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Terrain Cover and Shadow Discrimination from Landsat Data of the Great Smoky Mountains National Park

Vincent Gerard Ambrosia
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Vincent Gerard Ambrosia entitled "Terrain Cover and Shadow Discrimination from Landsat Data of the Great Smoky Mountains National Park." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Geography.

John B. Rehder, Major Professor

We have read this thesis and recommend its acceptance:

James R. Carter, Edwin H. Hammond

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Accepted for the Council:

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Vice Chancellor
Graduate Studies and Research

TERRAIN COVER AND SHADOW DISCRIMINATION FROM LANDSAT DATA OF THE GREAT SMOKY MOUNTAINS NATIONAL PARK

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Vincent Gerard Ambrosia

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ABSTRACT

Landsat satellite imagery of the Great Smoky Mountains in East Tennessee and Western North Carolina exhibits dark tonal reflectances within the Blue Ridge physiographic province unlike any other reflectance patterns found on the remainder of the imagery. Repetitive, seasonal imagery indicate that these unique patterns are dynamic. There also appear to be definable, minute reflectance variations within the patterns themselves, indicating that there are numerous factors accounting for the anomaly. Among the factors discussed are the cover characteristics of the red spruce (picea rubens) and Fraser fir or southern balsam fir (abies fraseri), effects of topography, slope, aspect and ridge orientation, effects of solar angle and azimuth, and shadow zones.

Data were collected for three test sites within the boundary of the Great Smoky Mountains National Park between January 1980 and October 1980. The selected areas were easily accessible and were studied in the field by the author. Landform characteristics were obtained from United States Geological Survey topographic maps of the region. Cover characteristics were obtained from field research and from ancillary data of the National Park Service, the Uplands Research Laboratory, and the University of Tennessee Department of Forestry.

Landsat spectral data were analyzed in a two step method. The first step consisted of visual and photo-mechanical enhancement techniques. This included obtaining Landsat image scenes from the Earth Resources Observations Systems Data Center (EROS). It was hoped that by utilizing numerous photo-processing techniques previously obscurred data could be enhanced, analyzed, and classified.

The second step consisted of applying a supervised computer classification program to a Landsat digital tape of the study area. The supervised classification program analyzes a Landsat scene on the basis of established training sites that correspond to known locations studied in the field. The computer classification proved more adaptable to enhancing and classifying discrete regions than did photo-mechanical techniques.

This study suggests that more research into the feasibility of utilizing Landsat multispectral data in areas of low accessibility or mountainous terrain needs to be developed. It also suggests that numerous factors influence scene spectral levels and that the best means of examining these factors is through computer classifications based on selected test sites.

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INTRODUCTION

I. THE PROBLEM

Landsat multispectral images collected over the Great Smoky Mountains National Park exhibit distinct dark tones on the high crests of the major mountain ridges. Two areas of dark signatures are located along the main ridge line between Tennessee and North Carolina and in the high elevations of the Cataloochee Range at the southeastern end of the Park. These two areas have similar reflectances. In the Cataloochee Range the dark tones extend approximately six miles north to south and one to two miles east to west. Along the Tennessee and North Carolina state boundary, the pattern extends from Silers Bald in the southwest section of the Park to Mt. Sterling at the northeast end, a distance of twenty-eight miles. The dark-toned region is also evident on numerous spurs joined to the main crest line. The pattern stretches eight miles north to south in the Balsam Mountain region at the rugged east end of the Park (see Figure 1).

Lakes and other water bodies can be discounted as causes of the unique reflectance pattern, for no water bodies occur in the higher elevations. Soil moisture content is not a significant factor because the shielding effect of the

Figure 1. Dark-Toned Signature Patterns in the Higher Elevations of the Great Smoky Mountains National Park. Landsat Scene E5899-141427, Band 7, 4 October 1977. The White Arrows Indicate the Location of the Pattern. Scale: 1:116,600.

vegetation canopy obscures understory features from Landsat. Bare rock outcroppings do not cause the anomaly, because bare rock, having a light-colored surface, reflects significantly brighter than the displayed pattern. Vegetation would appear to cause the dark-toned pattern, for the Great Smoky Mountains National Park is dominated by deciduous and coniferous forest cover. A majority of the conifers are located in higher elevations along the main crest line and on ridges extending out from the main divide where the unique tones also occur.

The purpose of this thesis is to describe and analyze from a geographical standpoint, the unique dark-toned reflectances found on Landsat imagery of the Great Smoky Mountains. This study will focus on the effects of topographic characteristics, Keplerian rhythms, vegetation cover characteristics, and phenological shifts upon reflectance level variations in the higher elevations of the Great Smoky Mountains National Park. Essential to this undertaking is the correct identification of influencing factors by both manual and computer analyses. It is hypothesized that the unique signatures are related to two primary factors: (1) the occurrence of red spruce (picea rubens) and Fraser fir (abies fraseri) stands in the higher elevations of the Park, and, (2) variations in slope and aspect coupled with low sun illumination angles. Emphasis is also placed on developing and testing computer analysis techniques that would be useful for effectively processing Landsat multispectral scanner data over mountainous areas. Mountainous, inaccessible terrain poses a difficult problem in assessing the extent of various land use or land cover classes. Another problem arises in assessing classes where the characteristics of the ground cover change significantly during short periods of time.[1]

The Earth Resources Technological Satellite (ERTS-1), later known as Landsat 1, was launched on 23 July 1972. Two other Landsat unmanned resource satellites were launched on 22 January 1975 and 5 March 1978. With these satellites in orbit, NASA enhanced the role of the U.S. Department of Interior's EROS program in resource inventories. It was hoped that data from these sun-synchronous, polar-orbital satellites could alleviate some of the accessibility problems of research areas around the world. Scientists hoped to develop an accurate land cover classification for the entire globe based on repetitive Landsat scenes.

The Landsat data system has proved to be extremely useful for providing detailed information about the earth's environments, but in areas of significant topographic relief the system has often been no more useful than conventional aerial photography. Because the Landsat satellites are sun-synchronous, in a near-polar orbit, and have repetitive

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[1]Hofer, Dr. Roger M., et al., Natural Resource Mapping of Mountainous Terrain by Computer Analysis of ERTS-1 Satellite Data (West Lafayette, Indiana: Purdue University, LARS Research Bulletin 919, Information Note 061575, (June 1975)), p. 7.

orbital paths, the reflectivity values of surface objects are directly influenced by topographic displacement coupled with sun angle and azimuth illumination indices. Previous research has proved the value of utilizing computer aided analysis of remote sensing data for resource inventories, but most of this work has been restricted to areas of minimal topographic relief.[2] Physical characteristics within study areas have been generally overlooked when analyzing reflectivity patterns. Slope orientation, aspect of ridges and slopes, and Keplerian effects have not been accounted for as significant factors altering reflectivity data.[3]

Studies have generally ignored the effects of shadow zones on Landsat imagery of mountainous terrain and researchers have failed to correctly classify and accurately map those zones. Some shadow areas are due to clouds; others occur where relatively high surface objects combined with low solar illumination angles produce areas of diminished signal return. Clouds and their associated shadows can usually be effectively dealt with by obtaining imagery without clouds within the boundaries of the chosen study areas. Shadow areas caused by object heights and illumination angles are more difficult, and in some instances impossible, to deal with. Since important forest, water, and geological

[2]Hofer, et al., op. cit., footnote 1, p. 7.

[3]Keplerian effects or rhythms refer to sun angle and azimuth effects during different solar/terrestrial seasons. Named after the astronomer Johannes Kepler (1571-1630).

resources of the world are found in areas of mountainous terrain, where topographic and solar illumination parameters could influence spectral response, research should be designed to test the usability of Landsat multispectral data (MSS) in such areas. If any analysis techniques using MSS data are to provide this operational capability, then the circumstances and conditions under which these techniques can be effectively utilized must be understood.

Previous research has indicated that there has been an incorrect merging of numerous reflective signature zones. Coniferous and deciduous vegetation types are easily separated with good ground-level field checking used to determine training sites. Areas in inaccessible mountainous terrain contain other factors influencing reflectivity which makes separation of vegetation types much more difficult. In numerous instances, shadow areas, which to the eye appear to be coniferous vegetation zones, are mistakenly classified.[4] This problem demands further attention, since proper classification is needed for future resource inventories.

Few studies have taken into consideration topographic effects, since slope data are difficult to obtain. With the recent advent of Digital Terrain Model Tapes (DTMT's), topographic effects can be more precisely incorporated into

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[4]DeSelm, J. R., and Taylor, T. W., "Vegetation Boundaries on ERTS-1 Imagery," technical paper reprinted from the Conference on Earth Resources Observation and Information Analysis System, Tullahoma, Tennessee, 26-28 March 1973, p. 925.

computerized studies. The Digital Terrain Model Tapes, produced by the Defense Mapping Agency for selected sections of the United States, have proven useful in numerous agency-oriented studies. The terrain tapes are not prohibitively expensive for research and development organizations such as Purdue's Laboratory for Applications of Remote Sensing, Technicolor Graphic Services Inc., California's Jet Propulsion Laboratory, or the Environmental Research Institute of Michigan, but are expensive for independent projects. For that reason, this study employed manual analysis of terrain conditions, using United States Geological Survey topographic maps. Although manual analysis from maps is more time consuming and in some cases not as accurate as digital tapes, it still proves useful.

To date, forest ecology research has not been conducted on phenological shifts of major vegetation types in the higher elevations of the Great Smoky Mountains National Park.[5] Phenological changes by major plant communities above four thousand feet in the Park need further analysis, since reflectivity varies from one plant growth stage to another. No research endeavors to date have considered this as a factor in seasonal reflectance variations on Landsat imagery within the Park boundary.

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[5]Interview with Susan Bratton, Uplands Research Laboratory, Gatlinburg, Tennessee, 5 March 1980.

Early studies by both Rehder and DeSelm have indicated that the pattern found in the higher elevations of the Park does exist as a surface anomaly. Both have considered the role of the vegetation cover but neither seems to correctly identify causes for the existence of the pattern. John B. Rehder, in his study based on a 15 October 1972 image, interpreted the dark toned signature in the higher elevations of the Park as wet needleleaf vegetation. Prior to the 15 October 1972 Landsat overflight, the upper elevations had been soaked with approximately two to three inches of rainfall from a passing cold front. Rehder surmised that water droplets had lodged between the needles of the red spruce, Fraser fir, and other coniferous species and had been responsible for the dark signatures on Landsat MSS band 7 imagery.[6] The signature described by Rehder appears on all subsequent Landsat imagery, even during dry periods, thereby discounting the hypothesis that the signatures are caused solely by heavy precipitation. H. R. DeSelm hypothesized that the pattern was caused by spruce-fir reflectivity, but he failed to distinguish boundaries between reflectances from spruce-fir, shadows, and valleys.[7]

Broad, generalized attempts have been made at mapping the red spruce and Fraser fir communities within the Park.

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[6]John B. Rehder, "Geographic Applications of ERTS-1 Imagery to Landscape Change" <u>Symposium Proceedings of Management and Utilization of Remote Sensing Data</u> (Sioux Falls, South Dakota, 19 October - 1 November, 1973), p. 604.

[7]DeSelm and Taylor, op. cit., footnote 4, p. 926-928.

The most recent study, by C. Christopher Eagar in 1978, offers what was thought to be an accurate map of the spruce-fir community. Eagar, however, did not define the parameters of his classification.[8] The study employed aerial photography as well as ground level field work, but test site locations and other influencing factors were left undefined. It could not be determined with what accuracy the spruce-fir forests were classified. It is questionable, therefore, whether Eagar's maps can be accepted as data bases upon which to establish accuracy standards in mapping spruce-fir vegetation cover.

II. STUDY AREA CHARACTERISTICS

Location

The Great Smoky Mountains National Park lies at the western edge of the Blue Ridge physiographic province of East Tennessee and Western North Carolina, a part of the Southern Appalachian Highlands (see Figure 2). This mountain wilderness was set apart for the American people and authorized by an act of Congress on 22 May 1926. Land was acquired gradually by the states of Tennessee and North Carolina with federal aid in addition to a contribution by John D. Rockefeller, Jr., through the Laura Spelman

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[8]C. Christopher Eagar, "Distribution and Characteristics of Balsam Woolly Aphid Infestations in the Great Smoky Mountains" (M.S. Thesis, University of Tennessee, Knoxville, August 1978), passim.

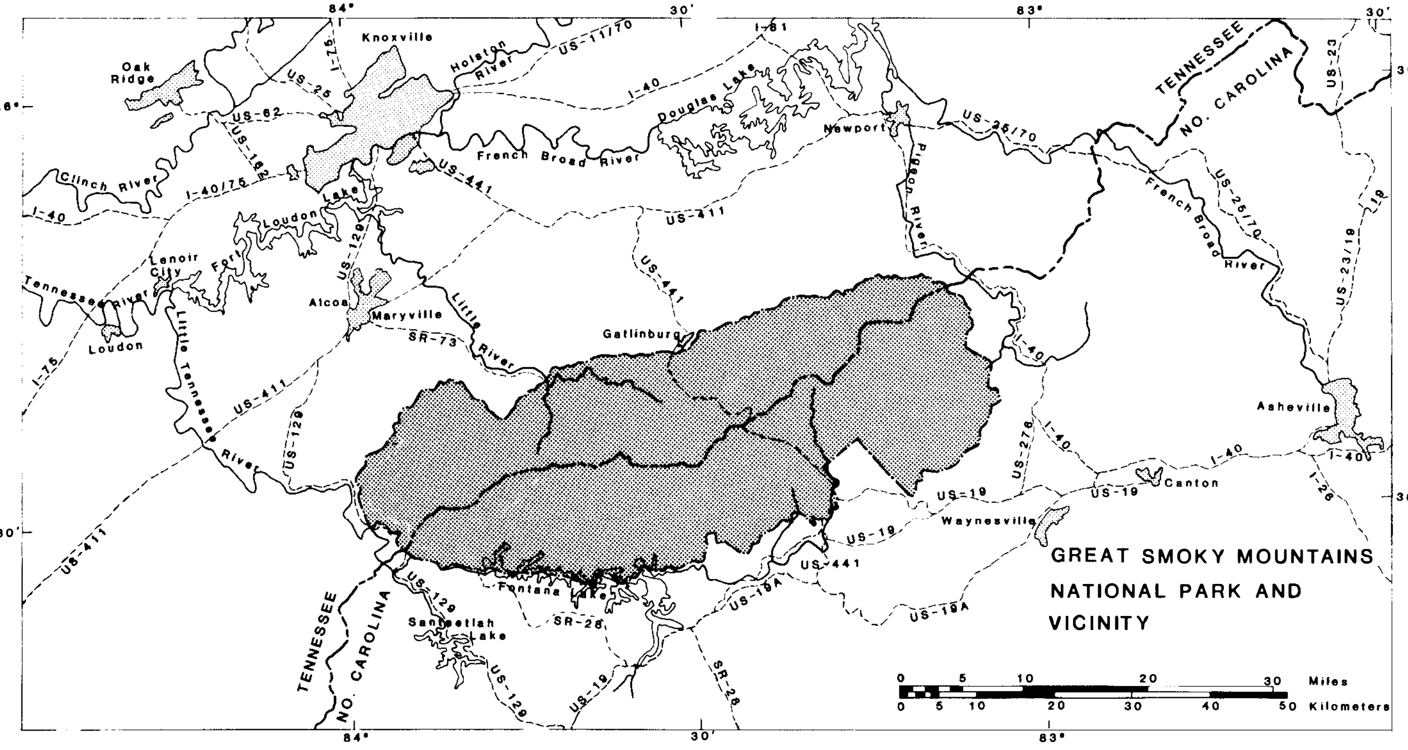

Figure 2. Location Map of the Great Smoky Mountains National Park and Vicinity.

Rockefeller Memorial. The Great Smoky Mountains became a national park in 1934 under the jurisdiction of the United States National Park Service of the Department of the Interior.[9]

The Great Smoky Mountains lie between the cities of Knoxville, Tennessee on the west, and Asheville, North Carolina, on the east. The Park is bordered on the north by the Big Pigeon River and on the south by the Little Tennessee River. The mountains form a major local divide, which is followed by the boundary between the states of Tennessee and North Carolina.

The Great Smoky Mountains include some of the highest land east of the Mississippi River. For 36 miles the main divide stands more than 5,000 feet above sea level, and 16 of the peaks rise to elevations greater than 6,000 feet, culminating in Clingmans Dome at 6,643 feet. Mount LeConte, on a spur that projects northward from the main range, stands more than a mile above the town of Gatlinburg, six miles away, forming one of the highest and steepest slopes in the eastern states. On the northern, or Tennessee side, the range projects in ramparts and massive bastions above much lower foothills and forms the skyline on the south when viewed from locations in the Tennessee Valley. On the

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[9]Philip B. King and Arthur Stupka, "The Great Smoky Mountains: Their Geology and Natural History," U.S.G.S. 1:125,000 Topographical Map of the Great Smoky Mountains (Washington D.C., United States Geological Survey 1972), passim.

southern, or North Carolina side the mountain front is poorly defined, and innumerable sharp-crested spurs branch out from the main divide (see Figure 3).[10]

Geology

During the Pleistocene Ice Ages the Great Smoky Mountains were well south of the ice sheets and contained no glaciers. Few of the gross features of the mountains have changed from the last ice age to the present, but minor modifications have occurred. During the ice ages the ridges of the Great Smoky Mountains above 4,000 or 5,000 feet may have been bare of forests. Projecting rocks were split by frost action and removed by slides to the valleys below. Modern plant life developed in the region during the post-Pleistocene (Holocene) Epoch, and was tremendously affected by ridge orientations, soil conditions, and micro-climatic regimes.[11]

The area of the main crest-line is underlain by intensively folded, faulted, and usually metamorphosed Precambrian rocks, Thunderhead sandstone, the silty to argillaceous slates, phyllites and schists of the Anakeesta

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[10] King and Stupka, op. cit., footnote 9, passim.

[11] P. B. King, R. B. Neuman, and J. B. Hadley, "Geology of the Great Smoky Mountains National Park, Tennessee and North Carolina," (U.S. Geological Survey Professional Paper 587, 1968), passim.

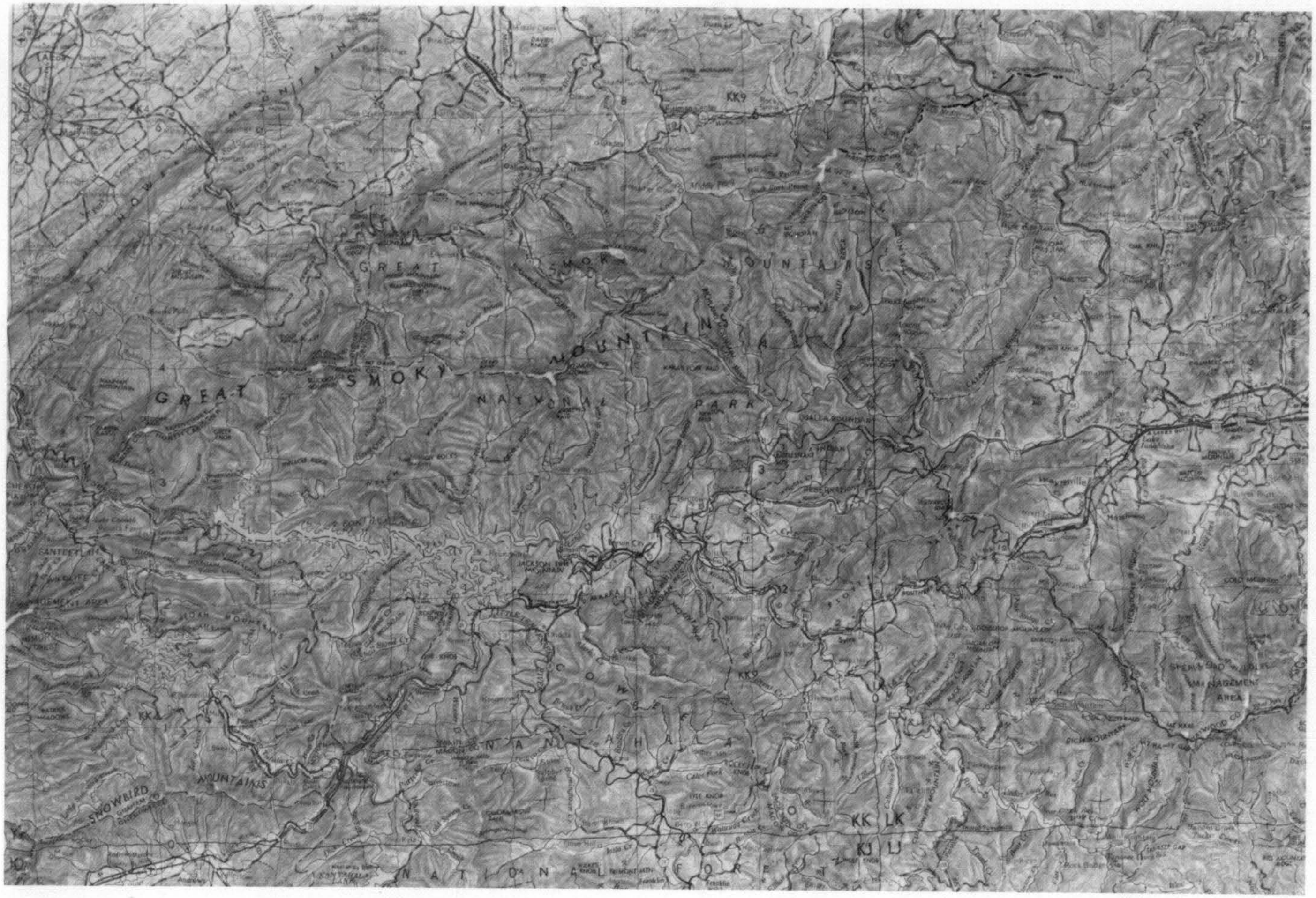

Figure 3. Topography of the Great Smoky Mountains National Park and Vicinity. Photograph of the U.S.G.S. 1:250,000 Knoxville Raised Relief Topographic Map.

Formation, and by muskovite and other schists and gneisses.[12,13] Soils in the higher elevations are Spodosols and Ultisols: Hapludults, Paleudults, and Dystrochrepts.[14] They are shallow, stony, sandy, acid, and of low fertility. Plant rooting is commonly shallow, often in contact with heavy litter layers which occur in the spruce vegetation.[15]

Vegetation Cover, Soils, and Climatic Factors

The Great Smoky Mountains National Park contains a greater number of native tree species than is found in all of Europe. Over 1,300 species of flowering plants are known, of which 131 are native trees.[16] One of the reasons for the great numbers of tree species are the laws protecting species within the Park from lumbering. Also, elevations in the Park range from 1,000 to 6,643 feet, which adds to the differences in growth conditions and favors a diversity of

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[12]King, Neuman, and Hadley, op. cit., footnote 11, passim.

[13]DeSelm and Taylor, op. cit., footnote 4, p. 926, citing J. B. Hadley and A. E. Nelson, Geological Map of the Knoxville Quadrangle, North Carolina, Tennessee, and South Carolina, Washington D.C.: U.S. Geological Survey, 1971.

[14]DeSelm and Taylor, op. cit., footnote 4, p. 926, citing U.S. Soil Conservation Service, "Distribution of Principle Kinds of Soils: Order, Suborders, and Great Groups Map" National Atlas of the United States, Washington D.C.: U.S. Department of Interior.

[15]DeSelm and Taylor, op. cit., footnote 4, p. 926, citing J. T. McGinnis, "Forest Litter and Humus Types of East Tennessee" (M.S. Thesis, University of Tennessee, Knoxville, 1958).

[16]King and Stupka, op. cit., footnote 9, passim.

species. Another reason is the local variation in climate produced by adiabatic cooling, and varying slope angles and aspects. Climates of the mountains vary with elevation, exposure, and position relative to sheltering from radiation and prevailing winds. Climates fall within the Caf and Cb types of Köppen, and those at 4,000 to 5,000 are similar to those in the eastern Great Lakes area and New England.[17] Higher elevation climates in the Smokies are most similar to low elevation climates of Maine and the Canadian Maritime provinces.[18,19] One five year study revealed a mean lapse rate of cooling of 1.3°C (2.3°F) with each one thousand foot elevation gain.[20]

The thirty-year mean annual precipitation was 55.54 inches at Gatlinburg, Tennessee (elevation 1,200 feet), and 82.26 inches at Clingmans Dome (elevation 6,643 feet), indicating an increase in precipitation with elevational increases. The maximum precipitation at Clingmans Dome occurs during the winter, is cyclonic in origin, and falls as snow. Rainfall during the summer months is primarily convectional.

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[17] DeSelm and Taylor, op. cit., footnote 4, p. 926, citing G. T. Trewartha, An Introduction to Weather and Climate (New York, N.Y.: McGraw-Hill, 1943), pp. 392-486.

[18] R. E. Shanks, "Climates of the Great Smoky Mountains," Ecology 35 (1954):354-361.

[19] Tennessee Valley Authority, Precipitation-Altitude Study, Snowbird Mountains, North Carolina (Knoxville, Tenn.: Hydrology Data Branch, Division of Water Cont. Planning Report 0-5620, 1955), passim.

[20] Shanks, op. cit., footnote 18, pp. 354-361.

At Clingmans Dome, the peak precipitation amounts occur during February (9.11 inches), March (8.34 inches), and July (8.18 inches).[21] These conditions have profound effects on vegetation cover characteristics in the Park.

Cooler climatic conditions caused by aspect and elevation in the Great Smoky Mountains give rise to the proliferation of northern tree species. About one-half of the native trees are of northern origin. High elevation vegetation are of several types: (1) heath slicks, (2) northern hardwood forests, (3) spruce-fir forests, and (4) intergrades among the above.[22,23] Two of the northern species native to the Park are the red spruce (<u>picea</u> <u>rubens</u>) and Fraser fir (<u>abies</u> <u>fraseri</u>). These trees occur primarily above four thousand feet and exist in the areas of unique signature patterns.

The red spruce is a tall conifer which occurs abundantly at the 4,000 to 6,000 foot elevation range over much of the eastern half of the Park. Although the bulk of the red spruce forest lies between 4,500 and 6,000 feet, mature

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[21] Donald J. Bogucki, "Debris Slides and Related Flood Damage Associated With the September 1, 1951, Cloudburst in the Mt. LeConte-Sugarland Mountain Area, Great Smoky Mountains National Park" (Ph.D. dissertation, University of Tennessee, Knoxville, 1970), pp. 29-31.

[22] R. H. Whittaker, "Vegetation of the Great Smoky Mountains," <u>Ecology Monograph</u> 26 (1956):1-80.

[23] U.S. National Park Service, <u>Vegetation Type Map, Great Smoky Mountains National Park</u>, Master Plan (1939).

specimens are found as low as 3,500 feet near the headwaters of the West Prong of the Little Pigeon River. In the western half of the Park the crest elevation of the range is appreciably less than in the eastern half. Nevertheless, most of the mountains along the twenty-mile ridge from Silers Bald southwest to Parsons Bald are high enough for the growth of red spruce, yet no spruce are to be found there, nor did this species occur there in historic times. Explanations have been offered for the spruce-fir cover based upon the assumption that a warm "xerothermic" period prevailed for a time following the last glaciation.[24]

> Climatic warming during the xerothermic period sufficient to displace the lower limits of spruce-fir forests upward from 4,500 ft. to approximately 5,700 ft. would account for present distribution of these forests. . . . the spruce-fir forests extended farther south during glaciation than at present--how much farther can scarcely be guessed. During the last xerothermic period they were pushed upward to 5,600-5,800 ft. elevation and were pushed off the tops of the lower peaks south of Clingmans Dome. As the climate cooled again, the forests advanced down the slopes from the higher northeastern peaks where they had found sanctuary and reoccupied the land above 4,500 ft. . . . The spruce forests should have been moving southwest along the ridge from Clingmans Dome in the 4,000 years since the peak of the xerothermic period (Flint, 1947), but are perhaps retarded or halted by the extensive beech forests of Double Spring Gap.[25]

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[24]Arthur Stupka, Trees, Shrubs, and Woody Vines of Great Smoky Mountains National Park, (Knoxville, Tenn.: The University of Tennessee Press, 1964), pp. 24-5.

[25]Stupka, op. cit., footnote 24, p. 25, citing R. H. Whittaker, "Vegetation of the Great Smoky Mountains," Ecology Monograph 26 (1956):n.p.

The Fraser fir, the second primary tree type associated with this study, is a coniferous needle-bearing species confined to the Southern Appalachian region. Between 5,000 and 6,000 feet it is usually associated with red spruce, with a greater percentage of fir with increase in elevation. Above 6,000 feet the tree forms almost pure stands. Its range in the Park is from near Cosby Knob and Mt. Sterling Ridge west along the higher uplands to a point about three miles west of Clingmans Dome on the main divide. On north-facing slopes and in sheltered ravines, some firs may occur down to approximately 4,000 feet (West Prong, Little Pigeon River), but usually the lower limit of this species lies between 4,500 and 5,000 feet. One of the best displays of this forest is along the half-mile trail to the summit of Clingmans Dome (see Figure 4).[26]

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[26]Stupka, op. cit., footnote 24, p. 21.

Figure 4. Red Spruce and Fraser Fir Vegetation Along the Trail Leading From the Forney Ridge Parking Area to Clingmans Dome.

CHAPTER II

METHODS OF ANALYSIS

Two basic methods of analyzing Landsat imagery have been used in this study: manual techniques and computer digital techniques. Manual techniques include photo-mechanical reproductions and enhancements of images in an attempt to classify reflectance levels on the Landsat imagery centered on the higher elevations of the Great Smoky Mountains National Park. Manual analysis also includes field studies to determine actual characteristics of the test sites. Computer analyses include locating, identifying, and classifying areas of the dark-toned pattern. Computer classifications are based on reflectance level statistics of pixels in the study area. Each method has its important place in remote sensing research, and both should be used in conjunction to yield precise and accurate results.

I. MANUAL TECHNIQUES

This section will focus on identifying by visual and photo-mechanical means the unique Landsat spectral signature patterns found predominantly above four thousand feet in the Great Smoky Mountains National Park. It will emphasize terrain, sun angle and azimuth, shadow area, and phenological characteristics.

The first task was that of selecting significant, representative Landsat images. It was felt that early attempts at natural resource or wildland mapping of the Great Smoky Mountains from Landsat imagery were inadequate because phenological or temporal data were not utilized.[27] For this reason, imagery was acquired for different seasons in an attempt to study the effects of changes in sun angle and azimuth, shadow areas, and phenological shifts of the dominant species.

Landsat 1:1,000,000 film negative imagery were acquired for the following dates, 14 December 1976, 1 April 1977, 18 July 1977, 4 October 1977, 14 April 1978, and 13 December 1978 (see Figures 5 through 10). The choices were based partly on season and partly on cloud cover characteristics and image quality ratings. Landsat images acquired from the Earth Resources Observation System Data Center (EROS) are rated for quality on a progressive scale of zero to eight and for cloud cover from zero to one hundred percent for each individual 115 by 115-mile scene. Images with quality ratings of eight and cloud cover ratings of zero to ten percent were selected to assure effective enhancement and accurate classification.

Film negative imagery was chosen because it provides higher resolution than paper positive imagery and lends

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[27]The author is referring to the studies done by DeSelm and Taylor (1973) and Eagar (1976).

Figure 5. Landsat Scene E2692-151927, Band 7, 14 December 1976.
Scale: 1:116,600.

Figure 6. Landsat Scene E2800-151457, Band 7, 1 April 1977.
Scale: 1:116,600.

Figure 7. Landsat Scene E2908-150927, Band 7, 18 July 1977.
Scale: 1:116,600.

Figure 8. Landsat Scene E5899-141427, Band 7, 4 October 1977.
Scale: 1:116,600.

Figure 9. Landsat Scene E21178-150627, Band 7, 14 April 1978.
Scale: 1:116,600.

Figure 10. Landsat Scene E30283-153247, Band 7, 13 December 1978.
Scale: 1:116,600.

itself more readily to photo-mechanical reproduction and enhancement. Film negative imagery involves one less generation than paper positive imagery, thereby reducing image quality degradation. Film negative imagery can also be processed into numerous scaled paper positive images through only one generation step, saving time and reducing costs.

Each Landsat image scene has four separate electromagnetic imaging bands, multispectral scanner (MSS) bands 4, 5, 6, and 7.[28] For this study, band 7 was used. Band 7 is a near-infrared band, which records reflectivity data in the .8 to 1.1 micrometer range of the electromagnetic spectrum. Two principle reasons for selecting band 7, were (1) band 7 imagery has maximum cloud and haze particle penetration and (2) band 7 appeared to show the finest detail of any MSS band and to afford the greatest separability of reflectance signatures of spruce-fir from deciduous vegetation in the higher elevations.[29] Haze penetration was especially important for this study because of the prevalence of haze over the higher elevations of the Park. Water droplets and perhaps other exudations from the dense vegetation cover give the Great Smoky Mountains their name, but in this study it was essential to penetrate this persistent haze layer in order to analyze cover characteristics.

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[28]An image band refers to the exact imaging wavelength on the electromagnetic spectrum of which the system is recording at the time of platform orbiting.

[29]DeSelm and Taylor, op. cit., footnote 4, p. 927-8.

The imagery was initially enlarged to a 1:250,000 scale format utilizing numerous ground control points. These included Walters Dam on the Pigeon River, Tricorner Knob, Mt. LeConte, Forney Ridge Parking Lot, Oconaluftee River, State Highway 73, Cades Cove, and the Little River water gap through Chilhowee Mountain. Reservoirs were not used as ground control because of fluctuating shorelines accompanying controlled water level changes (see Figure 11).

The 1:250,000 images were then compared to 1:62,500 and 1:250,000 United States Geological Survey topographic maps. Comparisons, matching, and pattern classification were done on a Bausch and Lomb Zoom Transfer Scope (ZTS). Pattern identifications were based on topography and comparisons with previous maps of the spruce-fir cover.[30]

Identification of the signature patterns required the locating of exact sites within the study area. One hundred ridges and slopes, primarily above 4,000 feet, were located on 1:250,000 scale imagery and labeled on the 1:62,500 topographic maps of the East and West Sections of the Great Smoky Mountains National Park (see Figure 12). The one hundred selected ridges and slopes were further classified and filed by their geographical name, general elevation, location in latitude and longitude, ridge orientation in degrees from north, slope in percent, and slope in degrees. It was

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[30]Eagar, op. cit., footnote 8, map.

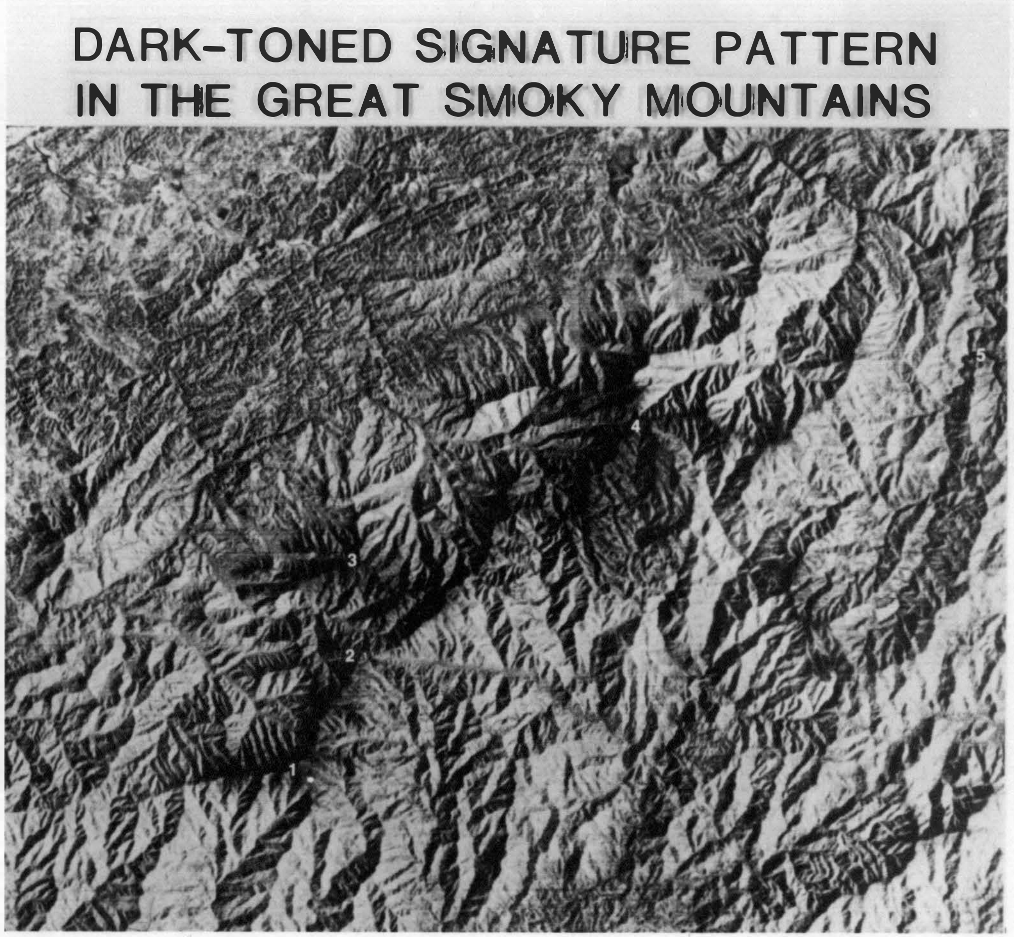

Figure 11. Enlarged Landsat Scene E5899-141427, Band 7, 4 October 1977. Dark-Toned Signature Pattern in the Great Smoky Mountains. (1) Clingmans Dome, (2) Newfound Gap, (3) Mt. LeConte, (4) Tricorners Knob, and (5) Walters Dam on the Pigeon River. Scale: 1:441,000.

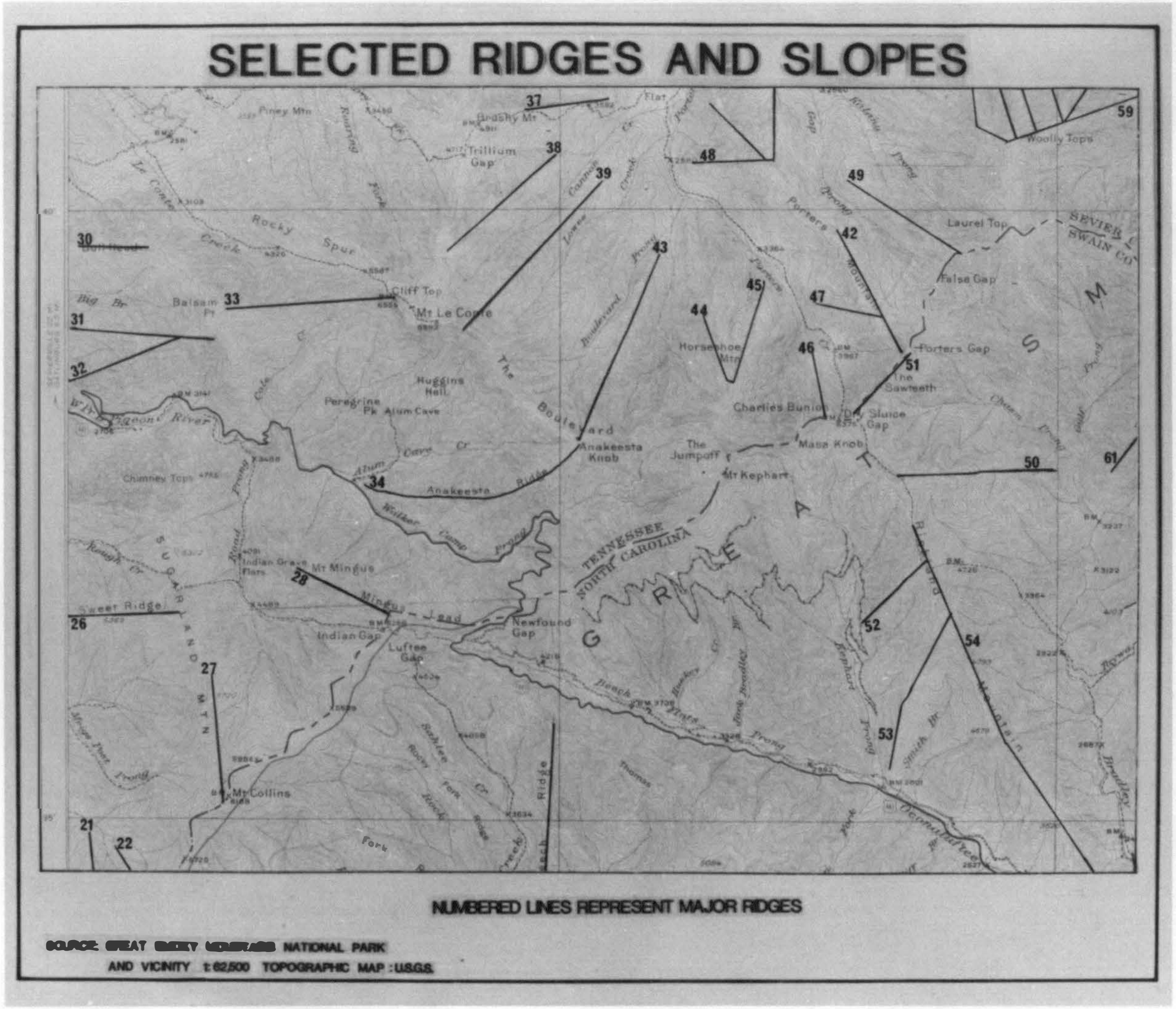

Figure 12. A Section of the U.S.G.S. 1:62,500 Great Smoky Mountains (East Half) Topographic Map Identifying Some of the One Hundred Selected Ridges and Slopes.

hypothesized that reflectance patterns were related to slope aspect, and degree, as well as to sun angle and azimuth.

Slopes were plotted on two circular grids. One grid was used to plot the slope aspect (from north) agains elevation. The second grid plotted slope aspect against slope steepness in degrees. These data were used to identify shadow and sunlit slopes, since shadowing was directly related to a north facing slope's steepness as well as to the sun's elevation and azimuth (see Figures 13 and 14).

Ground-level field work helped to determine the seasonal characteristics of the dominant tree cover in the study area. Photographs were taken from early winter through late summer of 1980. From these field investigations, it was possible to identify significant growth stages of northern hardwood tree species above 4,000 feet, particularly those of the American beech (Fagus grandifolia), which occurs in gaps within and surrounding the spruce-fir forests. No phenological data above 4,000 feet in the Great Smoky Mountains were available prior to the field work.[31]

II. COMPUTER TECHNIQUES

Minicomputer System

With the development of minicomputers and microprocessors, computer analysis of Landsat spectral data is no longer cost prohibitive and is coming into more frequent use

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[31] Bratton, op. cit., footnote 5, interview.

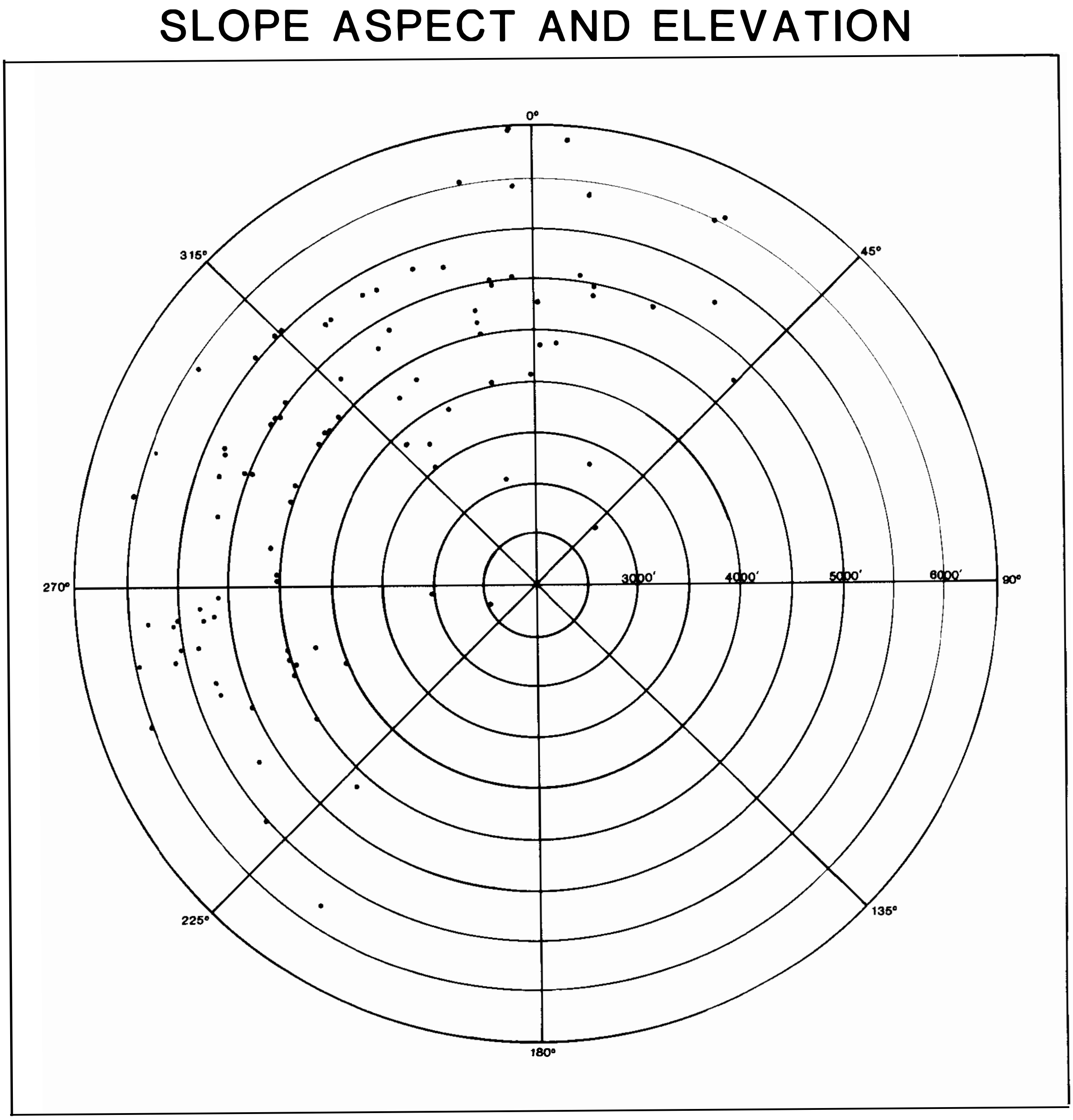

Figure 13. Circular Grid Plotting Slope Aspect Against Elevation.

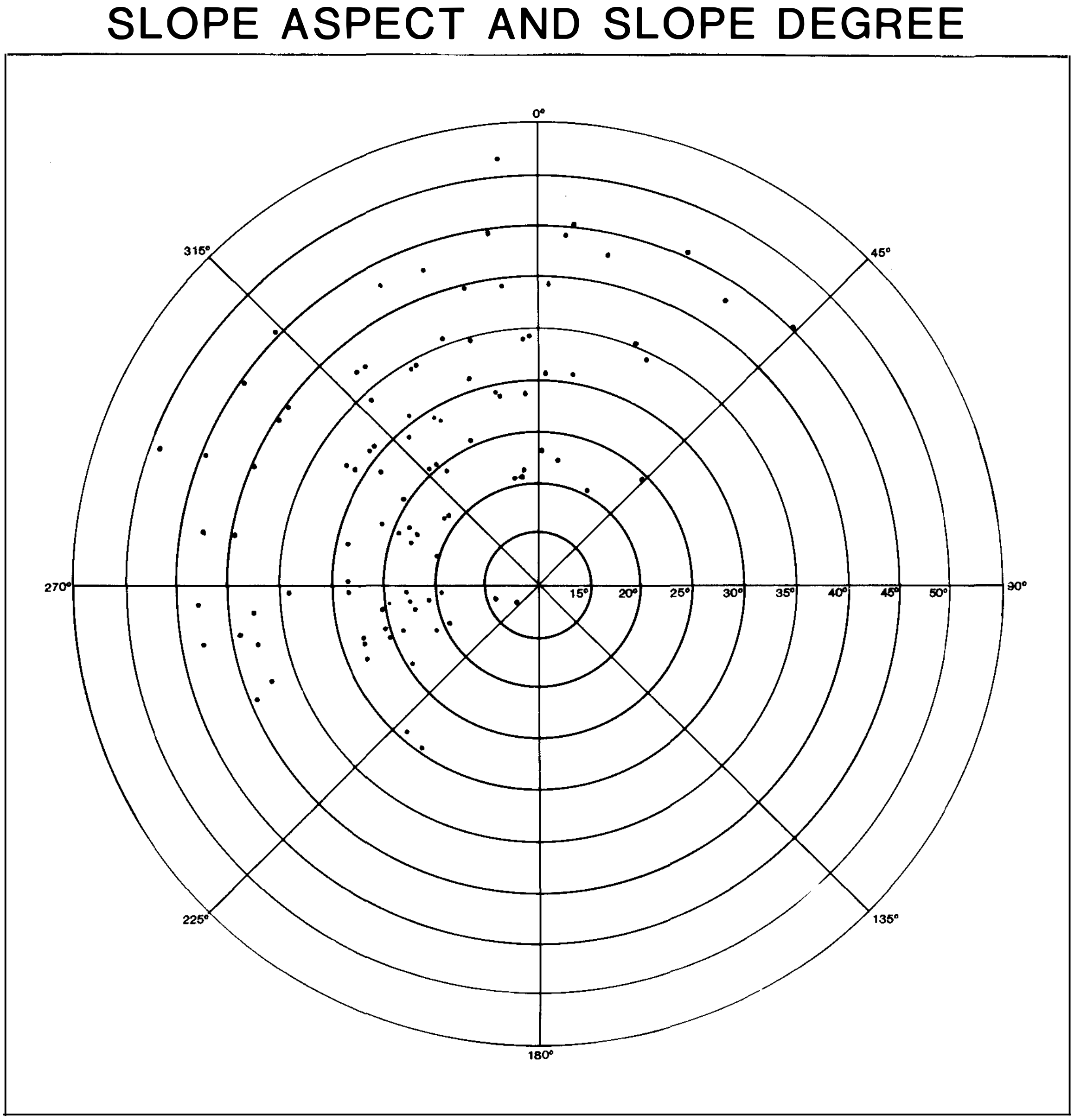

Figure 14. Circular Grid Plotting Slope Aspect Against Slope Degree.

by small schools and businesses. Computer analysis, if properly done, can be of much greater use than simple manual and visual analysis techniques. Data can be received in both hard copy imagery and numerical-statistical forms.

For this study Landsat Computer Compatible Tape (CCT) number E2800-15145, dated 1 April 1977 was obtained. The CCT is a Band Interleaf by Pixel tape (BIP) acquired for computer scanning and classification of spectral reflectances from the study area. The BIP tape records pixel reflectivity in each MSS band on four adjacent data strips from each Landsat scene. The computer was utilized for its unique ability to discriminate 256 gray levels on each Landsat scene.

The E2800-15145 digital tape was transferred onto a diskette and run on an interactive minicomputer which consisted of an ACT-V interactive video terminal, a Texas Instruments Omni 800/810 R. O. Terminal with 132 characters per line and six lines per inch, a 12 inch diagonal Sony Trinitron Cathode Ray Tube (CRT) modified to accept 16 gray scale levels with a pixel input of 256 gray scale levels and a screen capable of accepting an area of 128 by 128 pixels with a total coverage area of 16,384 pixels, and a Vector MZ microprocessor using four-inch diskettes.[32] The IMPAC

[32]A pixel (picture element) is the imaging area or effective resolution of the Landsat scanner. Presently, on Landsats 1, 2, and 3, each pixel along the direction of flight will measure 79 meters on the ground. The effective instantaneous field of view across track is 56 meters, giving a total coverage area of 1.1 acres per pixel.

software system, operated by CBASIC language, was used for this study and was tied in line with both the microcomputer and a Prime 550 mainframe computer (see Figure 15).[33]

The IMPAC system with the Sony CRT can process only a 7.5 x 10 kilometer area; therefore the image format was continually shifted to encompass each test site in the study area. The cost of computer operations prohibited identifying and classifying every 7.5 x 10 kilometer subscene of the Great Smoky Mountains. For this reason, three test sites were concentrated upon to determine the feasibility of computer analysis as a potential means of mapping signature patterns in rugged, mountainous areas. The three test sites were located in accessibly areas of the Great Smoky Mountains that were field checked and contained known areas of red spruce and Fraser fir stands. These areas were later computer trained for signature classification. Training involves selecting a small number of pixels from areas of known cover characteristics, obtaining statistics for those sites and instructing the computer to locate all other pixels of identical reflectances on the whole printed scene.

A supervised classification system was employed utilizing ground field data, reference photographs, topographic maps, RB57-F 1:60,000 and 1:120,000 color and color infrared aerial photography, and 1:1,000,000 and 1:250,000 Landsat

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[33]The IMPAC software system for use on minicomputers, was developed by Egbert Scientific Software Company of Greenport, New York.

Figure 15. Carroll College, Remote Sensing Laboratory, Department of Geography, Waukesha, Wisconsin. (From Left to Right) ACT-V Video Terminal, Sony Trinitron Cathode Ray Tube (CRT), Vector MZ Microprocessor, and a Texas Instruments Omni 800/810 R.O. Terminal.

scenes. A supervised classification involves having knowledge of an identifiable area, thereby training the computer to identify all other similar areas within the total data set. An unsupervised classification involves clustering pixels of similar reflectance values and then later classifying these clusters from known data points. Sample areas within specific test sites of known vegetation cover, topographic terrain, and shadow regions were selected and trained on for classification.

Eleven statistical computer transformations were available on the IMPAC software system, but only five were actually used in assessing reflectance variations in the study area. The transformations were already included in the software package and could not be altered. The five transformations used were: (1) First Four-Band Transformation, (2) Band Cosine Transformation, (3) Band Ratio Transformation, (4) Band Sum Transformation, and (5) Second Four-Band Transformation. These transformations are processes by which pixel data from one band or all four bands could be manipulated or combined in various methods to statistically analyze the Landsat scene.

First Four-Band Transformation

A four-band transformation using Landsat bands 4, 5, 6, and 7 was first employed. Training pixel selections were made from the Landsat band 7 near-infrared scene on the CRT screen because of high contrasts in radiance levels between spruce-fir and deciduous vegetation. The training pixels are data samples of known identity used to determine decision boundaries in the measurement or feature space prior to classification of the overall data set. Each training pixel measures 1.1 acres in size. One hundred training pixels were used from each of the three study sites. The one hundred training pixels exceed the minimum forty necessary for a four-band classification (4 bands x 10 pixels or 40 pixel values needed for representative training). The training pixels were all from areas of spruce-fir forests.

After the sampling was complete the computer scanned each Landsat scene's four MSS bands, clustering the spectral reflectance levels utilizing the parallelepiped classifier (also known as the minimum and maximum boxing classifier). In using the parallelepiped classification algorithm, which was the only one available on the IMPAC system, the analyst trains the computer on the miltispectral limits of the Landsat scene (in four spectral dimensions) by positioning an electronic cursor over a pixel represented by a particular cover type on the CRT screen. The computer determines the minimum and maximum brightness values within the training area for that cover type in the four Landsat bands. The computer then searches each pixel in the entire scene and determines which pixels have brightness values that fall within the maxima and minima for the training area. The pixels which occur within the restricted brightness ranges of the training area are classified and identified by a color code on the CRT screen or a letter code on a paper print-out.[34,35] Each pixel is identified by its own line and column number and can be easily located on the gray scale map of the test site. The pixel reflectance levels or brightness levels represent kilowatts per cubic centimeter per steradian (Kw/cm^3/steradian), where the steradian is the solid cone angle from the scanning system to the surface. Low brightness levels are dark-toned objects with low reflectivity.

Upper and lower reflectance signature limits for the one hundred training pixels are displayed, recorded, and printed. Signature limits can be changed prior to the classification if the analyst feels the values are not representative of the actual surface features to be classified. Histograms, pixel population means, and standard deviations are displayed and printed for the one hundred pixels in each band. With these available statistics, the analyst can determine which transformation classification is most correct, based on the lowest standard deviations and accuracy of the field work.

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[34]James V. Taranik, "Characteristics of the Landsat Multispectral Data System," United States Department of the Interior, Geological Survey Open-File Report 78-187, Sioux Falls, South Dakota, 1978. (Mimeographed.)

[35]Curtis E. Woodcock and Thomas L. Logan, "Stratification of Forest Vegetation for Timber Inventory Using Landsat and Collateral Data," paper presented at the 14th International Symposium on Remote Sensing of the Environment, San Jose, Costa Rica, April 1980. (Mimeographed.)

With the signature limits established, an image display map for each of the three test sites was developed based on the most current reflectance values of the training pixels from each site. The total number of classified pixels for each test site, as well as the percentage of the study area represented by those classified pixels, were displayed and printed.

Band Cosine Transformation

The removal of sun angle and slope shadow effects were attempted with the IMPAC system band cosine transformation. The cosine algorithm, if properly applied, can normalize solar illumination on sloping surfaces. If illumination effects on sloping surfaces could be controlled then spruce-fir forests in shadow areas could be identified. The inclusion of illumination and sun angle cosine data has proved useful in other mountainous terrain studies (Woodcock and Logan, 1980; Strahler, et al., 1978 and 1980; Sadowski and Malila, 1977; Hofer, et al., 1975; and Hartung and Lloyd, 1969). Woodcock and Logan, in their study, developed a technique for separating the Landsat image into categories based on the expected illumination at the time of the satellite overpass. With their research as a foundation, a similar transformation was attempted in this study.[36]

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[36]Woodcock and Logan, op. cit., footnote 35, (mimeographed.)

The cosine transformation available on the IMPAC software system is:

$$(\text{Band Z}) = A + B\cos(C(D + \text{Band X}) = E(F + \text{Band Y}))$$

where,

Band Z was the new computer cosine band,

Band X was computer band 4 (Landsat MSS band 7), and

Band Y was computer band 2 (Landsat MSS band 5).

Because this equation does not allow for the input of slope and sun angle data, this transformation was not used in the final analysis of this study.

<u>Band Ratio Transformation</u>

A band ratio transformation was next employed in an attempt to enhance reflectance data from the test sites. A ratio of two Landsat bands was obtained by dividing the average brightness value in one band by the average brightness value in another band for each pixel within the scene. The use of ratios tends to reduce shadow effects due to topography and to emphasize the changes in brightness values between objects.[37] Even though two slopes receive a different flux of radiation from the sun, and even though the same tree types have different brightness values on the opposed slopes,

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[37]Taranik, op. cit., footnote 34, p. 29, citing P. S. Chavez, "Atmospheric, Solar, and M.T.F. Corrections for ERTS Digital Imagery," <u>Proceedings of the American Society of Photogrammetry</u>, Falls Church, Virginia, October 1975.

the ratios of the brightness values should be the same on either slope.[38]

The band ratio transformation available on the IMPAC software system is:

(Band Z) = A + B(C + Band X)/(D + Band Y)

where,

Band Z was the new computer ratio band,

Band X was computer band 4 (Landsat MSS band 7), and

Band Y was computer band 2 (Landsat MSS band 5).

Landsat MSS bands 5 and 7 were used because of their haze penetrating ability and fine pixel level contrasts. Roads, parking lots, and other distinguishable features are easily seen on Landsat band 5 imagery, which helps in locating geographic reference points.

Band Sum Transformation

The band sum transformation is a summation of reflectance levels from two Landsat MSS bands used to create a density sliced image. The band sum transformation has the effect of enhancing the edges of reflectance boundaries, such as that between spruce-fir and deciduous vegetation. The sum transformation differentiates the spruce-fir forests from other reflectances on the image. New training pixel sites were selected and their reflectance values and signature

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[38]Taranik, op. cit., footnote 34, p. 28-29.

limits recorded. Pixel radiance levels from Landsat MSS band 5 and band 7 added together, created a new pixel reflectance value.

The band sum transformation available on the IMPAC software system is:

(Band Z) = A + (B x Band X) + (C x Band Y)

where,

Band Z was the new computer created band,

Band X was computer band 4 (Landsat MSS band 7), and

Band Y was computer band 2 (Landsat MSS band 5).

Second Four-Band Transformation

A second four-band transformation was employed utilizing new training sites and signature limits. A total of four tests were run with the second four-band transformation. The first test involved establishing new reflectance signature limits thought to be more representative of the spruce-fir forests than previous transformations. This shift in the signature limits helped develop a new classification map, which was used to determine the accuracy of the test. The second test involved the establishment of fifty-two new training pixels near Clingmans Dome. The new training site included northwest slope and shadow zones of the main ridge line and sunlit, southeast oriented slopes. Both areas contain dense stands of red spruce and Fraser fir. It was hoped that by combining reflectance values of known spruce-fir communities on both shadow and sunlit slopes, accurate classification maps of spruce-fir forests in shadow zones could be developed. The third test was designed to test the applicability of spruce-fir classification in shadow areas also. Forty-one new training pixels were selected in a light-toned shadow area on a northwest slope near Clingmans Dome and on the opposing, sunlit southeast slope. Both areas contained a dense spruce-fir cover. The final test involved selecting eighteen new training pixels in a dense spruce-fir cover area on the southeast slope of the main ridge near Clingmans Dome, and then developing a new classification.

Histogram levels, means, and standard deviations of each classification will be explained in Chapter III. The decisions on the most accurate classification were based on the author's confidence in the training sites selected and knowledge of spruce-fir forest locations.

As in any study, certain assumptions must be made to facilitate the obtaining and analysis of data. For example, this study assumes a correct assessment of the terrain characteristics of the one hundred selected ridges and slopes, including aspect, slope percentage and degree, and orientation. Another basic assumption is that the selected training sites were correctly classified based on the interpretation skills of the author, field work, and accuracy of available materials. A third assumption is that the parallelepiped, supervised classification program was the best classifier based on field work and ancillary data. It is beyond the scope of this investigation to document and classify the entire image area of the Great Smoky Mountains National Park, therefore, three representative test sites were selected.

III. TEST SITES

Three test sties were used in this study. In two of the sites extensive field work was done by the author from January to September 1980. The third test site was not field checked, but other studies of the Park indicate that the area contained dense spruce-fir stands in the higher elevations. Reflectance levels were documented and recorded in two of the three test sites. These levels were then applied to the remaining test site with the assumption that pixels within boundaries of similar terrain and cover characteristics should reflect the same.

The three test sites were corrected geometrically but not geographically. Geometric rectification involves correcting shifts in scan lines caused by the earth's rotation beneath the orbiting scanner. The skew caused by rotation of the earth under the satellite is a function of latitude and spacecraft heading. Each scene is deskewed by an algorithm that shifts scan lines to the right depending on the latitude of the line. This geometric adjustment insures that landscape features are in relative position with respect to each other throughout the scene.[39] The images remained rectangularly oriented eight to nine degrees from true north.[40] Each image area measures 7.5 kilometers east to west and 10 kilometers north to south. The area is thus 75 square kilometers, containing a total of 16,384 pixels, measuring 1.1 acres each. The three sites were identified by computer file names GSM77F2, GSM77R, and GSM77S (see Figure 16).

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[39]Taranik, op. cit., footnote 34, p. 12-13.

[40]B. F. Richason Jr., ed., Introduction to Remote Sensing of the Environment (Dubuque, Iowa: Kendall/Hunt Publishing Company, 1978), p. 172.

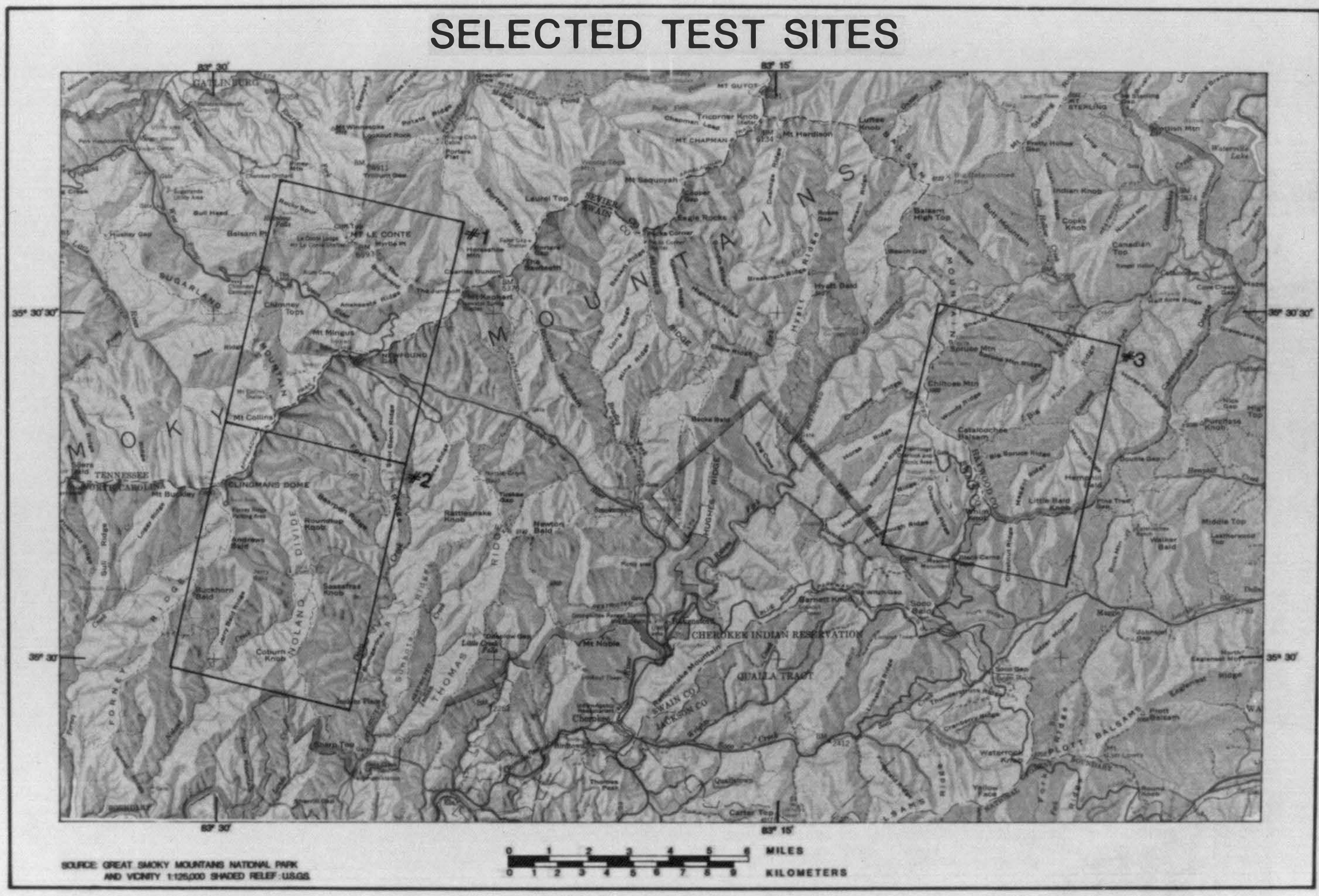

Figure 16. The Three Selected Test Sites Located on a U.S.G.S. 1:125,000 Topographic Map of the Great Smoky Mountains National Park and Vicinity. (1) Site Gsm77F2, (2) Site GSM77R, and (3) Site GSM77S.

CHAPTER III

RESULTS

This chapter examines the results of the two methods of analysis employed. The results of manual interpretation, which involves a qualitative assessment of reflectance patterns, are shown on selected maps and imagery as well as ground level photography. The results of the computer digital analysis are shown on computer-printout gray-scale maps, classification maps, and by statistical data of reflectivity variations. The first objective was to determine whether the reflectance patterns on the imagery are actually spruce-fir forests or, in part, shadow areas due to a low sun angle and variable sun azimuth. Another objective was to classify the test sites on the basis of the interpretation. The final objective was to determine, on the basis of manual interpretation and statistical data, which computer transformation technique was most accurate.

I. MANUAL INTERPRETATION AND CLASSIFICATION

Distinctive reflectance patterns on Landsat imagery are the result of the unique ways in which surface objects reflect the sun's wavelengths of light. Differing signatures are recorded by the MSS system on the basis of their orientation to the sun's angle of incidence, slope orientations, and the vegetation cover.

Vegetation types reflect variously because of growing season, area of leaf cover, and surface reflectances of the leaves. With the assumption that the unique dark patterns found in the Great Smoky Mountains are due in part to differences in vegetation cover, the first task was to study the test sites in the field to determine canopy cover species which could affect reflectances. From such study it was determined that the area contained large stands of spruce-fir forests above four thousand feet (see Figure 17). Since it was presumed that the spruce-fir cover caused the reflectance anomaly, available data on their reflectivity was reviewed. Red spruce and Fraser fir are both needle-bearing conifers. Conifers reflect significantly less than deciduous trees on Landsat band 7 near-infrared imagery because of the differences in chlorophyllic structure.[41]

The next step was to compare the imagery with topographic data. The extent of the dark-toned pattern lies within areas above the four-thousand-foot contour (see Figure 18). Even though the western section of the Park contains areas above four thousand feet, spruce-fir forests are absent.[42] The eastern section of the Park contains two separate areas of identical reflectance patterns. The

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[41]John R. Jensen, "Applications of Image Processing in Vegetation Analysis," notes from Recent Advances in Remote Sensing Short Course, Athens, Georgia, 19 February 1980.

[42]Stupka, op. cit., footnote 24, p. 25.

Figure 17. Spruce-Fir in the Great Smoky Mountains National Park. (Top) A Sunlit Slope Looking East 1½ Miles From Clingmans Dome. (Bottom) Looking East From Near Clingmans Dome on the Clingmans Dome Road. Photographed 4 April 1980.

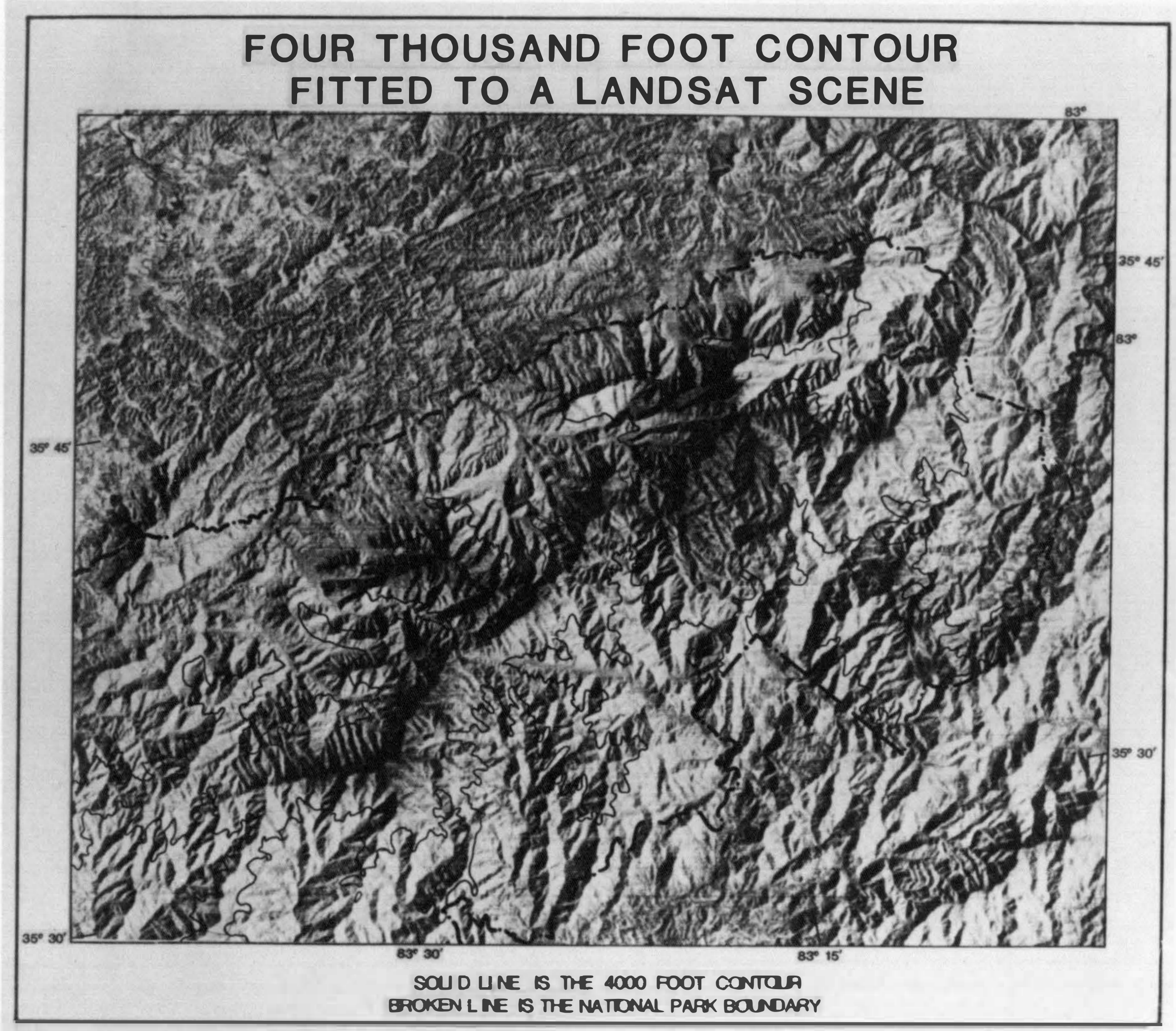

Figure 18. The Four Thousand Foot Contour Line Fitted to Landsat Scene E5899-141427, Band 7, 4 October 1977.

larger area is along the main ridge line, where the majority of spruce-fir are located. The second area, which coincides with the Cataloochee Balsam region, also above four thousand feet, contains a large conifer stand composed mostly of red spruce.

A visual comparison with maps from field work by Frank Miller in 1938 and C. Christopher Eagar in 1976 indicates a close correlation of the distinctive signature with the spruce-fir forests delimited by both (see Figures 19 and 20). Miller's study is dated, and vegetation boundaries have changed slightly, but the general location of spruce-fir has remained intact. Reduction of the spruce-fir area from Miller's to Eagar's study can be attributed to natural burn and insect infestation, particularly by the balsam woolly aphid, which appeared in the spruce-fir communities in the Park during the past twenty years.[43]

The identification of one hundred slopes within defined spruce-fir areas made orientation much easier. With detailed examinations of shadow and ridge areas with an 8X Agfa-Lupe magnifying lens, the location and extent of supposed spruce-fir cover and shadow areas were easily obtained and recorded on topographic sheets. Ridges were selected in areas where spruce-fir was thought to be on both slope faces, but where deep shadow areas prevented accurate mapping (see Figure 21). Topographic data for the one hundred ridges

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[43]Eagar, op. cit., footnote 8, p. iii.

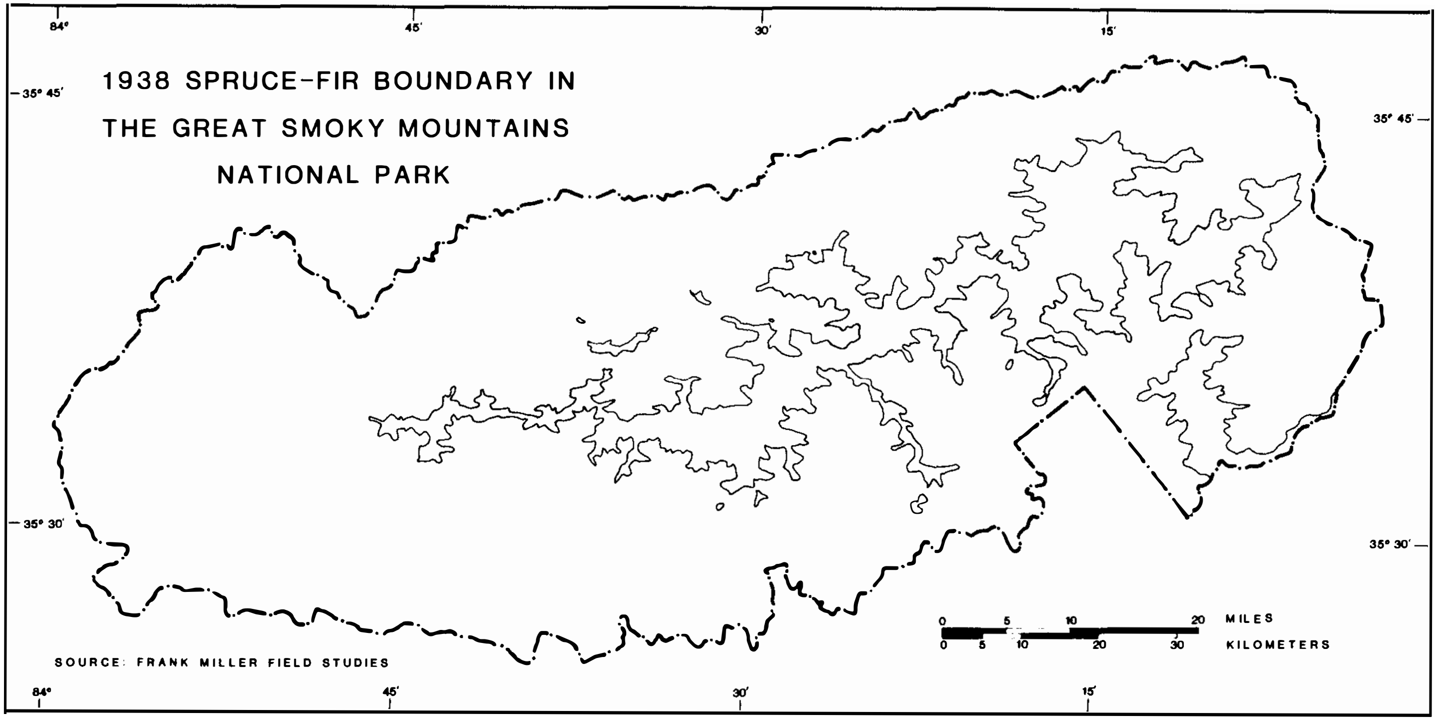

Figure 19. Spruce-Fir Forests Within the Great Smoky Mountains Based on 1938 Frank Miller Field Studies.

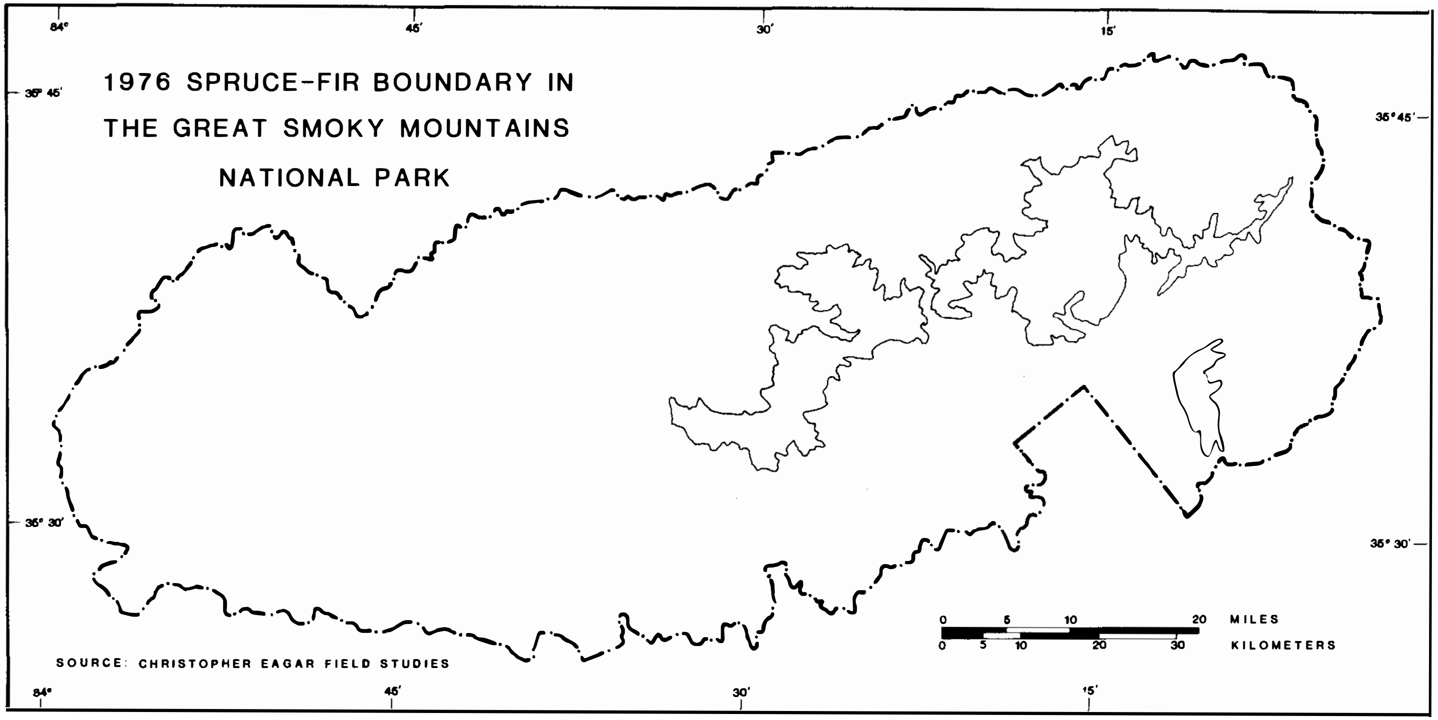

Figure 20. Spruce-Fir Forests Within the Great Smoky Mountains Based on 1976 C. Christopher Eagar Field Studies.

Figure 21. Shadows on North-Facing Slopes. Landsat Scene E5899-141427, Band 7, 4 October 1977. White Arrows Indicate Shadow Zones.

were originally to be included in a section on incident solar radiation. Because of time constraints, this section was omitted, but slope data could be incorporated into a cosine equation in order to determine minute reflectance changes in vegetation, given differing solar angles of incidence.

Reflectivity does relate to the angle of incoming solar radiation, but it is difficult to determine to what degree it affects the Landsat system response. Slopes oriented nearly perpendicular to the incoming solar radiation yield the brightest signatures. Spruce-fir vegetation can be readily identified in such areas. Small spurs in slopes cause reflectance signal variations. On the north, northeast, or northwest-facing slopes or spurs, shadow zones make delineations of spruce-fir areas impossible. Depending on the season, the sun's angle varies approximately 47° from north to south. This in turn, affects the incidence of radiation on variously angled slopes or ridges.

Boundary demarcations are extremely difficult on steep slopes facing north or northwest and containing heavy shadow areas. This can be a major problem if the lower edge of the spruce-fir vegetation is in shadow. On gentle slopes, those less than 44°, the lower limit of spruce-fir can be more readily mapped.[44] Since these conditions vary with sun

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[44]Imagery from 1 April 1977 was used for this section of the study. At the imaging time the sun elevation was 44° and the azimuth was 124°.

angle, different image dates provide different results.

Phenological variations in dominant plant species affect reflectivity responses. Deciduous vegetation develops through annual growth cycles of budding, full bud, leaf out, leaf stress, leaf drop, and winter dormancy. Between each of these stages profound changes occur within the A and B chlorophylls and the spongy mesophyll layers of the leaves.[45] This chlorophyllic change alters the response on any infrared sensor, such as Landsat's MSS near-infrared band 7. Coniferous vegetation, on the other hand, is "evergreen" throughout the year. Conifers do experience stress, but needle drop does not occur as completely as with deciduous trees. In general, reflectivity levels remain almost unchanged throughout the year in the spruce-fir forests.

Shifts of the dark-toned pattern on Landsat band 7 near-infrared imagery are related to season. The spruce-fir forest appears to extend its areal boundaries during winter, but in reality it is the decreased reflectance of deciduous trees in mixed forest environments which produces the change in tone. Deciduous vegetation yields brighter signatures in the infrared than conifers. In a mixed forest area, when deciduous trees are in full foliage in mid-summer, their reflectivity area (the total reflecting surface of their leaves) is much greater than that of the conifers and their reflectance level is brighter or stronger. Therefore, even

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[45]Jensen, op. cit., footnote 41.

though the mixed environment contains a larger share of spruce-fir, the area in summer will actually exhibit a reflectance response like that of a deciduous cover. The opposite holds true in the winter months. Conifers are the chief reflectors, because their chlorophylls are active and their needle-leaf area is full.

Sun angle and shadow also appear to cause pattern shifts by either enlarging or shrinking the boundaries of dark areas. Lower sun angles produce long mountains shadows, and these give the false impression of extending the areas of the spruce-fir vegetation zone.

Delimiting boundary shifts in mixed forest environments without considering sun angle data proved to be extremely difficult. Since phenological data are not available for major tree types above four thousand feet, mapping of vegetation types based on reflectance patterns alone was not reliable.

In the Great Smoky Mountains, American beech is a dominant species in the cove hardwood, northern hardwood, and hemlock forest types, and occasionally occurs in the spruce-fir forests.[46] Its occurence with spruce-fir along the state boundary ridge area is notable. During winter months the intermixed spruce-fir is easily recognizable, but during

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[46]R. E. Shanks, "Reference Lists of Native Plants of the Great Smoky Mountains." Botany Department, University of Tennessee, Knoxville, 1954. (Mimeographed.)

summer months separability from a distance is difficult (see Figure 22).

Figures 23 through 25 exemplify the problems faced when attempting to map forest types from reflectivity patterns using seasonal imagery. In many cases, pixel contrasts are low in winter months, partly because of low sun angles. In summer and fall, contrasts are greatly enhanced because of higher sun angles. Manual mapping is difficult when specific vegetation signature reflectances are visually confused with shadow areas (see Figures 23, 24, and 25).

Visual interpretation alone did not prove to be very accurate for analysis of seasonal variations of the reflectivity pattern. Minute differences in tone, which the eye could not discriminate, could be missed or misclassified. It seems apparent that pattern or boundary delineation might be more accurate with computer-digital analysis of Landsat MSS data. Mapping can be done from visual interpretation, but accuracy standards are justifiably low and are based on an individual's ability at pattern discrimination. The key appears to be to employ computer-digital analysis and to collect accurate data from field studies, ancillary research, maps, and visual interpretation in order to increase the accuracy standards.

II. COMPUTER INTERPRETATION AND CLASSIFICATION

This section of the study was designed to test the applicability of computer-aided analysis to identify and

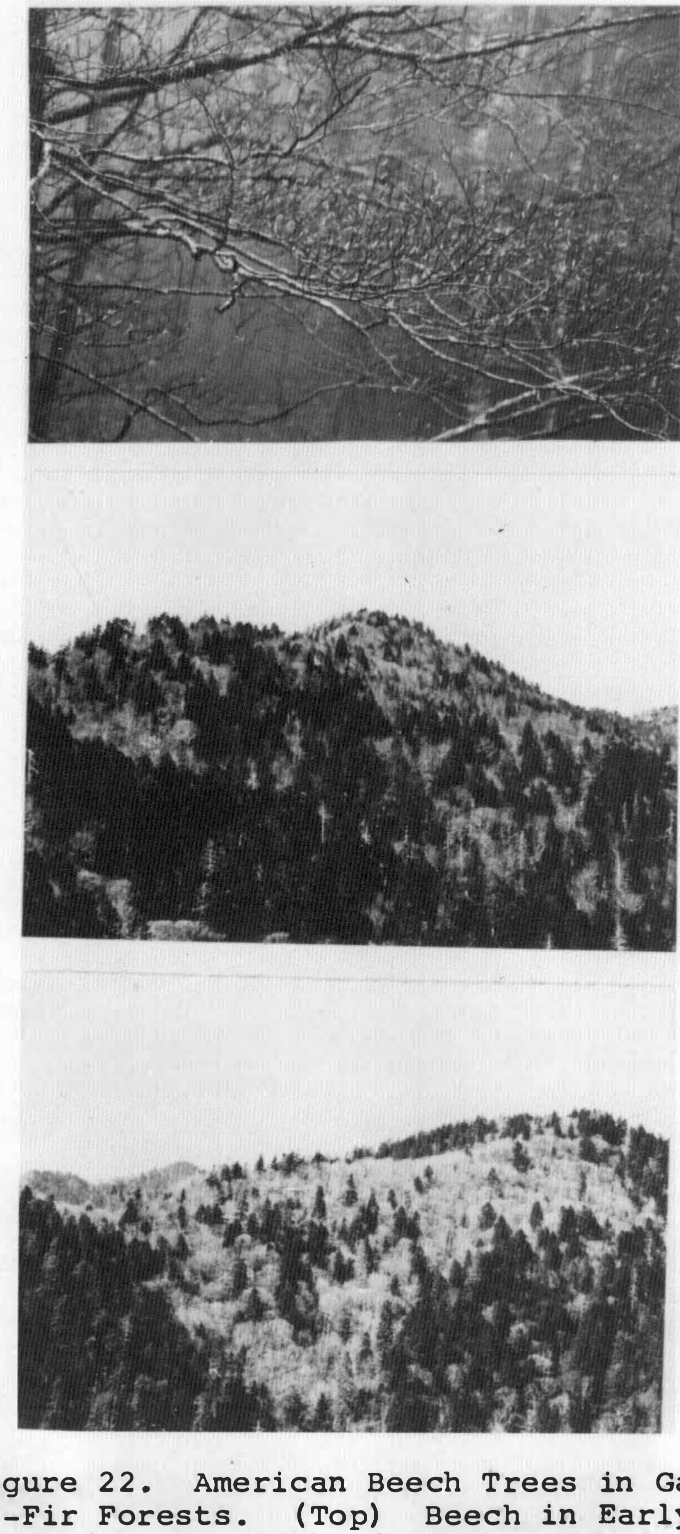

Figure 22. American Beech Trees in Gaps Surrounding the Spruce-Fir Forests. (Top) Beech in Early Budding Stage During Spring (16 May 1980), (Middle) Mixed Spruce-Fir and Beech Near Clingmans Dome, and (Bottom) Beech Gap Near Newfound Gap.

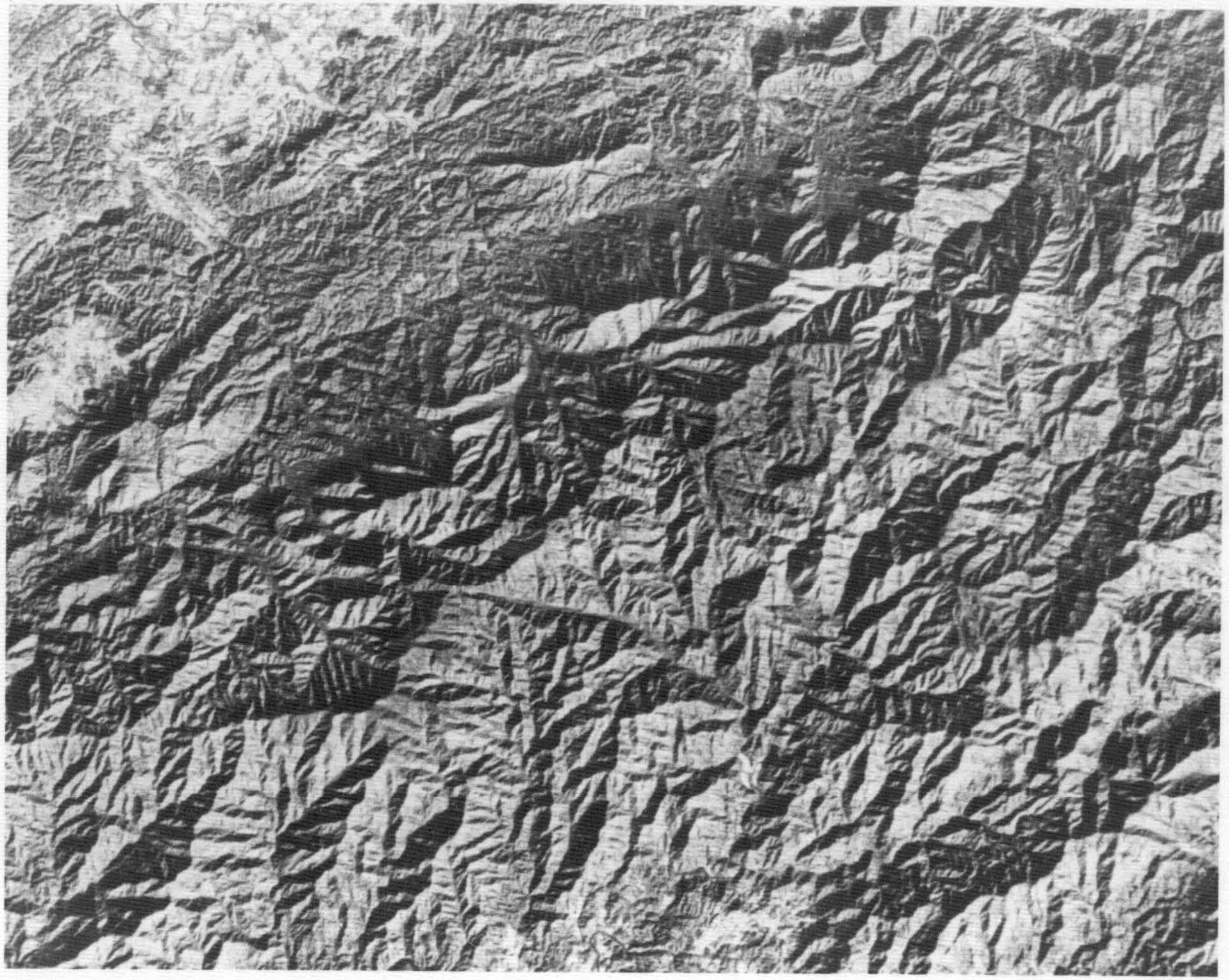

Figure 23. Enlarged Landsat Scene E2692-151927, Band 7, 14 December 1977.
Scale: 1:375,000.

Figure 24. Enlarged Landsat Scene E2809-151457, Band 7, 1 April 1977.
Scale: 1:375,000.

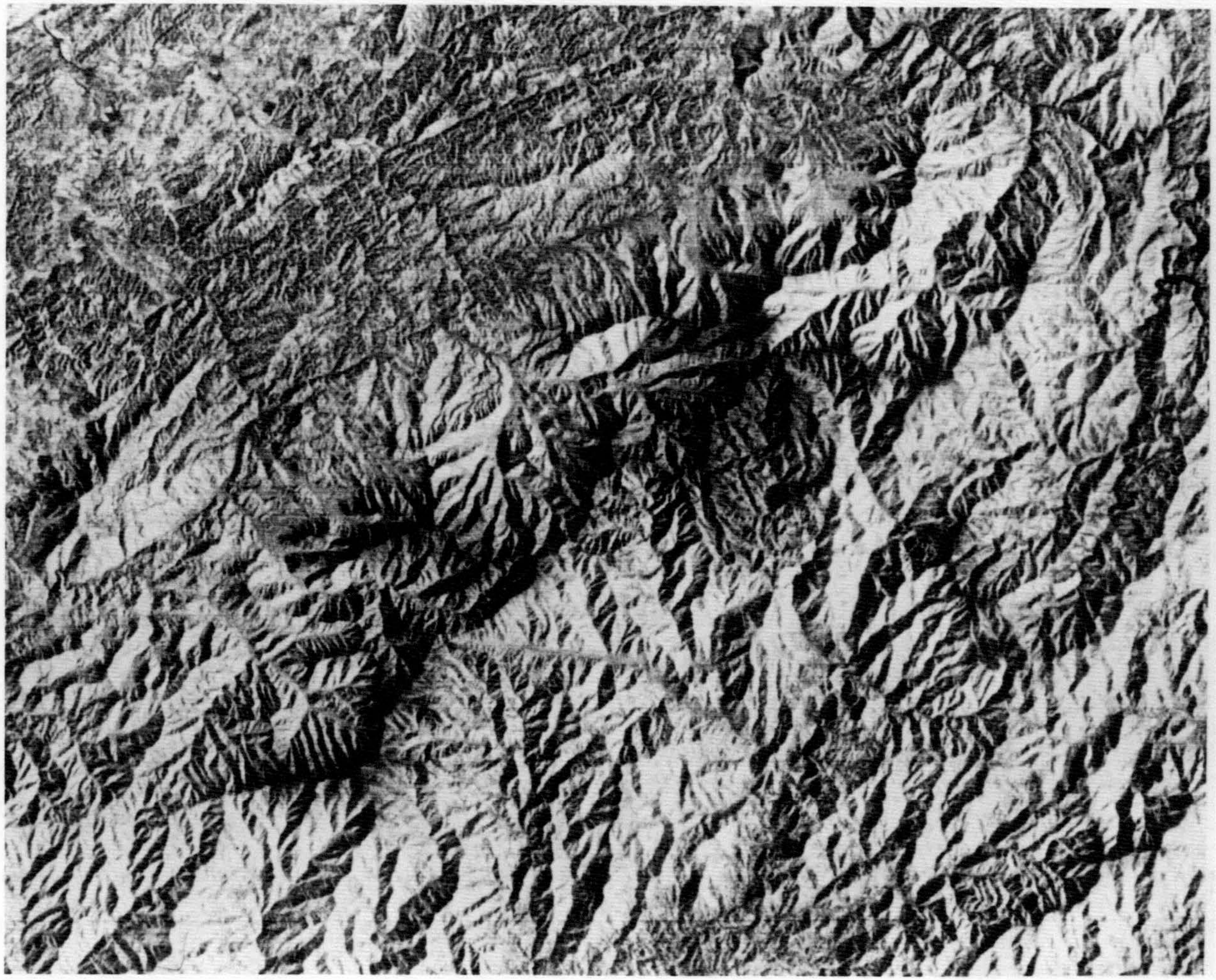

Figure 25. Enlarged Landsat Scene E5899-141427, Band 7, 4 October 1977.
Scale: 1:375,000.

classify the spruce-fir cover areas in selected test sites in the Great Smoky Mountains National Park. Four transformations were individually analyzed in order to assess their applicability for the identification of the dark-toned reflectances, hypothesized to be spruce-fir forests. The four transformations are: (1) First Four-Band Transformaion, (2) Band Ratio Transformation, (3) Band Sum Transformation, and (4) Second Four-Band Transformation. The Band Cosine Transformation was not used in the final analysis.

First Four-Band Transformation Results

During initial training and classification of the dark-toned reflectance pattern in each training site, a gray-scale map was developed. The gray-scale map exhibits sixteen reflectance levels discernible on each computer image. Each level is represented by a distinct symbol or letter (see Figure 26). The initial training sites for the classification were selected from areas of documented spruce-fir cover. Generally, the spruce-fir areas are represented by middle to dark tones on the gray scale maps. The darkest tones are shadows, and original training pixels were not selected from these regions. Pixel reflectance levels were taken at numerous known ground reference points (see Figures 27, 28, and 29).

The training sites selected in this transformation for GSM77F2 are reliable, based on the classifier's knowledge of the area, yet some shortcomings of the training site

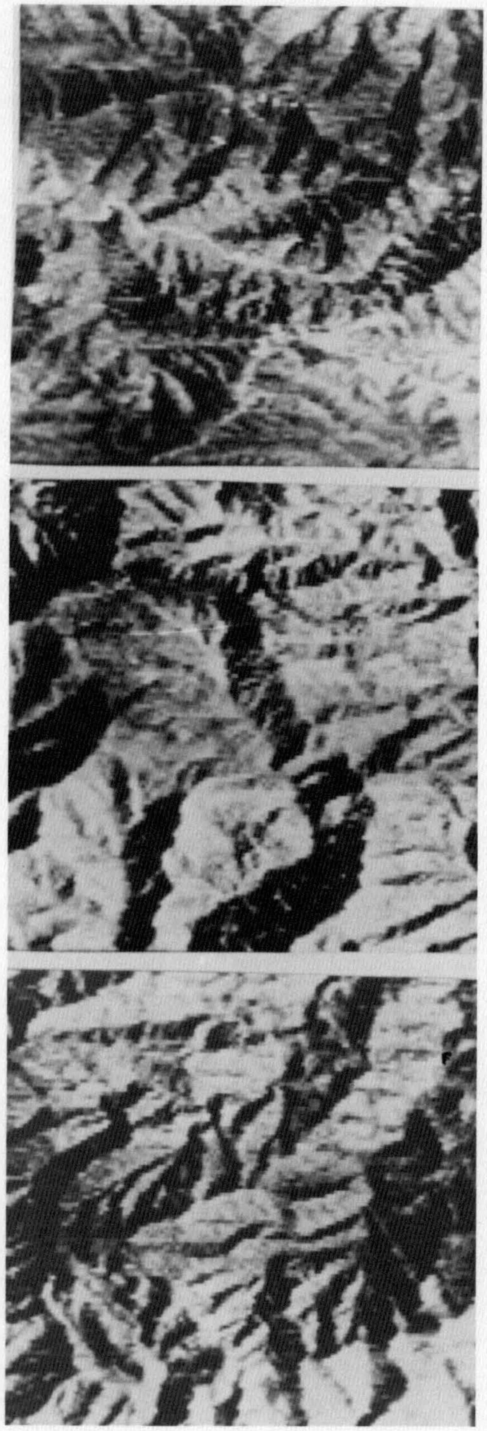

Figure 26. Cathode Ray Tube (CRT) Images of the Three Test Sites. (Top) GSM77F2, (Middle) GSM77R, and (Bottom) GSM77S.
Scale: 1:124,000.

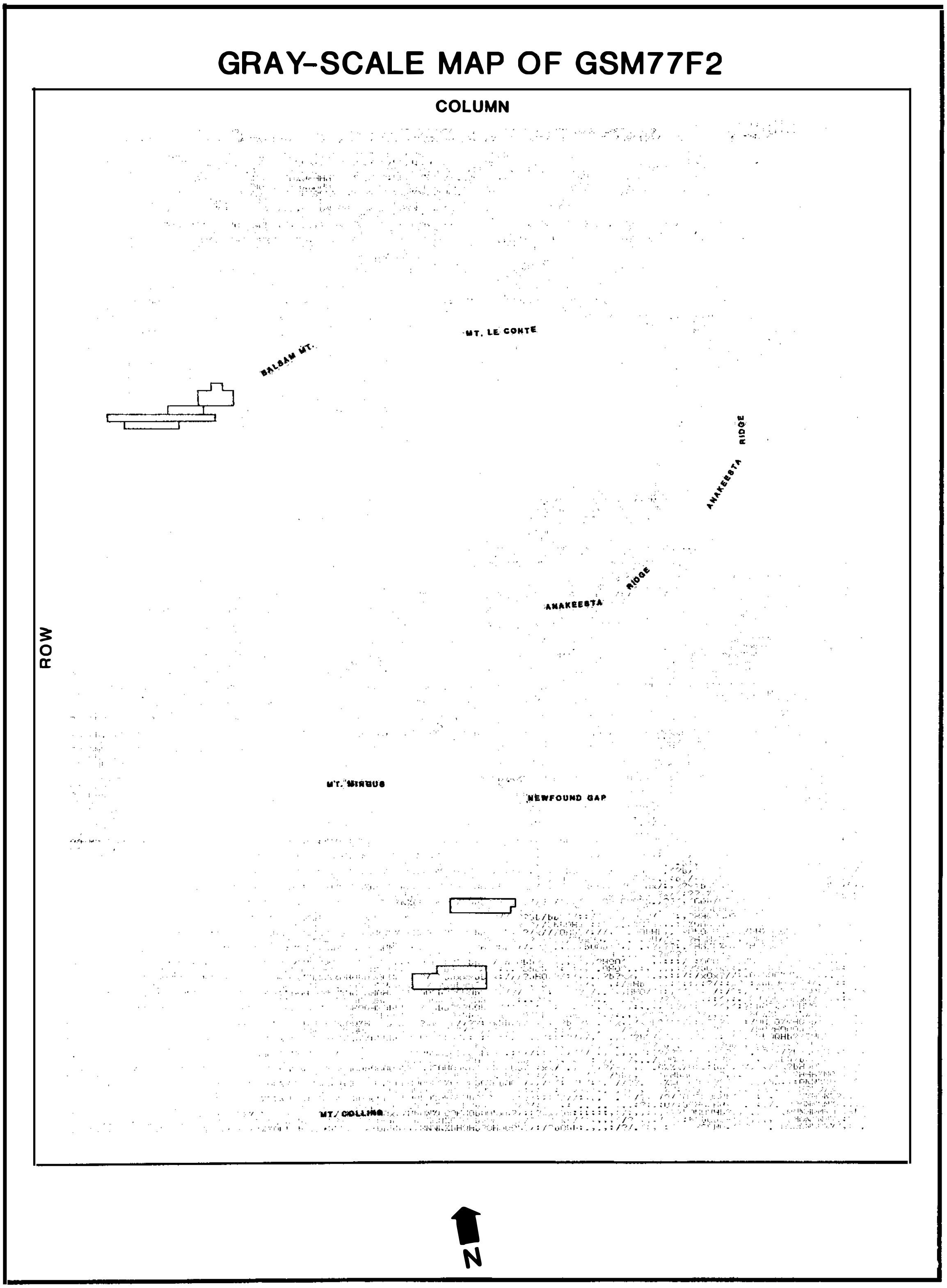

Figure 27. Gray Scale Map and Selected Training Sites of Scene GSM77F2. Rectangular Boxes Indicate Training Sites.

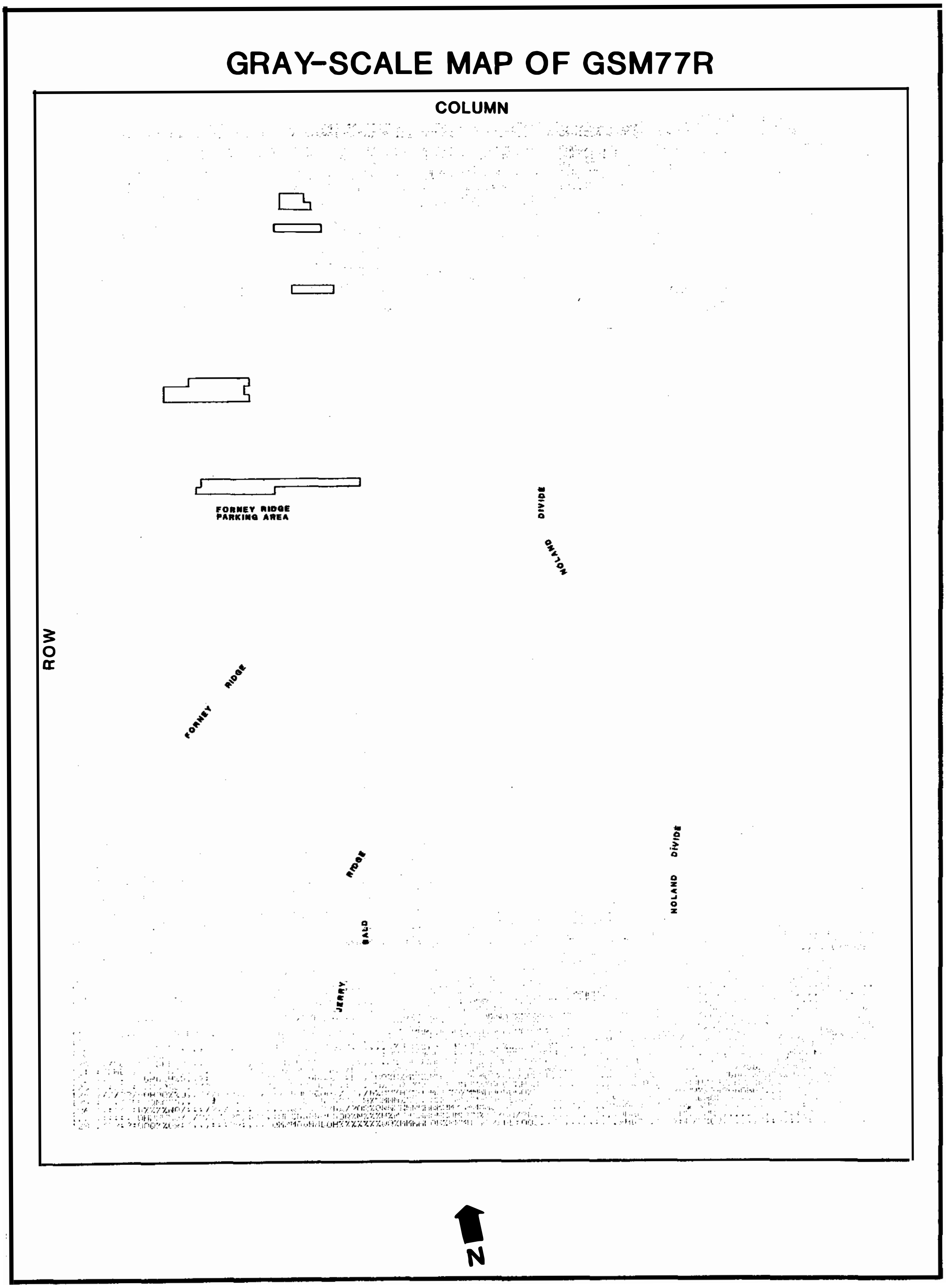

Figure 28. Gray Scale Map and Selected Training Sites of Scene GSM77R. Rectangular Boxes Indicate Training Sites.

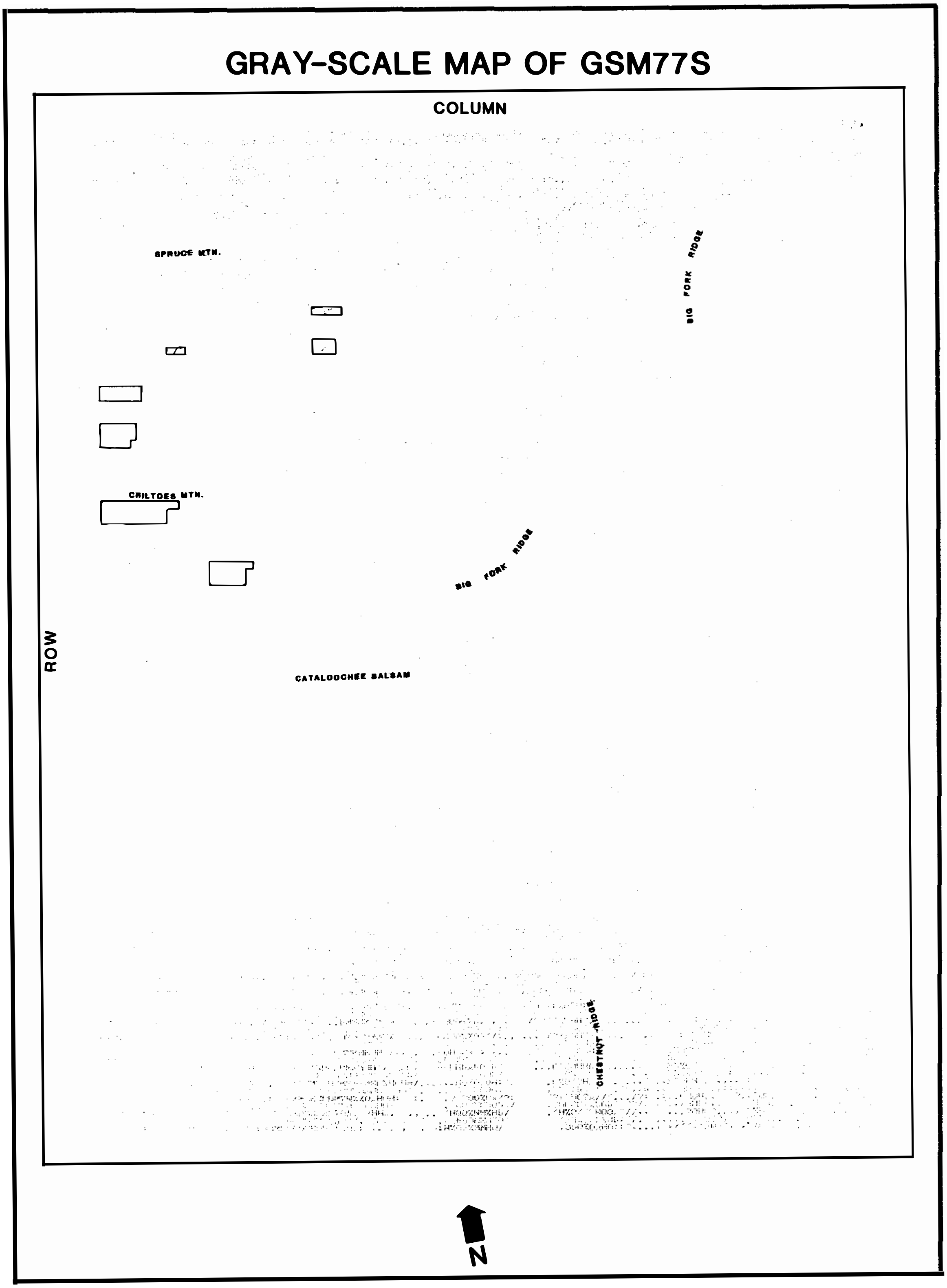

Figure 29. Gray Scale Map and Selected Training Sites of Scene GSM77S. Rectangular Boxes Indicate Training Sites.

selections made the use of further transformations necessary. By studying the statistical outputs for GSM77F2, it appeared that the reflectance level ranges for the training pixels selected were too broad because they possibly included unhealthy trees or other cover types. Table 1 shows the statistics for GSM77F2 utilizing the four-band transformation. Emphasis is placed upon the standard deviations for each band. Standard deviations below 3.0 were considered significant for identification of the spectral levels for each computer transformation. The standard deviations should be lowest in bands 6 and 7, since reflectance ranges are smaller than on bands 4 and 5. A high standard deviation represents a broad pixel class spread not indicative of the actual cover characteristics and probably too broad for accurate classification. The broad class range suggests an inclusion of other cover types. The possible inclusion of other cover types reduces the likelihood that the training pixel statistics are indicative of the spruce-fir cover.

A total of 9,175 pixels were classified as spruce-fir on the basis of the training statistics, which indicates that 56% of computer scene GSM77F2 was classified as a spruce-fir cover. The classification failed to identify any spruce-fir in shadow areas on north facing slopes or spurs, therefore it was assumed that this transformation lacked the ability to separate the vegetation and shadow reflectances. Field work does not indicate as large a spruce-fir stand in

TABLE 1

GSM77F2 STATISTICS

Classes	Band 1(4)	Band 2(5)	Band 3(6)	Band 4(7)
Total No. of Pixels in Histogram	16,384	16,384	16,384	16,384
Minimum Data Value	1	2	3	0
Maximum Data Value	29	41	52	30
Maximum Population[1] (Value/Classified Pixels)	9/3742	11/3018	16/1072	14/1343
Population Mean	10.53	10.89	22.89	12.26
Population Standard Deviation	1.71	2.95	7.63	4.66

[1]The maximum population represents the data value on a histogram with the greatest number of classified pixels.

test site GSM77F2 as the first four-band transformation suggests. These results indicate the need for further testing to develop a better classification based on tightly clustered class limits.

Band Ratio Transformation Results

The band ratio transformation was applied in an attempt to establish a new enhanced band utilizing spectral data from Landsat bands 5 and 7. It was anticipated that by proportioning spectral levels from the two bands to each other, differences between shadow and spruce-fir reflectances could be broadened.

The ratio transformation available on the IMPAC software system is:

(Band Z) = 0 + 1 (100 + Band X)/(100 + Band Y)

where,

Band Z is the new computer created ratio band,

Band X is computer band 4 (Landsat MSS band 7),

and

Band Y is computer band 2 (Landsat MSS band 5).

The ratio transformation did not significantly alter data results. The separability of shadow from spruce-fir areas on the created band ratio gray-scale map was not significant enough for detailed training pixel selection. The problem can be explained by low reflectivity differences between the two bands in the study area. Low or negligible pixel contrasts do not enhance the ratio data. Also, in using the variables selected by the analyst, pixel ratio levels were mostly lower than 1.0. If the variable B was replaced by 100, it appears that values would be considerably above 1.0. The gray-scale map has much lower signal contrasts than the maps developed from other transformations (see Figure 30). Standard deviations and other statistical data were not developed for the band ratio transformation, but it would appear that since a low-contrast, broad spectral gray-scale map was developed, the standard deviation for this band would be considerably higher than was desired. The band ratio transformation did not prove beneficial and did not develop the anticipated enhancement effects for this study, but in imagery in which contrasts between bands are greater or with new input variables, it might prove useful.

Band Sum Transformation Results

A number of substeps were taken when the band sum transformation was employed. The computer bands 2 and 4 (Landsat bands 5 and 7) were added together, creating a new computer band. The gray-scale map developed from this new band exhibited enhanced data in areas which previously had low reflectances in both computer bands 2 and 4 and enhanced the bright signatures in areas of high reflectances on both bands, thereby edge-enhancing minute reflectivity variations (see Figure 31).

The new computer band could be used in a single band classification or included with the other four computer bands

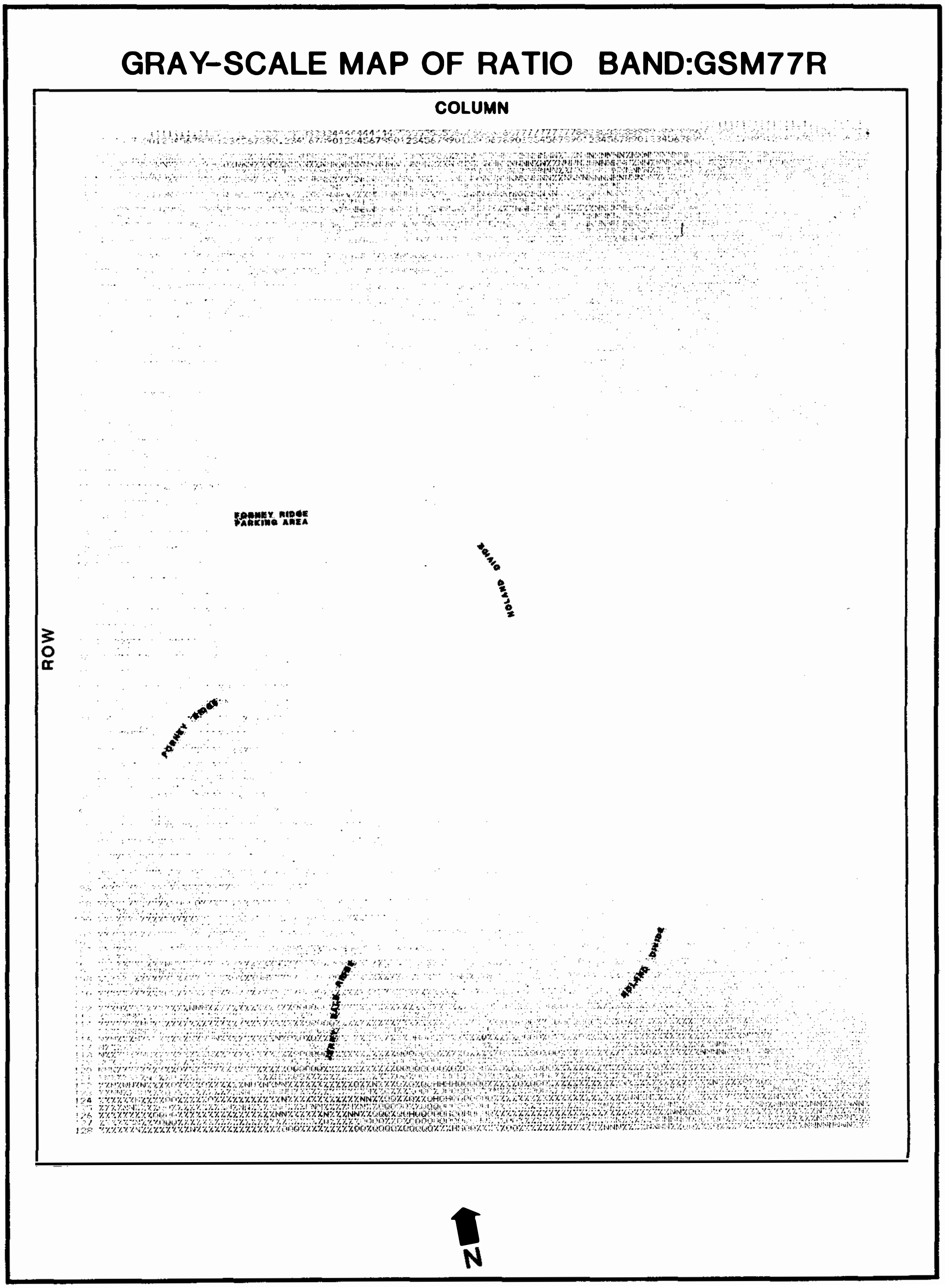

Figure 30. Gray Scale Map for Band Ratio Transformation of Scene GSM77R.

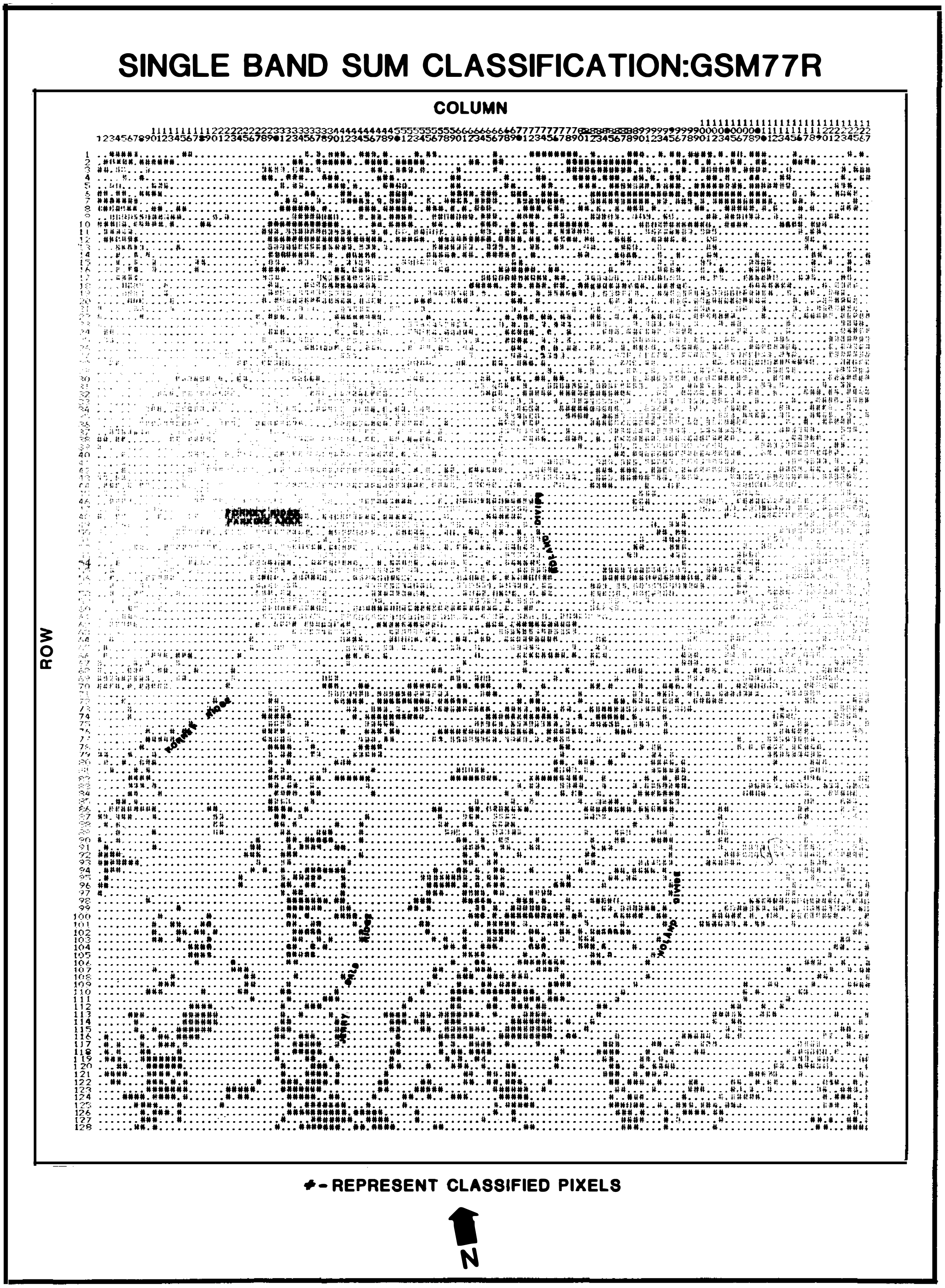

Figure 31. Gray Scale Map for Band Sum Classification of Scene GSM77R.

(Landsat MSS bands 4, 5, 6, and 7) in a five band classification using all the reflectivity statistics. Both of these steps were employed and some training pixels were shifted to other supposed spruce-fir areas in some subroutines to tighten statistical data when the classification appeared incorrect. The new sum band was created by adding together the reflectivity values of computer bands 2 and 4, as is seen in Table 2.

The classification, based on training pixels in spruce-fir areas, did not identify many areas of field investigated spruce-fir forests. Only 31.7% of GSM77R was classified as containing a spruce-fir cover, and these identified areas were widely scattered. In many instances, pixels located only in known shadow zones or in valleys below four thousand feet were identified as spruce-fir areas. Areas of known spruce-fir forests, such as those on the sunlit, southern slope of the main ridge in the Clingmans Dome region were not classified as a solid cover, but in a random, unconsolidated pattern (see Figure 32). Therefore, a single band sum transformation was employed using fifty-four new training pixels.

The new training pixel sites were selected from computer scene GSM77R in homogeneous spruce-fir areas due east of the Forney Ridge Parking Area near Clingmans Dome. All fifty-four selected pixels were located on a ridge slope above 4,500 to 5,000 feet, with an east-southeast exposure.

TABLE 2

FIRST BAND SUM SIGNATURE LIMITS

Image Band	Lower Limit	Upper Limit[1]
1	9	13
2	10	16
3	21	32
4	11	17
5	21	33

[1]The lower and upper limits, or brightness levels, represent kilowatts per centimeter squared per steradian, which is the solid cone angle of the scanning system, (Kw/cm^3/steradian). Low numbers indicate no reflectances or low reflectances of solar radiation while high numbers represent bright terrestial objects.

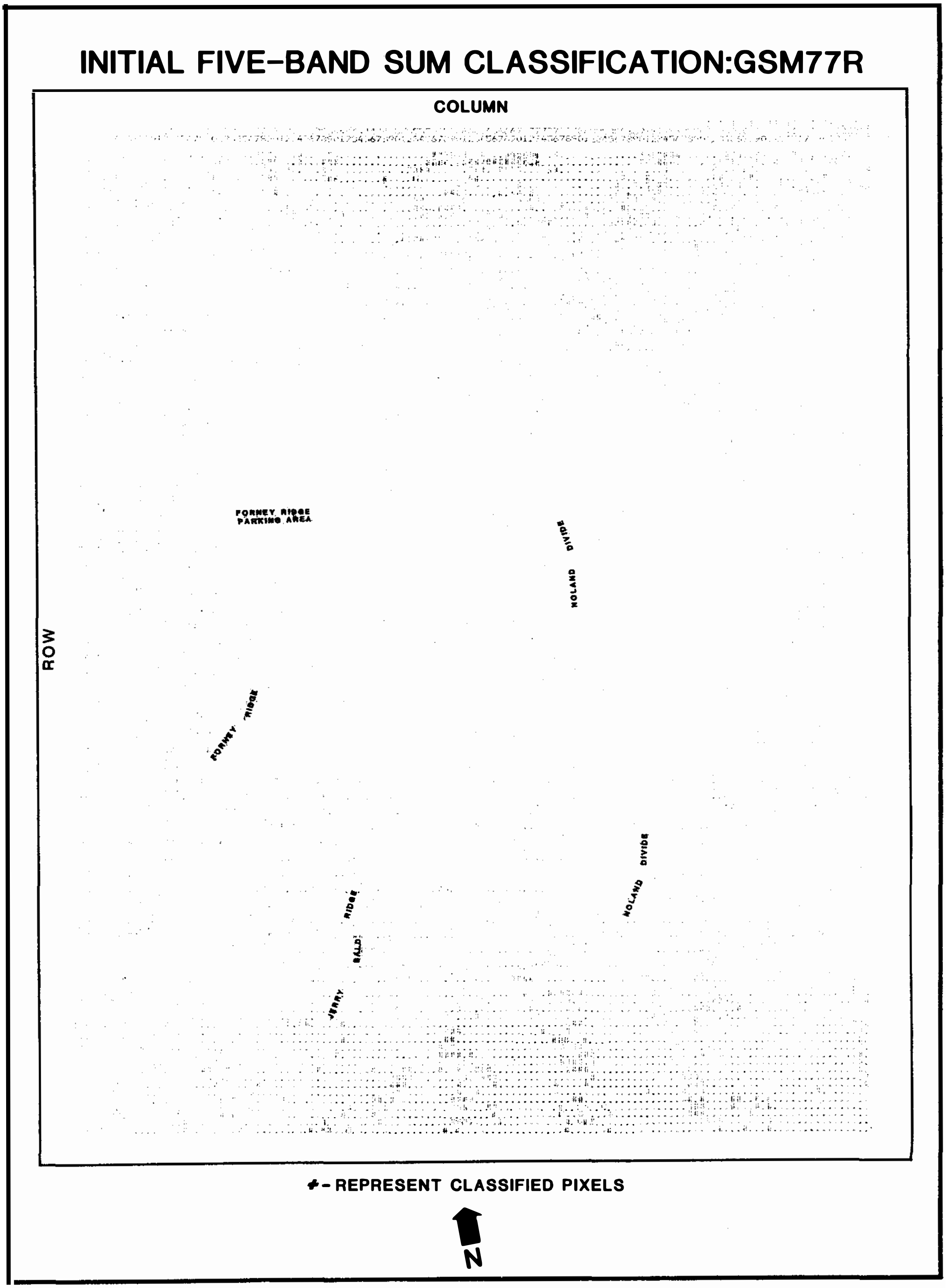

Figure 32. Initial Five Band Sum Classification of Scene GSM77R.

The training pixels were contained in five sets in close proximity and slightly downslope from the Clingmans Dome Road, so as not to include any road pixels. If road pixels had been selected, their reflectance levels would have been too high to be classified as spruce-fir areas. Careful attention was also given so as not to include pixels in any shadow areas on the northwest slope of the main ridge (see Figure 31 for training pixel locations).

Reflectance values were recorded for each training pixel in all five computer bands (1, 2, 3, 4, and the band sum 5) as an added security to assure similarity to previous spruce-fir training areas. Only signature limits from band 5, the sum band, were used to develop the single sum band classification. The signature limits for the original four computer bands remained the same (refer to Table 2), but the band 5 limits were changed to twenty-three and thirty.

The single band sum classification proved useful. The statistics, as shown in Table 3, are only moderately representative of the classification. The standard deviation for this classification was 1.68, which is within the selected limits, but some existing spruce-fir areas are not identified. This single band transformation failed to identify dense spruce-fir areas west of the Forney Ridge Parking Lot and Clingmans Dome Road in computer scene GSM77R. Also, spruce-fir was identified on sun-oriented slopes on the northwest side of the main ridge, but no indications of spruce-fir were found in the northwest slope shadows where

TABLE 3

SINGLE BAND SUM STATISTICS

Classes	Sum Band (Band 5)
Total No. of Pixels in Histogram	54
Minimum Data Value	23
Maximum Data Value	30
Maximum Population	15 at value 26
Population Mean	26.81
Population Standard Deviation	1.68
Classified Pixels	6046
Percent of Image Display Classified	36.90

dense stands of Fraser fir occur at elevations above six thousand feet. Third, a proliferation of spruce-fir classified pixels can be found in areas below four thousand feet, on sunlit slopes, and outside the areas of suspected spruce-fir cover (see Figure 33). An examination of the 1:250,000 Landsat scene for 1 April 1977, indicates that the reflectance limits might have included reflectivity values of light-toned shadow pixels as well as spruce-fir pixels. To solve this problem new training pixels in shadow areas as well as other spruce-fir areas were selected to determine if spruce-fir could be identified in known shadow regions. Seventy-eight training pixels were selected on the northwest slope of the main ridge line near Clingmans Dome. Twenty-three training pixels were selected on the sunlit southeastern slope of the same ridge in a defined spruce-fir forest immediately below the last bend in the Clingmans Dome Road.

A five-band sum classification was utilized again. The new signature limits were considerably broader than in past classifications. The new lower limits were caused by low reflectances from the shadow areas, which were included in the training set. The signature limits and the statistics are shown in Table 4.

Since there are only slight contrast differences between pixels in computer bands 1 and 2, the standard deviations of the training pixels in these two bands are low. For computer bands 1 and 2 the limits are tightly clustered

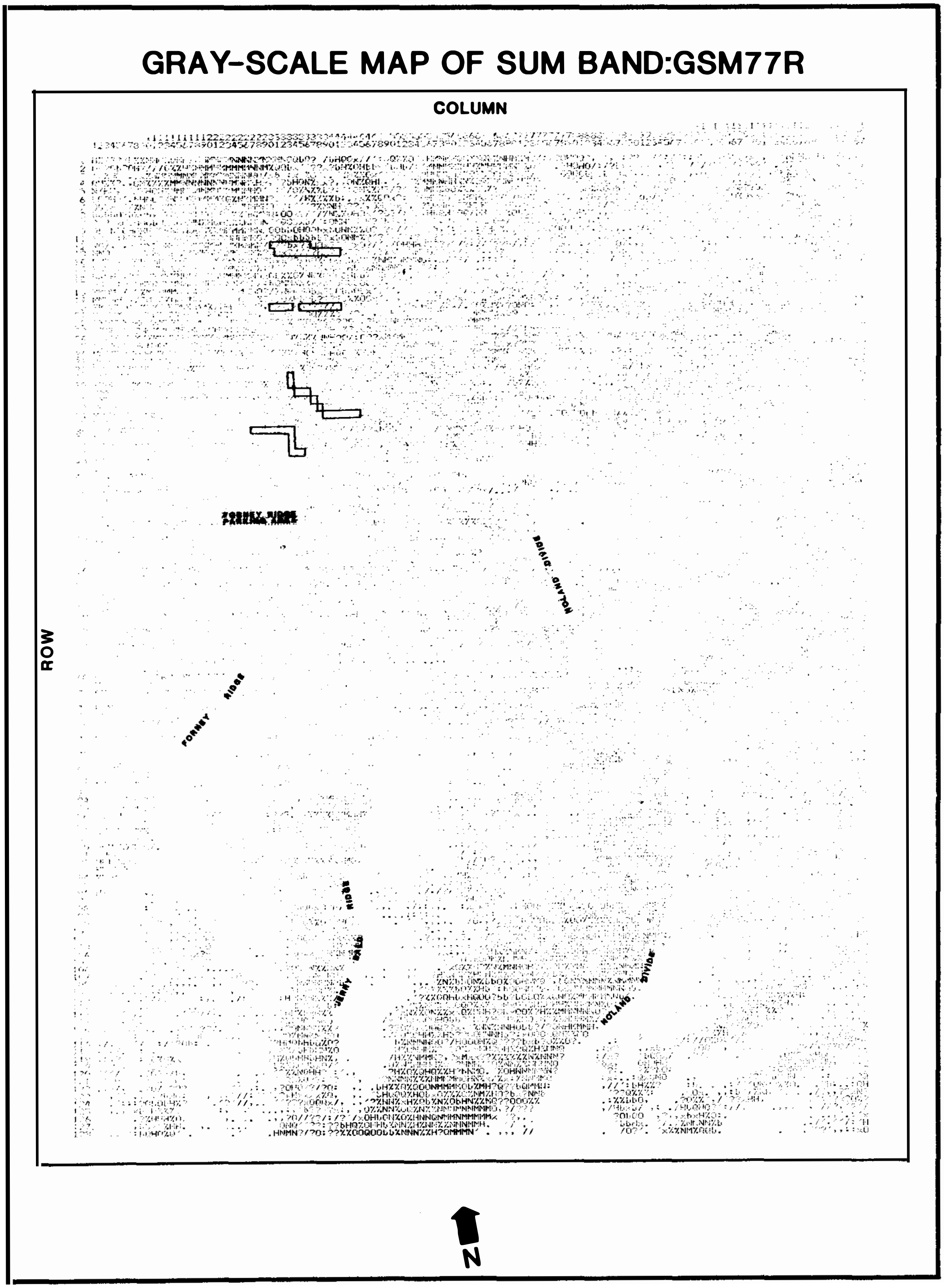

Figure 33. Classification Map of Single Band Sum Transformation of Scene GSM77R. Rectangular Boxes Indicate Training Sites.

TABLE 4

SECOND FIVE BAND SUM STATISTICS

Classes	Band 1	Band 2	Band 3	Band 4	Band 5
Total No. of Pixels in Histogram	101	101	101	101	101
Minimum Data Value	8	5	9	4	9
Maximum Data Value	12	12	33	18	30
Maximum Population[1] (Value/Classified Pixels)	10/47	11/25	23/14	12/18	22/11
Population Mean	9.60	9.36	19.82	10.24	19.59
Population Standard Deviation	0.86	1.63	5.05	3.11	4.56
Classified Pixels Remaining After Each Band	8986	6274	6217	6194	6194
Percent of Image Display Classified	54.84	38.29	37.94	37.81	37.81[2]

[1]The maximum population represents the data value on a histogram with the greatest number of classified pixels.

[2]This number represents the percent classified as spruce-fir for this transformation.

because of the masking of the spruce-fir by similar reflectances from shadow areas. In computer bands 3, 4, and the sum band 5, the standard deviations are much higher. Within the near-infrared computer bands 3 and 4, contrasts in reflectances from spruce-fir and shadow are greater, therefore, by combining the reflectance values of spruce-fir and shadows, the standard deviation naturally increases. A high standard deviation in the sum band is caused by the combination of low contrast reflectances from computer band 2 with higher contrast reflectances from computer band 4.

The classification map, which was produced from the statistics, identified 37.81% of computer scene GSM77R as spruce-fir (see Figure 34). The Clingmans Dome Road and the Forney Ridge Parking Area are easily located in the scene because of their high reflectivity value surrounded by a generally low reflectance area. Shadow regions on the northwest slope of the main ridge in the upper left hand corner of GSM77R are identified as containing spruce-fir. Noland Divide, which does not contain spruce-fir near its southern boundary was classified as containing these conifers, but only on its northwest-facing slope. If spruce-fir does exist there, it should also extend over the divide and onto sunny southeast oriented slopes, yet it is evident from Figure 34, that the boundary does not extend over the ridge. It seems apparent, therefore, that the training pixels used in the classification included shadows. Areas lacking

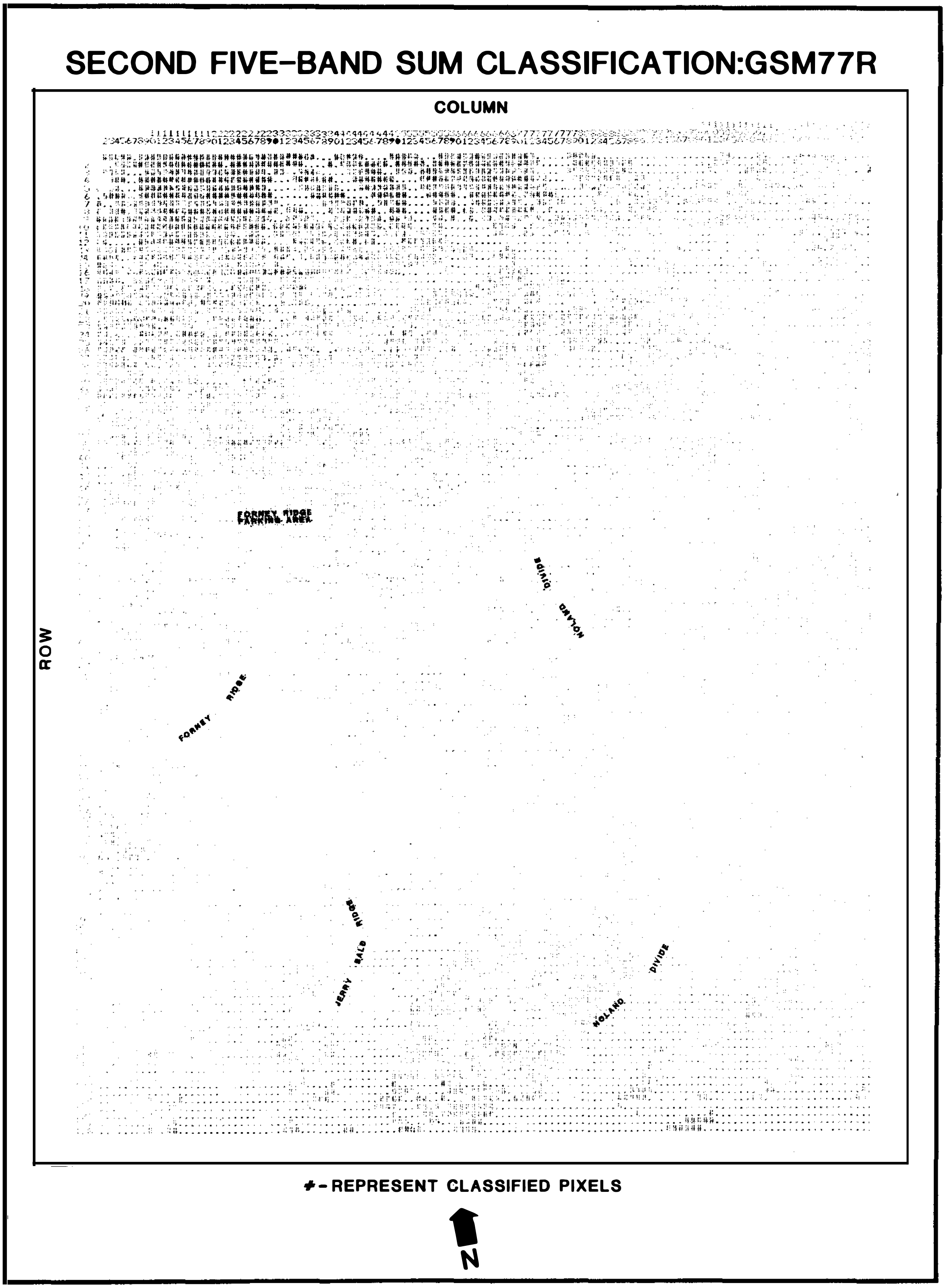

Figure 34. Classification Map of Second Five Band Sum Transformation Including Shadow Area Training for Scene GSM77R.

spruce-fir, but with a reflectance similar to the shadow areas trained on, were misclassified as spruce-fir. Sections where this occurs on GSM77R include Noland Divide, the main ridge line in the Clingmans Dome area, Forney Ridge, and Jerry Bald Ridge. Areas of deep shadow with extremely low pixel reflectance levels remained unclassified. These deep shadows can be seen as elongated open areas on the northwest slope of the main ridge line in the upper left corner of GSM77R.

It was not felt that the five-band sum transformation could be accepted as the most accurate. It seems evident that by combining reflectance levels of both spruce-fir and shadow training sites, an incorrect classification of the areal extent of the spruce-fir is produced. Areas which contained shadows but no spruce-fir were identified as spruce-fir. There also appear to be different reflectance levels for shadows and it does not appear possible to extract the spruce-fir reflectance levels from within these shadows with the five-band sum transformation.

Second Four-Band Transformation Results

The second four-band transformation employed in this study proved to be the most accurate. Four separate subtests were run with this transformation, each developing a more refined classification than the previous one.

The first test involved altering the signature limits of previously selected training pixels which were not felt to be representative of the actual spruce-fir reflectances. The new signature limits are shown in Table 5.

TABLE 5

SIGNATURE LIMITS FOR FIRST TEST: SECOND FOUR-BAND TRANSFORMATION

Image Band	Lower Limits	Upper Limits
1	9	14
2	8	16
3	21	34
4	11	17

With these new limits established, 6,514 pixels or 39.76% of image display GSM77R was classified as spruce-fir (see Figure 35).

Several problems made this first test inaccurate. First, the computer classified the Clingmans Dome Road as a spruce-fir cover. Second, large scattered areas east of Clingmans Dome were classified as spruce-fir where previous research does not indicate so extensive a stand. Finally, a large number of pixels classified as spruce-fir appear in lower elevations at the southern end of Noland Divide where previous research again shows little spruce-fir cover (refer to Figure 20, page 55).

The second test involved the establishement of fifty-two training pixels in a transect across the main ridge

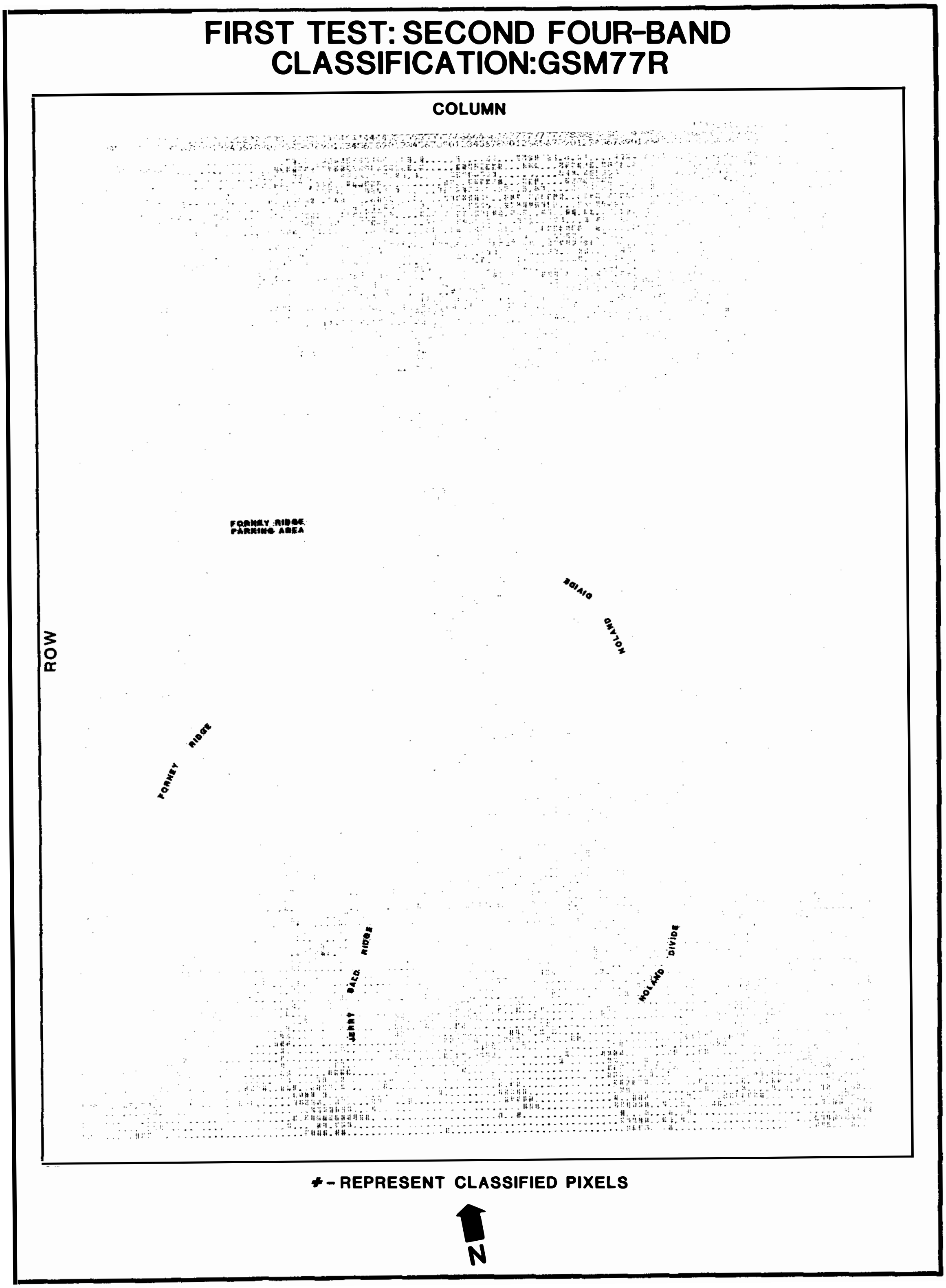

Figure 35. Classification Map of First Test: Second Four-Band Transformation of Scene GSM77R.

northeast of Clingmans Dome. The signature limits for the new transect training pixels are shown in Table 6.

TABLE 6

SIGNATURE LIMITS FOR SECOND TEST:
SECOND FOUR-BAND TRANSFORMATION

Image Band	Lower Limits	Upper Limits
1	6	13
2	5	19
3	6	29
4	2	17

The signature limits are low because of the inclusion of low-reflectance shadow pixels. The upper limits are standard for reflectances from spruce-fir areas. A gray-scale classification map was printed from these limits with 9,326 pixels or 56.92% of image area GSM77R classified as spruce-fir (see Figure 36).

From Figure 36, it is evident that more than spruce-fir has been so classified. All shadow areas northwest of Clingmans Dome were classified as spruce-fir, but other areas not known to contain spruce-fir were also classified. On Noland Divide, only areas on the northwest slope were classified as spruce-fir and if spruce-fir did exist, it should also be evident on the southeastern slope at similar elevations, yet none was identified there. The northwest

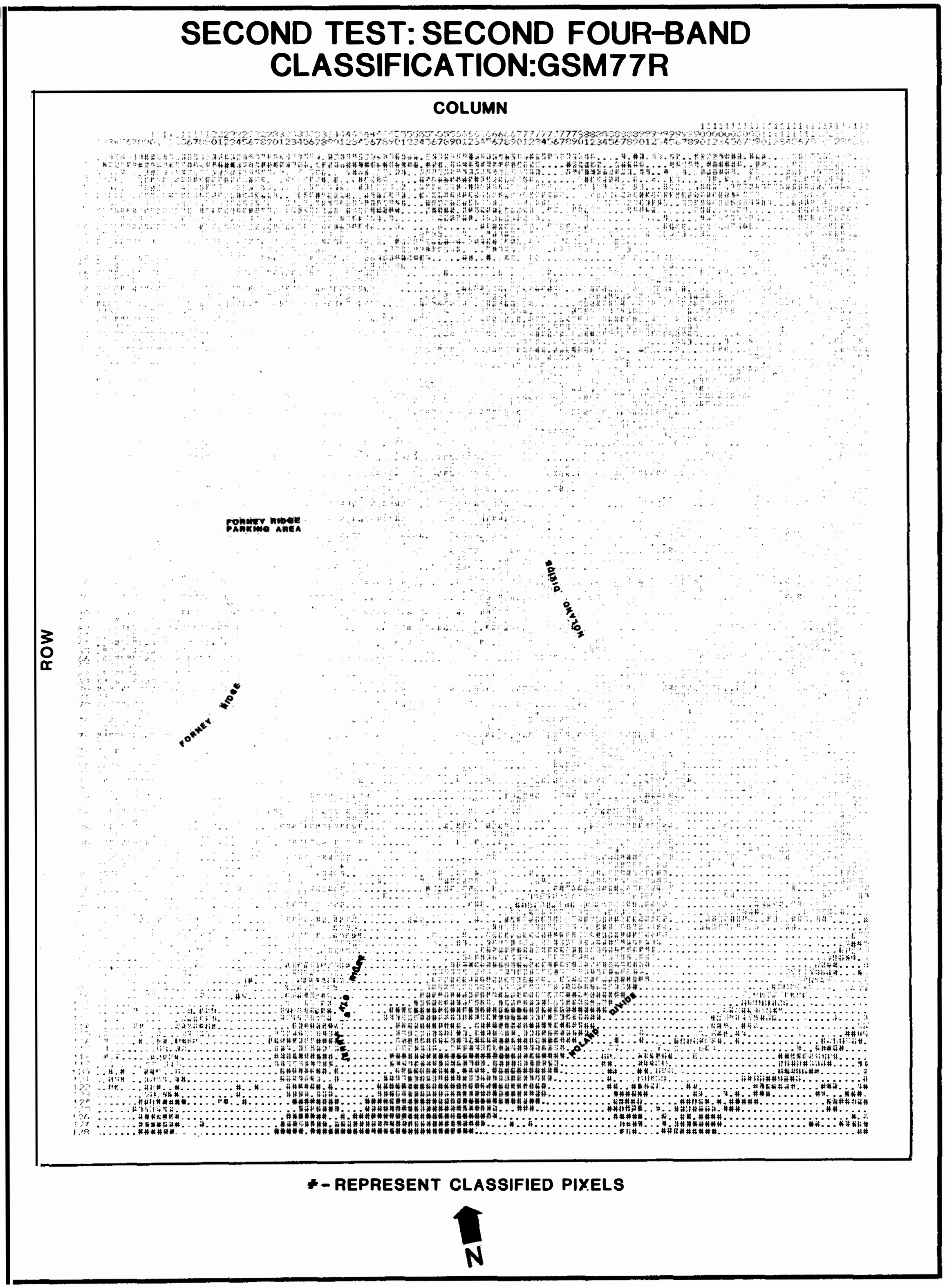

Figure 36. Classification Map of Second Test: Second Four-Band Transformation of Scene GSM77R.

slopes of Jerry Bald Ridge and Forney Ridge also exhibit similar phenomena. Since no spruce-fir was classified on the southeast slopes of these ridges, although it was classified correctly near Clingmans Dome, it indicates that either no spruce-fir exists as far south as these ridges, or that spruce-fir exists only in small detached pockets. Spruce-fir will thrive better on shadowed, cool north-facing slopes, but not to the extent that it appears in Figure 36. Therefore, this classification cannot be accepted as correct, because it includes shadow areas within the classification. An assessment of the southern extent of the spruce-fir forests can be made from the sparse number of classified pixels in the higher elevations on Jerry Bald Ridge and Noland Divide. This point is supported by R. H. Whittaker.[47]

In the third test an attempt was made to classify spruce-fir vegetation in a light-toned shadow area. Forty-one training pixels were selected from areas of light shadow and known spruce-fir cover areas located northeast of Clingmans Dome. To reduce the possibility of erroneous classification, pixels from dark-toned shadow areas and the highly reflective Clingmans Dome Road were excluded. Training pixels were selected on two spurs extending northwestward from an area near Mt. Love. These spurs appeared to contain lighter-toned pixels than the deep shadow areas.

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[47]Stupka, op. cit., footnote 25, p. 25, citing R. H. Whittaker, "Vegetation of the Great Smoky Mountains," Ecology Monograph 26, (1956).

The spurs also contained a spruce-fir cover. When reflectance levels were read from the CRT screen, it was obvious their values were similar to limits established for spruce-fir in other four-band transformations. The signature limits for this test are shown in Table 7.

TABLE 7

SIGNATURE LIMITS FOR THIRD TEST:
SECOND FOUR-BAND TRANSFORMATION

Image Band	Lower Limits	Upper Limits
1	8	12
2	9	15
3	16	29
4	8	15

The lower limits are slightly lower than those common for spruce-fir, but are higher than those of deep-shadowed areas. The upper reflectance limits are consistent with spruce-fir upper limits previously established (compare Table 7 with Tables 5 and 6). With these limits established, the computer classified 6,040 pixels or 36.87% of test area GSM77R as spruce-fir cover.

Although very dark-toned shadows on the northwest-oriented slope of the main ridge line were not classified as spruce-fir, other areas of known shadow were classified. Shadowed northwest slopes of Jerry Bald Ridge and Noland

Divide were again classified as spruce-fir. It appears that the light-toned shadows on these ridges still mask or simulate the spruce-fir cover. It seems more likely that a few training pixels were actually light-toned shadow areas and were therefore wrongly applied to the transformation (see Figure 37). The area identified as spruce-fir near Clingmans Dome is consistent through each test, but problems were still encountered when attempts were made to extract data from shadow areas without actually classifying shadows as a spruce-fir cover.

This test classification cannot be accepted as completely accurate because of the recurring problems encountered with shadow signatures within the classification. It is evident, however, that differing shadow reflectance densities do occur in a mountainous image scene depending on slope orientation, slope degree, and Keplerian rhythms.

The fourth test was operated on the premise that spruce-fir could not be classified in shadow areas, and therefore no training pixels were selected from northwest-oriented slopes. This final test was designed to accept reflectance values from training pixels clustered in a solid, healthy spruce-fir forest near the Forney Ridge Parking Area and Clingmans Dome. Only eighteen pixels were selected, which is below normal classification numbers, yet the pixels chosen significantly represent small tracts totalling 19.8 acres of red spruce and Fraser fir in an area known for its stand density. The eighteen training pixels were selected

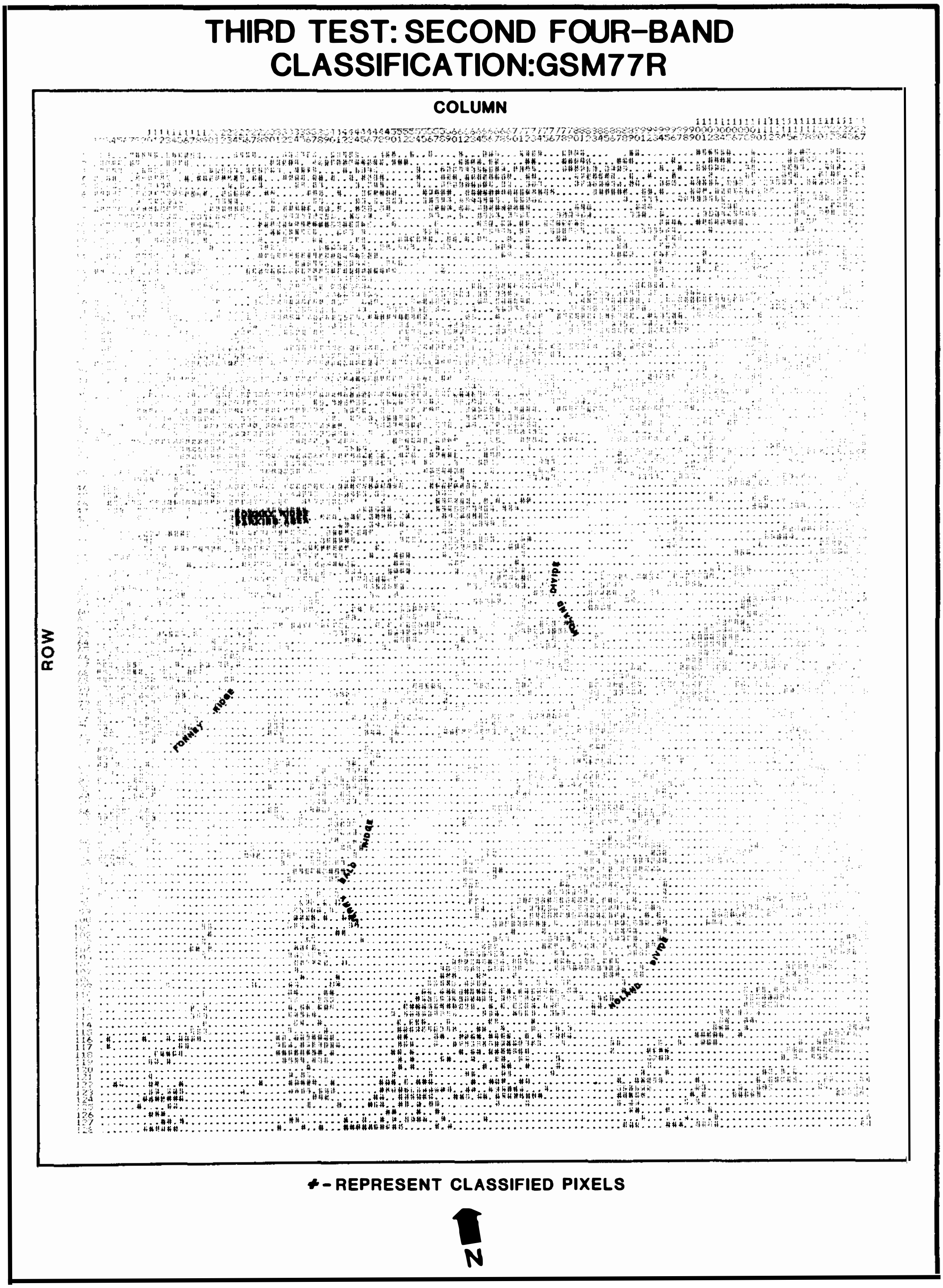

Figure 37. Classification Map of Third Test: Second Four-Band Transformation of Scene GSM77R.

from the GSM77F classification map (see Figure 38). A tight cluster of the eighteen training pixels was established, and the reflectance values found in Table 8 are similar to spruce-fir reflectance values used earlier in this study.

TABLE 8

SIGNATURE LIMITS FOR FOURTH TEST:
SECOND FOUR-BAND TRANSFORMATION

Image Band	Lower Limits	Upper Limits
1	9	13
2	9	14
3	21	28
4	11	14

Reflectance limits were altered in computer bands 3 and 4. In previous transformations the lower limits in these bands were slightly lower and the upper limits were higher, but in all instances the value means remained similar. The statistics for the eighteen training pixel classification are shown in Table 9. The population standard deviations are all low because: (1) the selected pixels represent actual cover characteristics of only the spruce-fir areas, since their spread on a histogram is minimal, or (2) because only eighteen pixels were chosen close to each other, ranges, will be lower than if many widely scattered training pixels had been selected. A standard deviation of .83 was the

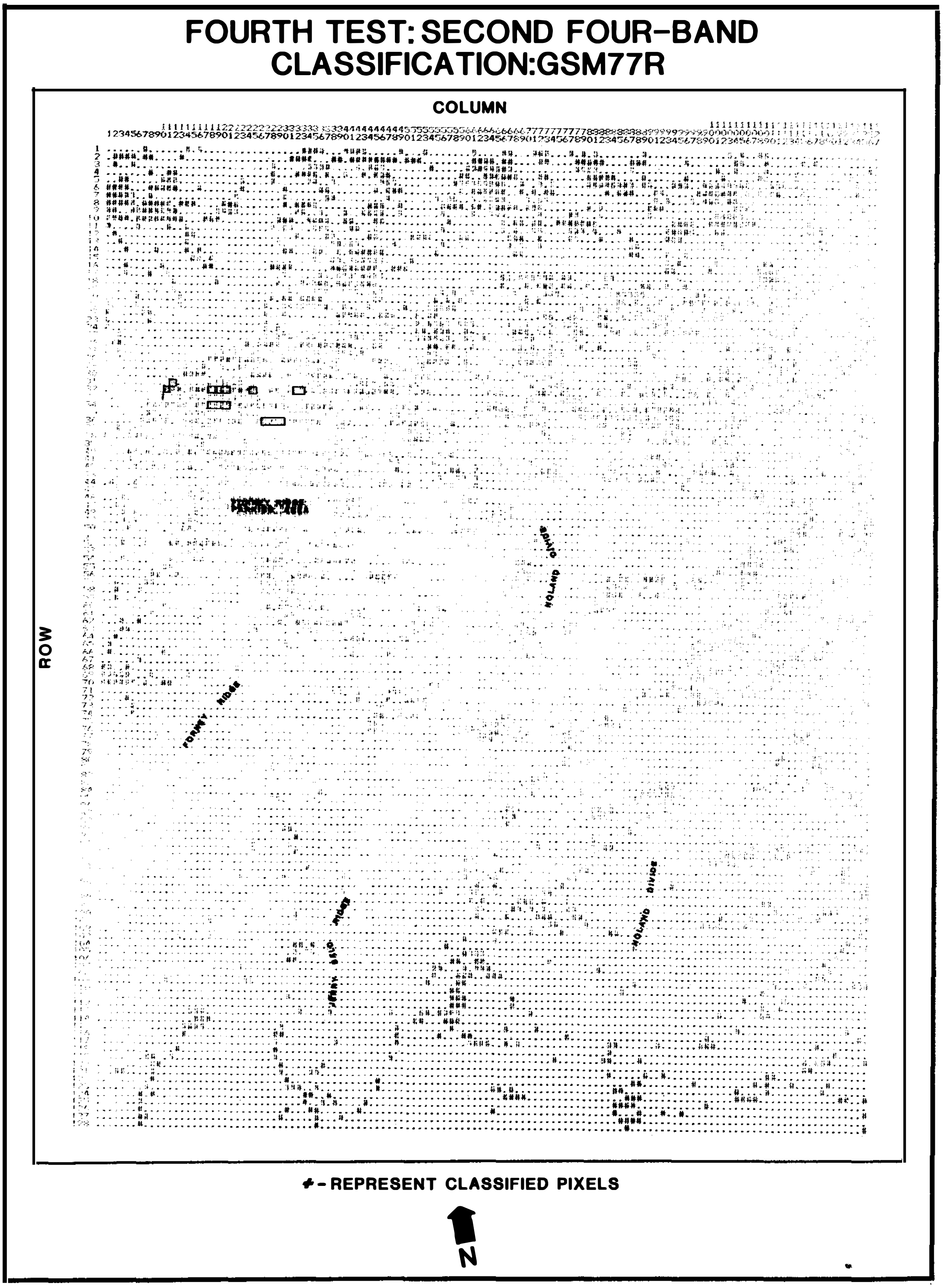

Figure 38. Classification Map of Fourth Test: Second Four-Band Transformation of Scene GSM77R. Boxes Indicate Training Sites.

TABLE 9

STATISTICS FOR FOURTH TEST:
SECOND FOUR BAND TRANSFORMATION

Classes	Band 1	Band 2	Band 3	Band 4
Total No. of Pixels in Histogram	18	18	18	18
Minimum Data Value	9	9	21	11
Maximum Data Value	13	14	28	14
Maximum Population (Value/Classified Pixels)	10/7	12/6	24/5	13/8
Population Mean	10.39	11.56	23.89	12.72
Population Standard Deviation	0.98	1.42	1.97	0.83
Classified Pixels Remaining After Each Band	11,086	8,352	4,196	3,146
Percent of Image Display Classified	67.66	50.97	25.61	19.20[1]

[1]19.20 represents the percent classified as spruce-fir for this transformation.

lowest encountered for computer band 4 in any transformation. This is significant, for vegetation type separability was not previously thought to be very accurate with this band (Landsat MSS band 7, near-infrared channel).

A total of 3,146 pixels, or 19.20% of image area GSM77R, was classified as containing a spruce-fir cover. Although this is a lower number of classified pixels than previous transformations have developed, its accuracy appears to be much greater than those transformations. In Figure 38, the problem of mountain shadows being classified as spruce-fir has been eradicated. The areas classified as spruce-fir occur only on sunlit slopes and spurs, visible just north of Clingmans Dome. The Clingmans Dome Road and Forney Ridge Parking Area are easily recognizable on the classification map, running parallel to the main ridge line in the upper left portion of the printout. The concentrated region surrounding the Forney Ridge Parking Area was correctly classified, as was anticipated, yet obvious gaps occur within and along the edges of this area. These gaps can be explained as the road and parking lot, slicks, balds, exposed rock, or beech gaps in the spruce-fir forest. Another possibility is that the gaps within the core area are slightly shaded spurs or areas of unhealthy spruce-fir vegetation affected by the balsam woolly aphid infestations. If training pixels were selected in pure, unaffected, healthy spruce-fir stands, then marked differences in reflectivity between those areas and diseased areas are possible. Since affected vegetation will exhibit stresses in the chlorophyllic layer of the needles, these stresses will definitely alter the reflectivity levels of the plant when imaged with an infrared scanner. The degree of reflectivity variations between healthy and aphid-affected spruce-fir areas are not known, and it is not within the scope of this study to examine these differences. Nevertheless, such differences may provide a possible explanation for gaps in areas believed to be dense spruce-fir.

Pixels were not classified as spruce-fir in the shadow areas of Jerry Bald Ridge, Noland Divide, or Forney Ridge as occurred in other transformations and tests. Outlier pixels, in small one to twenty acre plots, are noticeable at the southern and southeasternmost extent of the image. These areas may be either misclassified pixels or small pockets of red spruce in lower elevations. Although these small outliers are not within the spruce-fir boundaries established by Eagar in 1976, it is quite possible that they are small, heretofore unnoticed plots of red spruce which he did not identify. Since Eagar did not indicate reasons for his boundary line discrimination in his classification, it appears possible that these small plots were left unclassified because of their small size and distance from the core area, or were not distinguished in a mixed-cover environment containing dominant deciduous trees. It seems reasonable that small areas of red spruce could exist in sheltered valleys or higher elevations separate from the core area. These pixels occur within the elevation range suitable for red spruce, but it seems likely that Fraser fir could survive in dense stands below 5,500 feet also. Individual Fraser fir trees can exist at sheltered elevations as low as 4,000 feet, and they may be intermixed in small plots with the red spruce. They may also be prevented from extending their domain by the domination of much taller and more highly reflective deciduous trees.

This classification was accepted as more accurate than the others developed in this study but large areas in shadows remained unclassified. The signature limits from Table 8 were inserted in the four-band classification program for the other two study sites, GSM77F2 and GSM77S.

With new signature limits for GSM77F2 established, the computer classified 3,670 pixels or 22.40% of the site as spruce-fir. The pixels classified as spruce-fir were scattered over the entire computer image in a rather random pattern, but some well defined, clustered areas can be identified and located (see Figure 39).

A dense stand of spruce-fir was classified in the Mt. Collins region in the lower center of GSM77F2. This area is along the main ridge line just southwest of Newfound Gap and is the northern part of the large core are identified previously on test area GSM77R. The pattern thins out

FOURTH TEST: SECOND FOUR-BAND CLASSIFICATION:GSM77F2

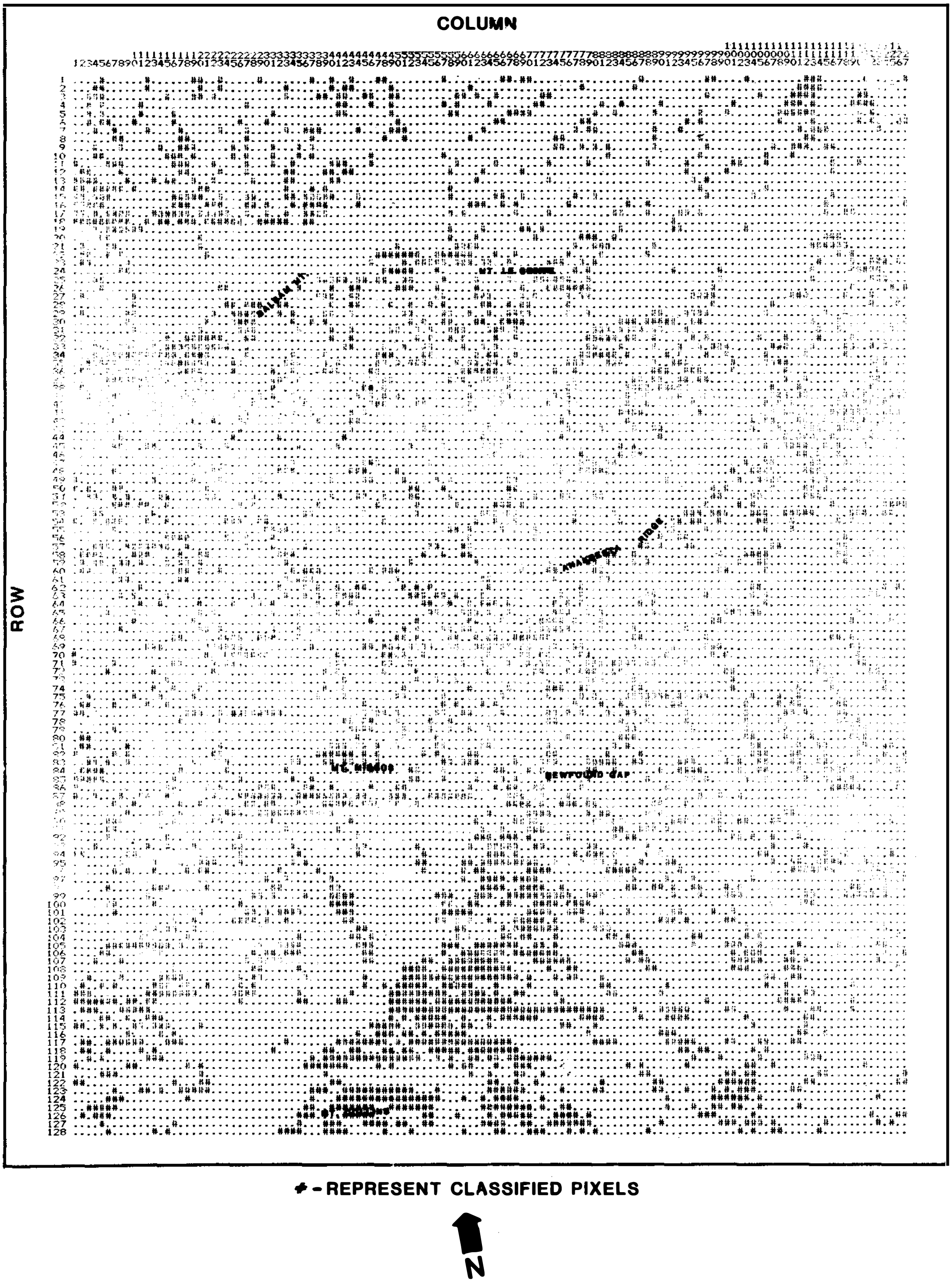

Figure 39. Classification Map of Fourth Test: Second Four-Band Transformation of Scene GSM77F2.

noticeably near Newfound Gap, where lower elevations, steep slopes, and extensive beech gaps limit the expansion of spruce-fir forests. This is also documented on Eagar's map. Spruce-fir areas were not classified on north and northwest-oriented slopes for GSM77F2, which is evident immediately north of Newfound Gap along the main ridge line. A small elongated strip of spruce-fir was classified on the south-eastern slope of the ridge, but it does not extend over into shadow areas. Another stand of spruce-fir can be located on the southern slope of Mt. Mingus, northwest of Newfound Gap. A few areas in the north and northeastern section of GSM77F2 contain rather dense classified stands. These regions correspond to the higher elevations of Mt. LeConte and Balsam Point. Both of these peaks have dense stands of spruce-fir on their southern slopes. Areas to the north of these two ridges are dominated by shadows where no spruce-fir forests were classified. The southern slopes of Anakeesta Ridge, immediately north of Newfound Gap, were classified as spruce-fir as well as areas along the Boulevard leading up to Mt. LeConte. The remaining scattered pixels are areas along higher ridges or in sheltered lower elevations of 3,500 to 4,000 feet where small stands of red spruce and Fraser fir exist.

When the new signature limits were applied to computer test site GSM77S, 3,057 pixels or 18.66% of the image area was classified as spruce-fir (see Figure 40). It is

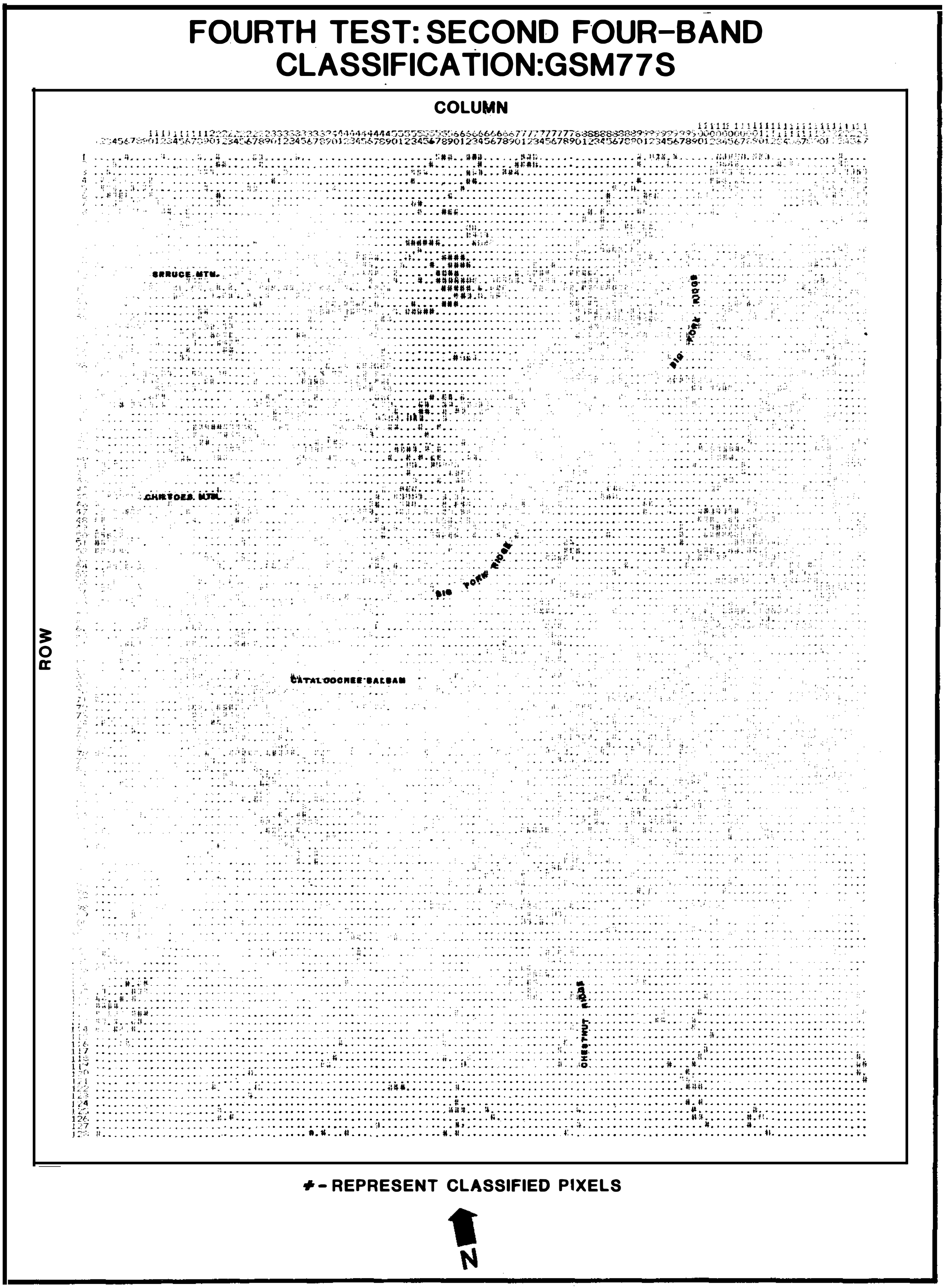

Figure 40. Classification Map of Fourth Test: Second Four-Band Transformation of Scene GSM77S.

evident that the area classified as spruce-fir in this rugged section of the Park is clustered on the major ridges which are high enough to support them. Very few outlier pixels occur. Again, spruce-fir was not classifed in shadowed, north-sloping areas. The top half of GSM77S contains the largest number of classified pixels, probably because of the higher elevation range. The lower half includes areas barely outside the Park boundary and at a lower elevation which probably cannot support extensive spruce-fir forests, yet a few small scattered sites occur there.

The elongated strip of classified pixels running northeast to southwest represents the southeast-facing slope of Big Fork Ridge. The clustered area of pixels located near row 73, column 25, is where Big Fork Ridge and Cataloochee Balsam meet, an area above 5,500 feet in elevation, high enough to support both red spruce and Fraser fir. Chiltoes Mountain, at 5,888 feet, contains another dense stand of classified pixels located near row 48, column 7. Spruce Mountain and Spruce Mountain Ridge in the upper left corner of GSM77S also contain a cluster of spruce-fir classified pixels. The elongated spurs containing classified pixels in the lower right corner are Chestnut Ridge, Maggot Ridge, and other unnamed ridges or spurs which are all high enough to support spruce-fir vegetation. This area was identified in Park records as containing a spruce-fir cover, separated from the core area north and west of it by lower elevations.

The fourth test of the second four-band transformation appears to classify the extent of spruce-fir reflectance areas correctly, given clustered training pixels in a well defined area and tight signature limits to exclude unnecessary "noise" from other vegetation types, bare rocky areas, slicks, balds, and large areas of mountain shadows. This transformation appeared to classify and delimit spruce-fir areas correctly, yet no data on northeast, north, or northwest-facing slopes were obtainable because of shadow problems. The transformation also appeared to locate and classify small plots of red spruce and Fraser fir not previously identified.

Table 10 compares the accuracy of the manual and computer techniques used in this study. The reflectance levels from manual techniques are assessed qualitatively, while the five computer transformations are assessed quantitatively. Accuracy in separation of reflectance levels are quality rated as Excellent, Good, Fair, or Poor.

TABLE 10

ACCURACY OF MANUAL AND COMPUTER TECHNIQUES

Techniques	Reflectance Levels		Accuracy of Separation	
	Spruce-Fir	Shadow	Spruce-Fir	Shadow
Manual[1]	Dark Gray 6-8	Black 9-10	Fair	Fair
Computer Transformations[2]				
First Four-Band				
Band 1	8-12	1-7	Good	Fair
Band 2	9-13	1-8		to
Band 3	19-28	1-18		Good
Band 4	10-14	1-9		
Band Cosine[3]	-----	-----	Poor	Poor
Band Ratio	1.089	1.222	Fair	Fair
Band Sum	21-33	1-20	Fair	Fair
Second Four-Band				
Band 1	9-13	1-9	Excellent	Good
Band 2	9-14	1-8		to
Band 3	21-28	1-20		Excellent
Band 4	11-14	1-10		

[1]The reflectance levels of spruce-fir and shadow using manual techniques are rated from a Kodak 10-step gray scale wedge.

[2]The reflectance levels of spruce-fir and shadow using computer techniques are rated by the IMPAC software system and represent the kilowatts per cubic centimeter per steradian (Kw/cm^3/steradian) of each pixel.

[3]No reflectance levels were recorded for the band cosine transformation.

CHAPTER IV

CONCLUSIONS AND RECOMMENDATIONS

Previous applications of digital computer aided analysis of Landsat scenes of mountainous terrain are limited. The incorporation of field studies for signature analysis of cover characteristics can be extremely difficult in mountainous, inaccessible terrain. Most work, therefore, has been restricted to areas of minimal topographic relief, although studies are clearly needed in mountainous areas, where much of the world's resources lie.

Emphasis has been placed on classifying and explaining the presence of unique dark-toned spectral signatures on Landsat MSS band 7 near-infrared imagery of the Great Smoky Mountains National Park. In accomplishing this task, however, it was necessary to develop and test analysis techniques and computer transformations that should prove useful for effectively processing satellite MSS data for other mountainous areas. Geographic data pertaining to the study area had to be developed to enhance and defend the classification. These data included topographic characteristics, Keplerian rhythms, vegetation cover characteristics, and phenological shifts, all believed to be factors affecting reflectance level variations in the higher elevations of the Park.

By using maps provided by other studies, it became increasingly evident that the distinctive dark-toned pattern in question was partially created by the reflectance of the red spruce and Fraser fir communities thriving in the higher elevations of the Great Smoky Mountains. Spruce-fir boundaries delimited by other researchers compared closely with those established from visual interpretations of Landsat 1:250,000 scale scenes in this study.

Computer-aided analysis indicated that the reflectance levels from selected training pixels could be utilized in a supervised classification by subjecting the data values to certain statistical transformations. The transformations were utilized for numerous reasons: (1) to enhance data in visually obscured areas, (2) to attempt to normalize shadow zones, and (3) to classify all spruce-fir areas in field studied test sites.

Shadows proved the most troublesome factor in the classification of spruce-fir areas. It can be concluded that unless proper statistical programs such as Digital Terrain Model Tapes (DTMT's) are available, data below or inside a shadow zone cannot be effectively analyzed or classified. Shadows, therefore, impose a large roadblock to the analysis of vegetation cover characteristics in areas where they are persistent and extensive, as in mountainous regions.

The four-band transformation is the best transformation available with the IMPAC system for Landsat reflectance classification. With easily definable and locatable training pixels, a correct assessment of cover characteristics and object identification can be readily accomplished.

This research effort has attempted to illustrate the usefulness of a two-method analysis of Landsat MSS data. While manual techniques seem antiquated for exacting requirements, they are still an integral part of any remote sensing study. Computer-assisted techniques should not be overlooked in any research effort where accurate and specific mapping or data results are needed. The two methods combined will produce accurate classifications if applied properly.

Extensions of this study to other regions, particularly in the Appalachians, could provide the data necessary to formulate models that would predict cover characteristics in mountainous inaccessible regions based on reflectance characteristics of vegetation and terrain. Complete analysis of the remaining sections of the Great Smoky Mountains National Park might provide sufficient data to map all the red spruce and Fraser fir areas, although the need for careful field work will still be essential.

Possibly, by combining comparatively scaled Landsat MSS scenes and RB57-F or U-2 infrared scenes, a total spruce-fir cover map could be developed. If MSS data are utilized for sun-oriented slopes, and RB57-F or U-2 data are utilized from the north and northwest-facing slopes, their combination, with the aid of computer analysis, could yield accurate cover type maps for the Great Smoky Mountains. If other computer-adaptable data were available, such as Digital Terrain Model Tapes (DTMT's), slope data, and elevation data, it might be possible to develop models to predict such unique vegetation types as red spruce and Fraser fir in inaccessible areas.

This study suggests that the distinctive dark signature patterns found on Landsat MSS data of the Great Smoky Mountains National Park represent the spruce-fir forests and mountain shadows, and that the best means for analyzing Landsat data is to employ manual and computer techniques in conjunction.

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While at Carroll College he worked for numerous agencies, including the Southeastern Wisconsin Regional Planning Commission and the Milwaukee County Planning Commission. He was also employed as the college cartographer and department teaching assistant and laboratory assistant for cartography. He worked as Production Manager for the Seeger Map Company of Racine, Wisconsin, from October to June 1978. During summer periods he was employed by the Santa Fe Railroad Company, and later, AMTRAK.

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