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Forest Cover from Landsat Thematic Mapper Data for Use in the Catahoula Ranger District Geographic Information System

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SUMMARY

Landsat Thematic Mapper (TM) satellite data were used to develop a forest cover map of the **Catahoula** Ranger District, **Kisatchie** National Forest, Louisiana. The project was designed to demonstrate potential uses of Landsat (TM) data classifications for additions and updates to a national forest geographic information system (**GIS**). The data were imaged in August, 1990. Supervised signature training and classification techniques were used to generate a digital map with the following categories of forest cover: harvested/open, pine regeneration, low crown density pine, high crown density pine, pine-hardwood, and hardwood. Geographic data base inquiries were used to demonstrate the utility of the Landsat map and **GIS** data for making management decisions and revising stand prescriptions. The highest overall agreement of the map with **GIS** and aerial photointerpretations for stand-level testing of the classification was 86.2 percent. The supervised classification techniques used in the project were recommended for use of Landsat TM data in operational settings on national forest lands.

ACKNOWLEDGMENTS

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INTRODUCTION

The Southern region of the USDA Forest Service is implementing geographic information systems (GIS) technology on all national forests in the area it encompasses. The Kisatchie National Forest in Louisiana was one of the first to obtain and to begin using GIS for delineation and tracking information on stands, streams, roads, and other geographic features.

The data base system in use prior to the implementation of GIS was referred to as Continuous Inventory of Stand Condition (CISC). Stands were manually delineated on aerial photographs and subsequently transferred to paper maps kept in files. A tabular data base was maintained for the forest and was used to track completion of stand prescriptions, harvest and regeneration activities, wildlife management, and other activities. However, before the advent of GIS, labels on paper maps and manual look-up procedures were used to establish relationships between the geographic units (stands) and data base information. A geographic data base of the Catahoula Ranger District was first delivered in 1989. This initial data base was followed by full implementation of GIS on all other Kisatchie ranger districts in 1992.

Map features (stand polygons, roads, streams, etc.) are now represented in digital form in the GIS and are cross referenced with the former CISC data and other forest attribute information. This relationship allows users to display multiple geographic features (i.e., stands) with the same attributes (e.g., age, condition, and size). Another important benefit of GIS is that stand and compartment boundaries (and associated attributes) can be updated more efficiently than with the old system of maps and CISC data. The Forest Service will soon begin nationwide implementation of GIS technology. This will provide natural resource professionals with an efficient and accurate set of tools for mapping and maintaining management information on national forests and grasslands.

Landsat satellite remote sensing has recently received much attention for its role in forest mapping, particularly in old-growth assessments of the Pacific Northwest (Congalton and others 1993). Many successful projects have been documented for analysis of western forest lands (Bain

1988, Born 1988, Walsh 1980, Woodcock and others 1990). Landsat data have been used less on Federal lands in the Southern United States due in part to limited availability of satellite analysis technology in the field. However, the use will be more widespread with implementation of GIS, improvements in data quality, and advances in computer technologies.

The South generally has a greater diversity of timber species than other regions in the United States. Furthermore, forest classifications cannot be easily modified based on sharp ecological gradients in elevation or on aspect in mountainous areas (Cibula and Nyquist 1987, Frank 1988). Other useful information such as vegetation maps and detailed soil maps (Bolstad and Lillesand 1992) have not been available in digital form. Therefore, data analysis procedures have relied heavily on the spectral characteristics of forest lands for separation of meaningful cover classes for forest management.

Research has demonstrated that simple forest cover classes in the South are discernable with Landsat Thematic Mapper (TM) and Multispectral Scanner (MSS) data (Evans and Hill 1990, Evans and others 1992). Landsat imagery may also be useful for identification of different age classes for pine stands (Coleman and Gudapati 1990).

This project was undertaken to identify and demonstrate procedures that can be repeated to provide current information on forest vegetation distributions and conditions on national forest lands. Satellite data were integrated into a GIS of the Catahoula Ranger District (fig. 1) to provide vegetation information useful for stand- and compartment-level forest management. Landsat TM data were selected because they provide broad-area coverage with a resolution that is appropriate for vegetation mapping at the ranger district level of detail. Thematic Mapper data have greater spectral resolution than System Probatoire d'Observation de la Terre (SPOT) data. This characteristic was considered important for separation of forest cover classes. A TM scene also covers a much larger area than SPOT, thereby increasing the chance for complete coverage of a ranger district with a single data set.

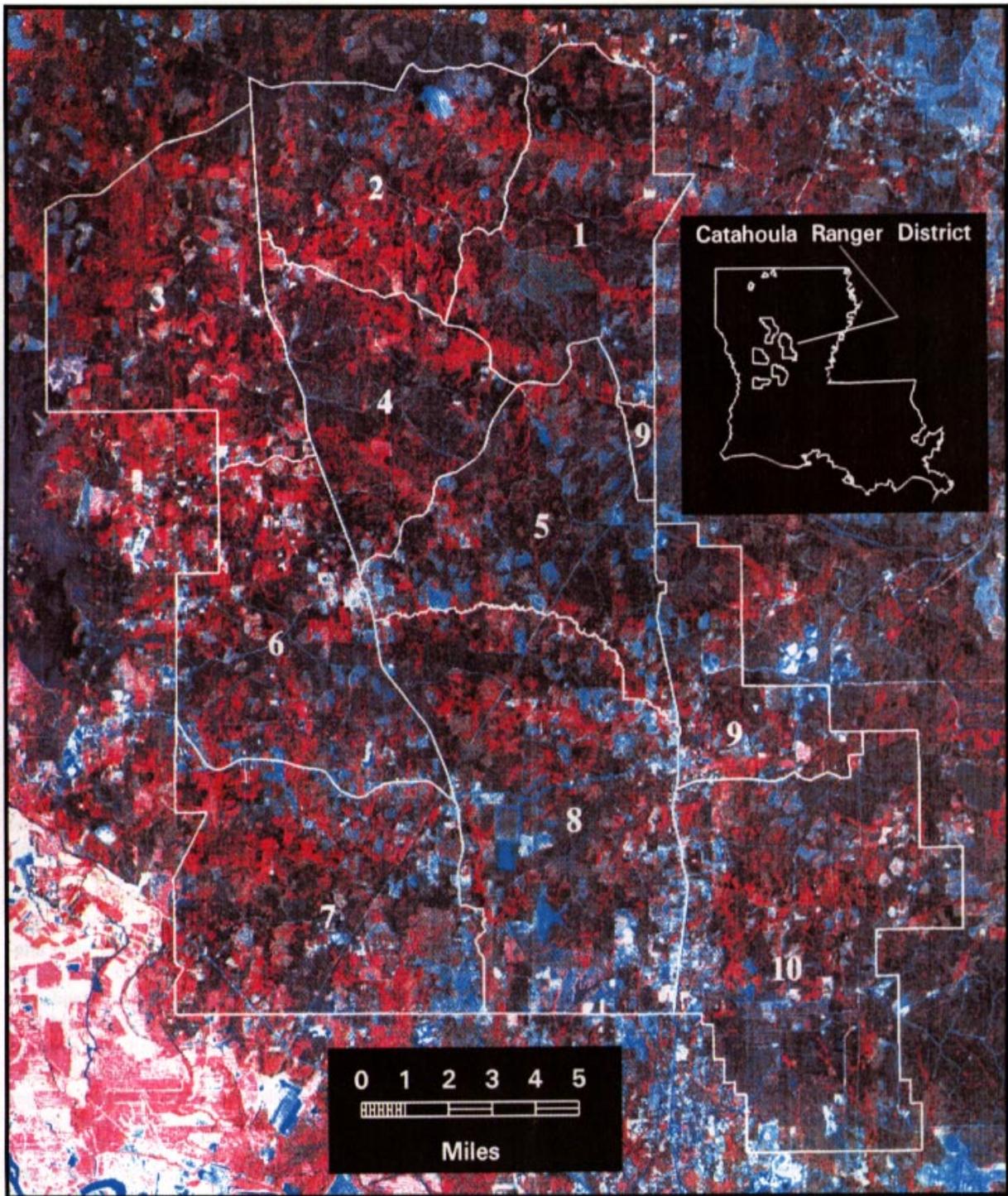


Figure 1.—Location of study area (inset at upper right) and Landsat Thematic Mapper data (channels 4, 5, and 3) depicted in false color with the Catahoula Ranger District cluster boundaries superimposed.

MATERIALS AND METHODS

Data Acquisition

Landsat TM data (Aug. 11, 1990, image date) were acquired for the study. Thematic Mapper data represent the reflectance of the Earth's surface in seven spectral regions (blue green through thermal infrared [IR]). Data for six of the channels (1, 2, 3, 4, 5, and 7) represent spectral information in 30- by 30-m (98.4- by 98.4-ft) picture elements (pixels). Channel 6 (thermal) has a ground resolution of 120 by 120 m (393.7 by 393.7 ft) per pixel. The red, near-IR, and two mid-IR channels (3, 4, 5, and 7) were used for the classification procedures. Data from the blue-green, green, and thermal IR bands (channels 1, 2, and 6)

were not used due to noise (data anomalies that can produce misclassifications). However, this problem is not a characteristic of all TM data sets. The only other problem in the data was smoke from an area that was being burned at the time of imaging. The smoke obscured portions of the extreme northern section of the ranger district (fig. 2)

The TM data were roughly 1 year more recent than the original GIS data base (acquired by the Kisatchie National Forest in the fall of 1989) used in the project. Thus, differences in TM classifications and the original GIS could be compared to demonstrate GIS updates.

The Catahoula Ranger District is divided into 104 compartments for timber management. Each compartment is a group of stands bounded by easily recognized geographic features such as roads and streams. The GIS data of the

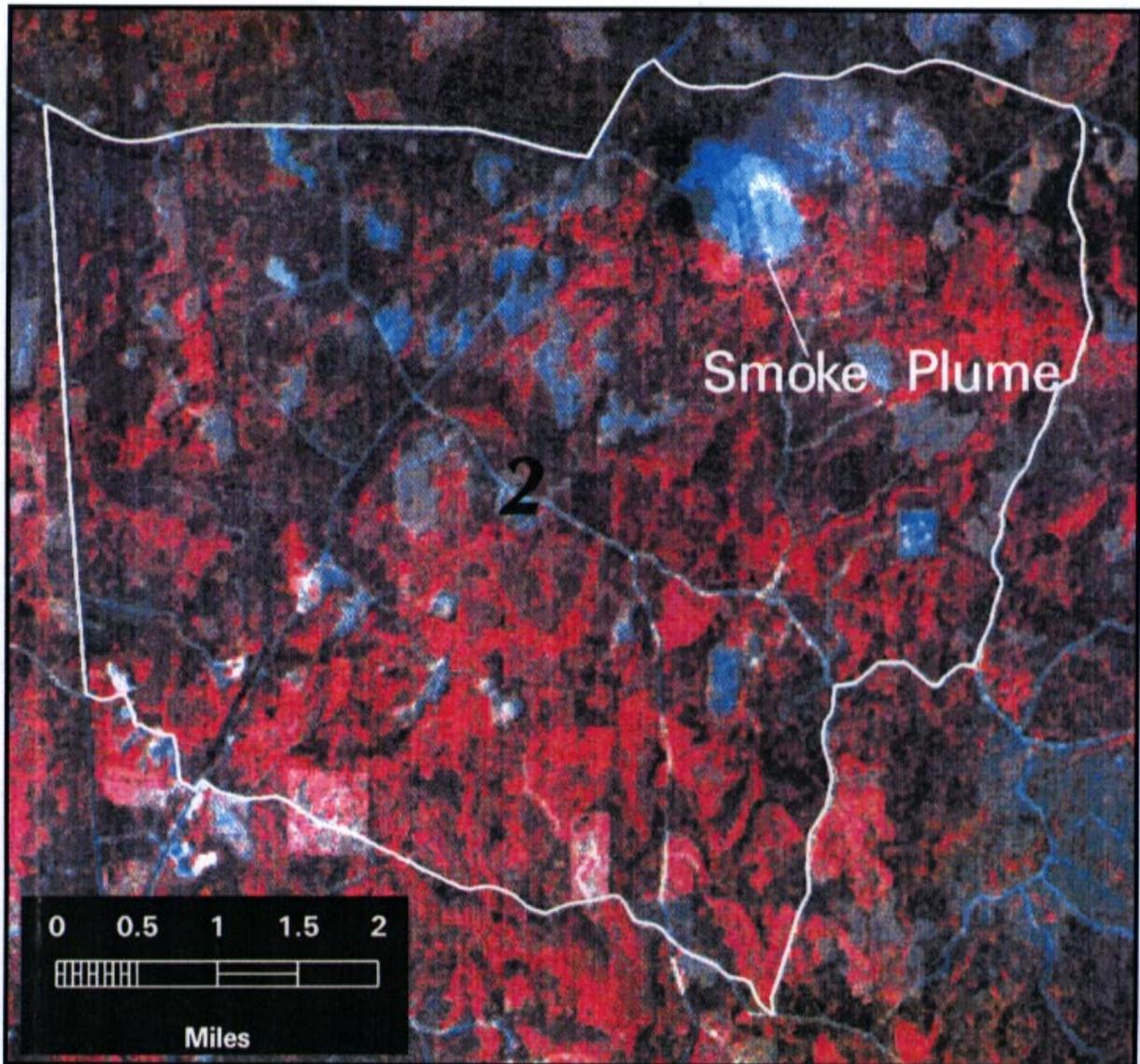


Figure 2.—Closeup view of Landsat Thematic Mapper data and smoke plume in the northern portion of the study area.

district were organized into 10 groups of adjacent compartments called clusters (fig. 1). The clusters formed a convenient way to organize data so artificial boundaries (i.e., map lines) would be avoided when data were recompiled based on inquiries.

The GIS data base and software were used on Sun workstations in a computer network. The ERDAS® image processing software was used for the Landsat data analysis; ARC/INFO was used for geographic comparison's and generation of all cartographic products. References to the specific ERDAS and ARC/INFO routines used for each task are given in this report (ERDAS 1991, ESRI 1991).

Color aerial photographs (1:24,000 scale, image date March 1991) of three clusters (1, 3, and 7) were provided by the Kisatchie National Forest for use in identifying forest cover classes. High-altitude (1:58,000 scale), color-infrared aerial photographs taken in February 1990 were used for clusters not covered by the color film. Both sets of photographs were used for selection of training sites and for classification verification.

Landsat Data Rectification

The Landsat data were georegistered to 1:24,000-scale quadrangles of the study area. This procedure was accomplished by selecting 10 or more control points from each quadrangle by use of a map digitizer. The control point coordinates were used to derive a set of transformation equations to rotate and resample the data into the Universal Transverse Mercator (UTM) projection. ERDAS software commands for these processes include: GCP (for selection of ground control points), COORDN (generates transformation coefficients), and LRECTIFY/NRECTIFY (transforms and resamples data). The data were then reprojected in ERDAS into State plane coordinates for use with the ARC/INFO coverages via the LiveLink. The LiveLink software provided by ERDAS allows simultaneous use of a display window by ERDAS and ARC/INFO. Image data are displayed via ERDAS functions while GIS coverages are displayed superimposed on the imagery by using ARC/INFO commands.

Landsat Classification Procedures

All classification work for this project was based on the supervised approach to spectral recognition of land cover types (Swain and Davis 1978). Forest cover and density classes were predetermined based on knowledge of general occurrence of forest species groups in the area. The ability to identify the same groups in subsequent years was an important consideration. Special attention was given to the management goals and expectations national forest personnel had for classifications generated from the data.

The initial supervised classification was performed to identify basic cover types: harvested/open, pine regenera-

tion, pine, pine-hardwood, hardwood, and water. A second supervised classification was performed to identify low and high crown density pine stands within the pine type. These cover types are defined in the appendix.

Initial Training and Classification.—Supervised classification of Landsat TM data began with interactive identification of training fields. These areas were defined graphically on a computer display as polygons that delineated spectrally homogeneous samples of various cover types (e.g., pine, hardwood, or water). Training-field pixel values for each spectral band were used to calculate statistical definitions (signatures) of the cover classes. Class signatures were developed for areas designated as: (1) harvested/open, (2) pine regeneration, (3) pine, (4) pine-hardwood, (5) hardwood, and (6) water. Training fields and test polygons were selected interactively by using the DIGSCRN command in the ERDAS software system. The test polygons were not used for signature generation but were stored for later use in evaluating the classification.

LiveLink software in ERDAS provided the means to overlay the ARC/INFO GIS coverages (stands, roads, etc.) onto the georeferenced image data. An ARC/INFO macro-program was written to select stands by their attributes and display the boundaries on the TM data. These selected stand boundaries served as a guide for polygon delineation in ERDAS. The actual stand boundaries were not used as training or test samples because some were known to have geographic positional errors in the original (unmodified) GIS (fig. 3). Stands, by definition, can contain small inclusions of vegetation that are not the same type of vegetation as the management type defined in the GIS (from the CISC data base). Training sample boundaries were placed to avoid edge effects of stand and compartment boundaries or small vegetation inclusions that could result in spectrally impure samples. All forest classes were sampled based on the GIS stand attributes and the aerial photographs.

Training fields and test polygons for each cover class were selected in each cluster to provide an even geographic distribution of all samples; 168 training fields and 162 test samples were selected for the classification. Although not entirely random, this procedure provided a good representation of all expected conditions within all the cover classes across the district. Statistics were calculated for the training fields (SIGEXT routine) and evaluated for homogeneity (SIGMAN routine). A sample was not used if the coefficient of variation (COV, a measure of statistical homogeneity) was greater than 10 percent of the mean reflectance value in any channel. Signatures that did not meet this criterion were replaced.

The groups of signatures for each class were merged to form final statistical definitions for the cover classes (SIGMAN). Transformed divergence (see ERDAS DIVERGE command) was calculated and checked to make sure the final class signatures were statistically separable and would produce satisfactory results when used with the maximum

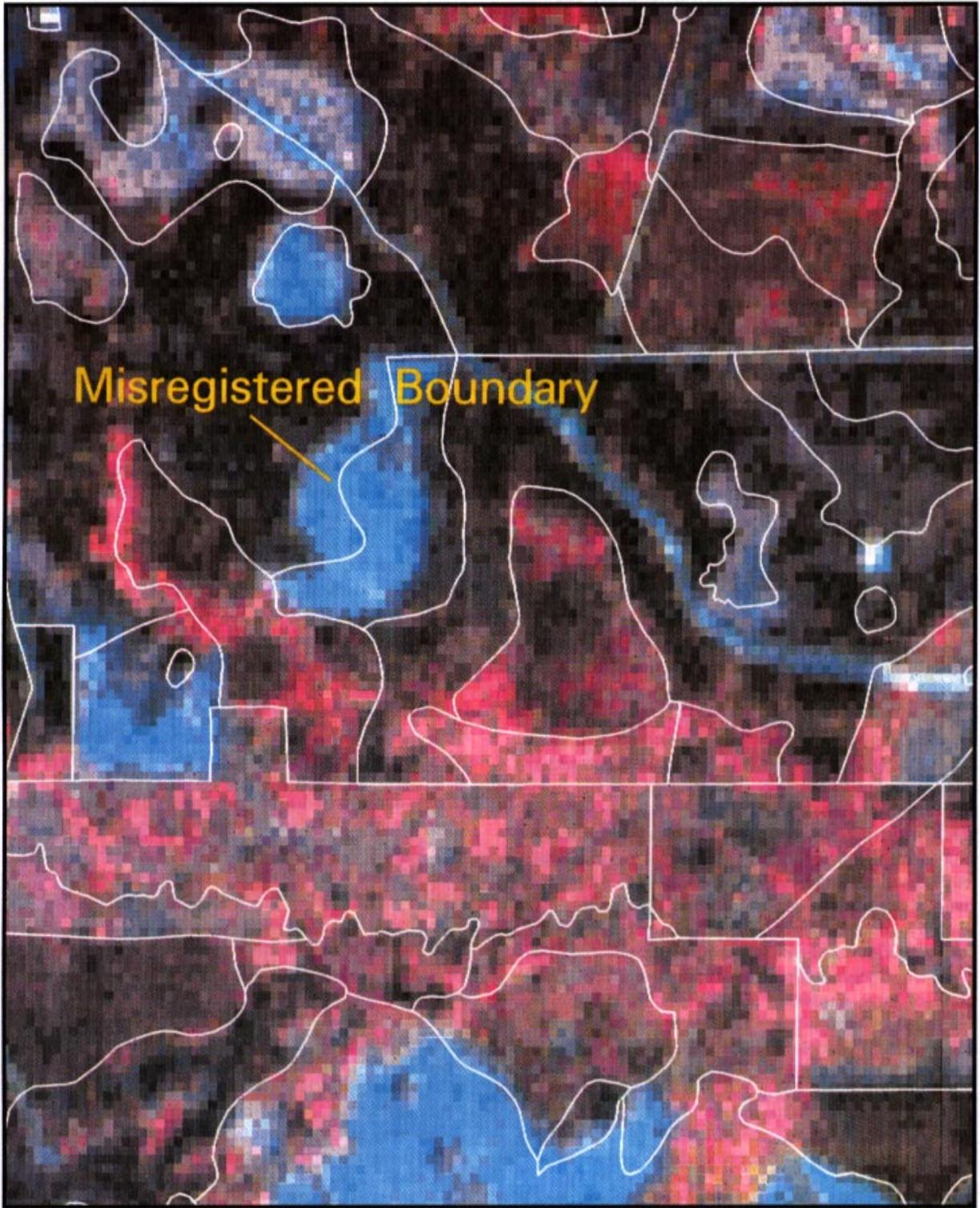


Figure 3.—Landsat Thematic Mapper data with stand boundaries of one cluster from the geographic information system; note misregistration of some harvest-area boundaries (blue tones).

likelihood classification algorithm (MAXCLAS). The classification produced a thematic map of the cover types, which was further refined in the next stage of the project.

Pine Crown Density Classification.—The pine cover type from the initial classification was used as a mask (MASK routine) to extract the original spectral data from the image. Then spectral training fields were selected of low and high crown density pine stands for use in classifying the densities of the masked data set. Training sample selection was based on interpretation of aerial photographs, field expertise of national forest personnel, and GIS stand attributes. The masked image data were then classified for pine density.

The two classifications were recombined into a final map of the ranger district by recoding the classes (RECODE) and overlaying the two files (STITCH). Ownership boundaries from the GIS were used to reduce the final classification to a cover map of Federal ownership. Class acreage data were compiled from this final map.

GIS Data Integration

In order to utilize the Landsat classification in the GIS environment, a series of conversions were performed on the ERDAS format file. The final ERDAS classification was converted into a single-variable file (SVF; ERDASSVF routine in ARC/INFO), which is a compressed raster (pixel) data structure (ESRI 1991). This SVF was imported to ARC/INFO and was used to produce a vector coverage of the classification. The vector coverage consisted of thousands of polygons that had numeric attribute codes equal to those of the original ERDAS classification.

The classification (converted to vector polygons) was intersected (ARC/INFO INTERSECT command) with the stand polygons in the GIS. The new polygons from this process included the classification labels and stand attributes. This procedure was done to permit access to class data at the stand level of interpretation. A representative set of standard inquiries and graphics was developed to demonstrate how the GIS and Landsat classification could be used for decision processes (such as stand prescriptions) on the district. Examples of processes include: identification of pine regeneration areas that may need release because of large hardwood components, identification of pine stands with high crown density for potential thinning or harvesting, and identification of upland hardwoods. Differences between stand boundaries and the classification and original imagery were also demonstrated to national forest personnel.

Verification Procedures

Accuracy of satellite classifications is often expressed in terms of correctly classified pixels cross referenced with some form of ground verification. The results are usually given in confusion matrices (Lillesand and Keifer 1979). Test pixels are chosen at random or in a sampling scheme

that can be used in field conditions. These techniques test the validity of spectral classes without consideration for nonuniform site conditions or tree species distributions that often occur in timber stands of the Southern United States. Both pixel-by-pixel and stand-testing techniques were used to evaluate the classifications in this project.

Pixel-by-Pixel Testing.—The test polygons (surrogates for stands) were used to construct a test raster file (ERDAS command POLYFIL), which was used to assess the final classification. A pixel-by-pixel comparison was made for all test pixels with the final classification. This technique, however, assumes that all pixels in a test polygon (stand) are the same ground category, a condition that is not necessarily true on southern national forest lands.

Stand Testing.—The test polygons were used to determine forest class (excluding density) agreement in a way similar to that by which aerial photointerpretation would be performed to produce a stand map. Photointerpreters mentally filter or merge small inclusions of nonhomogeneous forest cover into larger regions to define stands and stand composition. A similar procedure was incorporated into the stand-testing portion of this project. A stand interpretation approach was used to evaluate the Landsat classification. The class label for each test polygon was determined based on the corresponding GIS stand-type designation (originally in the CISC database) for the area and on the interpretation of the aerial photographs used in this project.

The SUMMARY command was used to determine class distribution of pixels in the test areas. Several classes could occur in any test area; however, the majority class in a test area was used to determine if the classified areas were correct. For example, the proportion of pine-hardwood forest pixels in pine test areas was divided by two (giving the assumed pine component of pine-hardwood areas) and was added to the total for pine pixels in the test areas to determine total correct pine pixels. The hardwood class was treated in the same way as the pine class. Pine pixels in pine regeneration areas were also considered correct.

Pine and hardwood pixels were incorporated into the pine-hardwood areas, and percentages of both components were used to determine if the area was stocked with 31 to 69 percent pines or hardwoods to meet the criteria for the mixed pine-hardwood class. The water class was not tested because there was an insufficient number of large water bodies within the ranger district boundary to derive test samples.

Agreement with the density classes was tested based on 19 test polygons selected during the density training phase of the classification. In this test, the central pixel or three-by-three window of pixels was evaluated to determine if the test polygon was correctly classified (POLYCAT routine in ERDAS).

Sample inquiries were formulated to determine whether the classification agreed with stand attributes in

the GIS. This procedure was done, not to test accuracy, but to discover areas in the GIS that may need updates. Plots of the classifications and stand queries provided graphic indications of stands that should be more closely assessed for prescription work such as thinning, hardwood control, or extended regeneration efforts.

Plot Generation

Plots of the forest classifications were produced with ARC/INFO. This software has extensive digital cartographic capabilities that are useful for combining the Landsat classifications with map features and management boundaries. Plots were produced of the entire ranger district, two sample clusters, and several individual compartments. Additional plots of detailed GIS inquiries were also produced and delivered to the ranger district.

RESULTS AND DISCUSSION

Georegistration of the image data was considered good for this data set. Subpixel (< 25 m [< 82 ft]) average residual error for the control points used in rectification provided an accurate match with stable GIS features such as roads and ownership boundaries. Note that an independent test of registration accuracy was not performed for this project. This could be done by selecting a test set of control points to evaluate using the rectification equations. Visual inspection of roads overlaid on the image data indicated that the registration was sufficient for the project goals.

The classification training procedures were easily implemented and can be repeated for future work. ARC/INFO and the LiveLink software in ERDAS were helpful for identifying a variety of stand conditions that were sampled in the training phase. Use of stand data and aerial photographs ensured that the training and test polygons represented a wide range of conditions across the forest.

Supervised classification provides a way to standardize signature training opportunities that are not available in unsupervised signature clustering and classification procedures. Unsupervised techniques usually require that the analyst define the number of final classes to be sought in the signature identification phase. The computer algorithm then defines spectral classes based on statistical distributions in the image data. This procedure ensures that separable classes are identified but does not provide any class labels; class labeling is up to the analyst. Note that unsupervised classification does not take into account changes in the environment that could alter spectral signatures from year to year (e.g., atmospheric haze, soil moisture, etc.). Therefore, even if scenes from the same time of year are analyzed, different signatures can result for the same cover classes, creating a confounding effect for the analyst when attempting to properly label the signatures.

Change detection (comparisons of changes between class distributions) is also more difficult because the spectral classes were not derived from the same locations.

The supervised approach allows the analyst to account for differences in scene characteristics by sampling the same locations for successive years. Thus, even though the signatures may have different characteristics, they can be confidently used to represent the same ground conditions. National forest personnel should consider polygons in areas that are not under intensive management for use in repeated signature training procedures. This consideration will ensure that the same stand conditions will be represented for future classifications although the spectral characteristics will vary with time. Consistency in training procedures will provide a common link between classifications so that change assessments will be possible in successive years.

GIS Data Integration

Although the task of converting the Landsat classification to a GIS coverage is straightforward, it requires a significant amount of time and disk space. Two steps were required to complete the conversion in this project. First, the ERDAS classification was converted to an SVF. This grid-format file was then converted to vector format in ARC/INFO. The vectorization process (conversion from SVF to ARC/INFO coverage) took an entire day to complete. Disk space used, including temporary files, exceeded 250 megabytes. The final coverage was slightly over 123 megabytes when processing was complete. This process could have been streamlined if the ERDAS SIEVE routine had been used to reduce the number of small inclusions within stands. However, this would have also eliminated potentially useful information for the forest manager by masking areas of stand vegetation or density diversity.

ARC/INFO can now handle grid format data in raster GIS functions, displays, and plotting operations. Grid GIS data can be manipulated in both ERDAS and ARC/INFO to perform many of the comparisons and tests described here. There are tradeoffs in using grid versus vector format data. Grid format comparisons are completely appropriate for comparing Landsat classifications because the original data type is also grid. However, data gridded from original vector format information will be spatially degraded and may not provide the details needed for some inquiries.

Other processes that consumed large amounts of disk space included intersecting the TM classifications with the stand data and developing plots for the electrostatic plotter. Similar classifications and online data layers for the entire Kisatchie National Forest (based on this ranger district project) would require nearly 750 megabytes of free storage. Additional space would also be needed for preliminary processing of the Landsat TM data and for temporary files for ARC/INFO processing. Thus, for continuation of this type of work forestwide, large amounts of magnetic and optical me-

Table 1.—*Areas of cover classes derived from Landsat TM data*

Cover class	Area	
	Hectares	Acres
Harvested/open	6,027.4	14,887.7
Pine regeneration	6,990.9	17,267.6
Low crown density pine	5,114.2	12,632.0
High crown density pine	16,218.5	40,059.6
Pine-hardwood	8,202.1	20,259.2
Hardwood	6,780.6	16,748.2
Water	15.3	37.9
Total	49,349.0	121,892.2

dia are recommended for data storage (Landrum and others 1992).

Classification Evaluation

The final classification categories (fig. 4) were: harvested/open, pine regeneration, low crown density pine, high crown density pine, pine-hardwood, hardwood, and water. Class acreage totals are given in table 1. The pixel-by-pixel test produced an agreement of 71.2 percent (8,933 of 12,545 pixels correct). Individual class agreement percentages ranged from 32.9 to 99.8 (table 2). This test did not take into account the concept of forest cover mixture that can occur in stand areas.

When areas with mixed pine-hardwood components were reevaluated based on the stand approach discussed in the "Methods" section, then the agreement for all areas was a much improved 86.2 percent (10,815 of 12,545 pixels correct). Individual class agreement percentages ranged from 65.5 to 99.8 (table 2). The average agreement for all classes was 84.6 percent. Agreement for the density classes

determined from the independent polygon test was 79 percent (15 of 19 polygons correct).

These results are satisfactory, considering the dynamic nature of the area and the fact that much of the training was based on stand information that was at least 1 year older than the TM data. The significant improvement, particularly in the pine-hardwood class agreement, must be attributed to the way pines and hardwoods actually occur in mixed-stand conditions. A spectral class of the mixed pine-hardwood condition is difficult to represent because the individual tree species probably tend to occur in clumps. These clumps may be distributed in spatial dimensions similar to the Landsat TM data pixel. Therefore, there may be good justification for using only pure cover classes and evaluating the mixed pine-hardwood condition of stands with GIS enumeration techniques after the spectral classification procedures.

Differences in classification and stand data should be taken as an indication of the information potential in these types of analyses. For instance, pine regeneration areas misclassified as hardwood may need release work to control hardwood competition (fig. 5). Thus the spectral characteristics of areas can be helpful in forest management. Areas of insect damage or beaver activity (flood-killed timber) may also be spotted by comparing subsequent classifications for areas that are seldom visited on the ground. Such areas may be classified as high crown density pine in one year and low crown density pine or partly open the next.

An alternative method for flagging stands for GIS modification is to compare the Landsat TM classification by stand with the CISC codes. Disagreements can be listed and plotted graphically to highlight stands that should be considered in reevaluating stand management practices.

Another practical use of the classification system is to identify stands with high crown densities (fig. 6). Such stands may need thinning because crown competition will eventually result in reduced annual increment growth. Stand boundaries can be easily redefined based on harvest

Table 2.—*Summary of agreement between Landsat TM classifications and stand attributes in the Catahoula Ranger District GIS*

Cover class	Total test pixels	Pixel test method		Stand test method	
		Correct pixels	Correct pixels	Correct pixels	Correct pixels
	Number	Number	Percent	Number	Percent
Harvested/open	1,375	1,372	99.8	1,372	99.8
Pine regeneration	1,235	789	63.9	809	65.5
Pine	5,330	4,469	83.8	4,803	90.1
Pine-hardwood	2,151	707	32.9	2,016	93.7
Hardwood	2,454	1,596	65.0	1,815	74.0
Total	12,545	8,933	71.2	10,815	86.2

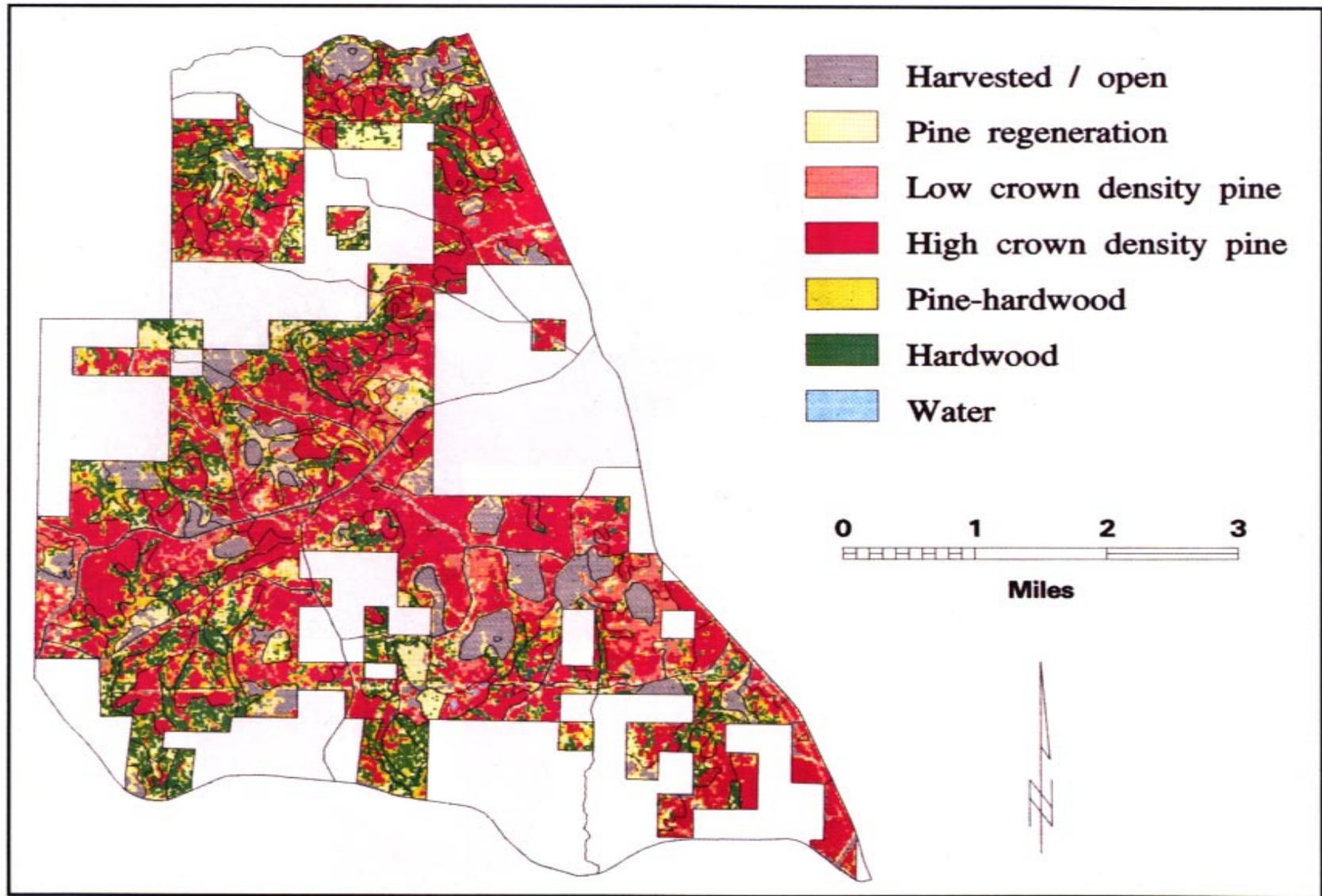


Figure 4.—Final Landsat Thematic Mapper classification of one cluster of compartments (thin lines are stand boundaries) on the Catahoula Ranger District.

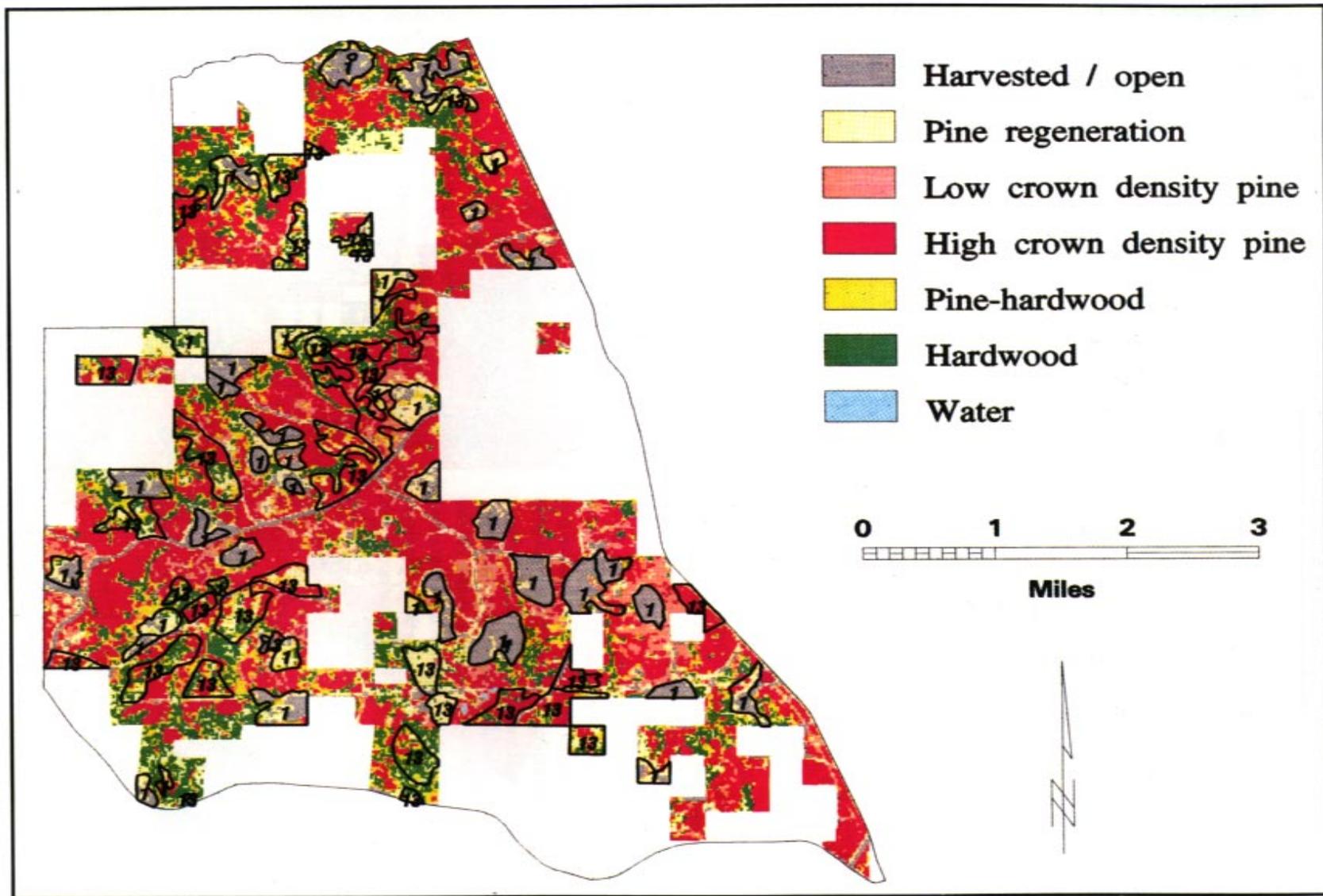


Figure 5.—Harvested areas (indicated by 1) and pine regeneration areas (indicated by 13) from geographic information system superimposed on the Landsat Thematic Mapper classification of one cluster of compartments. Note areas coded as 13 in the southwest part of the cluster with a large proportion of hardwoods.

patterns and logical groupings of similar species and stand densities that may not have been identified in the field.

Areas of upland hardwoods can be identified by superimposing the classification over soil data (fig. 7). These areas may be suitable for enhanced wildlife habitats.

Data Processing Considerations

The total time required to perform the data analysis phases of this project was about 2 person-months. However, some of this time was spent in preliminary meetings and development of strategies to perform the work. Repetition of this project would realistically take 1.0 to 1.5 person-months in an operational setting. This time estimate assumes that all data are on hand at the start of the work. It does not include development of cartographic products on specific GIS retrievals.

The time required to develop these products varies widely based on the complexity of the operations and the desired format for output products. The cost of the Landsat TM data was \$3,960 at the time this work was performed. The cost of other data and supplies was minimal.

CONCLUSIONS

This project demonstrated the utility of Landsat TM data for developing basic forest cover information on the Kisatchie National Forest. Specific commands in both ARC/INFO and ERDAS are given for processes used in this work. However, the reader should be able to apply the same concepts given here to other projects even if different software is used. The section on selected references provides general sources of information that would be useful for the reader.

Supervised methods of signature development and classification were chosen for ease of use and repetition in future classifications. The first basic cover-type classifications were harvested/open, pine regeneration, pine, pine-hardwood, hardwood, and water. The pine type was subdivided into low and high crown density classes.

All signature training and test polygons were selected based on the existing GIS, aerial photographs, and the expertise of national forest personnel. Overall agreement for the basic classification of the test area was 86.2 percent. The polygons for testing the pine crown density classes gave a 79-percent agreement.

Cartographic products (plots) of the basic classifications and selected GIS queries provided national forest personnel with useful tools for evaluating timber stand prescriptions and other management practices. Therefore, Landsat TM data can be processed to provide useful forest cover information at the ranger district level. Integration of Landsat TM products with existing GIS provides resource managers with new perspectives on stand characteristics.

LITERATURE CITED

- Bain, Stan. 1988. Landsat classification/field correlation methods for vegetation classification. In: Proceedings of the 2nd Forest Service remote sensing applications conference; 1988 April 11–15; Slidell, LA. Bethesda, MD: American Society for Photogrammetry and Remote Sensing: 172–176.
- Bolstad, Paul V.; Lillesand, T.M. 1992. Improved classification of forest vegetation in northern Wisconsin through a rulebased combination of soils, terrain, and Landsat Thematic Mapper data. *Forest Science*. 38(1): 5–20.
- Born, J. David. 1988. Comparing Landsat Thematic Mapper imagery with alternative data sources for woodland inventory of the Prescott National Forest. In: Proceedings of the 2nd Forest Service remote sensing applications conference; 1988 April 11–15; Slidell, LA. Bethesda, MD; American Society for Photogrammetry and Remote Sensing: 177–185.
- Cibula, William G.; Nyquist, Maurice O. 1987. Use of topographic and climatological models in a geographical data base to improve Landsat MSS classification for Olympic National Park. *Photogrammetric Engineering and Remote Sensing*. 53(1): 67–75.
- Coleman, T.L.; Gudapati, L. 1990. Evaluation of TM imagery for monitoring forest plantations. In: Proceedings of the 3rd Forest Service remote sensing applications conference; 1990 April 9–13; Tucson, AZ. Bethesda, MD: American Society for Photogrammetry and Remote Sensing: 147–162.
- Congalton, Russell G.; Green, Kass; Teply, John. 1993. Mapping old growth forests on national forest and park lands in the Pacific Northwest from remotely sensed data. *Photogrammetric Engineering and Remote Sensing*. 59(4): 529–535.
- ERDAS, Inc. 1991. ERDAS field guide. Atlanta, GA: ERDAS, Inc. 394 p.
- ESRI, Inc. 1991. ARC/INFO user's guides. Redlands, CA: Environmental Systems Research Institute, Inc. 20 vol.
- Evans, David L.; Hill, John M. 1990. Landsat TM versus MSS data for forest type identification. *Geocarto International*. 5(3): 13–20.
- Evans, David L.; Schoelerman, Lynn; Melvin, Tom. 1992. Landsat Thematic Mapper data for development and interpretation of vegetation information on the Kisatchie National Forest. In: Proceedings of the 4th Forest Service remote sensing applications conference; 1992 April 6–10; Orlando, FL. Bethesda, MD: American Society for Photogrammetry and Remote Sensing: 117–124.
- Frank, Thomas D. 1988. Mapping dominant vegetation communities in the Colorado Rocky Mountain front range with Landsat Thematic Mapper and digital terrain data. *Photogrammetric Engineering and Remote Sensing*. 54(12): 1,727–1,734.

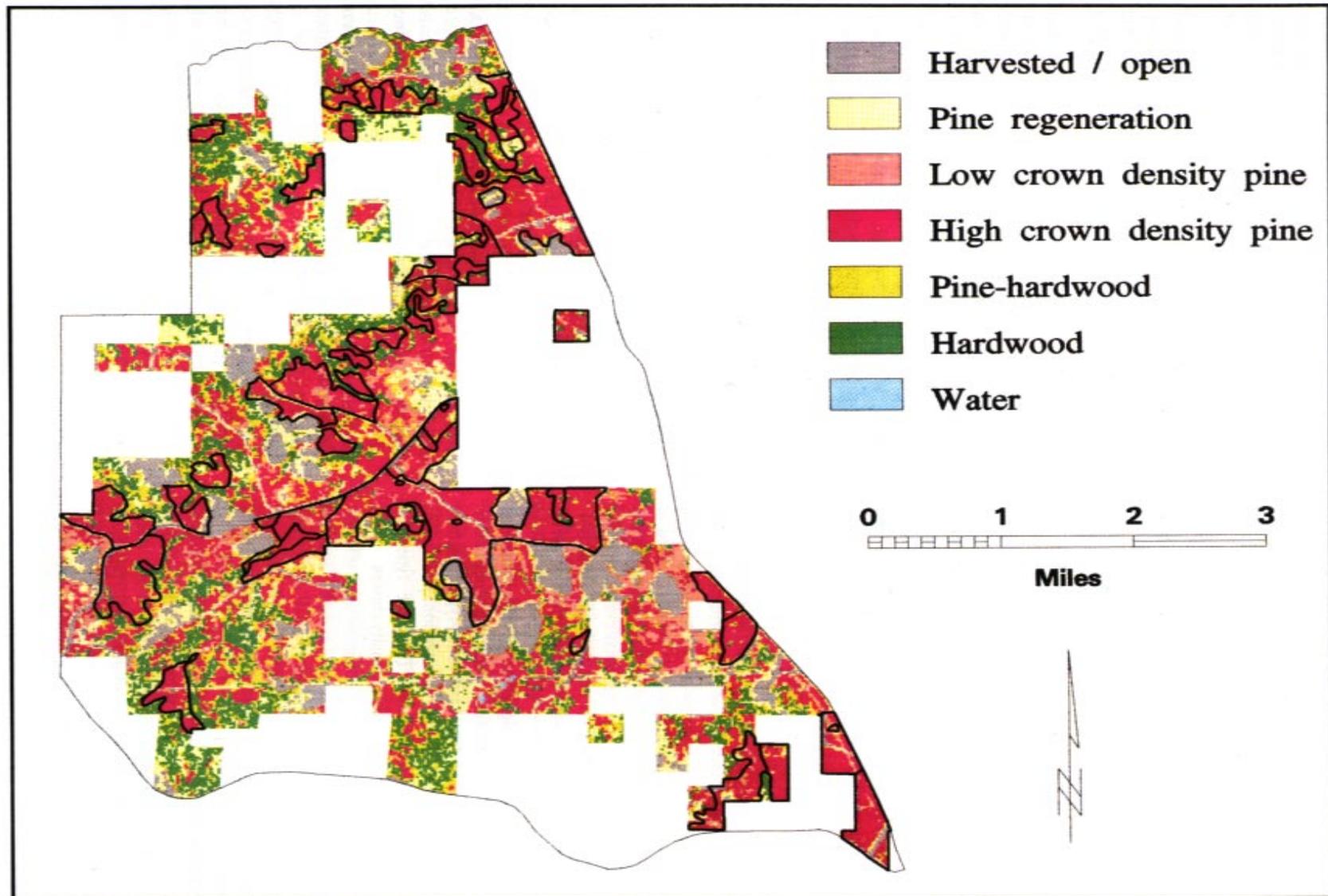


Figure 6.—Pine stands, with high crown density, that are greater than 15 years old (heavy lines) as derived from Landsat Thematic Mapper classification and geographic information system query on one cluster of compartments.

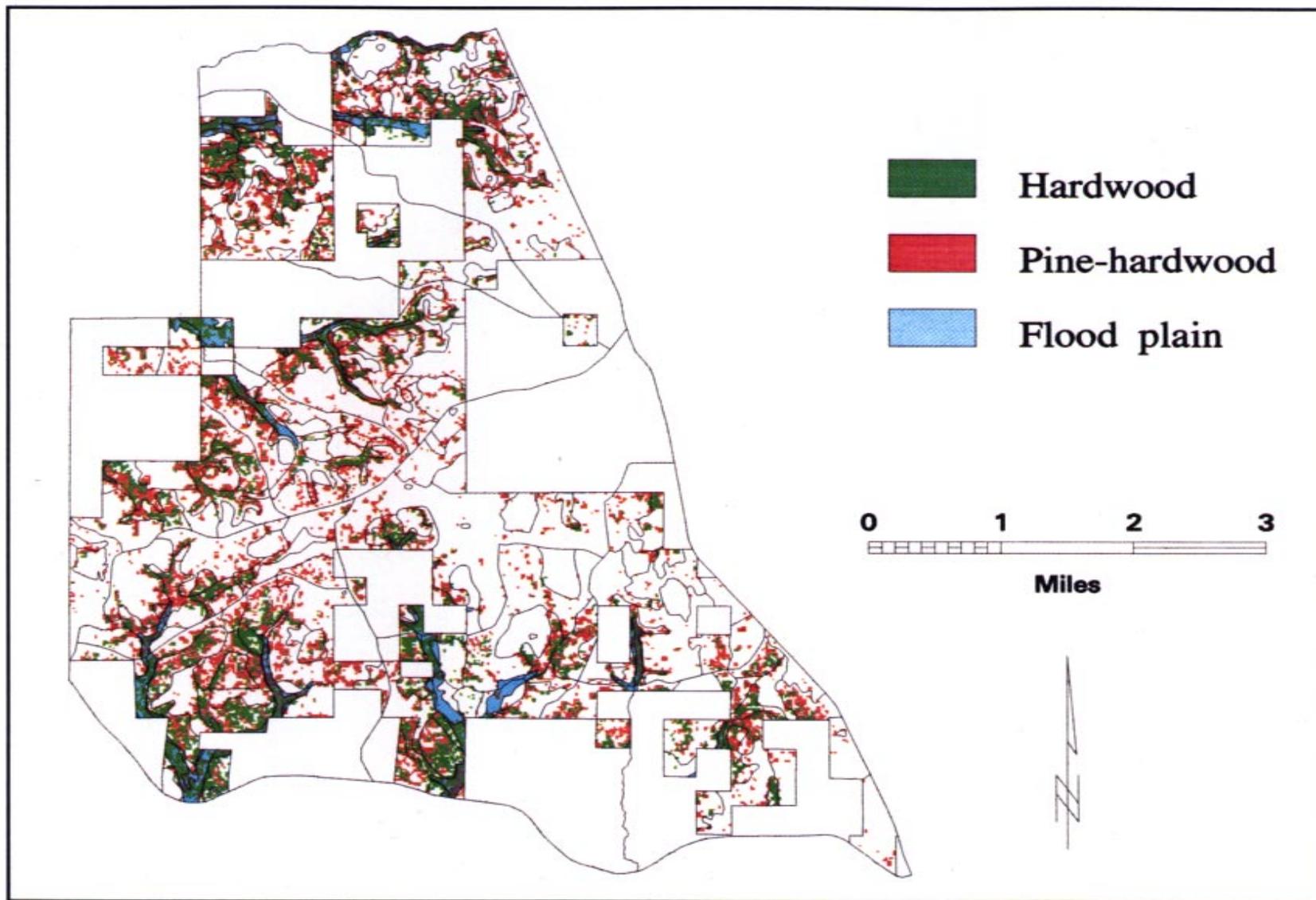


Figure 7.—Hardwood and pine-hardwood forests on upland (nonfloodplain) soil polygons of one cluster of compartments.

- Landrum, Vaughan; Lachowski, Henry; Steffenson, John. 1992. Data storage needs for remotely sensed digital data. *Engineering Field Notes*. Washington, DC: U.S. Department of Agriculture, Forest Service; 24: 21-24.
- Lillesand, Thomas M.; Keifer, Ralph W. 1979. *Remote sensing and image interpretation*. New York: John Wiley and Sons. 612 p.
- Swain, Philip H.; Davis, Shirley M. 1978. *Remote sensing: the quantitative approach*. New York: McGraw-Hill Book Company. 396 p.
- Walsh, S.J. 1980. Coniferous tree species mapping using Landsat data. *Remote Sensing of Environment*. 9: 11-26.
- Woodcock, Curtis E.; Harward, V. Judson; Jakabhazy, Vida [and others]. 1990. An overview of a new timber inventory system. In: *Proceedings of the 3rd Forest Service remote sensing applications conference; 1990 April 9-13; Tucson, AZ*. Bethesda, MD: American Society for Photogrammetry and Remote Sensing: 321-333

SELECTED REFERENCES

- Born, J. David; Lachowski, Henry M.; Landrum, Vaughan. 1992. Checklist for users of remote sensing data. *Engineering Field Notes*. Washington, DC: U.S. Department of Agriculture, Forest Service; 24: 11-19.
- Colwell, Robert N., ed. 1983. *Manual of remote sensing*. Bethesda, MD: American Society for Photogrammetry and Remote Sensing. 2 vol.
- Star, Jeffrey; Estes, John. 1990. *Geographic information systems: an introduction*. Englewood Cliffs, NJ: Prentice Hall. 303 p.

APPENDIX

Definitions of Cover Classes

Harvested/open—primarily intended to represent areas of recent harvesting activities where the entire timber stand was removed in preparation for stand regeneration; also includes other areas of open land such as fallow crop fields, pastures, roads, and rights-of-way.

Pine regeneration—areas that were harvested, replanted, and subsequently certified as successfully regenerated in pine as determined from the GIS.

Pine—areas that have pines in the dominant or co-dominant position in 70 percent or more of the crowns.

Low crown density pine—pine areas that, based on aerial photointerpretations and field expertise of national forest personnel, would not have sufficient standing timber to warrant stand-thinning operations. Crown closure was generally 70 percent or less as interpreted from aerial photographs.

High crown density pine—pine areas that, based on aerial photointerpretations and field expertise of national forest personnel, warrant checking for the possibility of performing stand-thinning operations. Crown closure was generally greater than 70 percent as interpreted from aerial photographs.

Pine-hardwood—areas that have either pines or hardwoods in the dominant or codominant position in 31 to 69 percent of the crowns.

Hardwood—areas that have hardwoods in the dominant or codominate position in 70 percent or greater of the crowns.

Water—water bodies large enough (generally > 0.4 hectare [1 acre]) to be detected in data classification.

Evans, David L. 1994. Forest cover from Landsat Thematic Mapper data for use in the Catahoula Ranger District geographic information system. Gen. Tech. Rep. SO-99. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 14 p.

A forest cover classification of the Kisatchie National Forest, Catahoula Ranger District, was performed with Landsat Thematic Mapper data. Data base retrievals and map products from this analysis demonstrated used of Landsat for forest management decisions.

Keywords: Forest mapping, GIS, image processing remote sensing, supervised classification.

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