EVALUATION OF A GIS RULE-BASED MODEL TO MAP FORESTED WETLANDS IN MAINE

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ABSTRACT

The objectives of this research were to analyze, revise, and test a Geographic Information System (GIS) rule-based model to improve the mapping of forested wetlands at two study sites in Maine. To determine the performance of satellite mapping techniques, three conventional image classification methods (unsupervised, tasseled cap, and hybrid classification) and a revised GIS rule-based model were evaluated. Accuracy assessment was conducted by cross tabulation of classification results to photo interpreted random sample plots.

The GIS model incorporated hydric soils, slope, National Wetland Inventory, and hydrography layers. After the GIS layers were analyzed statistically, a integrated model was formulated. The new integrated GIS model offered a greater degree of versatility and automation for a less subjective classification approach in the forested wetland mapping application.

The model had the highest classification accuracy among all tested methods at both study sites. Pairwise significance tests indicated that the integrated model was significantly better than unsupervised and tasseled cap classification methods at both study sites. The Kappa coefficients for the integrated model were slightly higher compared to the hybrid classification approach, however the significance test indicated no difference between the two methods at either study site.

The results suggest that the physical characteristics of the two study sites may have had more influence on the conventional classification methods than on the integrated model because the model incorporated the physical variables into the decision rule. Evaluation of new variables in the model (e.g. topographic position) and the effect of spatial error propagation in developing the GIS data base need to be investigated further.

1.0 INTRODUCTION

Forested wetlands are abundant in Maine and provide valuable services including moderation of downstream flooding, maintenance of water quality, provision of diverse habitats for wildlife, and pollution control (Wharton et al., 1982). The forested wetlands are described as lands transitional between terrestrial and aquatis systems where the water table is usually at or near the surface or the land is covered by shallow water and dominated by trees 20 feet or taller.

The first simple model to integrate remote sensing and GIS to address forested wetland identification was developed by Ahl (1994). This model consisted of a land cover classification (representing forest and non-forest) derived from satellite imagery and four hierarchical GIS layers National Wetland Inventory (NWI), hydric soil, slope, and hydrological data. However, the four GIS layers were assigned arbitrary weights based on their presumed contribution to identifying wetlands and this created some ambiguity in the model.

This research attempts to develop an improved GIS model. To avoid subjective criteria, the presumed weights for each GIS layer needed to be carefully examined. A data analysis procedure and non-site specific rule needed to be formulated to provide consistent results.

The specific objectives of this research were to analyze, revise, and test a rule-based model to identify forested wetlands in two Maine study sites. An integrated model was developed to weight selected attribute data residing in a GIS. Analyses were performed to:

1) Compare three conventional techniques of land cover classification including unsupervised, tasseled cap transformation, and hybrid (unsupervised and supervised) for delineating forested wetlands and understanding the limitations of spectral image classification.
2) Apply statistical analyses to evaluate the contribution of selected GIS layers in the prediction of forested wetland locations and determine the optimal model.
3) Develop a formulated rule in an integrated remote sensing and GIS model.
4) Verify the accuracy of forested wetland classification results using aerial photographs and field data as a reference source.
5) Develop the model on one study site (Acadia) and test the formalized model in a second study area (Orono) to compare the results with a previous model (Ahl, 1994).

2.0 LITERATURE REVIEW

2.1 Federal Wetland Mapping Programs in the U.S.A.

The interpretation of aerial photography is the most widely used method of deriving wetlands maps. In producing wetland maps (e.g. NWI), wetland types are identified primarily from aerial photographs by skilled interpreters using stereoscopic techniques. The NWI project claimed that leaf-off color infrared photography from early spring was the best for detecting forested wetland, especially for deciduous forested wetland. Furthermore, the dominant tree species and/or the hydrologic characteristic of wetlands are the primary features used to separate upland from forested wetlands (Tiner, 1990). Due to the limitations of the photo interpretation process, certain wetland types such as evergreen forested wetlands, temporarily flooded deciduous forested wetlands, and hydrologically altered forested wetlands are among the most difficult wetlands to detect. In such cases, subtle photo signatures, topographic position on the landscape, collateral hydric soil information and field work must be closely examined to aid in the interpretation process (The Federal Geographic Data Committee, 1992).

2.2 Satellite Imagery for Wetland Mapping

The use of satellite imagery for wetland mapping provides a number of advantages over conventional aerial photographs. For example, wetlands are very dynamic and have tremendous seasonal or yearly changes. Furthermore, satellite sensors cover broader wavelengths through their optical scanner systems. Each detector of the satellite scanner is positioned to record specific wavelength of energy. Although aerial photography may be appropriate for high resolution cartography, satellite imagery is better suited and less costly for rapid, repeated observations over broad regions assuming equipment and experienced human analysts are available to process the data (Ferguson et al., 1993). Besides, the major advantage of satellite data is it's digital format, making automatic analyses possible and the integration with GIS.

Satellite imagery may offer an efficient means of identifying forested wetlands in the future. Landsat MSS, TM and SPOT HRV imagery have been used successfully to detect major categories of wetlands (Haddad and Ekberg, 1987; Jensen et al., 1993). However, they have not been used previously to map or monitor forested wetlands for regional or national coverage.

2.3 Modelling Approaches

The primary reason for employing an integration of GIS and expert system (ES) is to reduce human labor and improve the consistency of results. A knowledge-based GIS and ES to manage wetland was developed by the USFWS (Wei et al., 1992). The model, based on Mitchell's (1991) wetland value assessment methodology, integrated knowledge-based capabilities into a GIS. However, the approach was limited to monitoring, producing maps, and analyzing changes in wetland habitat and indicated a need to integrate knowledge of wetland expertise (Wei et al., 1992).

Hepner et al. (1990) compared neural networks (NN) techniques with conventional supervised classification method. They concluded that NN offered a potential approach to land cover classification. The advantage of NN is it's ability to handle multispectral, multitemporal, and multisource spatial data (Civco and Wang, 1994). A NN model which incorporated multidate Landsat TM image with ancillary spatial information had an accuracy of approximately eight percent greater than a traditional single date image classification approach. However, the result for forested wetland were rather poor (Civco and Wang, 1994).

3.0 METHODS

3.1 Equipment and Data Acquisition

The experiments utilized three different commercial image processing and GIS computer software packages: ERDAS (1992), ARC/INFO (ESRI, 1990), IDRISI (Eastman, 1992) and three statistical programs: Cart methodology (Breiman et al., 1984), LIMDEP (Greene, 1992), Kappa (Congalton, 1983). The Landsat TM July, 1991 images were acquired to delineate forested wetland and other vegetation types using three image classification methods. Aerial photographs were obtained to support standard plot creation for data analysis and accuracy assessment. Land characteristics data derived from various sources were essential components in the development of the GIS data base.

3.2 Conventional Image Classification

Conventional techniques of image classification were employed to understand the limitations of classification based on spectral signature characteristics. Unsupervised, tasseled cap transformation, and hybrid classification approaches were conducted. The generalized land cover classification scheme includes the following classification types:

1. Urban / Open / Agriculture
2. Softwood Upland
3. Mixed Forested Upland
4. Hardwood Upland
5. Non-forested Wetland
6. Softwood Wetland
7. Mixed Wetland
8. Hardwood Wetland
9. Shrub Upland

3.3 Sample Design for Data Analysis and Accuracy Assessment

The purpose of the sample design was to create a set of stratified random plots as reference for data analysis and accuracy assessment. Three pure pixels on a side (3X3) were suggested as a minimum area to identify an object on an image (The Federal Geographic Data Committee, 1992). A plot size of 3x3 pixels was defined as the sample unit. In order to facilitate analysis, the nine land cover classification scheme was grouped into four super categories as follows:

1. Forested Wetland
- Softwood Wetland
- Mixed Wetland
- Hardwood Wetland

2. Other Wetlands
- Non-forested Wetland

3. Forested Upland
- Softwood Upland
- Mixed Upland
- Hardwood Upland

4. Other Upland
- Urban / Open / Agriculture
- Shrub Upland

3.4 GIS Data Base Development

The GIS layers were derived from existing map sources and selected under the assumption that the combination of these layers indicate a physical environment that may support wetland conditions. Consequently, this investigation selected NWI maps, hydric soils mapped by the SCS, a digital elevation model (DEM) and hydrography derived from digital line graph (DLG) compiled by the USGS, as the components of GIS data base. Through digitizing, editing, vector to raster conversion and registering procedures, the separate GIS layers were prepared in raster format using ERDAS software.

3.5 Statistical Analysis Model

The cross tabulation error matrix method was applied to evaluate the statistical association between the GIS variables and their contribution to predict the location of forested wetland. Furthermore, two analytical models support and verify the results derived from the cross tabulation error matrix method. Consequently, a discrete multivariate analysis technique was applied to assess and compare classification confusion matrices.

3.6 Integrated Remote Sensing and GIS Model

The integrated model was a logical approach based on an integration of four weighted GIS layers combined with the best classified image that stratifies the forest and non-forest area. The coding of the two basic groups (forest and non-forest) is 16 and 0 respectively. Each basic group was separated into two groups according to the rule of accumulated weight factor in the analysis matrix. The aggregated higher weight in each group will be assigned as forested wetland and other wetland separately. The aggregated lower weight in each group will be assigned as forested upland and other upland. The procedures of constructing the integrated model follow three steps:

1) Evaluate and weight the GIS layers: Each GIS layer was evaluated by cross-tabulation and analytical models to see what percentage of the forested wetland types conformed to the reference plots. The higher co-occurrence of GIS layers reflects higher probability of detecting forested wetland.

2) Assign binary recoding system to exaggerate a maximum range for data analysis: According to the evaluation results, a binary weight was assigned as a confidence value corresponding to forested wetland probability. The weighted GIS layers separate all combination levels by at least one unit and extend the possible levels to the maximum. In this case, four GIS layers will be assigned a weight of 1, 2, 4, 8 respectively. An analysis image with 32 combination levels (16 for each forest or non-forest) can be generated by map algebra of the additive approach with four GIS layers.

3) Formulate a general rule to optimize aggregation process: An analysis matrix can be generated by cross tabulating the reference data against the additive image. The aggregation rule was defined by setting the balanced ratio threshold in the two basic land cover groups (forest and non-forest). The balanced ratios divided forest area into forested wetland and forested upland and non-forest area into other wetland and other upland. The higher accumulated ratio represented the forested wetland and the other wetland and the lower accumulated ratio represent the other upland in each group. The final ratios between categories will control the producer agreement of the confusion matrix. The balanced ratio is intended to develop a homogeneous confusion matrix which reflects the highest agreement between user and producer accuracy.

4.0 RESULTS AND DISCUSSION

4.1 Comparison of Conventional Image Classification Results Between Two study Sites

Table 1 indicates that the accuracy (overall and Kappa) improved consistently in three conventional image classification approaches at both study sites. The overall accuracy was similar between study sites. However, the overall Kappa of Orono were 10% higher than Acadia. Compared to Acadia study site, the Orono study site had more comparable user and producer agreement which led to form a homogeneous confusion matrix. The poorer overall Kappa of the Acadia study, especially the unsupervised approach, might be explained by the difference in the physical characteristics of the two study sites. The larger area has potential to affect the signature evaluation during the aggregation process. The highly uneven sample size made Acadia difficult to form a homogeneous confusion matrix. In this case, the Kappa correction might more properly represent the accuracy assessment between the two study sites

The different sample size used in the three approaches was the result of the majority rule plot editing procedure. This might relate to the different classification methods. For example, the supervised classification produced greater scatter of classified pixels representing different cover types in the image. The pixel of the same cover type (e.g. forested wetland) did not always cluster within a 3X3 pixel neighborhood. As a result, the sample was reduced when many sample plots failed to meet the majority rule criterion.

All in all the results might be indicative of the Landsat TM sensors' insensitivity to distinguish spectral similarities of forested wetland versus forested upland. The accuracy of conventional classification methods might be affected by the size of study area. The conventional image classification approaches indicated very little confidence in the spectral based methods to delineate forested wetlands.

4.2 Evaluation of GIS Layers

The GIS layers were evaluated for the prospect of modeling. They were evaluated in cross tabulation which was performed in the same manner as accuracy assessment of the individual GIS layer. Hydric soils, slope, and National Wetland Inventory data were the most important variables in the integrated GIS model. However, the relative importance of the model variables in predicting wetland conditions differed between study sites

Table 1 Comparison of Classification and Model Results for Two Study Sites

Method	Site		Accuracy Forested Wetland	Other Wetland	Forested Upland	Other Upland	Overall	Overall Kappa
Unsupervised	Acadia (312)*	user	0.70	0.50	0.74	0.72	74%	0.46
		producer	0.12	0.06	0.96	0.85		
	Orono (431)*	user	0.58	0.62	0.81	0.81	72%	0.60
		producer	0.71	0.42	0.73	0.82		
Tasseled Cap	Acadia (309)*	user	0.41	0.41	0.81	0.94	75%	0.53
		producer	0.25	0.75	0.91	0.72		
	Orono (362)*	user	0.64	0.41	0.84	0.84	74%	0.63
		producer	0.65	0.47	0.73	0.97		
Hybrid	Acadia (282)	user	0.80	0.41	0.84	0.91	78%	0.61
		producer	0.35	0.91	0.95	0.56		
	Orono (253)*	user	0.75	0.82	0.80	0.86	81%	0.72
		producer	0.57	0.64	0.87	0.98		
Existing GIS Model	Orono (406)*	user	0.82	0.64	0.83	0.80	80%	0.71
		producer	0.66	0.71	0.87	0.92		
Integrated (Revised) Model	Acadia (309)*	user	0.62	0.90	0.90	0.81	82%	0.70
		producer	0.77	0.45	0.86	0.89		
	Orono (402)*	user	0.78	0.67	0.86	0.80	81%	0.72
		producer	0.78	0.70	0.87	0.76		

Notes: The classification results of Orono were derived from Ahl (1994) except the result of the integrated model.
Sample size is in parenthesis.

4.3 Integrated Model

The integrated model combined one classified image (forest recoded as 16 and non-forest recoded as 0) and four weighted GIS layers in a series of 2^{k-1}, where k indicated the order of layer. An analysis image with 32 combination levels were created by map algebra using an additive approach. An analysis matrix was generated (Table 2). The columns represent the reference data in four classes which were separated by row into two primary groups of forest and non-forest. The rows represented the 32 combination levels and indicated the distribution of reference data within levels. The aggregation of 32 combination levels into four classes was defined by the accumulated ratio and controlled by the balanced ratio.

In the non-forest group, the threshold for other wetland and other upland is obvious (Table 2), even the balance ratios, 0.48 and 0.58, are not comparable. It indicated that combination level 0 was a source of confusion and a poor outcome for the other wetland class as expected. On the other hand, the threshold for forested wetland and forested upland was set between combination level 20 and 21. It was observed that increasing the ratio of forested wetland will dramatically drop the ratio of forested upland. Besides, the final ratios would reflect in the producer agreement of the confusion matrix except in the other upland category (Table 1). The producer and user accuracy for forested wetland were 0.77 and 0.62 respectively. The overall agreement was 82% and the Kappa was 0.70. These results are the best among the two and four classes approach conducted in the Acadia study site.

4.4 Integrated Model Applied in the Orono Study Site

The same algorithm was applied using the Orono data set (Ahl, 1994). First, the slope percent layer was redefined by examining an analysis matrix. Second, individual GIS layers were evaluated by cross tabulation. The contribution of four GIS layers was the same as defined in the existing model (Ahl 1994). They were NWI, hydric soil, slope, and stream buffer layer. Similarly to Acadia, an analysis matrix can be generated for the four groups aggregation analysis. The final ratios reveal a homogeneous confusion matrix. Forested wetland producer and user accuracy were both at 0.78, and the overall agreement and the Kappa were 81% and 0.72 respectively. These results are the best among all the approaches that had been conducted in Orono study site (Table 1).

The integrated model improved the results at Orono by equalizing the accuracy between user and producer agreement. This can be observed by comparing the Orono integrated model results with other approaches (Table 1). This emphasizes the utility of the analysis matrix and balance ratio in the aggregation process. Beyond the majority editing rule, an expected result might be revealed through examining the final balance ratio. The integrated model makes both overall accuracy and Kappa correction more comparable at two study sites (Table 1). This result suggests that the integrated model was less influenced by the size of study area. Moreover, the significance test of Kappa correction performed consistently in both study sites when the integrated model was involved (Table 1). Although the integrated model provided the best result among all experiments on both study sites, it was not determined to be a significant improvement over the conventional hybrid approach.

5.0 CONCLUSIONS

The integrated model provided a flexible and promising approach for the mapping of forested wetlands from satellite and ancillary data (hydric soil, slope, NWI maps, hydrology). The formulated algorithm can be extended through a GIS expert system for an automated classification approach. However, the ancillary data set needs to be investigated further to broaden the consideration of GIS layers. For example, the slope layer may need to be referenced to terrain positions or shape because forested wetlands are less likely to occur on convex shape slopes and ridge topographic positions, and are more likely to occur on concave, flat terrain. Skidmore's (1989) topographic position model of ridge, side slope, toe slope, bottom was reviewed but a suitable program was not available to this study. The poor contribution of the stream buffer layer suggested that this variable can be ignored or possibly combined with a topographic variable. This investigation and Ahl's (1994) work suggest that a hybrid classification and the integrated GIS model are the most promising for identification and mapping of forested wetlands. On the basis of the two Maine study sites and the variables tested, the level of effort to develop and implement a forested wetland mapping model does not appear to be justified over the conventional hybrid classification approach. Furthermore, the satellite and GIS methods may not be an improvement over NWI (aerial photo methods) for mapping forested wetlands in Maine. However, the satellite mapping approach can provide more complete inventory of land cover types than is available from

Table 2 Analysis Matrix of the Integrated Model with Weighted GIS Layers: Acadia Study Site

Integrated Model of Weighted GIS Layers						Analysis Matrix					
						Aerial Photo Sample Plots					
HYS	SLP	NWI	BUF	FST	Combination Level	Forested Wetland	Other Wetland	Forested Upland	Other Upland	Total	Assigned Categories
0	0	0	0	0	0	6	35	112	**385**	538	**Other Upland**
0	0	0	1	0	1	0	0	0	**0**	0	
0	0	2	0	0	2	0	**8**	15	15	38	**Other Wetland**
0	0	2	1	0	3	0	**0**	0	0	0	
0	4	0	0	0	4	6	**23**	18	75	122	
0	4	0	1	0	5	5	**6**	3	9	23	
0	4	2	0	0	6	4	**7**	0	0	11	
0	4	2	1	0	7	0	**0**	0	0	0	
8	0	0	0	0	8	11	**10**	10	0	31	
8	0	0	1	0	9	1	**7**	2	0	10	
8	0	2	0	0	10	0	**0**	1	0	1	
8	0	2	1	0	11	0	**0**	0	0	0	
8	4	0	0	0	12	12	**18**	12	18	60	
8	4	0	1	0	13	1	**19**	0	0	20	
8	4	2	0	0	14	5	**15**	0	0	20	
8	4	2	1	0	15	0	**0**	0	0	0	
0	0	0	0	16	16	85	26	**1153**	120	1384	**Forested Upland**
0	0	0	1	16	17	6	9	**112**	3	130	
0	0	2	0	16	18	4	0	**1**	0	5	
0	0	2	1	16	19	0	0	**0**	0	0	
0	4	0	0	16	20	49	9	**209**	18	285	
0	4	0	1	16	21	**9**	1	20	3	33	**Forested Wetland**
0	4	2	0	16	22	**10**	0	4	2	16	
0	4	2	1	16	23	**0**	0	0	0	0	
8	0	0	0	16	24	**117**	9	155	1	282	
8	0	0	1	16	25	**18**	4	36	0	58	
8	0	2	0	16	26	**5**	0	3	0	8	
8	0	2	1	16	27	**4**	0	2	0	6	
8	4	0	0	16	28	**167**	11	56	17	251	
8	4	0	1	16	29	**20**	8	7	0	35	
8	4	2	0	16	30	**54**	9	4	0	67	
8	4	2	1	16	31	**4**	0	0	0	4	
					Total	**603**	**234**	**1935**	**666**	**3438**	
Threshold Control** by **Balance Ratio						***408/603 0.68***	***113/234 0.48***	***1475/1935 0.76***	***385/666 0.58***		

NWI maps (only wetland types). It is uncertain whether a similar modeling approach would be more successful in identifying forested wetlands compared to conventional methods (e.g. hybrid) in other states or regions of U.S.A..

The conventional classifications were based on class grouping derived from signature evaluation. The integrated model was based on class grouping derived from weighted GIS layer combinations. The analysis matrix technique can be used to analyze a multivariate discrete data set for optimal aggregation to category assignment. For example, an alternative approach can be simulated by analyzing spectral signatures derived from clustering or training samples to guide appropriate land cover class assignment. A reference data set is required to apply the analysis matrix technique. Consequently, the results avoid subjective signature evaluation and benefits from the formulated algorithm derived in the integrated model.

The integrated model approach will require further research and development efforts. There are many important research issues related to the acquisition, processing, and joint analysis of remote sensing and GIS. Error is one of the primary issues of concern in the integrated model. For example, the geometric accuracy of the collective GIS layers is probably worse than the corrected Landsat TM data. Integration of remote sensing and GIS data required digitizing, converting, geo-referencing, and registration. These transformations have potential errors deeply embedded in the overall data processing flow. On the other hand, the current accuracy assessment procedures have been adapted from statistical procedures to give a quantity measure of overall accuracy. However, the quality (e.g. spatial distribution) error was not evaluated. Techniques need to be developed for assessing the spatial structure of error in the integrated model product. Further research into the integration of remote sensing and GIS along with improvements in spectral and spatial resolution of remotely sensed data may lead to advancements in wetland inventory and monitoring in the future.

6.0 REFERENCES

Ahl, D.E., 1994, A Comparison of Satellite and GIS Classification Techniques for Delineating Forested Wetlands, Department of Forest Management, University of Maine, Orono, ME, pp. 51.

Breiman, L., J.H. Friedman, R.A. Olshen, C.J. Stone, 1984, Classification and Regression Trees, Wadsworth, Inc., Belmont, California, pp. 18-171.

Civco, D.L., and Y. Wang, 1994, Classification of Multispectral, Multitemporal, Multisource Spatial Data Using Artificial Neural Networks, ASPRS/ACSM Annual Convention & Exposition, Reno, Nevada, Volume One, pp. 123-133.

Congalton, R.G., R.G. Oderwald, R.A. Mead, 1983, Assessing Landsat Classification Accuracy Using Discrete Multivariate Analysis Statistical Techniques, Photogrammetric Engineering and Remote Sensing, Vol. 49, No. 12, pp. 1671-1678.

Eastman, J.R., 1992, IDRISI, Technicial Reference Version 4.0, Clark University, IDRISI Production, Worcester, Massachusetts.

Ferguson, R.L., L.L. Wood, and D. B. Graham, 1993, Monitoring Spatial Change in Seagrass Habitat with Aerial Photography, Photogrammetric Engineering and Remote Sensing Vol. 59, No. 5, pp. 1033-1038.

Greene, W.H., 1992, LIMDEP User's Manual and Reference Guide, Version 6.0, Econometic Software, Inc., Bellport, New York, pp. 423-441.

Haddad, K.D., D.R. Ekberg, 1987, Potential of Landsat TM Imagery for Assessing the National Status and Trends of Coastal Wetlands, American Society of Civil Engineers, New York, Vol. 5, pp. 5182-5195.

Hepner, G., T. Logan, N. Rittner and N. Bryant, 1990, Artificial Neural Network Classification Using A Minimum Training Set: Comparison to Conventional Supervised Classification, Photogrammetric Engineering and Remote Sensing, Vol. 56, No. 4, pp. 469-473.

Jensen, J.R., S. Narumalani, O. Weatherbee, and H.E. Mackey, 1993, Measurement of Seasonal and Yearly Cattail and Waterlily Changes Using Multidate SPOT Panchromatic data, Photogrammetric Engineering and Remote Sensing, Vol. 59, No. 2, pp. 519-525.

Mitchell, L.C., et al., 1991, Wetland Value Assessment Methodology and Community Models, The Environmental Work Group, Coastal Wetland Planning, Protection, and Restoration Act Technical Committee, Lafayette, Louisiana: U.S. Fish and Wildlife Service.

The Federal Geographic Data Committee, 1992, Wetlands Subcommittee, Application of Satellite Data for Mapping and Monitoring Wetlands, Technical Report 1.

Tiner Jr., R.W., 1990, Use of High-Altitude Aerial Photography for Inventorying Forested Wetlands in the United States, Forest Ecology and Management, Vol. 33, No. 34, pp. 593-604.

Wei, Ji, J.B. Johnston, M.E. McNiff, and L.C. Mitchell, 1992, Knowledge-based GIS: An Expert System Approach for Managing Wetlands, Geo Info System, pp. 60-64.

Wharton, C.H., W.M. Ketchens, E.C. Pendlton, and T.W. Sipes, 1982, The Ecology Bottomland Hardwood Swamps of the Southeast: A Community Profile. U.S. Fish and Wildlife Service, Biological Services Program, Washington D.C., FWS/OBS-81/37.