townships.

Urban development is not very extensive. No towns are located in any of the townships. The number and distribution of farmsteads and residences varies throughout the area. Paved roads are not common in this region of the state. Both Veldt and Golden Valley are bordered on the east and west sides by paved highways, and one paved highway runs north to south in the eastern half of Espelie. All other roads are either gravel or dirt.

METHODS AND MATERIALS

(A) Nest Surveys

(1) Preliminary Ground Surveys

Field work began during the latter half of April when most breeding cranes were arriving in the study area. From late April to early May, several preliminary ground surveys of each township were conducted between sunrise and late morning. The locations and times of all visual and audible observations of cranes were recorded on Plat maps and used to estimate the general territories of possible breeding pairs.

Additional surveys were completed during the afternoons to become familiar with landscape features within each township and to check the status of roads and buildings. Roads were assessed for their drivability under wet conditions, and building locations were recorded to verify those plotted on USGS 7.5 minute topographic maps.

(2) Aerial Surveys

Helicopter surveys were performed to detect active crane nests. Surveys were scheduled during the second and third week in May, but because of helicopter repairs and inclement weather, dates were often rescheduled for later in the month. Although 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.

(3) Local Habitat Analysis

Within a few days after an aerial survey, nests were located on the ground. At this time, hatching dates were estimated by floating the eggs in a container of water. After the projected hatching dates, a variety of habitat measurements were collected under the direction of Dr. Stephen J. Maxson using field protocols he has developed for a concurrent study of Greater Sandhill Crane nesting biology.

(B) Generation of Data Layers for the GIS Model

(1) Cover Type Map from the Classification of Landsat TM Data

A classified map of plant communities in eastern Roseau and Marshall counties was completed for the County Biological Survey with the assistance of the Natural Heritage Program. Portions of two Landsat-5 Thematic Mapper scenes were needed. Most of the study area was covered by the southwestern quarter of scene path 29, row 26; the southeastern corner of Marshall county was completed by scene path 30, row 26.

Acquisition dates for the imagery were September 23, 1987 for scene 29/26 and August 15, 1988 for scene 30/26. Data from the two Landsat scenes were geometrically rectified to UTM zone 15 and classified separately.

A hybrid approach was used to classify the Landsat data. Two unsupervised classifications 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 twenty 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, which involves manually collecting training sites from previously known areas. Training sites were then used to generate statistics for each desired information class. Means and standard deviations were calculated for all but the thermal TM band. Each training site had to consist of at least thirty 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 of the unsupervised and supervised passes were combined and a low pass filter was run to smooth the cover type map of the study area.

An accuracy assessment of the classification was performed using verification data from the Natural Heritage Program. The number of reference polygons per information class reflected the class proportions over the entire image. UTM coordinates of the center of each polygon were measured, and classes of the corresponding pixel plus the eight adjacent pixels were recorded. The eight adjacent pixels were considered to eliminate possible skewed results from isolated pixels.

To summarize the accuracy assessment, an error matrix was compiled (see results section A, Table 2) and errors of omission and commission and the percent of correctly classified pixels were calculated (see results section A, Table 3). In addition, Cohen's kappa statistic (khat) was calculated using the formula khat = (observed - expected) / (1 - expected), where observed equals the percentage of pixels correctly classified and expected is an estimate of the percentage of pixels that would be correctly classified by chance agreement determined from the classification of the reference data (see results section A and discussion section A1 for further explanations).

Sections of the cover type map that corresponded to the study areas were extracted and converted to EPPL7 format. The resulting cover type map included nine information classes:

(1) Agricultural and disturbed lands represented a combination of cultivated fields, hay fields, CRP land, pasture, and miscellaneous disturbed areas such as farmsteads.

(2) Disturbed grass included grasslands, old fields, meadows, and some agricultural areas which were primarily CRP plots, hay fields, and pastures.

(3) Open water.

(4) Emergent wetlands consisted mostly of cattails, bulrush and phragmites.

(5) Sedge fens/meadows corresponded to open fields of grass and/or sedge with small scattered shrubs. Shrubs were generally less than 1.5 meters tall and covered a minor portion (<30%) of the community. Areas labeled as sedge fen/meadow may also contain small scattered basins of emergent vegetation.

6) Shrub fens were a mixture of grasses, sedges and small (<1.5 meters tall) shrubs that covered 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.

7) Shrub swamps consisted of taller (>1.5 meters), denser shrubs that typically enclosed between 50-70% of the stand. Small trees may also be present.

8) Deciduous forests represented taller, older trees with less canopy dominated by shrubs.

9) Coniferous forests were primarily treed but also included some areas dominated by coniferous shrubs.

(2) Map of Road Network

Digital Line Graph (DLG) files of the road networks, which had been digitized from USGS 7.5 minute topographic maps by the Minnesota Department of Transportation, were obtained from the state Land Management Information Center (LMIC). The DLG files were converted to EPPL7 format and combined for continuous coverage of the study areas. EPPL7 is a raster GIS often used by the state of Minnesota. After preliminary ground surveys of the township roads were completed, the road network files were updated, because the status of many of the roads had changed since the topographic maps were produced. Files contained four road classes: (1) paved highways, (2) light duty roads which included gravel and dirt roads that were easily drivable during a wet spring, (3) unimproved roads which were dirt roads that were not easily passable during a wet spring, and (4) private dirt farm roads and trails (see discussion section A3 for assumptions).

(3) Map of Building Locations

Preliminary ground surveys in April and May were used to confirm buildings locations plotted on USGS 7.5 minute topographic maps. New buildings originally not plotted were added to the map and abandoned or absent buildings were removed. All confirmed building locations were digitized from the topographic maps into ERDAS files which were converted to EPPL7 format (see discussion section A3 for assumptions).

(4) Map of Nest Locations

All known nest locations were plotted on USGS 7.5 minute topographic maps. UTM coordinates of each nest site were determined using a digitizer and ERDAS programs. Point files of the UTM coordinates of each nest were generated and read into EPPL7.

(C) Model Approach

(1) Habitat Measurements using EPPL7

Six habitat features associated with the twenty-two known nest sites in Espelie and Veldt townships were measured using EPPL7. Distances from each nest site to the nearest paved highway, light duty road, unimproved road, building, and mapped agricultural land were calculated. Because EPPL7 is a raster system and the pixel size was 30 meters by 30 meters, all distances were measured in 30 meter intervals (see discussion section A4)

While several of the nest sites were directly adjacent to agricultural land, in each of these cases, undisturbed vegetation was present in all other directions. None of the nest sites were located in small pockets of nesting vegetation surrounded by agricultural land or other human disturbances. Nor were any of the nests found 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 nesting 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. A pixel was labeled as undisturbed vegetation if it corresponded to any class 2-9 on the cover type map (see class list in section B1) and was not "too close" to a road or building. (See the upcoming section, Format of the Model, for a discussion about acceptable distances from roads and buildings. See discussion section A2 for assumptions inherent in this procedure.) All remaining pixels that were labeled as agriculture and/or were near buildings or roads were combined into a disturbance class. A series of concentric rings at thirty meter intervals was generated from all edges of the disturbed class into the remaining undisturbed areas. Using the thirty meter intervals, the width of the undisturbed vegetation was calculated. Henceforth this habitat feature will be referred to as the width of the undisturbed area (see results section B, Table 4).

(2) Format of the Model

Seven measurable features in the landscape were thought to influence potentially suitable nesting habitat for Greater Sandhill Cranes. These variables were: (1) vegetation type, (2) width of the undisturbed area, (3) distance to nearest paved highway, (4) distance to nearest light duty road, (5) distance to nearest unimproved road, (6) distance to nearest building, and (7) distance to nearest agricultural land. Each township in the study area was divided into potentially suitable and unsuitable nesting vegetation. Potentially suitable nesting vegetation was represented by emergent wetlands, sedge fen/meadows, and shrub fens (see discussion section A2 for assumptions about vegetation classes).

The six remaining variables were divided into three or four zones of influence representing different degrees of suitability for cranes. Each zone was measured in meters from the associated variable. Distances delineating the zones of influence were selected using calculations from the twenty-two nests in Espelie and Veldt townships, observations of other nests in Kitson and Marshall counties, and intuitive reasoning (see discussion sections B1 and B2 for additional explanations).

The zones of influence were labeled 0, 1, 2, and 3. Zero zones were assumed to represent unacceptably high levels of human disturbance. For all variables, zones one, two, and three indicated increasingly desirable regions. Thus, the minimum acceptable distance from a road or building was delineated by the lower bound of zone one for each variable. Two variables were needed to demonstrate the positive and negative aspects associated with proximity to agricultural lands. Because cranes often forage in cultivated fields and pastures, distance to agricultural land showed that close proximity to agriculture can be beneficial. Width of the undisturbed area, which excluded agricultural land and unacceptable distances to roads and buildings, demonstrated that human activities in agricultural fields can inhibit cranes from nesting nearby (Table 1).

VARIABLE	ZONES OF INFLUENCE (in meters)			
	0	1	2	3
Width of Undisturbed Area	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	12-600	1-120

TABLE 1: Summary of the zones of influence for the six habitat variables.

(3) Statistical Analyses of the Variables

A principle components analysis was conducted to determine if any of the six variables accounted for a large proportion of the variance among the nest distributions. Input consisted of the calculated distances from each of the twenty-two nest sites in Espelie and Veldt townships to the nearest paved highway, light duty road, unimproved road, building, and agricultural field and the widths of the undisturbed areas associated with each nest. The SAS software was used to generate eigenvectors and eigenvalues (see results section C).

Chi square analyses were conducted to determine whether discrepancies existed between the observed and expected distributions of crane nests in Espelie and Veldt townships. Variables that were tested included width of undisturbed area, 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, the three EPPL7 files that contained zones of influence from the three road types were combined into a single file. With four zones of influence for each road type, sixty-four combinations of zones were possible. To simplify matters, each pixel in the new file was assigned to one zone of influence (0, 1, 2, or 3) which equaled that pixel's lowest corresponding zone of influence from any of the three road types. For example, if a pixel was located in zone one from a highway and zones three from both light duty and unimproved roads, in the new file that pixel was assigned to zone one. Likewise, if a pixel was found in zone three from a highway, zone one from a light duty road but zone zero from an unimproved road, in the new file that pixel was assigned to zone zero. The resulting file consisted of four zones of influence from the road network which were used to estimate expected distributions of nests (see results section D, Table 5).

(4) Characterizing Potentially Suitable Nesting Habitat

Using the results of the chi square analysis, the variables which significantly influenced the distribution of nest sites were identified and selected to classify habitat as potentially optimal, suboptimal, marginal, or unsuitable for nesting. Three variables; width of undisturbed area, distance to roads, and distance to buildings, were considered important for determining the suitability of potential nesting habitat (Table 5). Distance to roads refers to zones of influence associated with the entire road network that were generated for the chi square analysis.

To characterize potentially suitable nesting habitat, a new file was generated in which each pixel of potentially suitable nesting vegetation was categorized according to its specific combination of these three variables. 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. More important variables and more desirable zones of influence were given greater consideration. For example, distance to roads was shown to be more influential in the distribution of nests than distance to buildings. Therefore, a pixel associated with zone three from roads and zone two from buildings was considered more desirable than a pixel within zone two from roads and zone three from buildings. (See Table 6 for a summary, discussion section B2 for assumptions about crane behavior, and discussion section B4 for further explanations for assigning levels of optimization).

(5) Assessment of the Model

The model was based on the chi square analysis of the twenty-two known nest sites in Espelie and Veldt townships. Before applying the model to additional areas, it was tested on Espelie and Veldt. When the model was running properly, it was projected onto Poplar Grove and Golden Valley townships. Locations of five active nests and five nest sites of unknown status in the two new townships were used to assess the applicability of the model for other areas in northwestern Minnesota (see results section F, Tables 7 and 8).

All active nest sites contained eggs or egg shell fragments, while nest sites of unknown status provided no evidence that the nest had been used. Several speculations about why traces of eggs were not detected at five of the nest sites were plausible: some may have been practice nests built by young pairs that were not yet breeding; the cranes may have been scared off by some disturbance before eggs were laid; a predator may have carried off the eggs so that no traces were left behind; or, egg shell remains in the vicinity of the nests may have been overlooked.

RESULTS

(A) Results of the Classification Accuracy Assessment

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

Table 2: Error matrix summarizing specific errors of omission (by row) and commission (by column) for nine information classes, where A=agricultural land, B=water, C=emergent wetland, D=sedge fen, E=disturbed grass, F=shrub fen, G=shrub swamp, H=deciduous forest, and I=coniferous forest. Diagonal numbers represent the number of correctly classified pixels. Errors of omission occur when areas of a known information class are excluded from the corresponding class on the image; errors of commission occur when additional areas not corresponding to a particular information class are included in that class on the image.

CLASS	ERRORS OF OMISSION	ERRORS OF COMMISSION	CORRECT CLASSIFICATION
Agriculture	64/450=0.14	9/395=0.02	386/450=0.86
Water	0/36=0	0/36=0	36/36=1.0
Emergent Wetland	0/45=0	7/52=0.14	45/45=1.0
Sedge Fen	5/90=0.06	47/132=0.36	85/90=0.94
Disturbed Grass	21/45=0.47	38/62=0.61	24/45=0.53
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
OVERALL	187/990=0.19	187/990=0.19	803/990=0.81

Table 3: Summary of the errors of omission and commission and the percent of correctly classified pixels for each class and for the entire image.

Cohen's Kappa statistic (Khat) adjusts the percent correct measure by subtracting an estimate of chance agreement that would occur if pixels were randomly assigned to classes (Congalton et al., 1983). The expected percentage of pixels that would be correctly classified by chance agreement was estimated to be 22.6. Khat was calculated at 75.6%. According to this assessment, the classification results are 75.6% more accurate than if the image would have been randomly classified.

(B) Habitat Measurements of the Nest Sites in Espelie and Veldt Townships

NEST ID NUMBER	WIDTH	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
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

Table 4: A summary of the habitat measurements of the nest sites in Espelie and Veldt townships, where WIDTH = width of undisturbed area, HWY = distance to nearest paved highway, LD RD = distance to nearest light duty road, UN RD = distance to nearest unimproved road, BDG = distance to nearest building, AGRIC = distance to nearest agricultural land. All distances are indicated in meters.

(C) Principle Components Analysis

None of the six variables accounted for a large proportion of the variations in the nest distributions within Espelie and Veldt. The first three principle components accounted for 36.6, 64.9, and 83.5% of the variation, respectively. None of the eigenvectors of the first three principle components had a significantly large impact on the corresponding eigenvalue.

(D) Chi Square Analyses of Habitat Variables

Variables Zones of Influence	% of Area	Observed # Nests	Expected # Nests	χ^2	P-Value
Width of Undisturbed Area				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				0.87165	0.6467
1	3.81	0	0.8380		
2	47.94	11	10.5470		
3	48.25	11	10.6150		

Table 5: Summary of the chi square analysis of the four habitat variables, where % of Area = the percent of potentially suitable nesting vegetation within each zone of influence in Espelie and Veldt townships. Expected number of nests were based on twenty-two nests. Zones of influence for width of undisturbed area, distance to buildings, and distance to agricultural land are identical to those listed in Table 1. Zones associated with distance to roads refer to the combination of paved highways, light duty roads, and unimproved roads.

(E) Levels of Optimization

ZONES OF INFLUENCE FOR EACH VARIABLE			POTENTIAL HABITAT CLASS
Width of Undisturbed Area	Distance to Roads	Distance to Buildings	
1	1	1	Marginal
		2	Marginal
		3	Marginal
	2	1	Marginal
		2	Marginal
		3	Marginal
	3	1	Marginal
		2	Suboptimal
		3	Optimal
2	1	1	Suboptimal
		2	Suboptimal
		3	Suboptimal
	2	1	Suboptimal
		2	Suboptimal
		3	Suboptimal
	3	1	Suboptimal
		2	Optimal
		3	Optimal

Table 6: Summary of the levels of optimization associated with the eighteen possible combinations of the significant habitat variables. Zones of influence for the width of the undisturbed area and distance to buildings are identical to those listed in Table 1, while the road zones are those derived for the chi square analysis.

(F) Results of the Model

HABITAT	Espelie & Veldt		Poplar Grove & Golden Valley		
	% of PSNV	# Nests (active)	% of PSNV	# Nests (active)	# Nests (unknown)
Optimal Habitat	33.3	13	40.0	2	4
Suboptimal Habitat	38.4	9	26.2	1	0
Marginal Habitat	8.9	0	9.4	2	1
Unsuitable Disturbance	19.4	0	24.4	0	0

Table 7: Summary of the distribution of nest sites and status of potentially suitable nesting vegetation in the four townships, where % of PSNV = percent of potentially suitable nesting vegetation, active nests = those that contained eggs or egg shell fragments, and unknown nests = nests which were not definitively proven to be used..

Habitat	Proportion of Espelie & Veldt	Proportion of Poplar Grove & Golden Valley
Agriculture	59.6	38.3
Unsuitable Vegetation	20.5	33.3
Unsuitable Disturbance	3.9	6.9
Marginal Habitat	1.6	2.7
Suboptimal Habitat	7.7	7.4
Optimal Habitat	6.6	11.4

Table 8: Summary of the percentage of the six habitat classes within the four townships, where unsuitable vegetation equals disturbed grass, shrub swamp, deciduous forest, and coniferous forest; and unsuitable disturbance, marginal habitat, suboptimal habitat, and optimal habitat refer to the status of potentially suitable nesting vegetation.

DISCUSSION

(A) Assumptions and Limitations

(1) Limitations with the Vegetation Map

Two limitations with the satellite images prevented the generation of a detailed cover type map. While the vegetative composition of the study area in northwestern Minnesota was extremely heterogeneous, the spatial resolution of Landsat TM data (30m x 30m) was not sufficient to detect small patches of plant communities. The spatial complexity of the region made it difficult to locate enough extensive homogeneous stands for good training sites for supervised classifications.

The second and more significant limitation was a result of the spectral responses of the Landsat data. Several aspects of the desired information classes contributed to the difficulties associated with spectral responses. Some classes corresponded to communities with naturally heterogeneous compositions which cannot be reliably extracted from Landsat data. Second, distinctions among similar plant communities were not always clear because of natural gradients which existed both within and among communities. Several of the desired information classes represented an environmental gradient from open areas to heavily wooded stands. The third problem was that the desired information classes were not based on spectral characteristics detectable by the satellite.

Because of the spectral and spatial limitations, the resulting vegetation map was highly generalized. As a result, local measurements of vegetation were not feasible. For example, small emergent wetland basins were not detected by the classifier. The generalized classification also did not distinguish between subtle changes in vegetation, such as a shift from cattails to phragmites. Nor were uplands and lowlands differentiated because plant compositions of these communities were spectrally similar.

Another disadvantage with a generalized map was that boundaries between plant communities were not precisely and accurately delineated. Without distinct boundaries, habitat could not be reliably labeled as edge or interior and the degree of heterogeneity within a given area could not be characterized precisely.

Because desired information classes were not spectrally distinct and boundaries between plant communities were not accurately and precisely delineated, no finite, discrete communities were mapped. Neither the size nor the shape of plant communities were definitive on the cover type map. Consequently, although the classification was comprised of general information classes, the final map did not display large, solid blocks of single communities. Rather, areas associated with information classes were usually amorphous or scattered, and thus, measuring the size or width of a specific community was problematic. An attempt to measure the width of deciduous forest stands that were located between potentially suitable nesting vegetation and agricultural fields was unsuccessful because of this limitation.

Although the accuracy assessment indicated that eighty-one percent of the image was classified correctly, not all of the information classes exhibited high accuracies. The percent of correctly classified pixels associated with disturbed grass, shrub fen, shrub swamp, and deciduous forest were estimated at fifty-three, sixty-two, sixty-one and seventy percent, respectively. Also note that the error of commission for sedge fen/meadow was thirty-six percent, which means that a significant proportion of the area labeled as sedge fen/meadow actually corresponded to other communities. Errors of commission for disturbed grass, shrub fen, and shrub swamp were also high.

Furthermore, the results of the accuracy assessment must be reviewed with caution. Because adequate reference data were not available, some of the reference polygons used in the assessment had also been considered when gathering training statistics for the supervised classifications, and thus, results of the accuracy assessment may be inflated.

(2) Assumptions of the Vegetation Map

None of the mapped information classes represented pure communities. The degree of overlap among information classes, particularly those along environmental gradients, varied not only among classes but also among different regions within the study area. As a result, all of the classes were assumed to contain pockets of other plant communities, and more importantly, small, emergent wetlands were assumed to be scattered throughout sedge fens/meadows and shrub fens. This latter assumption was based on the fact that while most of the known nests were within small emergent wetland basins, on the cover type map many of the sites were labeled as sedge fen/meadow or shrub fen. Only emergent wetlands, sedge fens/meadows, and shrub fens were assumed to consist of substantial areas of potentially suitable nesting vegetation.

The best available indication of the presence of wetlands was provided by the three classes of potentially suitable nesting vegetation. Accurate, independent data of wetland locations were not available for inclusion in the model. Hydrology files were produced from the highly generalized, imprecise delineations of wetlands on USGS topographic maps. The county soils maps from LMIC provided no distinction between well-drained and poorly-drained soils at the township level. Unfortunately, National Wetlands Inventory data for the study area will not be available before early 1992.

Several other assumptions about the cover type map were important. All information classes, except open water, were assumed to have screening vegetation that could conceal nest sites or block the view of a nest from a road, building, or agricultural field. Areas classified as disturbed grass were assumed to have no adverse impact on nesting cranes. None of the disturbed grass was considered to be heavily managed.

Finally, all agricultural land was assumed to have the same degree of human disturbance and to provide equal foraging opportunities.

(3) Assumptions and Limitations of the Remaining Data

The road network files from LMIC had to be updated by field checking every road within the study area. Classes were assumed to reflect different frequencies of use and degrees of disturbance during a wet spring. Most roads that were marginal in a wet year may be more drivable under dry conditions. By basing the model on assumptions about road conditions during a wet spring, the final assessment of potentially suitable nesting habitat may be more liberal than it would have been if conditions were assumed to be dry. However, surveys were conducted during relatively dry years, so this assumption may not be very influential.

Two additional assumptions about the road network should be noted. All roads of a particular class were assumed to have the same level of disturbance. Secondly, private dirt farm roads and small trails were not considered to be important disturbances. Most of the private farm roads were surrounded by agricultural fields. Subsequent discussions of the road network refer to paved highways, light duty roads and unimproved roads.

Like the road network, the building locations plotted on the USGS 7.5 minute topographic maps had to be confirmed by field checking the entire study area. All buildings were assumed to have equal levels of human disturbance.

(4) Limitations of EPPL7

All geographic information systems have advantages and disadvantages. One problem with EPPL7 that may hinder modeling wildlife habitat is the inability to precisely identify edge habitat. With a raster format, the only method of recognizing habitat edges is to convert pixels along an edge to a unique class. However, pixels can only be assigned to one class per file. If the study area contains a number of unique edge habitats, separate files for each type may need to be generated. Consolidating subsequent files may be extremely difficult.

Using EPPL7 to calculate the width of a selected area was also problematic. Most EPPL7 programs that measure distances were not directionally controlled, and the one program that specifies directions was not designed for detailed calculations. In addition, the EPPL7 files had square pixels. Although the distance along the diagonal of a pixel was longer than across the side of a pixel, all distance calculations were assumed to be in equal increments.

(5) Assumptions about Crane Behavior

Several assumptions that were derived from the literature about the behavior of breeding cranes were inherent in the model. (1) Cranes nest in relatively open wetlands that typically contain screening vegetation such as tall emergent vegetation or scattered shrubs. (2) Nest sites may be found in a range of habitats from small isolated marshes to large homogeneous wetlands. (3) Distances from the nest site to the nearest human disturbance is a function of the availability of quality habitat, the number of cranes in the area, and the levels of human disturbance. Distances reported in the literature are highly variable (Johnson, 1976; Carlisle, 1981; Hoffman, 1983). (4) Cranes forage in all vegetative cover types, except perhaps conifers, but select open areas more often. Wooded stands sometimes serve as cover for broods.

(B) Format of the Model

(1) Implications of Habitat Measurements

The distribution of nest sites with respect to each habitat feature was extremely variable. Because more than one landscape component may have influenced nesting pairs, high variabilities in the distribution of nests may have been a result of combinations of variables and/or factors that were not considered. While descriptive statistics of the distribution of nest sites were not very useful, two thresholds were suspected to influence how cranes responded to habitat variables. Nesting pairs were assumed to have minimum tolerances to disturbances. Below these thresholds, distances to disturbances or the width of undisturbed areas were deemed unacceptable. On the other hand, human disturbances and the width of an undisturbed parcel of land were no longer considered to influence nesting cranes beyond certain maximum distances. Obviously, roads and buildings do not impact areas beyond where they can be seen or heard.

(2) Assigning Zones of Influence for Six Variables

In part, zones of influence were selected according to three assumptions about crane behavior. (1) Larger, undisturbed areas were considered more desirable than smaller patches of undisturbed land because cranes have historically nested in expansive, isolated areas (Walkinshaw, 1949; Coffin and Pfannmuller, 1988). (2) The likelihood of finding nesting pairs was presumed to increase as the distance to human disturbance increased. (3) Areas near agricultural land were regarded as more desirable than remote locations because agricultural fields provide important foraging habitat for cranes.

The immediate vicinity around a human disturbance was considered undesirable for nesting cranes. The size of this unsuitable zone was chosen based on the minimum distance to a nest in Espelie and Veldt townships or on other known nest sites in that region of the state. For example, the minimum acceptable distance to a light duty road was determined from a nest in East Park Wildlife Management Area in Marshall county, which was closer to a light duty road than any of the nests in Espelie and Veldt. Consequently, none of the nests in Espelie or Veldt were located within any of the undesirable zones. If all known nests were far from a considered variable, conservative minimum acceptable distances were estimated to prevent eliminating too much area as potential nesting habitat. Likewise, the minimum acceptable width of undisturbed land was conservative to ensure that more area was considered potentially suitable.

Beyond a certain threshold, human disturbances were assumed to have no impact on nesting cranes. The third zone of influence associated with roads and buildings and the second zone of influence for the width of the undisturbed area were regarded as the cutoff points. These distances were selected to ensure that most of the nest sites in Espelie and Veldt townships were located within the presumed optimal areas. Familiarity with the study areas acquired during the ground surveys was also used to reasonably estimate appropriate distances.

The zones of influence from agricultural fields were listed in reverse order to demonstrate that agricultural land provided important foraging habitat for cranes. The third zone of influence (1-120 meters) was selected because half of the known nests in Espelie and Veldt were located within 120 meters from an agricultural area. The remaining eleven nests were scattered between 121 to 600 meters from agriculture. Because none of the nests were found beyond 600 meters, this was used as the cutoff point for the least desirable, first zone of influence.

(3) Statistical Analyses of Habitat Variables

The results of the principle components analysis were inconclusive. None of the habitat features was responsible for a large proportion of the variability in nest distributions. Instead, all of the factors contributed fairly evenly to the observed variability. As previously discussed, distances to human disturbances and the width of the undisturbed area were considered to be unimportant beyond a threshold point. Although most of the nests in Espelie and Veldt were located in the presumed optimal areas, the distribution of nests which was highly variable within these zones affected the results of the principle components analysis.

The chi square analysis was used to determine whether any discrepancies between the observed and expected distributions of nests existed. The expected distributions of nests were calculated using the proportions of potentially suitable nesting vegetation within each zone of influence of a landscape feature. A more applicable test would have been to look for patterns favoring optimal zones of influence for each variable.

The results of the chi square analysis indicated that both the size of the undisturbed area and the proximity to the road network significantly influenced the locations of crane nests. A visual comparison of the observed and expected distributions of nests showed that cranes favored optimal zones of influence for these two variables. Distances to buildings and to agricultural fields did not significantly impact the selection of nesting habitat. However, the proximity to buildings was somewhat important; pairs tended to select further distances from buildings than what was expected. Distance to agricultural land appeared to have no influence on the nest distributions in Espelie and Veldt townships. 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.

Because estimates of the zones of influence tended to be conservative (see discussion section B2), results from the chi square analysis may also be conservative. By keeping zones of influence short, more potentially suitable nesting vegetation was located in the optimal and suboptimal zones. If the nest distributions would not change from shifting the zones of influence outward, numbers of nests within each zone would remain the same while the proportion of potentially suitable nesting vegetation would be reduced in the optimal and perhaps suboptimal zones. Thus, the chi square analysis may underestimate the influence of a habitat variable.

(4) Characterizing Potentially Suitable Nesting Habitat

To characterize potentially suitable nesting habitat, all possible combinations of habitat variables should ultimately be compared. To illustrate this need consider combinations of the two habitat variables that significantly influenced the distribution of nests. Which, if either, of the following was more desirable to breeding cranes: a site in a narrow undisturbed area within zone two from a road or a site in a large undisturbed area within zone one from the same type of road? Likewise, if a site was within a narrow undisturbed area, would the suitability of the site differ depending on whether it was within zone one or zone two from a road?

A quantitative analysis of all the combinations of variables was not feasible with a very small sample size and relatively large number of possible habitat combinations. Therefore, no evidence was produced to indicate whether the impacts of habitat variables were additive or whether the least desirable feature present controlled nest site selections. With a small sample size, the best indications of which variables significantly influenced where cranes nested were the results of the chi square analysis. Unfortunately, the chi square analysis could not differentiate among the three road classes.

Differences within and among habitat variables were systematically compared. A series of ranks and weights were devised to indicate which variables and which zones of influence within each variable had the most impact on breeding cranes and to assign a value to each pixel associated with potential nesting vegetation. However, this system did not provide a logical means of distinguishing among potentially optimal, suboptimal, and marginal habitat.

Rather than methodically assigning values to pixels of potentially suitable nesting vegetation, each pixel was categorized according to the specific combination of habitat variables at that location. Three variables; size of undisturbed area, distance to roads, and distance to buildings, were used to determine whether a given pixel was potentially optimal, suboptimal, marginal, or unsuitable. Assumptions about crane behavior that were already described (discussion section B2) and the results of the chi square analysis were considered to categorize combinations of variables.

All locations unaffected by roads and buildings were considered potentially optimal habitat. In addition, sites in wide undisturbed areas, unaffected by roads but within zone two from a building were regarded as optimal because the presence of buildings did not significantly hinder nesting pairs. Potentially suboptimal habitat was characterized as wide undisturbed regions relatively near roads (zones 1 and 2) and/or buildings (zone 1). Narrow bands of undisturbed vegetation were also considered suboptimal if the area was not impacted by roads (zone 3) and if buildings were only a minor disturbance (zone 2). Whereas, narrow bands of undisturbed land were categorized as potentially marginal habitat when either roads (zone 1 and 2) or buildings (zone 1) affected the area.

(C) Application of the Model

(1) Why Aren't All Crane Pairs in Optimal Habitat?

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. A second reason may be that, 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 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 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 are available.

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, but did not account for local variability. Cranes typically nest in emergent wetlands that contain standing water. Unfortunately, data on water levels and specific information about vegetation were not available. Incorporating data on local variability would probably alter the status of some areas.

Besides local features being excluded from the model, other landscape variables could not be reliably measured with EPPL7 and the available data. For example, cranes were suspected of selecting against wetlands which were isolated from agricultural land by large forested stands. Although chicks are precocial, they do not fledge for approximately 60 days (Walkinshaw, 1949). Large stands of dense forest were presumed to be too much of a barrier for young broods to cross. Because of limitations previously addressed (discussion sections A1 and A4), the width of forested stands could not be accurately measured. Consequently, wetlands that were isolated by large forested stands were not identified, and wetlands within the large, undisturbed region in the eastern side of East Park township were labeled as potentially optimal habitat. Although these emergent wetlands contained standing water and were far from human disturbances, they were separated from agricultural fields by extensive forested stands. Because no nest sites were found in this area, perhaps wetlands in this region were not optimal nesting habitat.

To make matters more complicated, active nest sites may have been undetected during aerial surveys. Espelie was the only township that was surveyed by helicopter on two days during a nesting season. Each of the other three townships were surveyed by air only one day during a nesting season. Of particular concern were the surveys in Poplar Grove and Golden Valley. During the first three weeks in May 1991, the helicopter was grounded for repairs, so surveys of the two townships were conducted on the 27th and 30th of May. Being late in the season, early nests may have gone undetected. During the aerial survey in Golden Valley, a suspected brood was detected, but no inactive nest was found in their vicinity. Furthermore, Golden Valley was not thoroughly surveyed because of problems with the helicopter. (Surveys were conducted in Espelie in 1990 and in Veldt in 1989 and 1990.)

(2) Applicability of the Model

Before the model can be applied to additional areas covered in the vegetation map, the road network file from LMIC must be updated and a file of building locations must be generated. Unfortunately, both of these procedures require extensive field checking.

The output from the GIS model does not differ greatly from interpretations of high resolution aerial photography. In fact, if emergent wetlands could be detected, aerial photos would provide more precise information about a study area. However, two important limitations with aerial photography should be noted. Not only would a large number of high resolution photographs be needed to cover an extensive area, but also each photograph would need to be manually interpreted and entered into the GIS. If a reliable, systematic and documentable procedure could be developed to classify satellite data, the temporal resolution of Landsat would provide an opportunity to detect changes in wetlands and potentially suitable nesting habitat over a large area relatively quickly.

CONCLUSIONS AND RECOMMENDATIONS

Spatial and spectral variability of plant communities in Roseau and Marshall counties limited the detail of the cover type map that could be derived from a single Landsat scene. The lack of distinct spectral responses of the desired information classes was the primary problem. Distinguishing among similar vegetative communities was difficult because of natural gradients which existed within and among communities. The resulting cover type map from the satellite data contained generalized plant communities that exhibited varying degrees of overlap. Mapped borders between different communities were not necessarily accurate or precise. An accuracy assessment of the Landsat classification was conducted but must be reviewed with caution because of the lack of adequate reference data.

Prior to additional classification attempts, tests should be run to determine whether desired information classes are spatially and spectrally distinguishable. In heterogeneous areas, the spatial complexity of the vegetation may be too great to map single communities. If desired information classes are not spectrally unique, the classifier will not adequately discriminate among classes. Rather than training the classifier on inappropriate classes, the desired information types should be redefined so that they correspond to distinct spectral properties. Multitemporal classifications, which require two or more Landsat images, would likely improve the capability of identifying the spectral responses of information classes.

The model's level of detail was limited primarily by the generalized map of plant communities and by the absence of accurate, precise data on wetland locations. A series of assumptions about the composition of mapped vegetation classes, the levels of disturbance imposed by buildings and different road types, and the current understanding of the nesting behavior of Greater Sandhill Cranes were fundamental to the model. The principle assumption was that potentially suitable nesting habitat was found only in areas classified as emergent wetlands, sedge fens/meadows, and shrub fens.

Suitability of potential nesting vegetation was determined by three variables: width of undisturbed area, distance to roads, and distance to buildings. Using observations of known nest sites and assumptions about crane behavior, each of the three variables was divided into three or four zones of influence which represented different levels of suitability. Habitat was characterized as potentially optimal, suboptimal, marginal, and unsuitable according to specific combinations of the zones of influence associated with the three habitat variables. Suitability depended upon the degree of isolation from specific cultural features in the landscape and the estimated frequencies of human disturbances from roads and buildings that impacted a site.

Results from a chi square analysis indicated that the width of an undisturbed area and the proximity to roads both significantly affected where pairs nested, while the distance to buildings was somewhat influential. A fourth variable, distance to agriculture, was not included in the model because the chi square analysis indicated that proximity to agricultural land did not influence the distribution of nest sites. However, distance to agriculture may be an important feature in areas where farming practices are not so common.

Additional data and a larger sample of nest sites could improve the descriptive GIS model. Incorporating specific locations and types of wetlands, including water regimes, would have enhanced the precision of the model. The most obvious source of such data is the National Wetlands Inventory, but their database for northwestern Minnesota is not expected to be complete before early 1992. Another means of improving the model would be to include a more rigorous test of the habitat variables. A three-way analysis of variance would provide a quantitative assessment of the importance of the different zones of influence from each variable. However, to conduct an analysis of variance, a much larger sample of nest sites would be necessary.

Considering the limitations encountered during this research, if a wildlife habitat model requires an analysis of edge habitat, a satellite classification would be recommended only for areas comprised of large, homogeneous, and spectrally unique plant communities. Furthermore, ARC/INFO would provide a better GIS tool than EPPL7 for measuring the length and abundance of edge habitat.

Results of the model in all four townships indicated that some pairs nested in marginal and suboptimal areas despite the availability of optimal habitat. The absence of nesting pairs in optimal habitat may be accounted for by the inability to model or detect certain landscape features and local variables, the uncertainty that all nest sites in the study area were known, and the unanswered questions concerning the behavior of nesting pairs. To alleviate some of these problems, aerial surveys should be conducted in the beginning, middle, and end of the nesting season to increase opportunities to detect nesting pairs, particularly early and late breeders. Additional long-term studies are needed to address questions concerning the breeding behavior of cranes.

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