Monitoring Wood Stork Foraging Habitat Using Remote Sensing and Geographic Information Systems

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ABSTRACT: Wetland habitats suitable for foraging by the Wood Stork (*Mycteria americana*) were inventoried and analyzed using remotely sensed imagery, digital image processing, and geographic information system (GIS) techniques. Maps of foraging habitats were created from Landsat Thematic Mapper imagery, one for a "wet" year and one for a "dry" year. Change detection, proximity to the Wood Stork Colony, and size of foraging site analyses were performed on the maps using GIS algorithms to obtain quantitative foraging habitat statistics. Results of the analyses indicate a 47 percent reduction in foraging cover during the "dry" year. The largest concentration of foraging cover was within about one kilometre of the Colony nesting site during both years.

INTRODUCTION

MONITORING AVIAN HABITATS requires a thorough knowledge of the foraging characteristics and nesting habitats of the species, and a geographically extensive data source. Because many birds have a far-ranging foraging area, the inventory of foraging habitats using *in situ* survey techniques is an extremely time-consuming and costly method (Coulter, 1986b). Several studies have documented methods for using digital image processing and remotely sensed imagery to map wetland habitats used by waterfowl (Work and Gilmer, 1976; Colwell *et al.*, 1978; Nerassen *et al.*, 1981; Koeln *et al.*, 1986; Hodgson *et al.*, 1987). Others have used remote sensing to map the upland nesting habitats of Kestrel falcons (Lyon, 1983) and Ruffed grouse (Kind *et al.*, 1986). For a more thorough analysis of the spatial and temporal characteristics of habitats, processed remotely sensed data may be used as input to a geographic information system (GIS). Lyon (1983) utilized a single-date of Landsat MSS imagery and spatial measurements commonly found in a GIS, such as distance, contiguity, shape, and area, to predict the nesting locations of Kestrel falcons. The proximity of foraging cover of the Wood Stork (*Mycteria americana*) with respect to the colony nesting area was computed using a GIS by Hodgson *et al.* (1987). While the focus of Lyon's study was to identify the nesting areas of a species, mapping the foraging cover for a single colony nesting area was central in the previous study of Wood Stork foraging habitats. The foraging range of the Kestrel falcon and Wood Stork are dramatically different. The Kestrel falcon nesting area is approximately 0.5 km^2 while the foraging area of a Wood Stork colony may range over 400 km^2.

An assessment of an avian foraging habitat requires not just a single year inventory, but monitoring of the habitat through time. For example, as Wood Stork foraging habitats are confined to shallow water ecosystems, the wetlands can and do *change* from one year to the next and during the year due to changes in precipitation patterns. Furthermore, the location of the foraging habitats with respect to a nesting site is important as adequate resources must be available in close *proximity*, particularly during the earlier stages of the breeding season. Finally, the identification of the relative *size* of foraging sites can be ranked in habitat importance if the size and distance of each site from the nesting site are known.

The overall focus of this study was to monitor the available foraging cover for Wood Storks from the Birdsville Colony in east-central Georgia. This study elaborates on the monitoring of Wood Stork foraging acreage using remotely sensed imagery and GIS techniques by comparing habitats during a "wet" and "dry" year. Specific objectives were to (1) map the foraging cover available during a "wet" and a "dry" year, (2) determine the overall and site-specific reduction or increase in foraging cover between the two years, (3) inventory the amount of foraging cover with respect to distance from the Colony, and (4) identify the size of individual foraging cover sites and their distance from the Colony.

THE BIRDSVILLE COLONY WOOD STORKS

WOOD STORK CHARACTERISTICS

Wood Storks are among the largest wading bird found in the southeastern United States. They generally weigh 2.0 to 3.4 kg, are slightly taller than 1.0 m, and have a 1.7-m wing span. Breeding adults complete from one to several trips daily between the colony and foraging areas depending on the distance to the feeding areas (i.e., fewer trips to more distance areas). Wood Storks are especially adapted to foraging in shallow water about 25 centimetres deep. Because the leg length of adult storks reaches only about 50 cm, this imposes an upper limit on the foraging water depth (Coulter, 1986a). Their diet consists principally of 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 foraging sites are mostly open or with limited tree cover and usually covered with still or slow-moving water. During the last fifty years the Wood Stork population in the United States has decreased from an estimated 20,000 breeding pairs in 1930 to 3,650 pairs in 1983 (DOI, 1983a,b). The major threats to this endangered species are loss of feeding

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habitats having adequate food resources and reduction in the number of available nest sites (Ogden and Patty, 1981; DOI, 1983c).

The most northern and inland Wood Stork colony in the United States is the Birdsville Colony located at Big Dukes Pond, a 567-hectare 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 studies were conducted to monitor the reproductive success, nesting habitats, and foraging characteristics of the Birdsville Colony (Meyers, 1984; Coulter, 1986a,b,c).

Known Foraging Sites

Meyers (1984) and Coulter (1986b, 1986c) used a fixed-wing aircraft to follow Wood Storks to foraging sites. They found that approximately 83 percent of the foraging sites were within 20 km of the Birdsville Colony during 1984 and 90 percent in 1985. The mean distance to foraging sites from the colony site for the years 1983 through 1985 was 14.36 km (Table 1). The general distribution of adult Wood Stork foraging sites for data collected in the spring and summer of 1985 is shown in Figure 1 (Coulter, 1986b). Each site was annotated on a U.S. Geological Survey 7-1/2 minute topographic map and the Universal Transverse Mercator coordinates of each site were recorded. Ground truth information was available from low altitude 35-mm, natural color oblique aerial and *in situ* photography taken by personnel of the Savannah River Ecology Laboratory (SREL), University of Georgia, who track the Wood Storks (Coulter, 1986b).

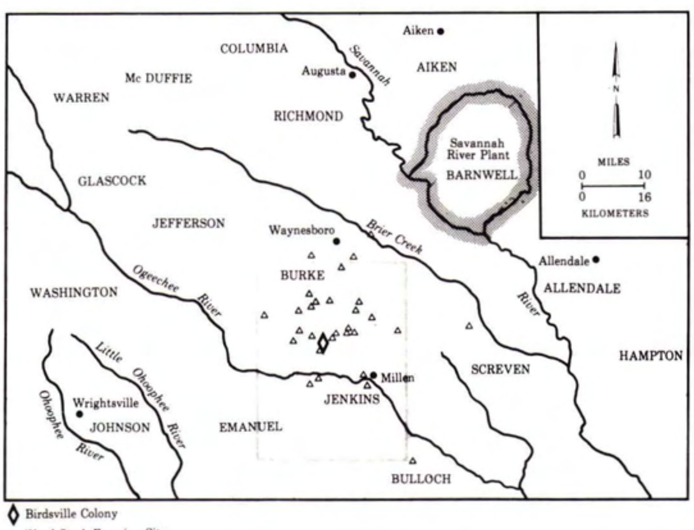

FIG. 1. Map of foraging sites around the Birdsville Colony identified during 1985. The remote sensing study area is identified (from Coulter, 1986b).

TABLE 1. MEAN DISTANCE OF FORAGING SITES FROM THE BIRDSVILLE COLONY (COULTER, 1986b)

Year	Number of Sites	Mean Distance (km)	Standard Deviation
1983	30	17.39	15.60
1984	55	13.75	13.16
1985	39	11.94	7.87
Mean	–	14.36	–

REMOTE SENSING INVENTORY

Remotely Sensed Data Sources

Mapping the foraging habitats of a stork colony requires a geographically extensive data source. The Multispectral Scanner (MSS) and the Thematic Mapper (TM) sensor systems onboard the Landsat-4 satellite provide coverage of the Birdsville Colony study area every 16 days. The TM sensor has a spatial ground resolution of 30 by 30 metres for six of its seven spectral bands. The 30 by 30-m spatial resolution and the visible (TM1, TM2, and TM3), near (TM4), and middle-infrared (TM5 and TM7) spectral bands were previously shown to be suitable for mapping wetlands vegetation and shallow water habitats used by the Wood Stork (Hodgson *et al.*, 1987).

To compare yearly fluctuations in shallow water foraging environments, it was necessary to acquire at least two TM data sets, ideally, in "wet" and "dry" years. The 1984 and 1985 rainfall totals for the colony site are summarized in Table 2. Throughout the chick-raising season (May through July) in 1984, there was greater than average rainfall. However, from September, 1984, through May, 1985, there was an extreme shortage of rainfall, and the Storks had low reproductive success. It is believed that these two years are representative of the general extremes in foraging habitat availability in this study area.

Late spring TM data were acquired for the wet and dry years on 5 May 1984 and 22 April 1985, respectively. Late spring is not only an important time for chick hatching and feeding, it is also the ideal time of the year to discriminate between the major wetland classes found in the southeastern United States using remote sensor data (Jensen *et al.*, 1984).

Subscenes of each image, centered on the Birdsville Colony at Big Duke's Pond, were extracted. This large database was adequate for mapping land cover up to 14 km away from the Colony at Big Duke's Pond. The entire study area covered portions of Jenkins, Burke, Emanuel, and Bulloch Counties in southeastern Georgia. A portion of the study area for the two dates is shown in Plate 1. (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 the concepts discussed in this report). Natural color vertical aerial photography at 1:147,800 scale, obtained on 18 November 1983 and color infrared photography acquired on 9 March 1981 from the National High Altitude Photography (NHAP) program were also available.

Transformation and Multispectral Cluster Identification

As the TM data contained spectral measurements in six visible, near-infrared, and middle-infrared bands and the study region was large, it was determined important to reduce the dimensionality of the dataset. Rather than selecting a subset of these original bands, a Kauth-Thomas transformation was applied to the data (Kauth and Thomas, 1976; Crist and Cicone, 1984). This transformation reduced the dimensionality from six bands to three spectral features representing measures of Brightness, Greeness, and Wetness (Crist and Cicone, 1984; Jensen, 1986). These features were considered to be ideal for the identification

TABLE 2. RAINFALL AT MILLEN, GEORGIA IN 1984 AND 1985 IN INCHES

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1984	3.61	4.50	5.38	2.51	6.95	4.02	3.38	2.98	1.19	0.99	0.62	1.48	37.61
1985	1.05	4.54	1.22	0.77	1.25	3.84	9.69	7.18	0.30	4.84	8.73	5.09	48.50

of Wood Stork foraging habitats which were shallow water areas with limited tree cover. The Kauth-Thomas transformed images of a portion of the Birdsville Colony study area are shown in Plate 1.

As the study region was quite large, containing 1.68 million pixels per band, it was undesirable to attempt to use the entire scene for signature development. Using a methodology similar to the "multi-cluster blocks" technique developed by Fleming and Hoffer (1977), small areas representative of known foraging habitats and other land cover found in the region were chosen. Fourteen 50-by 50-pixel subscenes representing known foraging sites and their surrounding area were extracted from the 1984 TM data and nine subscenes were extracted from the 1985 data. The subscenes were used in an unsupervised clustering approach to develop the spectral signatures for the land-cover classes. Additional clusters were added by the analyst in a supervised manner.

Classification and Rectification

The cluster sets for 1984 and 1985 were applied to their respective 1984 and 1985 entire study scenes to generate a preliminary classified Wood Stork foraging map of the region. Natural clusters were identified which were then labeled as belonging to one of seven categories: deep water (typically nonforaging sites), shallow water, macrophytes (marsh), cypress/mixed wetland, bottomland/hardwoods, pine/mixed uplands, and agriculture/clearings (Plate 2). The primary foraging cover were the categories of shallow water and macrophytes. The deep water areas may contain food resources; however, the water depth limits their use as a foraging site.

Ground control points (GCPs) from U.S. Geological Survey 7-1/2 minute topographic maps and the TM images were identified and used to compute the rotation, translation, and scaling parameters to rectify the 1984 and 1985 Birdsville Colony scenes to a UTM basemap with ± 0.5 pixel root mean square error (RMSE) registration accuracy. The rectified classification map of the Birdsville Colony study region included 1519-square kilometres (151,959 hectares).

Accuracy Assessment

Classification accuracy was evaluated by examining the Landsat TM derived land-cover classification at Wood Stork foraging sites which were previously verified by aerial tracking techniques. Thirty-nine and 16 known foraging sites were used to determine the accuracy of the 1984 and 1985 foraging site maps, respectively. These known foraging sites were compared to the digital foraging site map by relating the UTM coordinates of each site with mapped sites. At each site location, if one or more pixels of foraging land cover (i.e., shallow water or marsh) were found, then the site was considered to be classified accurately. If no foraging land cover was found at the site, then an error of ommission occurred. Commission errors were not evaluated, because it cannot be determined if a site had never been or will be used by Wood Storks. For this reason, the categories of shallow water and marsh are collectively referred to as "available" or "potential" foraging cover.

The Wood Stork classification accuracy assessment results are summarized in Table 3. Seventy-four and 88 percent of the known foraging sites were classified correctly for the years 1984 and 1985, respectively. Oblique aerial photography and foraging site log books were consulted to determine the cause of classification ommission error. Eight and two known foraging sites classified as swamp forests in 1984 and 1985, respectively, were actually small canopy openings in the cypress/mixed or bottomland/hardwoods categories. The openings in the canopy were not large enough to be identified with the TM data.

Table 3. Foraging Site Classification Accuracy Assessment

Landsat Derived Land Cover	Known Sites 1984	Known Sites 1985
Deep Water	–	–
Foraging Cover		
Shallow Water	12	3
Marsh	17	11
Swamp Forest		
Cypress/Mixed	5	2
Bottomland/Hardwoods	3	–
Pine/Mixed Upland	–	–
Agriculture/Clearings	2	–
TOTAL	39	16
Overall Accuracy	74%	88%

THE GIS ANALYSIS

Raster-Based GIS

The primary types of data representations used by geographic information systems (GIS) are vector and raster. The digital maps of foraging cover produced from the Landsat TM remotely sensed data were in a raster structure. Thus, a raster-based GIS system was most suited for processing of the classified maps. An ERDAS raster-based GIS (ERDAS, 1986) in combination with in-house developed software were used for all of the spatial analyses of the raster data.

Change Detection

Two primary methods for assessing land-cover change were considered: (1) a comparison of the *land-cover areal totals* for the entire study area, and (2) a *pixel-by-pixel change detection* analysis. Changes in the total foraging cover for the entire study area may be derived from a simple comparison of the land-cover acreage for each category. This method is simple and does not require highly accurate spatial registration between land-cover maps. Unfortunately, it does not provide information about the site specific changes in the study area. Digital change detection (i.e., pixel-by-pixel) between spatially registered maps can provide site specific changes in the form of a *matrix of changes* and a *map of changes*. The matrix of changes indicates the total amount of land cover in each category and year and the nature of the change for that category (e.g., x amount of deep water in year 1 changing to y amount of shallow water in year 2). The map of changes displays the location and nature of site specific changes. The accuracy of the change detection map and statistics generated from it are dependent on the spatial registration accuracy between each map and the classification accuracy of each map. In general, the composite map produced from digital change detection analysis will not have an accuracy greater than the least accurate map in the analysis (Newcomer and Szajgin, 1984).

There are a variety of algorithms available for pixel-by-pixel change detection studies (Jensen, 1981). The phenomena under investigation, the quality of the data set, and the suitability of the algorithm for the change detection desired influences the choice of the appropriate algorithm. In this study, it was desirable to identify the land cover on each date and determine what the category changed from or to in the two-year analysis. Thus, a *post-classification comparison* (Jensen, 1986) of the nominal category of each pixel was performed.

The total amount of foraging land cover (i.e., shallow water and marsh) for 1984 and 1985 is summarized in Table 4. In 1984, approximately 1.04 percent of the study area was suitable for Wood Stork foraging (shallow water = 0.36; macrophytes = 0.78). In 1985, the amount of foraging habitat dropped to 0.61 percent (shallow water = 0.26; macrophytes = 0.35). There was

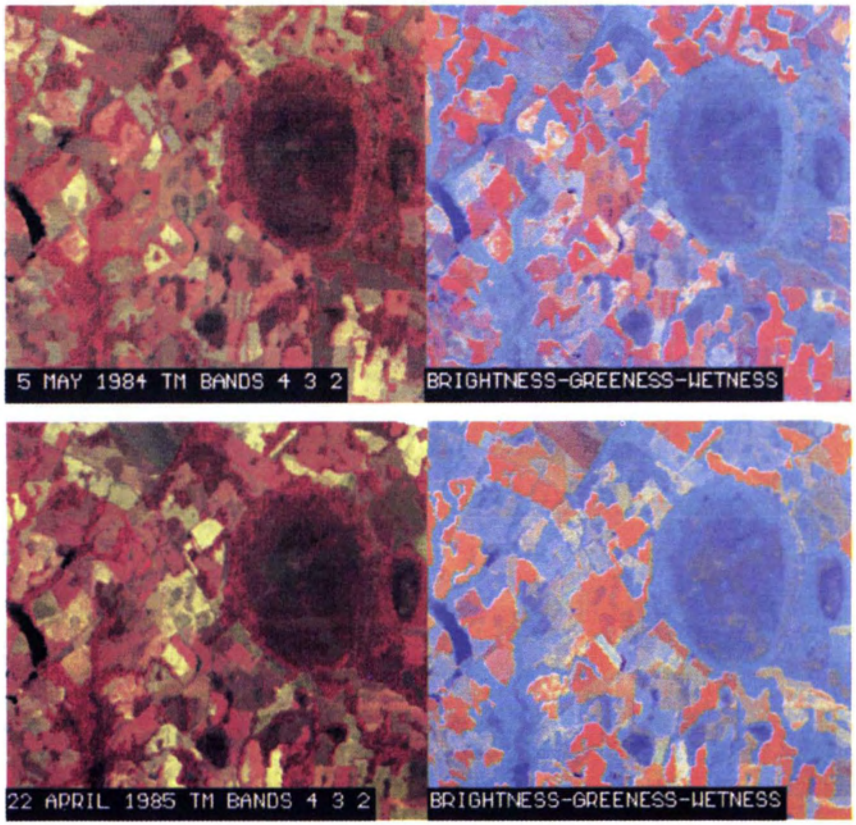

PLATE 1. A portion of the study area showing the Birdsville Colony at Big Duke's Pond (right of center) shown in TM bands 4, 3, and 2 (filtered through the red, green, and blue guns, respectively) for 5 May 1984 and 22 April 1985. Also shown are the composite Brightness, Greeness, and Wetness images (filtered through the red, green, and blue guns, respectively).

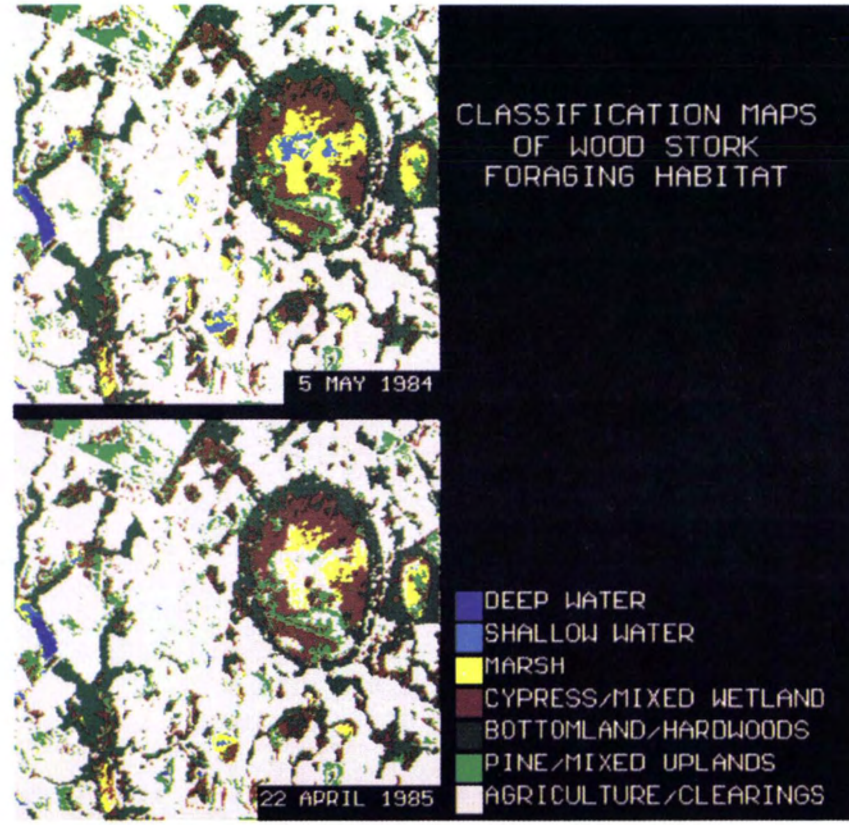

PLATE 2. Classification maps of available Wood Stork foraging habitat and other land cover for a portion of the Birdsville Colony study area on 5 May 1984 and 22 April 1985 based on an analysis of Landsat Thematic Mapper Data.

TABLE 4. STATISTICS FOR THE BIRDSVILLE COLONY RECTIFIED STUDY SCENE

Land Cover	1984 Hectares	Percentage of Total	1985 Hectares	Percentage of Total	Percentage Change*
Deep water	555.4	0.36%	198.9	0.13%	−64.2%
Foraging Cover	1744.6	1.14%	916.8	0.60%	−47.4%
Shallow water	555.0	0.36%	390.6	0.26%	−29.6%
Macrophytes (Marsh)	1,189.6	0.78%	526.2	0.35%	−55.8%

* Calculated as 100 - ((1985 acreage / 1984 acreage) * 100)

a 47.4 percent decrease in the total foraging acreage between 1984 and 1985.

The change in foraging cover and deep water around the Birdsville Colony between 5 May 1984 and 22 April 1985 is portrayed in Plate 3. The other land cover (i.e., deep water, forested wetlands, and agriculture/clearings) depicted is that land cover in 1984. The reduction of foraging cover within 1 km of the site occurred predominately within Big Duke's pond. Examples of new foraging cover (change in water depth of deep water in 1984 to become shallow water in 1985) can be seen in the large pond on the left.

Results of the pixel-by-pixel change detection analysis revealed the amount of stable, new, and reduction in foraging land cover from 1984 to 1985 (Table 5). Approximately 677 hectares of potential foraging cover (shallow water and marsh) in 1984 remained consistent in 1985 (shallow water = 146.6 + 126.6; macrophytes = 69.1 + 334.3). Approximately 1068 hectares of foraging cover dried up, becoming unsuitable for Wood Stork use in 1985 (282.0 hectares of shallow water and 786.2 hectares of marsh). There were 240.1 hectares of deep water area in 1984 which decreased in water depth to become potential foraging cover in 1985. Overall there was a net loss of 828 hectares of foraging cover in the 1519-square kilometre study scene. This net loss of foraging cover in the early part of the chick feeding season appeared to have been large enough to result in a low reproductive success of the Colony. The average number of fledglings per nest in 1985 was only 0.33 compared with 2.04 in 1984 (Coulter, 1986b).

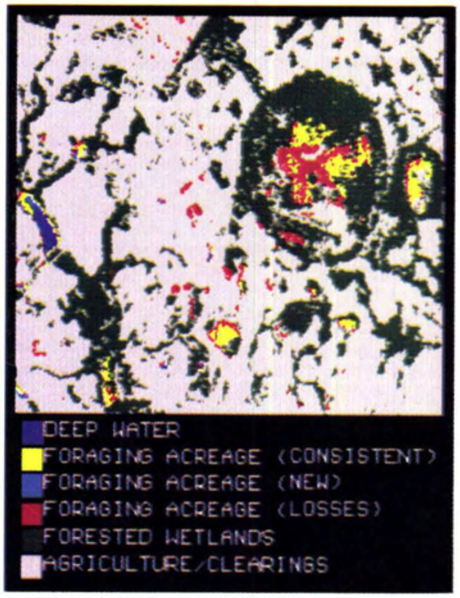

PLATE 3. Change in Wood Stork foraging habitat from 5 May 1984 to 22 April 1985 based on analysis of Landsat TM data.

TABLE 5. CHANGE IN POTENTIAL FORAGING LAND COVER FROM 1984 TO 1985 BASED ON ANALYSIS OF LANDSAT TM DATA

	1985 Land Cover				
1984 Land Cover	Deep Water	Shallow Water	Marsh	Agriculture/ Clearings	1984 TOTAL
Deep Water	198.9	174.9	65.2	115.5	555.4
Shallow Water	–	146.6	126.6	282.0	555.0
Macrophytes(Marsh)	–	69.1	334.3	786.2	1189.6
1985 TOTAL	198.9	390.6	526.2	1183.7	2299.5

PROXIMITY ANALYSIS

In addition to the regional statistics, the proximity of the potential Wood Stork foraging land cover to the Birdsville Colony was determined from the 1984 and 1985 habitat maps. The distance of each pixel to the colony site was computed using Euclidean distance. (The Colony site was located at UTM coordinates 402,250 east and 3,636,400 north.) All pixels were aggregated into 1-kilometre class intervals from the colony site. Statistics for each zone are summarized in Table 6.

The highest percentage of potential Wood Stork foraging cover in any zone (0 to 1 km) is located in the immediate vicinity around the Birdsville Colony. Approximately 77.7 hectares of foraging cover were within 1 km of the Birdsville Colony on 5 May 1984. On 22 April 1985, the foraging cover within 1 km of the Colony was considerably less with only 37.1 hectares of foraging cover. The total amount of potential foraging cover dramatically decreased at 2 km from the colony site and then gradually increased through a distance of 10 km on both dates. However, beyond a distance of 2 km, the percentage of each zone covered by foraging cover was only about 2 percent for the 1984 and 1985 seasons.

TABLE 6. WOOD STORK FORAGING COVER STATISTICS BY PROXIMITY TO THE COLONY BASED ON ANALYSIS OF 1984 AND 1985 LANDSAT TM DATA

Distance	Total	1984		1985		Change	
(Km)	(Ha)	(Ha)	% zone	(Ha)	% zone	(Ha)	% zone
0 - 1	325	77.7	23.9	37.1	11.4	−40.6	−52.3
1 - 2	905	86.1	9.5	32.7	3.6	−53.4	−62.0
2 - 3	1650	21.6	1.3	6.2	0.4	−15.4	−71.3
3 - 4	2195	43.4	2.0	14.4	0.7	−29.0	−66.8
4 - 5	2808	34.5	1.2	9.1	0.3	−25.4	−73.6
5 - 6	3537	42.7	1.2	9.1	0.3	−33.6	−37.2
6 - 7	3922	45.5	1.2	25.6	0.7	−19.9	−43.7
7 - 8	4808	87.5	1.8	48.2	1.0	−39.3	−44.9
8 - 9	5458	83.9	1.5	55.8	1.0	−28.1	−33.5
9 - 10	5928	79.3	1.3	32.5	0.5	−46.8	−59.0
1 - 10	31538	602.3	1.9	288.4	0.9	−313.9	−52.1

Area statistics listed were calculated using whole number pixels as radius measurements from the colony site (e.g., 1-33 pixels away for 0 to 1 Km, 34-66 pixels for 1 to 2 km, etc.) and therefore will not show exact area measurements surrounding the site.
Ha = hectares

Size of Foraging Sites

The pixels in a raster-based GIS may be spatially aggregated into contiguous groups of similar land-cover categories referred to as clumps. A "clumping" algorithm may determine *contiguity* of pixels by comparing the center pixel of a 3 by 3 moving window with its four adjacent neighbors (Figure 2a) or 8 adjacent neighbors (Figure 2b) (Davis and Peet, 1977; Tomlin, 1983). *Similarity* of contiguous pixels is determined by examining the value or category of each pixel, such as the nominal category of a land-cover classification system. For measuring the size of clumps representing the foraging site in this study, eight neighbors around a pixel were used to determine contiguity. Shallow water and the macrophytes (marsh) categories were both considered to be foraging habitats, so two contiguous pixels were similar if both pixels were classified as shallow water, both as macrophytes, or one pixel as macrophytes and one pixel as shallow water.

A clumping analysis was conducted for the 1985 foraging map as this was indicative of a critical year for Stork reproductive success. Results of the clumping analysis for the 1985 map are displayed in Figure 3. There were 811 unique clumps or sites within 10 km of the nesting site, with the largest site comprising 20.88 hectares. This large site was the foraging area immediately adjacent to the Colony nesting site. Also, the next two largest sites of 14.94 and 15.39 hectares were approximately 1 km from the Colony which may explain in part why the Storks chose this location as their nesting site. There was a gradual increase in the number of smaller sites as the distance from the Colony increased.

SUMMARY

Analyses of Landsat Thematic mapper data for a 1519-square-kilometre area surrounding the Birdsville Wood Stork Colony for the spring of 1984 and 1985 indicate that remotely sensed data can be useful in evaluating the distribution, quantity, and change of potential foraging habitat on a regional basis for this species. Wood Stork foraging sites are typically shallow water and marsh environments which lend themselves to detection and mapping with TM data. Summary statistics of multiple dates of classified Landsat scenes indicate net gains and losses of potential Wood Stork foraging cover. GIS techniques can be used to determine the total amounts, the spatial location, and the nature of land-cover change among individual categories. Thus, locations and acreages which remain consistent in foraging habitat suitability can be mapped. The amount of foraging cover at various distances from a colony site can be determined using proximity procedures. Finally, the size of each foraging site can be measured through clumping analysis.

This initial study indicates that the use of TM data and GIS procedures can provide potentially powerful inventory and management tools for assisting in the recovery of this endangered species. Mapping of the reduction in total foraging cover from the wet year (1984) to the dry year (1985) aids wildlife analysts in understanding the success or failure of the Colony in years with varying amounts of rainfall. The amount of available foraging cover and its location in 1985 may have been inadequate to sustain a successful reproductive colony. It has not been determined what is the critical amount and distribution of foraging cover necessary for reproductive success. Future research will continue to monitor the foraging habitats and attempt to relate the size, number, and spatial arrangement of the foraging cover to the historical reproductive success or failure of the Birdsville Colony.

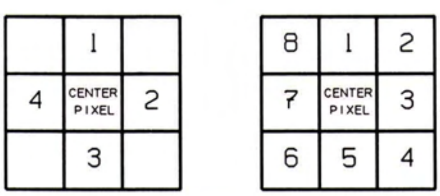

FIG. 2. The four contiguous neighbors of a cell in (a) and the eight neighbors of a cell in (b).

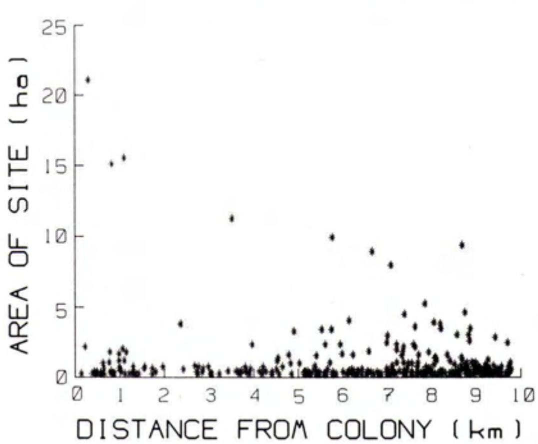

FIG. 3. The size of available Wood Stork foraging sites at given distances from the Birdsville Colony site in 1985.

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REFERENCES

Colwell, J. E., D. S. Gilmer, E. A. Work, Jr., D. L. Rebel, and N. E. G. Roller, 1978. *Use of Landsat Digital Data to Assess Waterfowl Habitat Quality*. Technical Report, Environmental Research Institute of Michigan: Ann Arbor, Michigan, 83 p.

Coulter, M. C., 1986a. *Wood Storks of the Birdsville Colony and Swamps of the Savannah River Plant: 1984 Annual Report*, SREL-20, Savannah River Ecology Laboratory: Aiken, South Carolina.

———, 1986b. *Wood Storks of the Birdsville Colony and Swamps of the Savannah River Plant: 1985 Annual Report*, SREL-23, Savannah River Ecology Laboratory: Aiken, South Carolina.

———, 1986c. *Wood Stork: Comprehensive Cooling Water Final Report*, SREL-24, Savannah River Ecology Laboratory: Aiken, South Carolina.

Crist, E. P., and R. C. Cicone, 1984. Comparisons of the Dimensionality and Feature of Simulated Landsat 4 MSS and TM Data. *Remote Sensing of the Environment*, 14: 235–246.

Davis, W. A., and F. G. Peet, 1977. A Method of Smoothing Digital Thematic Maps, *Remote Sensing of Environment*, 6: 45–49.

Department of the Interior (DOI), 1983a. Regional Briefs. *Endangered Species Technical Bulletin*, 8(7): 9.

———, 1983b. Stork Population Declines; Endangered Status Proposed, *Endangered Species Technical Bulletin*, 8(3): 1–8.

———, 1983c. Review of the Status: U.S. Breeding Population of the Wood Stork. *Federal Register*, 47(31): 6675–6677.

ERDAS, 1986. *ERDAS PC and PC-KIT Image Processing Systems User's Guide*, ERDAS: Atlanta, Georgia.

Fleming, M. D., and R. M. Hoffer, 1977. *Computer-Aided Analysis Tech-*

niques for an Operational System to Map Forest Lands Utilizing Landsat MSS Data, LARS Technical Report No. 112277, Purdue University: West Lafayette, Indiana.

Hodgson, M. E., J. R. Jensen, H. E. Mackey, Jr., and M. C. Coulter, 1987. Remote Sensing of Wetland Habitat: A Wood Stork Example, *Photogrammetric Engineering and Remote Sensing*, 53(8): 1075–1080.

Jensen, J. R., 1981. Urban Change Detection Mapping Using Landsat Digital Data, *The American Cartographer*, 8(2): 127–147.

———, 1986. *Introductory Digital Image Processing: A Remote Sensing Perspective*, Prentice-Hall, Inc.: Princeton, New Jersey, 380 p.

Jensen, J. R., E. J. Christensen, and R. Sharitz, 1984. Nontidal Wetland Mapping in South Carolina Using Airborne Multispectral Scanner Data. *Remote Sensing of Environment*, 16: 1–12.

Kauth, R. J., and G. S. Thomas, 1976. The Tassled Cap-A-Graphic Description of the Spectral-Temporal Development of Agricultural Crops as seen by Landsat. *Proceedings, Symposium on Machine Processing of Remotely Sensed Data*, Purdue University: West Lafayette, Indiana, pp. 4B41–4B51.

Kind, T. C., J. L. Benson, R. L. Lowe, M. E. Cope, 1986. Remote Sensing of Ruffed Grouse Habitat in the Kentucky Portion of Land Between the Lakes, TVA, Utilizing Landsat MSS and TM Data Sets, *Proceedings, American Society for Photogrammetry and Remote Sensing*, pp. 322–334.

Koeln, G. T., P. Caldwell, D. E. Wesley, J. E. Jacobson, 1986. Inventory of Wetlands with Landsat's Thematic Mapper, *Proceedings, Tenth Canadian Symposium on Remote Sensing*, pp. 153–162.

Lyon, J. G., 1983. Landsat-Derived Land-Cover Classifications for Locating Potential Kestrel Nesting Habitat, *Photogrammetric Engineering and Remote Sensing*, 49(2):245–250.

Meyers, J. M., 1984. *Wood Storks of the Birdsville Colony and Swamps of the Savannah River Plant*, SREL-15, Savannah River Ecology Laboratory: Aiken, South Carolina.

Newcomer, J. A., and J. Szajgin, 1984. Accumulation of Thematic Map Error in Digital Overlay Analysis, *The American Cartographer*, 11(1): 58–62.

Nerassen, T. G., A. J. Macauley, and R. P. Mroczynski, 1981. Pintails and Pixels: A Potential Application of Landsat Technology to Waterfowl Habitat Inventory, *Proceedings, Seventh International Symposium of Machine Processing of Remotely Sensed Data*, pp. 214–219.

Ogden, J. C., and B. W. Patty, 1981. The Recent Status of the Wood Stork in Florida and Georgia, *Proceedings of the Nongame and Endangered Wildlife Program*, Georgia Department of Natural Resources, Game and Fish Division: Atlanta, Georgia, Technical Bulletin WL5: 97–103.

Tomlin, C. D., 1983. *Digital Cartographic Modelling Techniques in Environmental Planning*, Ph.D. Dissertation, (Yale University).

Work, Edgar A., Jr., and D. S. Gilmer, 1976. Utilization of Satellite Data for Inventorying Prairie Ponds and Lakes, *Photogrammetric Engineering and Remote Sensing*, 42(5): 685–694.