Remote Sensing of Wetland Habitat: A Wood Stork Example

*Michael E. Hodgson** and *John R. Jensen*
Department of Geography, University of South Carolina, Columbia, SC 29208
Halkard E. Mackey, Jr.
E. I. du Pont de Nemours and Company, Inc. Savannah River Laboratory, Aiken, SC 29808
Malcolm C. Coulter
Savannah River Ecology Laboratory, Aiken, SC 29801

ABSTRACT: Foraging sites for an endangered species, the Wood Stork (*Mycteria americana*), were identified using Landsat Thematic Mapper (TM) data obtained on 5 May 1984 for a region in north-central Georgia. This was accomplished using innovative "guided clustering" techniques applied to known Wood Stork foraging sites in the Birdsville Colony in Georgia. The signatures for known foraging sites were then geographically extended to a 1519-km^2 region surrounding the Birdsville Colony. Thematic maps were produced and foraging area acreages were computed, providing a regional assessment of existing and potential Wood Stork foraging sites. Seventy-four percent of 39 known foraging sites were correctly classified. Most of the error was associated with sites that approached the 30 by 30-m Landsat TM spatial resolution.

INTRODUCTION

WOOD STORKS (*Mycteria americana*) are the largest wading bird found in the southeastern United States. They weigh 2.0 to 3.4 kg and are sightly taller than 1 m with a 1.7-m wing span. During the last 50 years the Wood Stork population has decreased from an estimated 20,000 breeding pairs in 1930 to 4,800 pairs in 1980 and 3,650 pairs in 1983 (DOI, 1983a,b). The major threats to the existence of the Wood Stork are loss of feeding habitats with adequate food resources and reduction in the number of available nest sites (Ogden and Patty, 1981). At their present rate of decline, breeding Wood Storks in the United States may be extinct before the end of this century. This declining population prompted the United States Fish and Wildlife Service to list the Wood Stork as an endangered species (Baker, 1982; DOI, 1984).

Twenty-three Wood Stork colonies were identified in Florida and Georgia in 1982 (Baker, 1982). The most northern and inland Wood Stork colony in the United States is the Birdsville Colony located at Big Dukes Pond, a 567-ha cypress swamp, 12.6 km (7.9 mi) from the city of Millen in Jenkins County, Georgia (Figure 1). Beginning in 1983, a number of *in situ* studies were conducted to monitor the population of the Birdsville Colony and its reproductive success, nesting habitats, and foraging characteristics (Meyers, 1984; Coulter, 1986).

These surveys of the location and characteristics of Wood Stork foraging habitats were primarily based on tracking selected storks from the Birdsville Colony to their foraging habitats. Using a light aircraft, the rookery was circled at a reasonable altitude by an observer until a Wood Stork left the colony. The Wood Stork was followed until it landed and began foraging. The location of the foraging site was recorded, and a ground crew was directed to the site for *in situ* measurements. These sites identified by following selected storks were referred to as *known* sites. While this method of surveying Wood Stork foraging characteristics is accurate and allows detailed *in situ* measurements to be made, it does not provide information on the total amount and location of the other foraging habitats.

The objective of this remote sensing study was to evaluate the use of Landsat Thematic Mapper (TM) data for estimating the potential foraging acreage and locations which may be utilized by the Wood Storks from the Birdsville Colony. Spectral signatures of known stork foraging sites were used to predict the amount and location of potential foraging land-cover type in a 1519-km^2 study area. While other studies have examined the use of satellite imagery for mapping wildlife nesting habitats (Lyon, 1983), this study represents the first attempt to use Thematic Mapper data to evaluate foraging habitats of any wide-ranging, foraging wading bird such as the Wood Stork. The location and acreage of the foraging sites a certain distance from the Birdsville Colony (e.g., 10 kilometres) were then compared using a Geographic Information System (GIS) proximity analysis.

KNOWN WOOD STORK FORAGING SITES

Based on Wood Stork surveys described above by Meyers (1984) and Coulter (1986), it was known that approximately 80 percent of the Wood Stork foraging sites were within 20 km of the Birdsville Colony, especially in the early part of the breeding season when feeding of the young chicks is most important. The general distribution of adult Wood Stork foraging sites for *in situ* data collected in the spring and summer of 1984 is shown in Figure 1 (Coulter, 1986). Wood Storks fly to foraging sites by flapping or by soaring and gliding. Breeding adults complete from one to several trips daily between foraging areas and the colony depending on the distance to the feeding areas. Distances to foraging sites have been reported up to 130 km, but are usually a maximum of 60 to 80 km (Ogden and Patty, 1981).

Wood Storks are especially adapted to foraging in shallow water. They feed in water about 25-cm deep and, because the leg length of adult storks reaches only about 50 cm, this imposes an upper limit on the foraging water depth (Coulter, 1986). They subsist on a diet of aquatic species - primarily fish, amphibians, and crustaceans.

Storks forage in both natural and man-made wetlands including ponds, marshes, cypress and hardwood swamps, drainage ditches, and submerged, abandoned roads. The sites are usually covered with still or slow-moving water. The swamps are mostly open but can range from sparse to almost full canopy closure. Sixty-three percent of all foraging sites have a canopy cover of less than 20 percent, and 89 percent of all sites have less than 65 percent canopy coverage (Coulter, 1986).

DATA SOURCES

As previously mentioned, the foraging range of the Wood Stork may extend up to 60 to 80 kilometres from the colony. Thus, mapping the foraging habitats of a stork colony requires

*Presently with Department of Geography, University of Colorado, Boulder, CO 80309.

PHOTOGRAMMETRIC ENGINEERING AND REMOTE SENSING,
Vol. 53, No. 8, August 1987, pp. 1075–1080.

0099-1112/87/5308–1075$02.25/0

1984 WOOD STORK FORAGING SITES

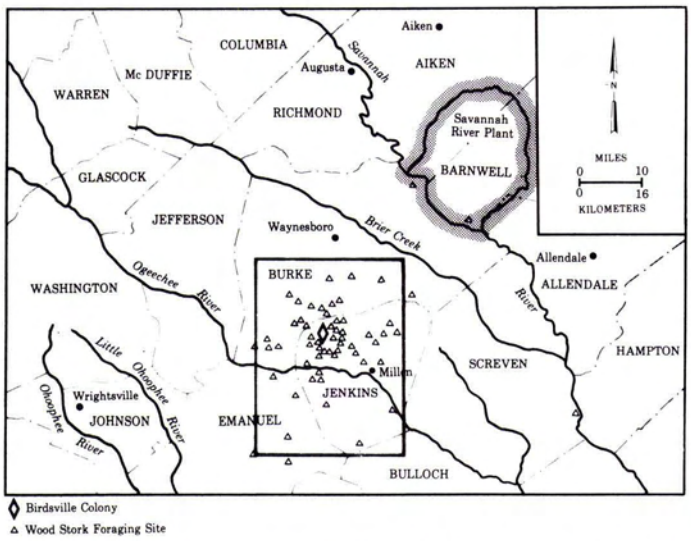

FIG. 1. Map of foraging sites around the Birdsville Colony in 1984. The remote sensing study area is identified (from Coulter, 1986).

a geographically extensive data source. Both the MSS and the TM sensor systems onboard the Landsat satellite provide coverage of the entire study area every 16 days. One of the imaging systems, the TM, has a spatial ground resolution of 30 by 30 metres and seven spectral measurements in the visible, near- and middle-infrared, and thermal infrared portions of the electromagnetic spectrum. These spectral bands and the relatively high 30- by 30-m spatial resolution were anticipated to be well suited to mapping wetlands vegetation and shallow water habitats used by the Wood Stork.

Based on previous wetland mapping research in the southeastern United States, it was known that imagery obtained in the spring provided improved wetland discrimination (Jensen *et al.*, 1984; Jensen *et al.*, 1986). Therefore, a near cloud-free, late spring TM image obtained on 5 May 1984 was utilized for this analysis.

Ground truth information of known foraging sites was available from low altitude 35-mm natural color oblique aerial photography taken by Savannah River Ecology Laboratory (SREL) personnel who track the Wood Storks, and from *in situ* photography and vegetation measurements obtained at the foraging sites (Coulter, 1986). Typical sites contained open water, shallow swamps, marshes, and ponds with lower percentages of emergent and submergent vegetation.

Natural color vertical aerial photography at 1:147,800 scale was obtained on 18 November 1983. Color infrared photography at approximately 1:62,000 scale was obtained on 9 March 1981 by the National High Altitude Photography (NHAP) program. This photography was useful for identifying other land-cover classes to be included on the foraging maps.

To examine the feasibility of using Landsat TM imagery to map foraging habitats, a 1534 row by 1100 column subscence centered on the Birdsville Colony was extracted from the 5 May 1984 TM data. This large data base was adequate for mapping land cover up to 14 kilometres away from the colony site at Big Dukes Pond. A portion of the study region is shown in Plate 1A. (Because of the magnitude of the study region and the relatively small size of the foraging sites, only a portion of the region centered on the Birdsville Colony site will be used to illustrate concepts discussed in this article.)

METHODOLOGY

KAUTH-THOMAS TRANSFORMATION

Because the TM imagery contains spectral measurements in seven bands and the study region was so large, it was important to reduce the dimensionality of the dataset. Rather than selecting a subset of the spectral bands, information from all six of the visible and near- and middle-infrared bands was incorporated by performing a Kauth-Thomas transformation of the data using the coefficients listed in Table 1 (Kauth and Thomas, 1976; Crist and Cicone, 1984). The Kauth-Thomas transformed image of a portion of the Birdsville Colony study area is shown in Plate 1B. The transformation reduced the dimensionality from six bands to three spectral features representing measures of brightness, greenness, and wetness (Jensen, 1986). These features were considered to be ideal for the identification of Wood Stork foraging habitats.

TRAINING SITES FOR DEVELOPING SIGNATURES

The goal of this project was to map the land-cover categories representative of potential Wood Stork foraging acreage in the study area. A number of other land-cover categories exist in the study area such as forest, agricultural fields, clearings, deep water, etc. Mapping these "other" land-cover categories was not of primary importance. However, the available digital image classification software performs most efficiently if representative categories of all land-cover categories in the study area exist in the classification scheme.

For the above reasons, a three-step classification procedure using "guided clustering" techniques was performed to allow more attention to be directed toward the Wood Stock foraging categories. The first step identified multispectral clusters for cover types representative of foraging cover, i.e., shallow water and macrophytes. Signature for land-cover categories other than foraging cover were determined in the second step. Finally, the two sets of clusters were merged together and the entire study area was classified.

The study region contained 1.68 million pixels; therefore, it was undesirable to attempt to use the entire scene for signature development. Using a methodology similar to the "multi-cluster blocks" technique presented by Fleming and Hoffer (1977), small areas containing known foraging habitats as well as other types of land cover found in the region were chosen. Twelve 50- by 50-pixel subscenes containing nine of the known foraging sites and their surrounding area together with an additional three areas of other types of land cover found in the region were extracted from the study area (Plate 2). These 12 subscenes were used in the guided clustering approach to develop the spectral signatures for the land-cover classes.

PHASE ONE: FORAGING SITE CLUSTER DEVELOPMENT

Nine subscenes centered on known foraging sites were used to develop spectral signatures of the land-cover categories found in the sites (Plate 2). Personnel from the Savannah River Ecology Laboratory (SREL) delineated the exact areas where the storks were sighted within each foraging site (Coulter, 1986). Only pixels falling in the delineated areas of each site were used in the cluster development. A clustering algorithm was then applied to the brightness, greenness, and wetness features of the Kauth-Thomas transform data of these sites to identify natural clusters. Twenty natural clusters were identified which were then labeled as belonging to one of three categories: deep water (typically nonforaging sites), shallow water, and macrophytes (marsh). These clusters typically exhibited high wetness values and relatively low greeness values (Figure 2).

PHASE TWO: BACKGROUND CLUSTER DEVELOPMENT

Spectral signatures for the other land-cover categories found in the study region were developed using the areas surrounding the delineated known foraging sites and the three additional blocks representing other land cover (Plate 2). Thirty-five clusters were identified during this clustering phase. These clusters were labeled as belonging to one of seven land-cover categories: cypress/mixed swamp forest, pine/mixed upland forest, bottomland hardwoods, and agriculture/clearings/urban as well

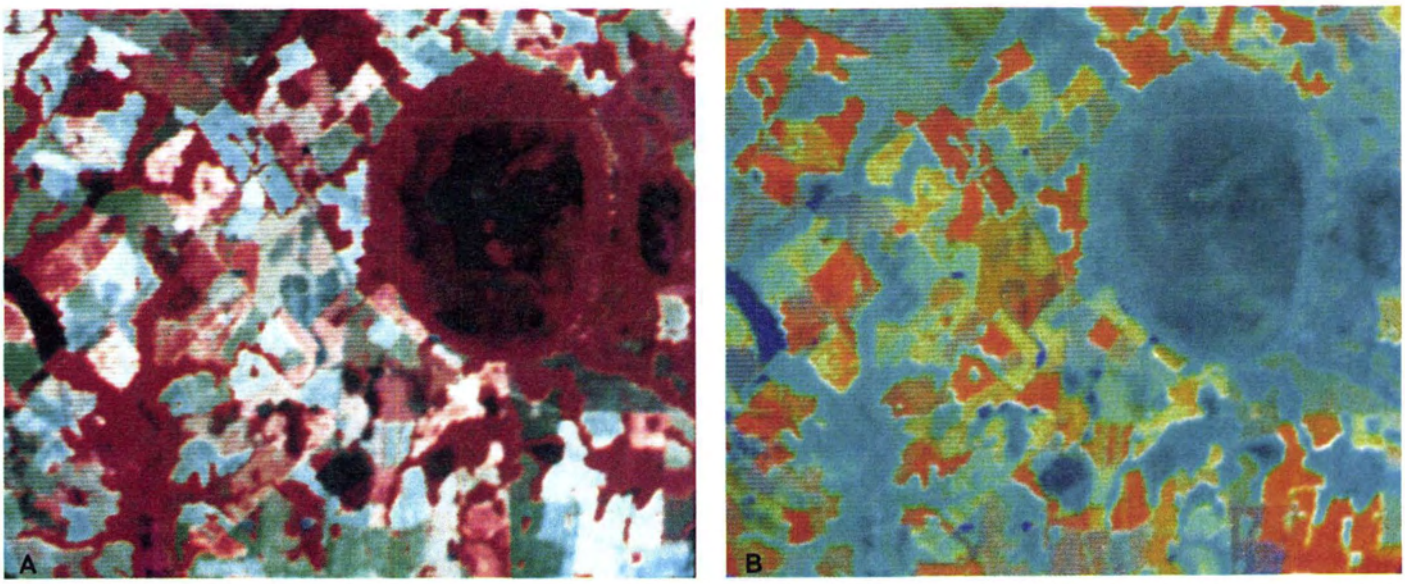

PLATE 1. (A) A color composite of a portion of the study area showing the Birdsville Colony at Dukes Pond (right of center) using TM bands 2, 3, and 4 filtered with blue, green, and red light, respectively. (B) A color composite of a portion of the study area displayed using, Wetness, Greeness, and Brightness filtered with blue, green, and red light, respectively.

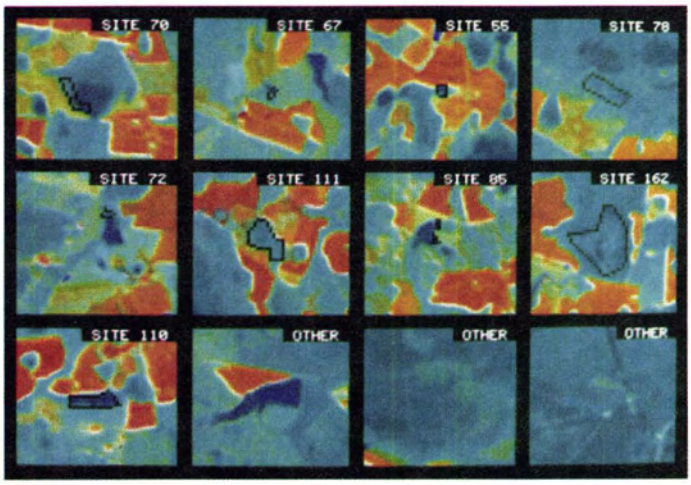

PLATE 2. Kauth-Thomas transformed images of nine known foraging areas and three areas of other land-cover classes used for cluster signature development. Foraging sites are delineated in black.

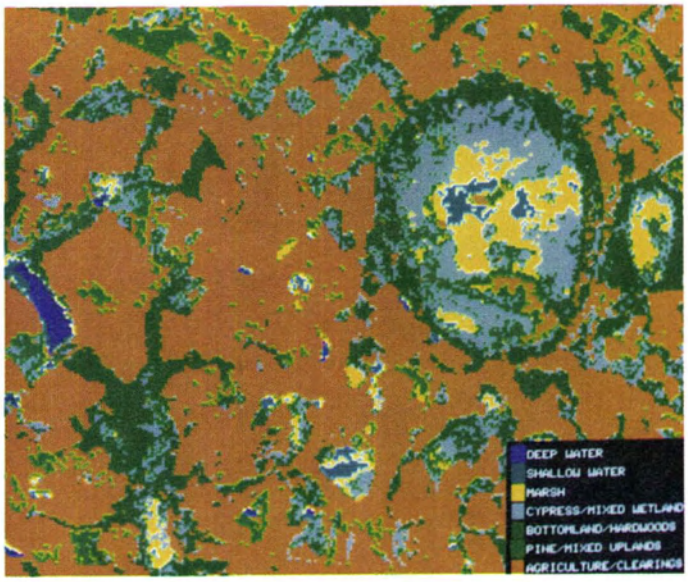

PLATE 3. A classification map of potential Wood Stork foraging cover for a portion of the Birdsville study area derived from an analysis of Landsat TM data.

as the previous three wetland classes of deep water, shallow water, and marsh. The forested land-cover cluster (cypress/mixed marsh, bottomland hardwoods, and pine) usually had higher greeness values and lower wetness values. The agriculture/clearing/urban clusters exhibited the lowest wetness values.

Clustering Merging

As the region surrounding the known foraging sites likely contained other foraging areas not identified by SREL personnel, duplicate clusters may have been identified in the second clustering phase. To avoid duplication, the two cluster sets were merged together, and similar clusters identified in phase two were deleted if they were within ten brightness values in three-dimensional spectral space (brightness, greeness, wetness) of those from phase one. Thirty-two clusters were present after the two sets were merged.

The 32 clusters were used in a minimum-distance classification of just the 12 subscenes used for cluster development. Some confusion between macrophytes, cypress/mixed forest, and pine/upland forest (e.g., a macrophyte area incorrectly classified as cypress) was apparent in this preliminary classification. A supervised approach was used to identify the spectral signatures of the confused classes. These spectral signatures were added to the original cluster set as new clusters, resulting in a final cluster set of 37 spectral clusters (Figure 2). A Wood Stork foraging map of the entire study region was then produced using the 37 spectral clusters in a minimum-distance classification procedure.

CLASSIFICATION AND RECTIFICATION

One hundred and twenty-nine ground control points (GCPs) from U.S. Geological Survey 7 ½-minute topographic maps were identified in northing and easting Universal Transverse Mercator (UTM) coordinates. The row and column coordinates of these same points were found in the TM imagery. The GCPs were used in generating the appropriate rotation, translation, and scaling parameters to rectify the Wood Stork foraging map to a UTM basemap using the nearest-neighbor resampling logic. The Wood Stork foraging map was reduced to a region extending from 384,000 east, 3,609,000 north to 417,000 east and 3,655,000 north. The rectified classification map of the Birdsville study region represented 151,959 ha. The area statistics for the regional foraging map are summarized in Table 2. A portion of the rectified foraging map is shown in Plate 3.

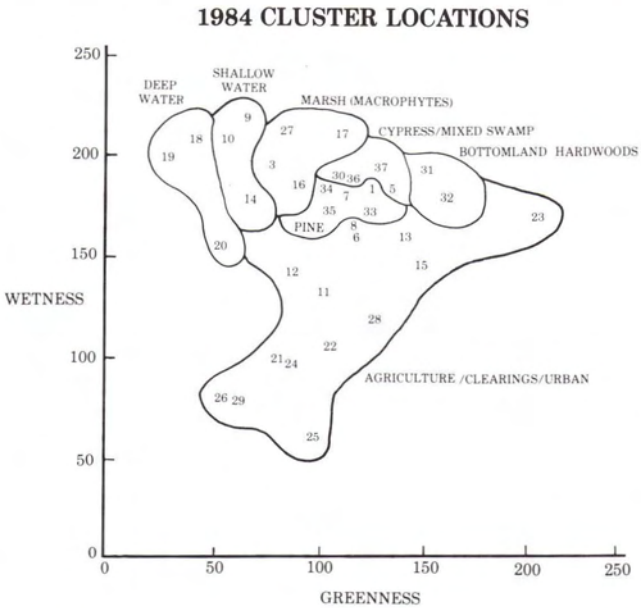

FIG. 2. Two-dimensional display in Greeness/Wetness feature space of the 37 clusters used in the classification of Wood Stork foraging habitat based on Landsat TM data.

ACCURACY ASSESSMENT

As described earlier, aerial tracking of Wood Storks provided a small but accurate data base of known foraging sites. Low altitude, oblique aerial photography and recorded locations of these known sites enabled these sites to be used as ground truth to evaluate the classification accuracy of the remote sensing derived Wood Stork foraging map. The locations of 39 of these known foraging sites were identified on U.S. Geological Survey 7 ½-minute topographic map sheets according to their UTM coordinates. The same UTM locations for these sites were found on the remote sensing derived Wood Stork foraging map and the land cover was noted. For each of the 39 known site locations, if one or more pixels of foraging land cover (i.e., shallow water or marsh) were found on the remote sensing derived map, then the site was classified accurately. If no foraging land cover was found at the site, then the site was incorrectly classified and an error of ommission had occurred. Classification accuracy of the other land-cover classes was not evaluated in this study.

The results of the Wood Stork foraging cover classification accuracy assessment are shown in Table 3. Of the 39 known foraging sites, 29 were classified correctly as foraging land cover, resulting in an overall accuracy of 74 percent. The 74 percent accuracy is similar to the 70 percent accuracy obtained by Lyon

TABLE 1. KAUTH-THOMAS TRANSFORM COEFFICIENTS FOR EACH TM CHANNEL (from Crist and Cicone, 1984)

Feature	1	2	3	4	5	6
Brightness	0.33183	0.33121	0.55177	0.42514	0.48087	0.25252
Greeness	−0.24717	−0.16263	−0.40639	0.85468	0.05493	−0.11749
Third*	0.13929	0.22490	0.40359	0.25178	−0.70133	−0.45732

*This feature is usually considered to measure the amount of wetness.

TABLE 2. STATISTICS FOR THE BIRDSVILLE COLONY RECTIFIED STUDY SCENE

Category	Hectares	Percent of Total
Deep water	555.4	0.36
Shallow water	555.0	0.36
Macrophytes (Marsh)	1,189.0	0.78
Cypress/mixed	16,792.1	11.05
Bottomland/hardwood	29,717.9	19.56
Pine/mixed upland	15,876.5	10.45
Agricultural/clearings/urban	87,272.7	57.43
Total	151,958.6	100.00

TABLE 3. FORAGING SITE CLASSIFICATION ACCURACY

Land Cover	Wood Stork Foraging Sites Assigned to Various Land Cover
Deep Water	0
Foraging Cover	
Shallow Water	12
Marsh	17
Swamp Forest	
Cypress/Mixed	5
Bottomland/Hardwoods	3
Pine/Mixed Upland	0
Agriculture/Clearings/Urban	2
TOTAL	39

Overall Classification Accuracy = 29/39 = 74%

(1983) when identifying the kestral falcon nesting habitat. Eight of the sites were "incorrectly" classified as swamp forest (i.e., cypress/mixed and bottomland hardwoods) and two sites were "incorrectly" classified as agriculture/clearings/urban.

For each of the ommission errors, the oblique aerial photography and foraging site log books were consulted to determine the cause of classification error. The eight known foraging sites classified as swamp forests were actually small canopy openings in cypress and mixed swamp forest. The openings in the canopy were not large enough to be identified on the Thematic Mapper imagery. Similarly, the two sites classified as agriculture were a small pond and an irrigation ditch — each surrounded by agricultural fields. In all cases the ommission errors were due to the inability of the 30- by 30-metre imagery to identify the smaller sites.

PROXIMITY ANALYSIS

In addition to the regional statistics, the proximity of the potential Wood Stork foraging land cover to the Birdsville Colony location was determined. The classified land-cover map was input into a geographic information system (GIS) and a proximity procedure was used to determine the total area in 1-km zones from the colony. The results of the proximity analysis are summarized in Table 4.

It was not surprising that 24.0 percent (2.7 percent shallow water and 21.2 percent marsh) of the zone (0 to 1 km) located immediately around the colony site was potential wood stork foraging cover. Thus, 69 hectares of marsh and nine hectares of shallow water were within 1 km of the colony. Further analysis of the table revealed that the total amount of potential foraging cover dramatically decreased at a distance of 2 km from the colony site and then gradually increased through a distance of 10 km. However, after a distance of 2 km, the percentage of each zone covered by foraging cover was only about 1.0 to 2.0 percent.

DISCUSSION

Satellite multispectral data have been used to map wildlife habitat over large areas (Colwell *et al.*, 1978; Neraasen *et al.*, 1981; Saxon, 1983). Analyses of TM data for the 1519 km^2 area surrounding the Birdsville Colony of the Wood Stork for the spring of 1984 indicate that this approach can be useful in evaluating the distribution and quantity of potential foraging habitat on a regional basis for this species. The Wood Stock foraging sites are typically shallow, open water environments which lend themselves to detection and mapping with TM data.

The Wood Stork has a potential foraging range of up to 50,000 km^2. However, most of the known foraging sites are within an area of about 700 to 1250 km^2 around the colony, particularly during the earlier portion of the foraging and nesting season (Coulter, 1986). As the chicks mature, the adult storks spend more time away from the nest and forage at greater distances (Coulter, 1986). The analyses performed on the TM data could identify potential foraging sites within the greater ranges of the colony.

It is important to remember, however, that this study used only one date of imagery from the spring of 1984. Foraging site availability changes throughout the breeding season and from year to year (Coulter, 1986). Thus, analyses through time are required to identify dramatic changes in Wood Stork foraging habitats. However, this initial study does indicate that the use of TM data can provide a potentially powerful inventory and management tool for assisting in the recovery of this endangered species.

TABLE 4. WOOD STORK FORAGING STATISTICS BY PROXIMITY TO COLONY*

	Distance (Km)	Total (Ha)	Cumulative (Ha)	Shallow Water		Marsh	
				Ha	% of zone	Ha	% of zone
	0 - 1	325.1	325.1	8.9	2.7	68.8	21.2
	1 - 2	905.0	1230.1	18.3	2.0	67.8	7.5
	2 - 3	1650.2	2880.3	3.3	0.2	18.3	1.1
	3 - 4	2195.3	5075.6	15.0	0.7	28.4	1.3
	4 - 5	2808.4	7884.0	6.4	0.2	28.1	1.0
	5 - 6	3537.4	11421.4	9.8	0.3	32.9	0.9
	6 - 7	3922.6	15344.0	10.3	0.3	35.2	0.9
	7 - 8	4808.2	20152.2	30.1	0.6	57.4	1.2
	8 - 9	5458.3	25610.5	27.1	0.5	56.8	1.0
	9 - 10	5928.1	31538.6	28.4	0.5	50.9	0.9
TOTAL	1 - 10	31538.6	31538.6	157.7	5.0	444.6	1.4

*Area statistics listed were calculated using whole number pixels as radius measurements from the colony site (e.g., 1-33 pixels away for 0-1 Km, 34-66, 67-100, etc.).

ACKNOWLEDGMENTS

The authors would like to express their gratitude for the assistance of Albert L. Bryan in locating and describing the known Wood Stork sites and James W. Romines for graphic support. The information contained in this article was developed during the course of work under contract No. DE-AC09-76/SR00001 with the U.S. Department of Energy.

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