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# MECHANICS OF MONITORING FOREST CLEARCUTS AND THEIR REGENERATION

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## ABSTRACT

A framework for the identification and monitoring of forest clearcuts and their regeneration is presented. LANDSAT digital data are classified to detect clearcuts and their major regeneration components, including brush, grass, bare soil, and conifer. Historical LANDSAT digital data are used to provide a change-detection analysis of forest conditions. Area summaries of land cover are obtained for the entire study area or for subunits. A graphic digitizer is used to provide an overlay to the LANDSAT digital land cover classification in order to summarize land cover area by physical and/or political boundaries. Individual clearcuts are analyzed within each summary unit for the size of the clearcut, the type of regenerated land cover, and other site-specific accounting information. Output products include tabular summaries of the area of each land cover, and black and white or color maps of geographically referenced land cover data.

Ancillary data affecting land cover management decision-making, such as topography or climate can be graphically interfaced with LANDSAT-derived land cover information and "specialized" composite maps produced. These "specialized" maps provide an added dimension in resource management planning.

## I. INTRODUCTION

Forest resources today are under tremendous pressure to provide the public with multiple benefits, such as timber production, recreation, and wildlife habitat. As the pressure increases on our forests, the need grows for greater efficiency in the management of timber resources. Timber reserves must be rapidly and accurately appraised. The stage and condition of forest harvest and regeneration must be recognized, mapped, and assessed periodically. New techniques of timber mapping and monitoring should be blended with the traditional techniques to improve efficiency and accuracy.

Remote sensing surveys using LANDSAT data currently show great potential for monitoring and inventorying forest cover and canopy alteration on a timely, reliable, and updateable basis. Forests intensively managed on a large-scale basis can be monitored with existing LANDSAT resolution and spectral bands. LANDSAT information can supplement analyses from ground surveys and aerial photography. LANDSAT can provide forest managers with a technique to inventory the location of forest clearcuts, the rate of forest clearcutting, and the areas of concentration of clearcutting through the use of historical and repetitive multi-temporal LANDSAT digital data. Vegetation regeneration in forest clearcuts can be assessed with emphasis on vegetation density, vegetation type, and amount of bare soil. Relative degrees of regeneration within forest clearcuts relate to the age and condition of the reestablishment of the forest. LANDSAT data can also be used to pinpoint and highlight areas of interest over extensive areas for detailed study through field excursions and large-scale photointerpretation.

The size, complexity, and dynamics of forest operations necessitates the need for a complementary system which blends land cover information, gathered through remote sensing techniques, with an interactive, graphic-oriented, computerized data base containing variables such as terrain, wildlife habitat, stream characteristics, and silvicultural practices. The data base should be capable of updating forest cover type information and producing graphic overlays of digitized ancillary data. Selected combinations of

cover type, terrain variables, and site conditions within digitized physical and/or political boundaries can prove very efficient and effective to forest managers interested in obtaining specialized post-land cover classification data for resource management.[3] Detection of large areas of bare soil within forest clearcuts may indicate the need for replanting of seedlings; the identification of excess brushfields may indicate the need for chemical treatment; and the observation of clearcuts with dense crown closure may necessitate thinning operations. Such detailed information from remote sensing techniques when combined with Data Base information assists the forest manager in effective decision-making for the wisest use of the resource.

## II. THE STUDY AREA

The study area, located in the extreme southeastern corner of Oklahoma, Figure 1, covers approximately 6,125 square km (3,800 square miles) in McCurtain, Pushmataha, and the southern one-half of LeFlore County. Approximately seventy-five percent of the area is forested with shortleaf and loblolly pine, and various oaks, hickory, and sweetgum. The study area contains virtually all of the commercial softwood timber resources in Oklahoma.

The northern three-quarters of the study area lies in the Ouachita Mountain physiographic province. The area consists of rugged hills with elevations exceeding 762 m (2,500 feet) and local relief up to 457 m (1,500 feet). Resistant sandstone promotes steep slopes and narrow ridges while the valleys are underlain by less-resistant shales. Slopes, rock type, and
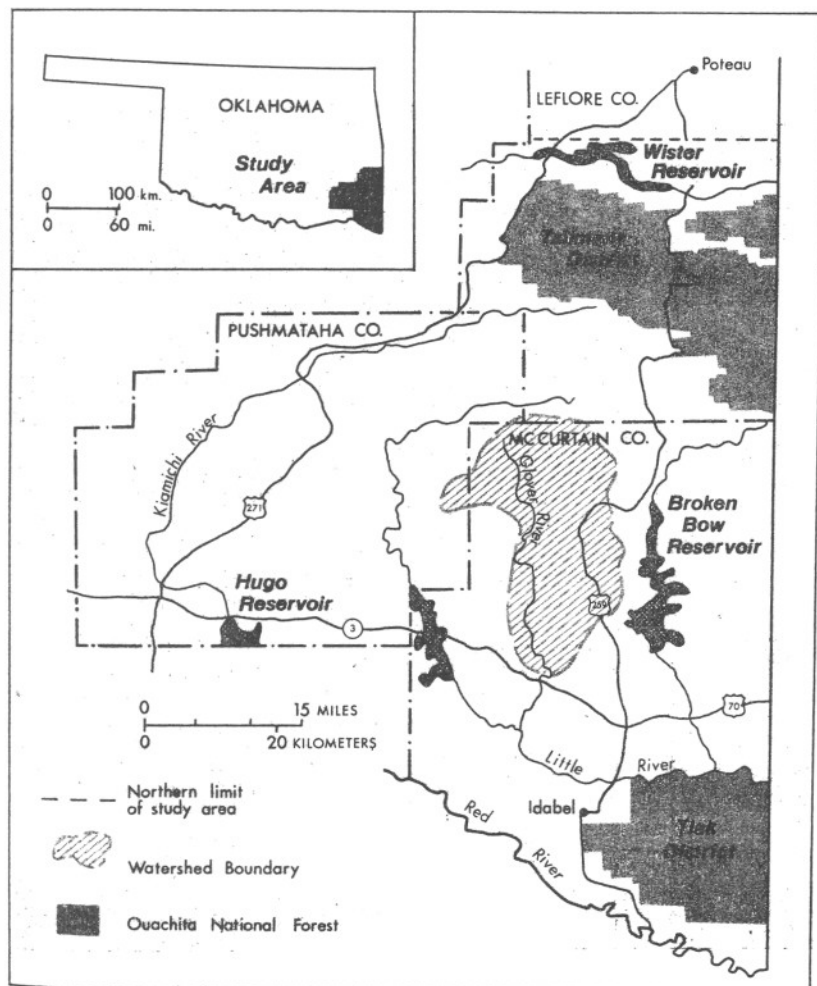


Figure 1. The study area. The watershed identified on this figure, the Glover River, indicates the location of figures 2 and 3.

soils contribute to an environment poorly suited to most agricultural activities. The southern one-quarter of the study area, in contrast, consists of gently rolling hills and a wide alluvial plain along the Red River. Change from forest to agricultural land use is directly related to the topography within the study area.

The study area has a moist sub-humid climate. Average yearly precipitation exceeds 117 cm (46 inches) throughout, although some sections in southern LeFlore County receive over 142 cm (56 inches) of precipitation per year. Annual runoff averages 38 cm (15 inches) with some parts of the region exceeding 51 cm (20 inches) per year. The average yearly temperature is approximately $17^{\circ}C$ ($62^{\circ}F$) and the growing season is about eight months long.

### III. LANDSAT ANALYSIS

The LANDSAT digital data for this study was processed at the Oklahoma State University Center for Applications of Remote Sensing (CARS), Stillwater, Oklahoma. CARS' computer system includes a Perkin-Elmer 8/32 mini-computer, tape drives, disc system, line printer, operator terminals, Comtal image processing system, Versatec electrostatic printer/ plotter, and a Altek graphic digitizer. The computer software utilized by CARS is the Earth Resources Laboratory Applications System (ELAS) software developed at NASA/Earth Resources Laboratory, National Space Technology Laboratories, Mississippi.

The study area is comprised of sections of three separate scenes of LANDSAT digital data, and portions of each were processed and merged. Since analysis was conducted for two time periods, 1972 and 1979, sections of six LANDSAT scenes of data were processed. The 1972 analysis includes digital tapes for 28 November 1972 (ID. 1128-16300), and 4 October 1972 (ID. 1073-16233 and 1073-16235). LANDSAT digital tapes for 26 September 1979 (ID. 21708-16131), 16 September 1979 (ID. 31560-16115), and 4 October 1979 (ID. 30578-16110) were processed for the second time period. These dates were selected because of an absence of cloud cover, high quality rating of data collected per band, and the lower sun angle of the fall season. The selection of relative low sun angle data represents a compromise between late fall or winter LANDSAT digital tapes, which have been shown to enhance openings in the forest canopy better than higher angle summer dates, and late spring or summer tapes

where vegetation discrimination would be enhanced.[1] The compromise between each of these situations results from the purpose of the analysis, which is to monitor both the change in forest canopy due to forest clearcutting activity, and the level of regeneration within identified forest clearcuts.

The processing of the LANDSAT digital data began by "Reformatting" the data into a format compatible with the ELAS software. The data sets were then "Destriped" to reduce the sixth-line banding problem and "Searched" to acquire homogenous training field statistics. The "Search" procedure of the ELAS software employes a 3 x 3 pixel window lagging operation over the data. Classes are derived by identifying pixel groups whose standard deviation in each band falls between an established upper and lower bound and the scaled distance between each class is greater than a specified minimum distance.[4] The raw data are then classified into one of the statistical classes produced by the "Search" utilizing the principle of maximum likelihood. Finally, the data are "Geo-referenced" into the Universal Transverse Mercator (UTM) coordinate system to reduce the geometric distortion inherent in the LANDSAT data. This is accomplished by locating several points within the data through use of the image processing system, and locating the identical points on U.S.G.S. quadrangles. The element and scan line coordinates of the digital data are related to the UTM Eastings and Northings map coordinates, so that an equation can be derived to convert all of the digital data to a standard UTM coordinate system.

All three of the 1979 scenes of data were processed separately, as was the 28 November 1972 data. The two 4 October 1972 scenes of data, however, were combined to form one data set for analysis. Scenes of successive LANDSAT data collected on the same date, generally exhibit a difference in brightness between the scenes. Consequently, algorithms have been developed which not only geometrically correct and register LANDSAT images, but also correct for differences in brightness between scenes of data.[2] This brightness correction was not utilized prior to combining the two 4 October 1972 scenes of data, because the scenes were consecutive frames of data from the same flight strip of LANDSAT I. In addition, no significant difference in mean count values for any of the four bands cound be determined for the area of overlap between the two scenes. Since the area of overlap was exactly 300 scan lines, geometric registration of the two

scenes was easily and accurately accomplished. The two consecutive overlapping scenes were combined into a single data set, and the process of "Destripe", "Search", "Classify", and "Geo-reference" were completed.

The time period between the 28 November 1972 and the 4 October 1972 data sets hinders the merging of the separate scenes of data. The time between the two dates is significant, because most brush and deciduous species have begun losing their leaves. This allows the underlying bare soil to impart a greater influence in the count values of each pixel. The overlap of data between these two scene data sets is also considerable, since approximately 25 percent of each data set covers the same area. Conceivably, an accurate classification of both dates of data should provide the same, or at least quite similar, classification of vegetation cover types. Before classification of the data, however, it is not apparent which set of raw data would provide the most accurate classification of the overlapped area. Consequently, the two dates of data were processed separately and merged together only after the classifications were completed and both data sets "Georeferenced" into the same UTM coordinate system. Accurate mosaicing of separate LANDSAT frames can be accomplished by locating control points of known locations within each image.[5]

As with any project, an attempt is made to achieve a classification accuracy as high as possible. A high accuracy can be accomplished, if the initial classification provides enough statistical classes to account for all vegetation cover types relevant to the analysis. Classes representing similar cover types can be aggregated or merged later in the analysis.[2] Therefore, an unsupervised classification process was conducted on each of the data sets in the analysis to generate the largest possible number of statistical classes.

The unsupervised classification produced 56 statistically different classes of land cover for the 28 November 1972 data set, and 37 separate classes for the 4 October 1972 data set. The greater number of classes for the 28 November 1972 data set probably resulted from the later season and the greater influence of the highly reflective bare soil on the count values. In addition, the study area experienced an extensive rain just prior to the 28 November 1972 date which resulted in several "wet" classes not found in the 4 October 1972 analysis. This was particularly evident in the relatively flat,

southern one-fourth of the study area. Unsupervised classifications of the 26 September 1979, 16 September 1979, and 4 October 1979 data sets produced 58, 45, and 48 statistically different land cover classes, respectively. The large number of classes identified in 1979 is due primarily to the large number of brush classes which regenerated within the extensive network of forest clearcuts since 1972.

Since the classification has produced more classes than needed and more detail than required, classes are grouped into generalized cover type categories. Grouping of classes was accomplished by displaying the classified data on the color video display image processing system. The entire 185 x 185 km (115 x 115 mile) LANDSAT scene of data was displayed on the image processing system by compressing the areal distribution of the color-coded classes. Particular areas within the study area can also be viewed and enlarged, if necessary, to appraise the distribution of the color-coded classes and to visually assess the accuracy of the classification. Available aerial photography, and extensive ground truth information previously gathered are all utilized to combine the computer generated classes into single classes of water, bare soil, grass, brush, predominantly deciduous forest, and predominantly coniferous forest. Statistical output for each class derived from the "Search" procedure, such as mean reflectance for each band, divergence matrix between classes, and a two-space plot of bands five and seven also aid in combining classes.

The image processing system utilized in this analysis has the capability to display a 512 x 512 pixel area on the screen at one time. Figures 2 and 3 however, represent only a portion of one such area. The area shown is the watershed of the Glover River in southeastern Oklahoma for 1972 and 1979, respectively. The color-coded data have already been "Georeferenced" and mosaiced together with the original classes aggregated into the six basic land-cover classes of this study. Most noticeable in these two figures is the difference in cover type between the two years for certain sections of the watershed. The irregular shaped, gray areas in figure 3 represent the location of forest clearcuts in 1979 that were not present in 1972. Inspection of figure 2 indicates that as of 28 November 1972 forest clearcutting was not a common practice in southeastern Oklahoma. Most of the clearcuts shown in the 1979 classification are three to six years old, and are dominated by various brush species.

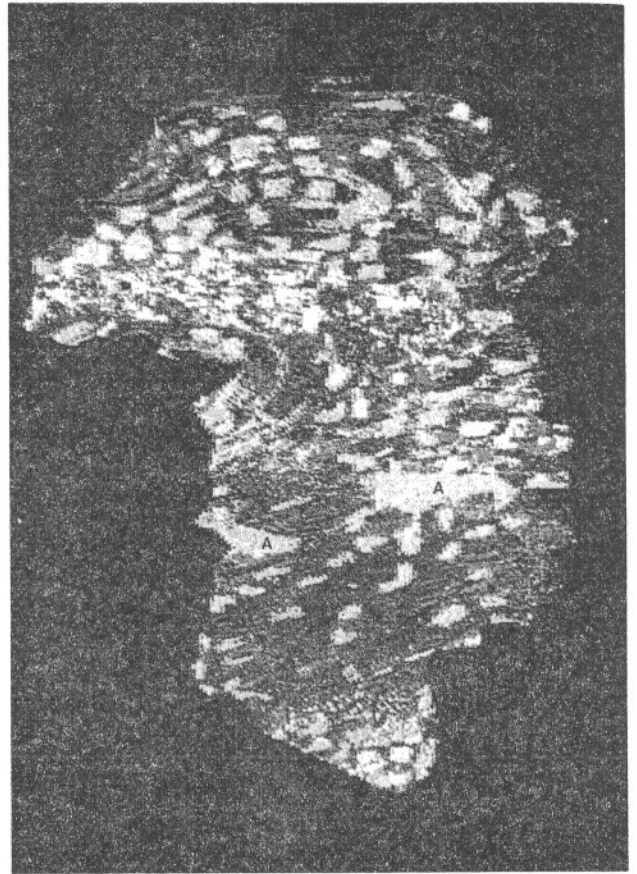Figure 2. A 1972 classification of the Glover River watershed with six basic land-cover categories.



Figure 3. A 1979 classification of the Glover River watershed which reveals the pattern of clearcuts since 1972. The regions labeled "A" represent smoke plumes from a slash fire.

TABLE I. Area Summary of Land-Cover Categories, Glover River Watershed

|  | 1972 | 1979 | Difference |
|---|---|---|---|
| Coniferous | 134,603 acres | 94,082 acres | -40,521 acres |
| Deciduous | 71,083 | 65,112 | -5,971 |
| Brush | 4,060 | 44,242 | +40,182 |
| Grass | 10,842 | 14,509 | +3,667 |
| Bare Soil | 1,075 | 3,752 | +2,677 |
| Water | 36 | 2 | -34 |
| TOTAL | 221,699 acres | 221,699 acres | |

Portions of these clearcuts are classified as grass or bare soil and represent areas of very sparse vegetation indicating a young clearcut (1-3 years) or possibly older clearcuts which have been eroded.

This dramatic change in vegetation cover type is summarized in Table 1. It appears quite evident that the major force of change in vegetation cover type for this time period and area is due to forest clearcutting activities. The large reduction in acreage of conifers in 1979 confirms this conclusion. Although the portions of the forest first clearcut in this watershed generally represent the denest, most mature stands of conifers, the reduction in conifers across the area is less than the gain in area of brush, grass, and bare soil categories. The difference between the conifer acreage decrease and the brush, grass, and bare soil acreage increase in 1979 is due to the loss of deciduous forest, which occurs when clearcutting a mixed hardwood/softwood forest. In reality, the majority of the areas classified as brush in 1979 represent dediduous species. However, these areas consist primarily of scrub oak and hickory which represent the first stage of natural regeneration. At an early stage, the forest manager determines when the scrub oak and hickory are to be chemically treated, thereby allowing the plantation pine in the clearcut to emerge and dominate. The reduction in the acreage of water in 1979 is due to the extreme dry conditions and the corresponding reduced stream dimensions.

IV.   DEVELOPMENT OF SUMMARY UNITS

County political borders were initially used for collecting and reporting area statistics for cover types. The counties in this area of Oklahoma, however, are quite large, therefore statistics gathered on such a basis had little relevance to any specific area. In addition, the area is characterized by rugged terrain with few major roads or section lines. Orientation and location within the study area is difficult, so neither townships nor sections were thought suitable as a format for aggregation and reporting of the data. Aside from the rugged terrain, the other dominant physical feature of the area is the numerous streams and rivers which form a systematic pattern of drainage basins or watersheds. These basins or watersheds represent an intermediate size of a reporting unit and also appear to be relevant to some of the problems associated with forest clearcutting activities. Specifically, the possible degradation of water quality

through increased turbidity downstream from clearcutting activities. The selection of the drainage basin or watershed unit as the standard format for data collection also provides a systematic method for recording smaller areal units, if needed, in the form of sub-watersheds. Watershed boundaries, also, do not change significantly over time, as do some political or other arbitrary boundaries. Subsequent monitoring or updating activities are performed more easily if analyses from different time periods can be overlaid upon one another through the coordinates of the watershed boundaries.

Within each watershed, individual clearcuts can be digitized and identified. Each clearcut is graphically displayed and their size and land-cover acreage is summarized. Site-specific data is maintained on each clearcut and change-detection analysis is periodically performed for each watershed and clearcut. A forest manager can review the conditions of the forest by watersheds, or by counties. Moreover, he can inspect any individual clearcut with corresponding land-cover annotation and cover type area summaries for previous and current time periods. This review procedure allows the detailing of clearcut regeneration through time and the evaluation of silviculture practices.

V.   CLEARCUT ANALYSIS

Removal of tens to hundreds of acres of forest through clearcutting is readily detected by LANDSAT scanners as forests are transformed into a mosaic of brush, grass, and bare surfaces. This section indicates that changes in the clearcuts are detectable and can be incorporated into effective forest management.

Three clearcuts from southeastern Oklahoma were selected as examples to illustrate distinct differences in regeneration (Figures 4, 5, and 6). Interactive computer graphics permits ready access to any watershed and its respective clearcuts. Upon enlargement of a clearcut to a screen size image, different color-coded classes and their associated patterns are visible. The classes seen in Figures 4, 5, and 6 represent the results of the initial search and classification. The identification of bare soil representing a statistical class, for example, in one clearcut should indicate bare soil wherever that class is found on the image. The total amount of bare soil in all clearcuts can be tallied with computer methods, saving field time, and expense.
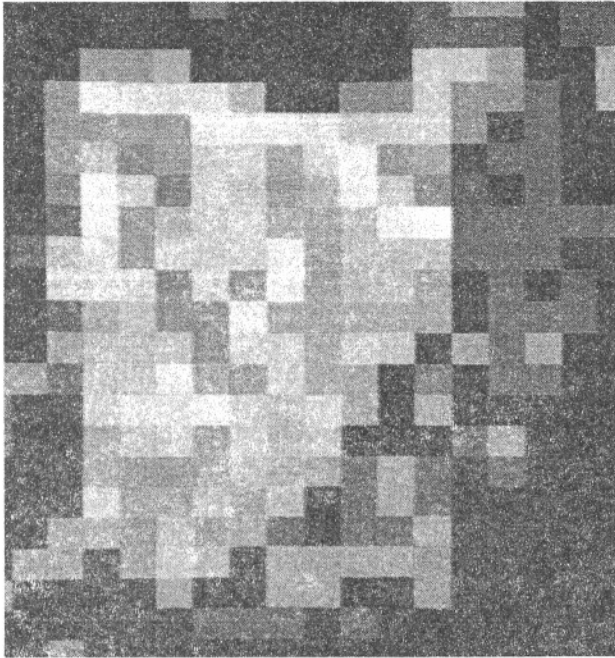
The initial search and classification

Figure 4. The initial classific-
ation over a forest clearcut reveals the
diversity of bare soil categories across
a recent clearcut. Each square represents
a resampling of the classification into
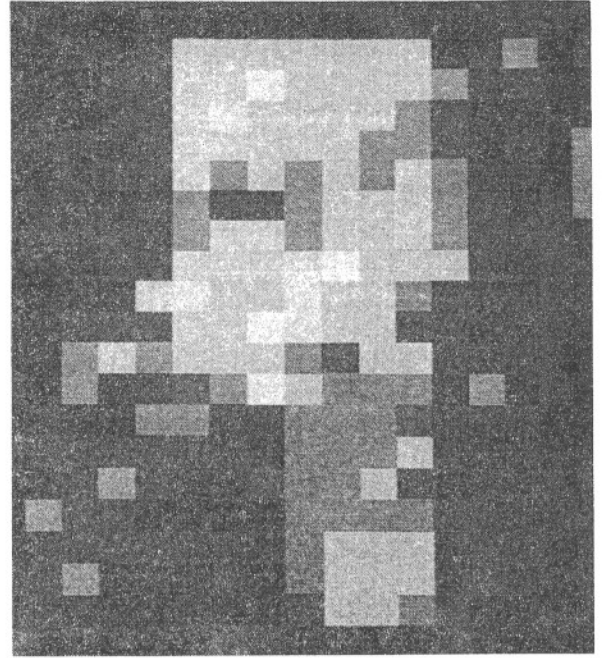one hundred meter cells (1 hectare).



Figure 6. Within this clearcut, a
uniform and dense cover of scrub oak and
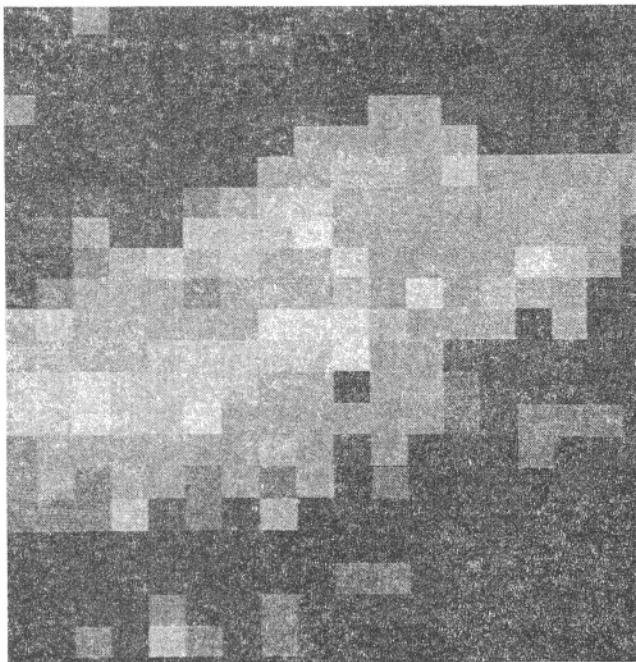sumac dominate the reflectance character-
istics.



Figure 5. A clearcut area in which
brush, pine regeneration, and areas of
bare soil are intermixed over an area of
variable topography. Ridges trend from
WSW to ENE across the photograph.

provides the forest manager with detailed information about the clearcuts. Each square on Figures 4, 5, and 6 represents one pixel (1.12 acres). The number of initial reflectance classes determined is a function of the land-cover and the classification parameters initialized by the analyst. A new clearcut with bare soil, slash piles, and very sparse vegetation regeneration, such as Figure 4, exhibits a pattern of reflectance values totally different than a clearcut with dense vegetation regeneration (Figure 6). Figure 5 illustrates an intermediate condition where the clearcut regeneration is approximately three years old. Since different plants and different plant densities reflect light differently, distinctions can be made between scrub hardwood, young plantation pine, and combinations of vegetation likely to regenerate in a forest clearcut. Detection of high density scrub hardwoods, may indicate the need to chemically treat the site, and plantation pine stands below desired density levels caused by erosion, disease, etc. may require replanting. The basis for such decisions is adequate and reliable field work to relate the classification to those conditions which may require action by the forest manager. The classification can then be aggregated to show general trends (Figures 2 and 3) or remain specific (Figures 4, 5, and 6) to involve more detailed consideration. In any event, thorough field work in representative areas allows extension of knowledge from those known areas throughout the study area.

## VI. SUMMARY

With field information plus known dates of cutting, planting, and other field operations, LANDSAT becomes more than just a tool with which to map major changes in the forest. Changes in vegetation regeneration are revealed in the reflectance data which permit information about density, age, and vegetation type to be ascertained. A Geographic Data Base System is a further extension of remotely sensed information for assisting the forest manager in resource assessment and planning. In addition to viewing individual watershed units and particular clearcuts within the watersheds with appropriate annotation, soil data, topographic information, timber characteristics, and climatic variables, for example, can be graphically interfaced to provide customized resource maps for the land manager. Management questions, involving road construction, size of water quality buffer zones, and site conditions can be interactively addressed on the data base prior

to and after the harvesting operation. LANDSAT information would continue to provide major land-cover data on a repetitive basis.

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