MONITORING FOREST CANOPY ALTERATION AROUND THE WORLD WITH DIGITAL ANALYSIS OF LANDSAT IMAGERY

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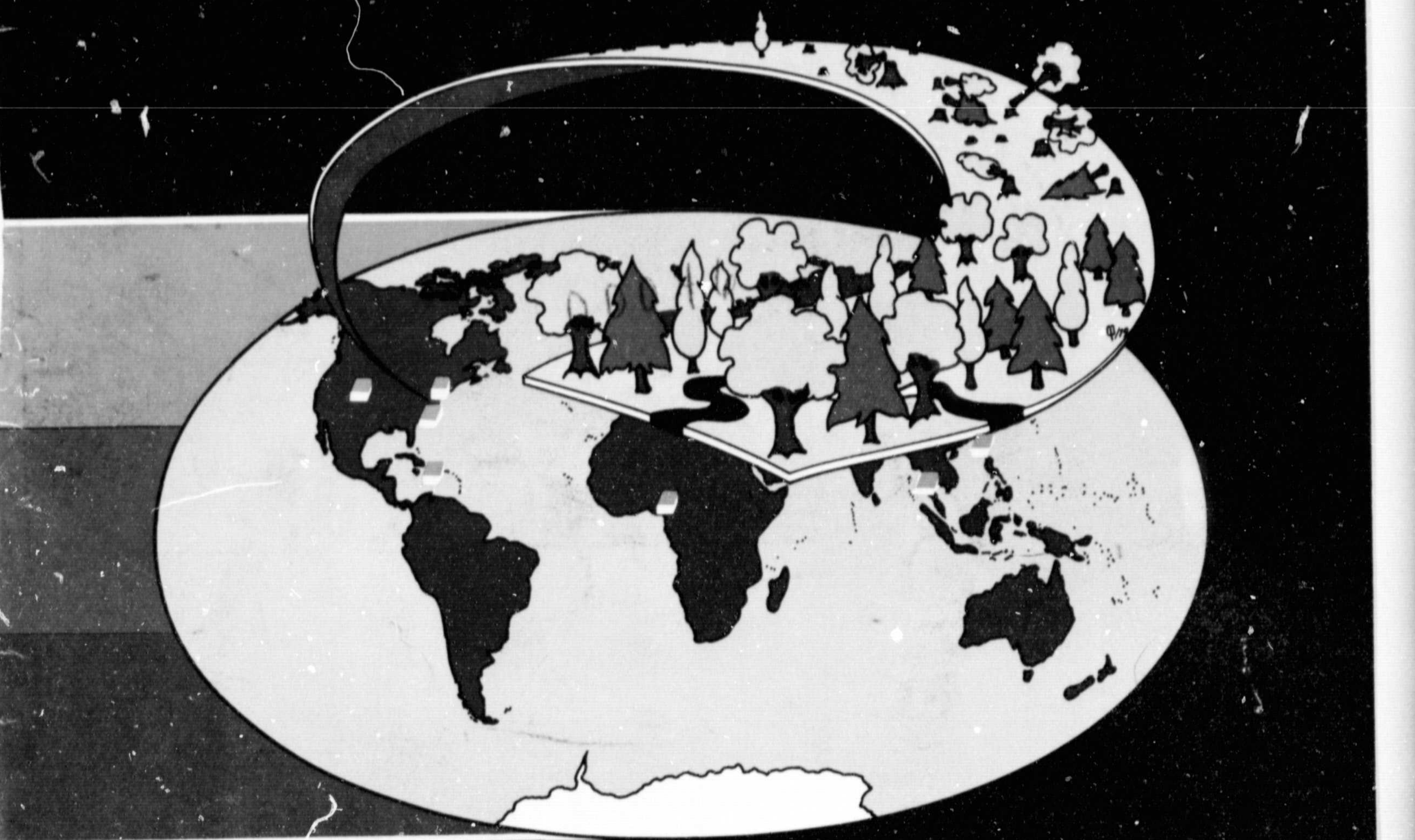

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Monitoring Forest Canopy Alteration Around the World With Digital Analysis of Landsat Imagery

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Abstract

Sufficient experience has gradually been accumulated to indicate that the greatest potential for the sustained applications of Landsat-type imagery by the forestry profession is the monitoring of areas where forest cover is subject to alteration by either natural or manmade activities. Preliminary tests of the hypothesis that forest canopy alteration can be readily monitored with digital processing of Landsat MSS data have been completed. A collection of the results achieved by several small, individual research efforts involving forest sites from around the world are presented to illustrate the types of forest canopy monitoring which can be undertaken, the approaches available, and the potential results which can be achieved. All of these case studies deal with digital analysis of Landsat imagery, but they vary considerably in complexity and types of analysis procedures employed. The specific types of forest alterations addressed include:

- Land Use Alterations of the Forested Watersheds of the Republic of China
- Forest Exploitation in the Central Nigerian Forest Reserves
- Forest Exploitation Along the Haiti and Dominican Republic Border
- Canopy Closure in the Pine Forests of North Carolina
- Forest Insect Defoliation in Pennsylvania
- Forest Site Index Mapping in North Central Colorado
- Shifting Cultivation in the Forests of Northern Thailand.

MONITORING FOREST CANOPY ALTERATION AROUND THE WORLD WITH DIGITAL ANALYSIS OF LANDSAT IMAGERY

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OVERVIEW

A substantial portion of the reported applications of satellite remote sensing to forest ecosystems has dealt with attempts to identify tree species or forest types.[1] Sufficient experience has gradually been accumulated to indicate that this may not be the most important application of the Landsat-type satellites by the forestry profession. The normal progression of events in the application of remote sensing to each new topic area has generally been "to detect," then "to identify" and finally "to monitor." Usually the supportive research activity has progressed from one plateau to another in this chain, often spending several years at each level. Remote sensing research on the applications of satellite imagery to forestry has just reached the third plateau (i.e., "to monitor") and it promises to be the most fruitful.

Successional changes in fo· st land cover generally take 20 to 50 years or more. Airphotos and their interpretation have proven quite successful for forest tree species and type inventories, especially with the recent increased use of color photographic materials. Since ecological succession from one forest type to another forest type occurs over long time-frames of tens of years, the existing airphoto-based forest cover type mapping and inventory programs will continue to be "appropriate technology." It seems unreasonable to assume that a viable, economically justified program for the remote sensing of forest lands from space could be built around making these measurements

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*A portion of the work reported upon was completed while serving as a Senior Post-doctoral Research Associate of the National Research Council assigned to the Earth Resources Branch at the National Aeronautics and Space Administration's (NASA) Goddard Space Flight Center.

[1]Mead, R. A., and Meyer, M. P., 1977. Landsat digital data application to forest vegetation and land-use classification in Minnesota. Proc. of the 1977 Machine Processing of Remotely Sensed Data Symposium, IEEE Cat. No. 77CH1218-7 MPRSD. LARS, Purdue, Indiana. pp. 270-279.

at frequencies of once every five or ten years, regardless of how easy or economical it might currently be to obtain satellite imagery in comparison to airphotos. This is not to imply that measurements of forest cover type should not or will not be made from satellite images. However, should that objective be retained as the primary focus of research, the forestry profession may have to continue to depend upon imagery from satellite sensors optimized and designed for other prime purposes.

The greatest potential for the sustained application of space systems in the forest management process is the monitoring of areas where forest cover is subjected to alteration by either natural or man-made activities. These alterations are widely varied in their nature and causes, ranging from shifting cultivation, tropical forest exploitation, insect infestations, natural canopy closure, and many others. However, the majority result in a significant alteration in the standing crop of leaf biomass present per unit area. Extensive research dealing with the grassland ecosystem [2,3] has already clearly shown that the alteration of the amount of leaf material per unit area is much more readily measured in the visible and photoinfrared spectral regions currently available on spacecraft, than are the subtle variations in spectroreflectance due to variations in species composition in that ecosystem. Certainly the division of the forested areas of the world into the two "big" ecosystem classes consisting of areas dominated by needle or broadleaf types can readily be made using Landsat satellite imagery. However, within these two subdivisions, the determination of the status of the forest canopy based upon variations in leaf biomass per unit area provides a much more viable alternative. It provides a much clearer justification for a forestry remote sensing program from space platforms than to continue looking for the subtle variation in spectroreflectance needed to further subdivide the forest ecosystem into more specific cover types or species classes. The improved management of the forest canopy which would result from using such information will certainly require yearly imagery, if not imagery at several key seasonal points during the year. Clearly, this requirement and associated techniques would provide a much more viable basis for justifying a space program dealing with forestry applications.

Preliminary tests of the hypothesis that forest canopy alteration can be readily monitored with digital processing of Landsat-type imagery have been completed. No large quasi-operational program is yet underway, but this collection of small, individual research efforts will be presented to illustrate the results achieved to date in a variety of geographic settings around the world. All of the summaries which follow deal with digital analysis of the Landsat imagery, but these examples vary considerably in their complexity and the analysis procedures employed. Therefore, it is felt that as a group they serve as examples of the types of forest canopy monitoring which can be undertaken, the approaches available, and the potential results which can be achieved. Each of the summaries that follows has been deliberately briefed to conserve space. However, references to detailed reports on each topic are provided and are readily available from the respective researchers whose names and addresses are included for this purpose.

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[2] Pearson, R. L., and Miller, L. D., 1972. Remote mapping of standing crop biomass for estimation of the productivity of the shortgrass prairie, Pawnee National Grasslands, Colorado. Proc. for the 8th International Symposium on Remote Sensing of Environment, Univ. of Michigan, Ann Arbor. pp. 1357-1381.

[3] Tucker, C. J., 1978. Hand-held radiometer studies of vegetation in situ: a new and promising approach. Proc. of the International Symposium on Remote Sensing for Observation and Inventory of Earth Resources and the Endangered Environment, International Society of Photogrammetry and the International Union of Forestry Research Organization, Freiburg, Germany. 6 p.

LAND USE ALTERATIONS OF THE FORESTED WATERSHEDS OF THE REPUBLIC OF CHINA

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BACKGROUND AND OBJECTIVE OF THE TEST

The island of Taiwan is 394 kilometers long by 144 kilometers wide at its widest point. Its total area of 35,961 square kilometers is very closely equal to that of one Landsat frame. Approximately one-half of this area is rugged, mountainous terrain with 62 peaks which rise abruptly from sea level to over 3,000 meters along its eastern margin. Mean annual precipitation in these mountains range from one to two meters due to the continual orographic uplift process at work on the moisture laden tropical atmosphere. This combination of abrupt mountainous terrain and torrential rains has given rise to several major river systems which headwater in the mountains along the eastern edge of the island and flow westward across its narrower dimension. These rivers currently fluctuate significantly in flow but their unit hydrographs are moderated by extensive tree cover on the very steep upland slopes.

The steep nature of these upland areas has preserved them from extensive development until recently. Unfortunately, population pressure has now grown to the point where, when coupled with certain ex-official policies, extensive upland forest clearing is taking place which converts the forested slopes into orchards and other truck crops which grow well in the cooler, high altitude climates. Serious landsliding frequently occurs in areas where the forest cover has been removed. These same watersheds have significant hydroelectric potential if sedimentation processes can be controlled, and at one location a major high arch dam is nearing completion.

It is clear to resource managers in Taiwan that they are headed toward watershed disaster if the present course of events is continued. Military restrictions on the collection of airphotos and maps, especially for use in field checking, have limited the clear, objective monitoring of the extent and development of this problem. Gradual progress is being made toward the alteration of these policies, but even if airphotos were now readily available and freely used, their application would be hard pressed to keep up with the dynamic nature of the alteration of critical watershed forest cover.

The objective of this test was to determine if the digital analysis of Landsat imagery would provide a mechanism for continual monitoring of the status of forest cover on these upland watersheds. Because of the coarser resolution of the Landsat imagery relative to low altitude airphotos, it has been certified as unclassified and placed in the public domain by the military of the Republic of China. Thus, success in the fulfillment of the stated objective might provide the basis for both a politically and technically practical monitoring system.

The original analysis efforts reported on this topic were supported by an agency of the Government of the Republic of China and by Colorado State University. The interpretation of the forest alteration process and its significance as outlined above are those of the first author.

STUDY SITE

The results described here are a reinterpretation of the results of a test application of the digital analysis of Landsat imagery for mapping the general land cover of the entire island of Taiwan at a scale of 1:25,000. Two Landsat frames from the same orbit path cover about 95% of the land area of the island. These frames have been designated as path 126 and rows 43 and 44, and only one clear set of imagery has been collected to date. This coverage occurred on 1 November 1972, and the imagery collected at that time were utilized in this analysis. The site employed for this study is located on the western side of central Taiwan in the northernmost image and represents 2,100 square kilometers, or about 6% of the total island area. The study site represents three of the 67 China Map Service 1:50,000 scale topographic maps of Taiwan. It begins on the west coast of the island at the Taiwan Strait and extends eastward through the coastal plains and terrace table lands of the Taichung Basin and into the steep foothills of the central, north/south-oriented mountain range. The area was selected because it contains a complete sampling of the types of land use practiced in Taiwan. Those portions of the study area containing upland and mountainous terrain are generally forested, but some initial clearing is underway. Thus, the simultaneous comparison of the location of the agricultural land cover classes relative to forested cover and terrain roughness will provide a preliminary insight into the utility of the Landsat imagery for monitoring forest canopy conversion to agricultural lands.

APPROACH AND RESULTS

The three 1:50,000 topographic maps of the test area were photographically enlarged to transparent overlays of precisely 1:25,000. Using an affine transformation, the digital imagery of these three areas was extracted, rectified, and displayed to match the transparent map overlays. Extensive experimentation was next undertaken to optimize both the classifications sought and the optimal spectral bands to be employed. The classification scheme was subsequently reduced to 17 cover types consisting of 2 urban, 5 agricultural, 3 forest, 3 barren land themes and 4 water depth/sediment classes (figure 1.1). The training data for these tests and the subsequent classification runs were interpreted in Taiwan from airphotos. Since only one set of Landsat imagery was available for the island, the classification and spectral band optimization were restricted to the 4 MSS bands and their 6 ratios. The optimizations performed established that for the 17 land cover classes sought, a two-spectral space classification employing MSS bands 5 and 7 would be the most effective when using a maximum likelihood classification algorithm. These classifications were verified by the air photointerpretation of the land cover for a 3 by 3 array of 9 Landsat cells taken at grid intersections of every 30 rows and 30 columns in each map (figure 1.2). Close agreement can be found in the comparison of the areal extent of agricultural and forested land cover in the classification maps and the estimates from the airphoto grid sample (figure 1.3).

The upland or mountainous terrain can be readily observed on the easternmost classification map (figure 1.1c), which also portrays the encroachment of agricultural land uses into areas of forested land cover on steep slopes. The pending completion of a Landsat ground station in Japan and the possibility of a direct global satellite relay link between Landsat and NASA will provide the opportunity for at least yearly image coverage of Taiwan. Thus, a practical program for continual monitoring of forest watershed dehabilitation or reclamation appears feasible.

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Experimenters

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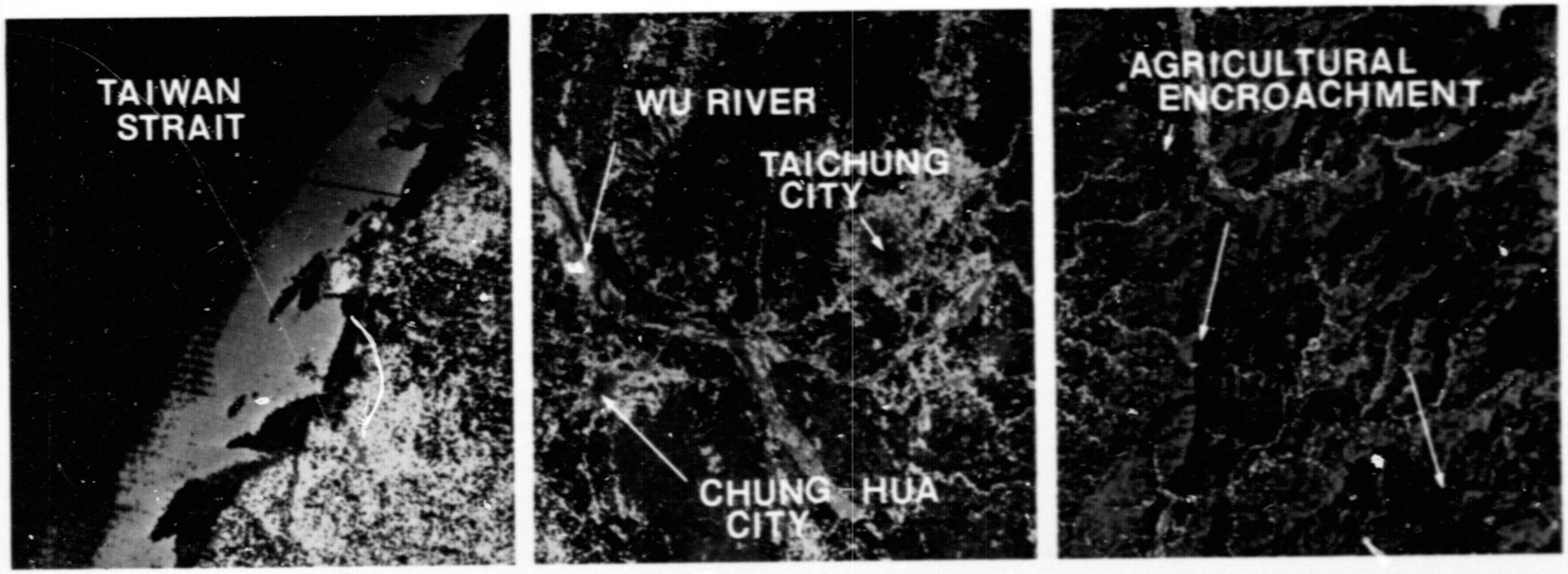
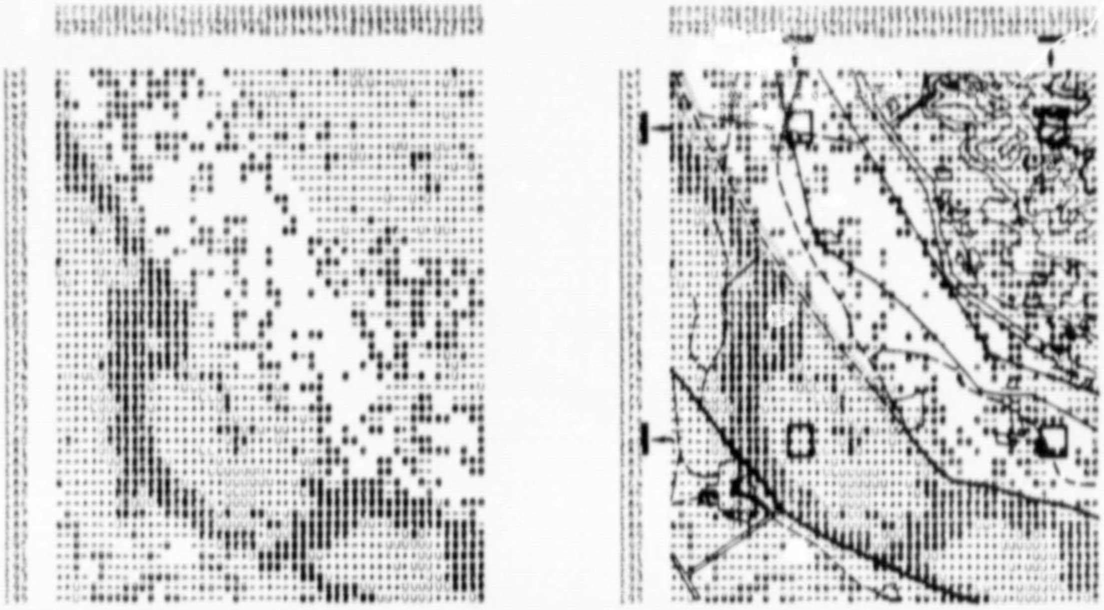


(a) Lu-Kang map (b) Taichung map (c) Kuo-Hsing map

Figure 1.1. Land cover classification maps of Taiwan illustrating land use alteration of forested watersheds. Seventeen land cover classes were extracted by stepwise discriminant analysis from the 1 November 1972 Landsat image using MSS spectral bands 5 and 7 for the areas of 3 of the China Map Service 1:50,000 scale topographic maps. The Kuo-Hsing or right classification map clearly portrays the agricultural classes (yellows, gray and dark brown) which are rapidly replacing the forest cover (three shades of green) on the steeper mountainous slopes.



(a) MSS band 7 (b) MSS band 7 with contours overlaid

Figure 1.2. A symbol map of a small segment of Landsat MSS band 7 with registered contour lines and airphoto verification arrays. Transparent overlays of 1:50,000 scale maps enlarged to 1:25,000 were registered upon geometrically rectified Landsat displays. Rectangles show how the arrays of 3 by 3 cells were specified for airphoto identification by in-country photointerpreters for training and verification purposes.

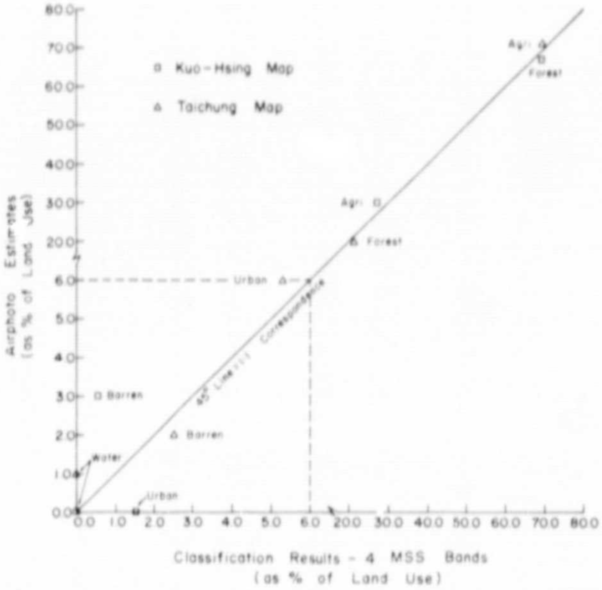


Figure 1.3. Comparison of the relative amounts of the major types of land cover as obtained by air photo sampling and Landsat classification. Note the similarity of the amount of each major land use as estimated from the detailed interpretation of airphotos (vertical axis) and summed from the classification maps portrayed in figure 1 (horizontal axis).

FOREST EXPLOITATION IN THE CENTRAL NIGERIAN FOREST RESERVES

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BACKGROUND AND OBJECTIVE OF THE TEST

Extensive areas of the African equatorial forests are being rapidly cleared of forest cover to provide merchantable lumber and pulpwood. The economic drive to harvest such areas is so great that a major portion of the virgin tropical forests of Nigeria have been harvested. Often the harvesting is an iterative process consisting of individually locating and cutting the premium wood, such as mahogany, on a tree-by-tree basis; next the valuable sawtimber is sought and taken; and finally the area is clearcut for pulpwood. Current forest management practices and environmental characteristics are such that the extensive cleared areas do not readily regrow as forest cover, but either as a persistent brushland of low potential value or as subsistence level agricultural lands.

The need to preserve islands of natural first growth forest to act as seed, gene, and wildlife reserves prompted the Nigerian Government to establish a widespread network of approximately one hundred forest reserves under the control of a National Forest Service. Unfortunately this organization is new and small and the forest reserves so widely distributed that they cannot be maintained under close observation. Thus, illegal cutting and exploitation of the national forest reserves takes place. Generally the cloud cover over these areas is so persistent that it has not been possible to collect periodic airphotos for surveillance purposes. It has proven very expensive to have a contract aircraft standby waiting for that one clear day over a given area, whereas systematic attempts to collect satellite imagery would probably result in at least one usable image per year for maintaining such surveillance. The objective of this small test effort was to determine if the analysis of available Landsat imagery could be used to provide a mechanism for detecting and monitoring the physical boundary and internal forest cover of these forest reserves. The original analysis efforts reported here on this topic were supported by the United Nations/FAO Forestry Division, Rome. Subsequently, the digital analysis was repeated at NASA/GSFC to provide geometrically rectified imagery and color display products. However, the interpretations of the exploitation process noted above are purely those of the authors.

STUDY SITE

The general area of this test application consists of approximately one-fifth of the Landsat frame whose location is designated as path 204, row 55. The total frame is just east of Lagos and Ibadan and just touches the Gulf of Guinea and the Bight of Benin on its southern boundary. Only one frame of usable Landsat-1 imagery has been collected to date and it was imaged on 7 November 1972.* An inventory of high plains forest resources being conducted by FAO in the general area encompassed by this Landsat frame was initially thought to be available to provide ground control. Unfortunately two-thirds of the frame was covered with clouds and was unusable, thereby negating the possible correlation of the Landsat-derived information with the existing field data. A cloud-free study area representing approximately 7,000 square kilometers was selected in the northern portion of the image. This area had been totally cut over except for six forest reserves ranging from approximately 50 to 100 square kilometers each. These reserves had been established for 5 to 10 years at the time of imaging and had well defined legal boundaries. Thus, close examination of the reserves with special attention to their boundaries provided an easy test of the utility of Landsat digital image classification procedures for monitoring forest exploitation.

APPROACH AND RESULTS

Due to the presence of heavy cloud cover in the lower two-thirds of the 7 November 1972 Landsat image, the standard black and white and color composite prints of the cloud-free, upper portion of the image were overexposed and of little value for direct interpretation. However, after the digital data for the study area were extracted and nominally rectified using a simple affine transformation, a contrast stretch algorithm was applied to each MSS band and the false color composite rendition of the subimages was markedly easier to interpret (figure 2.1). The individual forest reserves could be delineated, as well as inconsistencies in the forest cover conditions within each reserve.

The areas of three specific forest reserves were selected from within the 7,000 square kilometer subimage: the Oni (approximately 100 sq. km), the Ikeji (approximately 60 sq. km), and the Ogbesse (approximately 80 sq. km). Supervised classification maps of these subareas were produced using a simple parallelepiped algorithm and the GE Image 100 system at NASA/GSFC. Five general land cover classes were mapped consisting of areas of virgin forest, permanent agriculture, villages, and two types of cutover brushlands (figures 2.1c, 2.2, and 2.3).

The image employed in this digital classification was one of the very early Landsat-1 frames collected when the MSS instrument was being "shaken down" and thus significant detector stripping occurs in the image and the resulting classification maps. While unfortunate, the presence of this stripping does not deter from the conclusion that significant forest exploitation was occurring and could be mapped by digital analysis of the Landsat image in two of the three forests examined. Significant encroachment had been made by permanent agriculture into the Ogbesse Forest Reserve

*Only a few attempts have been made to date to collect imagery of this frame as it did not contain any official NASA experiment and was not within range of any ground tracking station.

(figure 2.2). At the time of the image collection, about one-fourth of the western edge of this reserve had been cutover and replaced by permanent agriculture. Examination of a geologic map of the area indicates that the general area mapped into this agricultural class coincides with the area of a specific geologic unit. This unit undoubtedly has yielded a favorable soil type and is therefore being followed into the forest reserve regardless of the politically drawn boundary. The classification map of the Oni and Ikeji forests shows that the general area of their setting is not under permanent agriculture, but consists of low value brushland (figure 2.3). The southeastern corner of the Oni Forest Reserve is showing significant forest clearing and replacement by this brushland type. Direct field inspection of this area confirmed that clearcutting of the reserve was taking place by fully mechanized crews with logging trucks, etc.

At the present time the limited opportunities for the collection of Landsat imagery of this area has substantially restricted the image resources available for routinely monitoring forest exploitation. The installation of a Landsat ground station in Zaire will markedly increase the opportunity for yearly image coverage of all the forest reserves of Nigeria. Thus, a practical program for continual monitoring of the harvesting of the remaining forest reserves appears to be feasible.

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Experimenters

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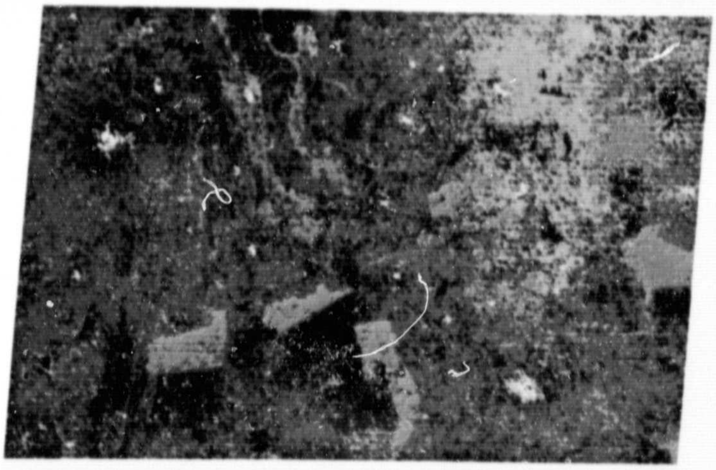
(a) portion of original Landsat color composite

Figure 2.1. Comparison of Landsat color products of the Nigerian forest reserves. The area illustrated is about 1/6 of the 7 November 1972 Landsat image. Due to the extensive cloud cover in the balance of the frame not shown here, the original color IR composite product (a) is of low color contrast. The color IR contrast stretched image (b) was computed from the digital image tapes and provides a significantly improved image. The 5-theme classification map (c) was extracted from the 4 MSS spectral bands by a simple parallelepiped classifier.

(b) contrast stretched version of subimage



(c) classification theme map

RED = forests
YELLOW = villages
GREENS = brushland
TAN = permanent agriculture

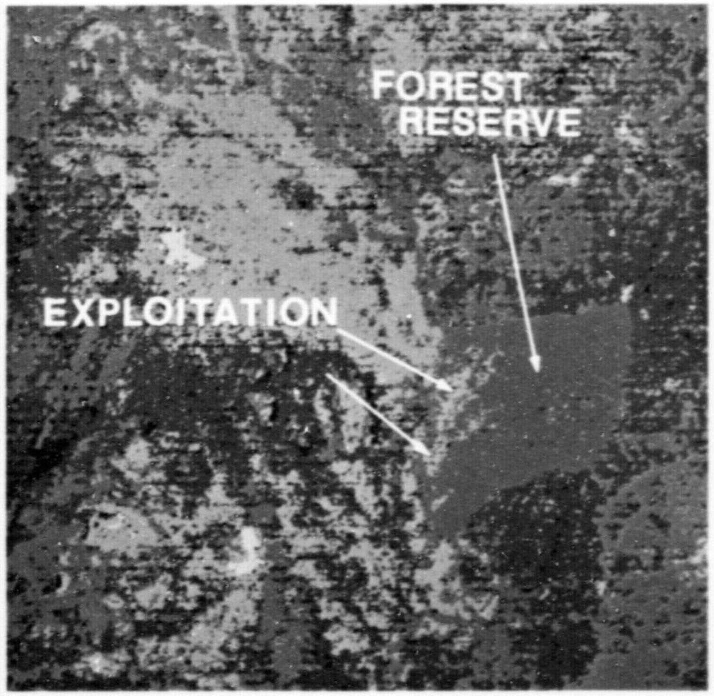


Figure 2.2. Classification map showing exploitation of the Ogbesse forest reserve of Nigeria. Five land cover classes were extracted by a simple parallelepiped classifier using all 4 MSS spectral bands for a portion of the subimage shown in figure 2.1. Note how permanent agricultural cultivation has obliterated the left one-fourth of the forest reserve as it persistently follows a preferred soil type into the formal area of the reserve.

RED = forests
YELLOW = villages
GREENS = brushlands
TAN = permanent agriculture

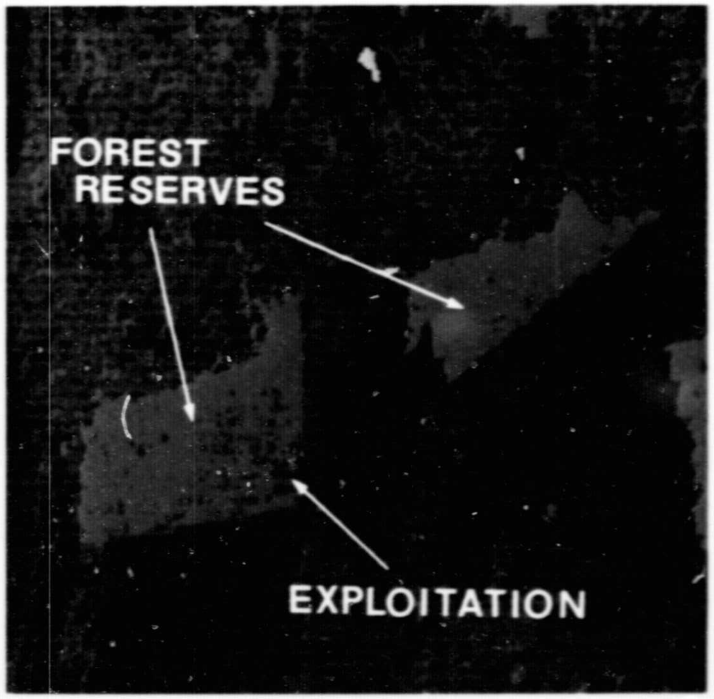


Figure 2.3. Classification map showing exploitation of the Oni (left) and Ikeji (right) forest reserves of Nigeria. Five land cover classes were extracted by a simple parallelepiped classifier using all 4 MSS spectral bands for a portion of the subimage shown in figure 2.1. Note how serious exploitation of the Oni Reserve by commercial cutting is encroaching along the lower portion of its eastern boundary.

RED = forests
YELLOW = villages
GREENS = brushlands
TAN = permanent agriculture

FOREST EXPLOITATION ALONG THE HAITI AND DOMINICAN REPUBLIC BORDER

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BACKGROUND AND OBJECTIVE OF THE TEST

There has been considerable interest in utilizing Landsat digital imagery as a source of reliable, up-to-date information for conducting regional or national-scale land use assessments. The dollar and informational value of the Landsat imagery for this purpose is directly dependent upon the quality and availability of alternate data sources. Land use information extracted from Landsat imagery has the greatest potential value in those areas of the world where data describing various physical, economic and cultural characteristics is not currently available. This situation is particularly true in many of the lesser developing countries. Before these countries can initiate programs to stimulate their economic and cultural growth, accurate assessments of their current resources and land uses must be conducted on a national scale. Landsat imagery is the only potential up-to-date source of this information in many instances. Thus, as a test application, digital analyses of Landsat imagery for the delineation of current land use in two provinces of the Dominican Republic was conducted at NASA/GSFC in cooperation with the U.S. Agency for International Development (AID). The specific objectives of the NASA/GSFC study were: a) to perform digital analyses of Landsat data for two test sites within the Dominican Republic and derive land cover classification maps for each; b) to provide the classification results and ancillary data in a format compatible with a data base management system being developed by AID; and c) to apply various subsampling schemes to the Landsat digital data to assess how such sampling would affect the validity of subsequent land cover maps. A discussion of the analysis and results for one of the test sites, the Dajabon Province, is presented here relative to its value in detecting forest exploitation.

STUDY SITE

The Dominican Republic occupies the eastern part of the Caribbean Island of Hispaniola, covering an area of 48,279 km^2. Dajabon Province is located in the northwest corner of the Republic and its entire western perimeter forms part of the border with Haiti. The physiography, land use, and climate within the 2,000 km^2 province is quite varied. The northern section of the province is relatively flat and dry, quickly giving way to rolling hills dominated by mixed agricultural crops and pastureland. The southern portion of the province is dominated by steep, forest-covered mountains which rise to nearly 3,000 meters. The economy of the area is depressed and an ever increasing amount of the remaining forest land within the province is being cleared to plant agricultural crops and to provide charcoal for cooking and heating. This phenomenon has occurred in an even more accelerated fashion just across the border in neighboring Haiti, with the result that the Haitian mountain slopes are practically devoid of forest vegetation and are severely eroded.

APPROACH AND RESULTS

The distinct contrast in vegetative cover characteristics along the international border was apparent on Landsat imagery, especially on a geometrically rectified and contrast stretched subimage of the study area (figure 3.1a). This subimage was extracted from a relatively cloud-free 3 November 1973 Landsat image for the frame designated as path 8, row 47. These data were resampled to produce 67 by 67 meter cells which would readily interface the subsequent classification results with AID's data base management system. A euclidean distance algorithm was utilized to classify the resampled Landsat digital data using spectral signatures and associated statistics obtained via training areas and/or radiance cluster analysis. The validity of the preliminary classification scheme and map was assessed by the first author during a field trip in May of 1977. A detailed, statistical verification of the preliminary and subsequent final classification maps was virtually impossible due to the small-scale, heterogeneous nature of the land uses, coupled with the fact that nearly 3-1/2 years had elapsed since the November 1973 Landsat coverage. However, the delineation of broad land cover categories such as wetlands, agricultural areas, forests, brushlands, and barren areas, suitable for a national-scale assessment, was very good. A few discrepancies in the preliminary classification map were noted in the field and appropriate revisions in the training data were made. A final classification map representing the previously noted broad land cover categories was generated using a total of 17 spectral signatures, as several spectral signatures were needed to properly map some of the major land cover categories (figure 3.1b). The concentration of forested areas and brushlands in the south central portion of the province was readily apparent upon inspection of the final classification map. This corresponds to the increased topographic relief and the associated forest cover in the mountainous areas in the southern portion of the province. Non-forest land cover classification categories are scattered throughout the province and predominate on the Haitian side of the border, indicating the high level of forest exploitation which has occurred.

The final land cover classification map of the Dajabon Province, based on 67 by 67 meter cells, was summarized into 1 km by 1 km cells for input to AID's computer-based land management system. Each new 1 kilometer cell was an aggregation of the predominate classification categories within approximately 220 of the 67 meter cells. A 1 km^2 cell map depicting various percentages of forest canopy cover within the province was generated as a test output product (figure 3.1c). This type of aggregation reduces spatial noise and future processing costs, and more clearly illustrates the spatial distribution of the forest cover within the Dajabon Province.

Additional experiments were conducted to determine the effects of classification subsampling or aggregation techniques upon the validity of the resulting land cover maps. These sampling experiments indicated that at the province level, a sampling of as little as 1 or 2% of the classified Landsat cells would provide an adequate representation of land cover. This indicates that image sampling before classification may be feasible for reducing processing costs in monitoring large-scale forest alteration on a national or worldwide basis.

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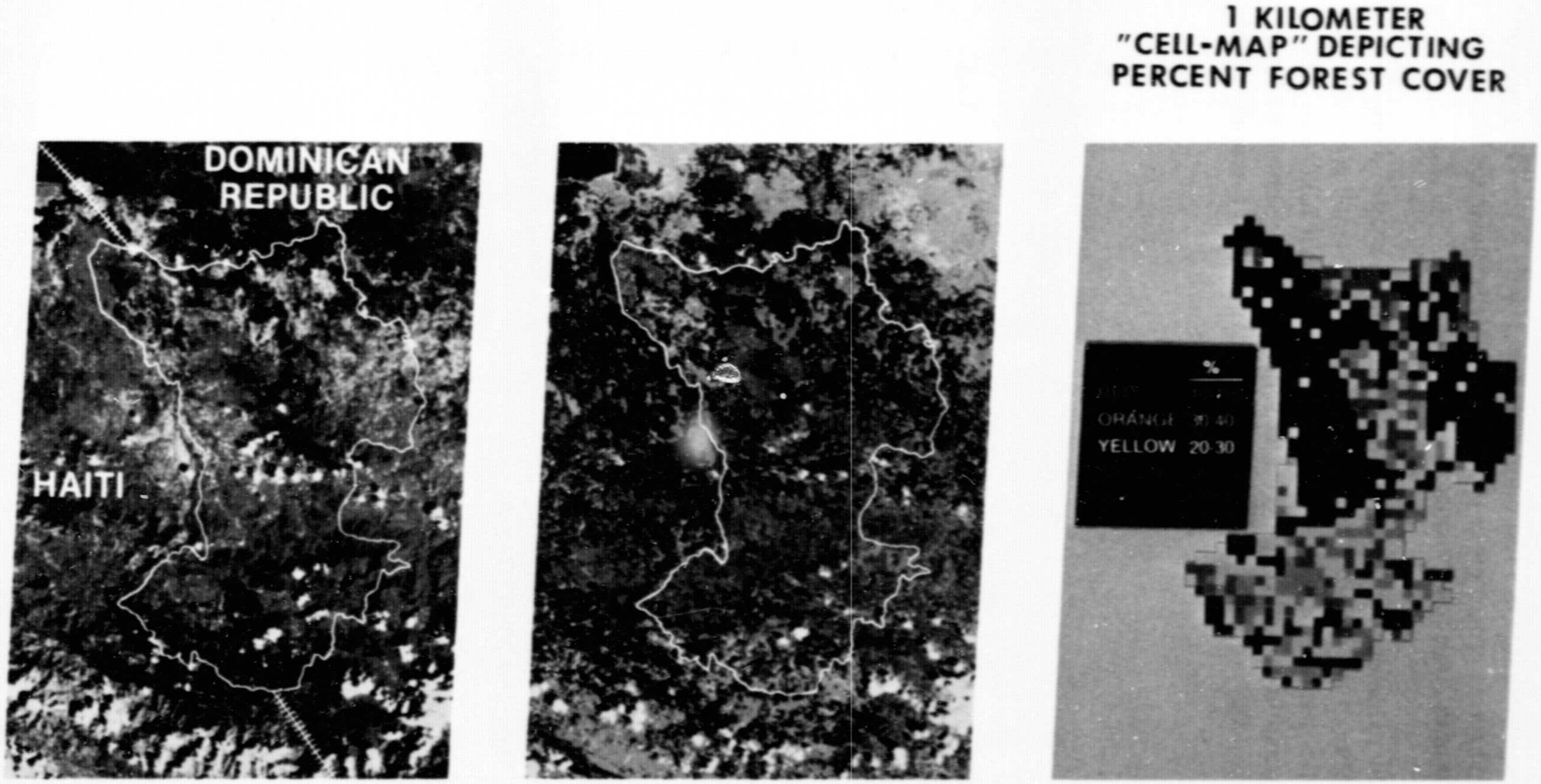

(a) contrast stretched color IR subimage (b) land cover classification map (c) aggregated land cover map

Figure 3.1. Illustration of the forest exploitation along the Haiti and Dominican Republic border. The left-hand display (a) is a simple, geometrically rectified and contrast stretched Landsat color IR subimage of the study area. The area enclosed by the solid white line demarks the Dajabon Province in the Dominican Republic. Haiti lies to the left of the Province. The center display (b) is a euclidean distance classification map which illustrates the areas of heavier forest cover in shades of red. The right display (c) portrays an aggregation of the 67 by 67 meter classification map in (b) to one square kilometer cells each of which represent approximately 220 resampled and classified Landsat cells. This aggregation was performed to reduce spatial noise and future processing costs in the data management system and to more clearly illustrate the amount of forest cover in the Dajabon Province of the Dominican Republic. Note the invasion of the colors representing light forest cover into the lower portion of (c). This area is dominated by mountainous terrain with steep slopes which are very vulnerable to erosion, especially when cleared and cultivated for agricultural crops.

CANOPY CLOSURE IN THE PINE FORESTS OF NORTH CAROLINA

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BACKGROUND AND OBJECTIVE OF THE TEST

Commercial forest companies in the United States are faced with the challenge of producing more wood, over shorter periods of time, on a dwindling land base due to rapidly increasing demands for wood and wood fiber products. They are investing a considerable amount of manpower, time, and money in research to develop improved forest management practices to meet this challenge. This research has led to the adaptation and refinement of intensive management practices such as harvesting natural forest stands and replanting prepared sites with genetically superior seedlings. The result has been such that the "seedling to harvest" cycle in the Southern Pine Region of the United States has been reduced from approximately 45 years, to 20 or 25 years. Accurate monitoring of the growth status of these artificially regenerated stands is of prime importance to these companies due to the increased initial investments required by these intensive management practices. Conventional monitoring techniques, such as ground observations and low altitude aerial photography, can be costly and the results variable because of the time required to complete data collection over large areas. It was hypothesized that remote sensing techniques using imagery from Landsat-type satellites would provide an economical means of obtaining supplemental information regarding the status of the forest canopy as input to forest inventory systems. The Information Transfer Laboratory at NASA/GSFC participated in a cooperative project with Weyerhaeuser Company's North Carolina Region to investigate the applicability of Landsat digital analysis for this purpose.

STUDY SITE

A 24,300 hectare forest tract in North Carolina was chosen as the study site. This site falls within the Southern Pine Region, which is essentially co-extensive with the Atlantic Coastal Plain physiographic province. The most prominent vegetational feature of much of this region is evergreen trees growing on the rather low-lying, poorly drained soils. Intensive forest management has been practiced in this area for several years, resulting in a variety of forest cover conditions ranging from recent clearcuts, to various stages of growth following artificial regeneration of pine, and natural stands of both pine and hardwood. Approximately 305 kilometers of logging access roads dissect the site and this extensive road system was helpful for quickly and accurately identifying any given forest compartment within the tract (figure 4.1). Black and white, color, and color IR aerial photographic coverage was available for the site, as well as detailed maps and records showing stand age and species composition by compartment.

APPROACH AND RESULTS

Winter (26 February 1974) and summer (30 August 1973) Landsat-1 imagery of the study site, designated as path 15 and row 35, were analyzed individually and then geometrically registered and overlaid in order to take advantage of temporal changes in the forest canopy. Prior to the detailed digital classification of the imagery, a contrast stretched color IR composite image of the study area was generated using the 26 February 1974 Landsat data (figure 4.1a). Visual photointerpretation and delineation of stand conditions was generally found to be easier using this color composite image than interpreting a black and white aerial photograph taken approximately 20 days after the Landsat overpass (figure 4.1b). There is also a high degree of similarity in the spatial information contained in both types of imagery when they are reproduced at a common scale.

Computer image classification was accomplished using the standard analysis approach of rectifying the image, selecting training areas, obtaining spectral signatures and related statistics for these areas, and then classifying the study area using a euclidean distance algorithm. Classification of the 4 spectral bands of winter imagery proved the most useful for obtaining an accurate delineation of hardwood and pine forest canopies, while analysis of the 4 spectral bands of summer data resulted in the delineation of three different levels of pine canopy closure (i.e., closed, partial, and open canopy). This appraisal of crown closure allows a relative assessment of average tree size where regular tree spacings occur due to artificial regeneration practices. The periodic combination of this type of information with existing inventory records would provide observations of closure advancement over time, allowing forest managers to draw conclusions regarding the growth rate and quality of forest stands.

In the final stage of analysis, an 8 spectral band multitemporal classification was performed and it resulted in the best overall classification results (figure 4.2). The winter data contributed to the accurate delineation of hardwood and pine stands and the summer data simultaneously contributed to the delineation of pine subcategories based upon the degree of crown closure. Forest tracts that were clearcut during the six-month interval between the two Landsat overpasses were also easily delineated as they had a rather unique 8 band spectral signature due to the presence of a lush forest canopy in August and the absence of a vegetational canopy in February.

The accuracy of the final, 8 band multitemporal classification map was verified by randomly sampling 232 classified picture elements and individually comparing them to the corresponding area on a forest cover-type map generated via an independent photointerpretation of 1:36,000 scale color IR stereo photos. The results of these comparisons show a 94% agreement for hardwood, a 96% agreement for the four combined pine categories, and a 54% agreement for clearcuts, for an overall agreement of 90%. The relatively poor agreement for clearcuts was a result of using photos which were 18 to 24 months out of phase with the date of acquisition of the Landsat imagery. For example, recent clearcut areas that had been replanted with seedlings were distinguishable on the high resolution photos and were therefore classified as regenerated by the photointerpreter, but they still appeared to be devoid of vegetation on the Landsat image.

These results indicate that intensive forest management practices on a large-scale basis can be monitored with the existing Landsat resolution and that forest managers can obtain useful information relative to the condition of the forest canopy to supplement that which is available via more conventional techniques.

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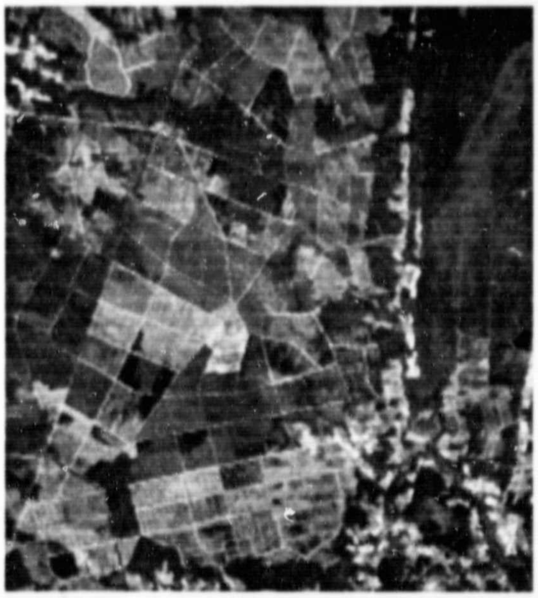
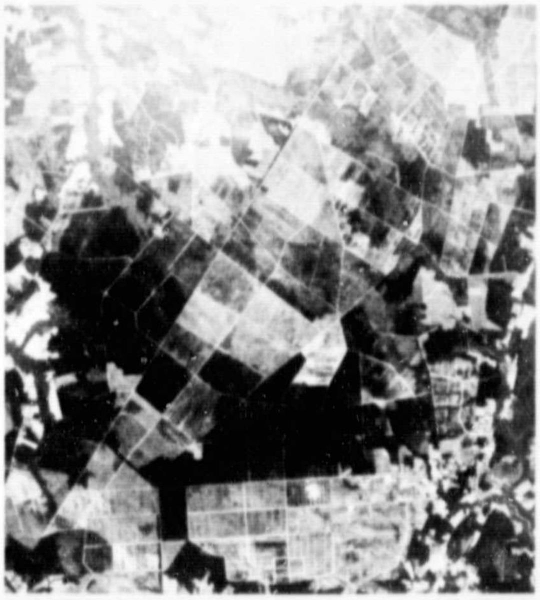
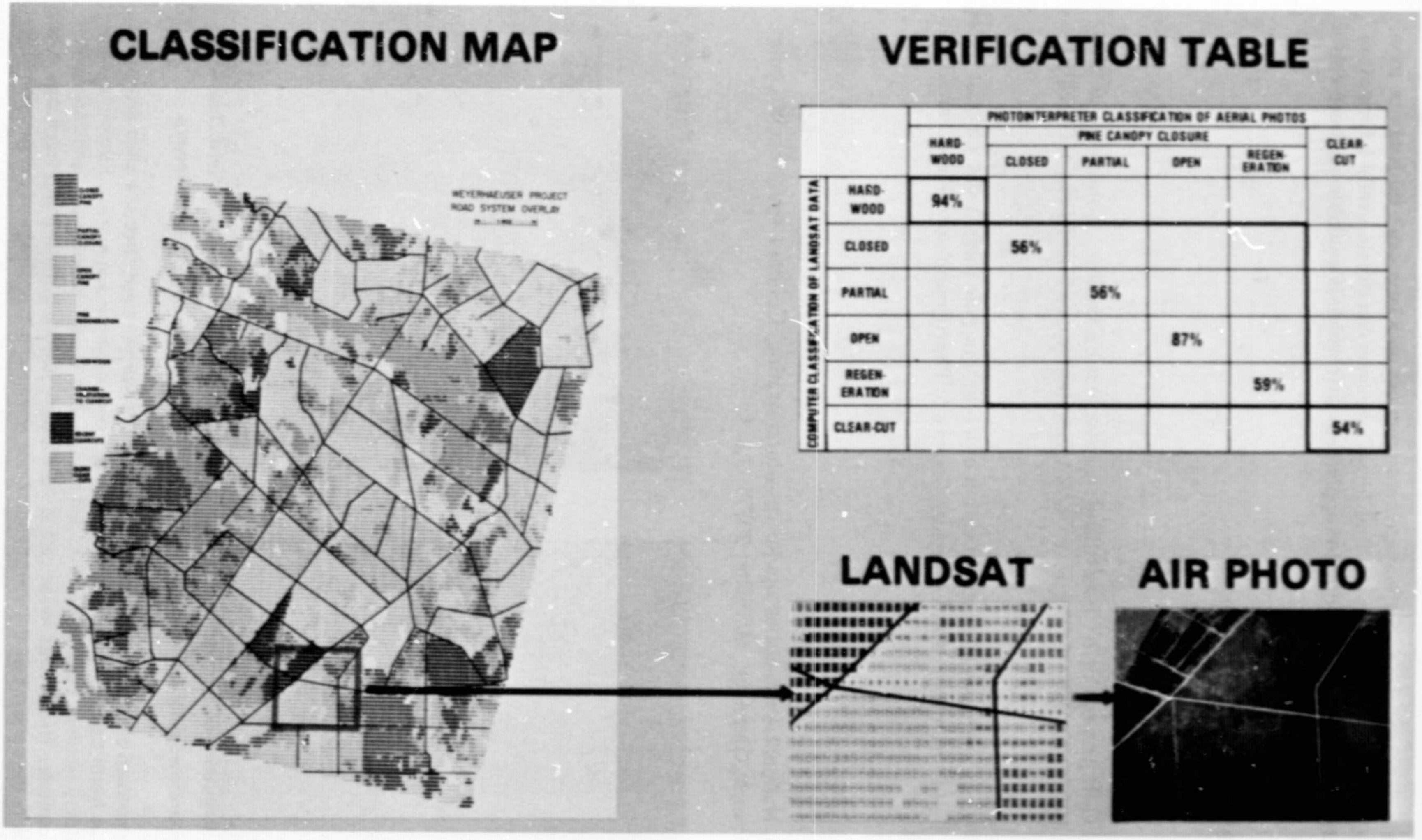


(a) contrast stretched color IR subimage



(b) black and white airphoto

Figure 4.1. Comparison of a Landsat contrast enhancement and a conventional black and white airphoto of a forest tract in North Carolina. The Landsat contrast stretched subimage was extracted from the digital tapes, geometrically rectified, contrast stretched and MSS bands 4, 5 and 7 superimposed and displayed on a digital film recorder. The Landsat image date is 26 February 1974 and the airphoto image date is 15 March 1974. Note the similarity of the spatial information contained in both images at this common scale.



COMPUTER CLASSIFICATION OF LANDSAT DATA	PHOTOINTERPRETER CLASSIFICATION OF AERIAL PHOTOS: HARD-WOOD	PINE CANOPY CLOSURE: CLOSED	PARTIAL	OPEN	REGEN-ERATION	CLEAR-CUT
HARD-WOOD	94%					
CLOSED		56%				
PARTIAL			56%			
OPEN				87%		
REGEN-ERATION					59%	
CLEAR-CUT						54%

Figure 4.2 Forest cover classification map and associated verification table. The classification map was derived from multitemporal Landsat imagery using a euclidean distance classifier. Eight spectral bands were employed consisting of the four MSS spectral bands from both the 30 August 1973 and the 26 February 1974 scenes. The verification table summarizes the results of a comparison between 232 *randomly sampled* pixels from the final classification map, with the corresponding area on high resolution, large scale color IR aerial photography. The relatively low percentage of agreement for the clearcut category was due to the aerial photos being acquired 18 months after Landsat overpass, and several acres of forest were harvested during this time period. The four pine sub-categories, as a group (i.e., total pine vs. hardwood), were identified with 96% accuracy.

FOREST INSECT DEFOLIATION IN PENNSYLVANIA

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BACKGROUND AND OBJECTIVE OF THE TEST

Several forest insect infestations have increased exponentially in recent years and are threatening the major forest regions of the United States. Epidemic forest insect populations often cause substantial economic losses by reducing annual incremental growth and increasing tree mortality as a result of feeding upon favored tree species. The responsible regulatory agencies must have accurate, timely, and efficient methods of detecting and mapping damage to the forest canopy in order to suppress these infestations and maintain them at endemic levels. These agencies have been keenly interested in using the repetitive and synoptic coverage provided by the Landsat satellites for monitoring widespread forest insect damage. A research effort has recently been initiated at NASA/GSFC in response to this need in order to develop and evaluate digital image processing techniques that will facilitate the assessment of the intensity and spatial distribution of forest insect damage using Landsat imagery.

STUDY SITE

Recent outbreaks of heavy gypsy moth defoliation in the forests of central and eastern Pennsylvania make this a particularly attractive study area for this test application of Landsat imagery. A 30 by 30 kilometer Landsat subimage extracted from the frame designated path 16, row 32 and containing Harrisburg, Pennsylvania is being utilized as a study site. This area is located in the Appalachian Ridge and Valley physiographic province. The ridges within the test site are heavily forested by mixed deciduous tree species with oaks (Quercus sp.) predominating, while the valleys are dominated by agricultural land uses. Landsat imagery of the area representing healthy forest stand conditions was obtained on 19 July 1976, while 27 June 1977 imagery of the same area depicts several thousand hectares of gypsy moth defoliation (figures 5.1a and 5.1b).

APPROACH AND RESULTS

Forest insects generally attack a particular tree species or species association which have a fairly well defined and documented geographic distribution. Thus, the delineation of tree species via Landsat multispectral signature extraction and classification is of minor importance for forest canopy damage detection. Development of techniques for monitoring insect defoliation has therefore been slanted towards isolating and assessing changes in the forest canopy due to fluctuations in the amount of leaf material per unit area.

Preliminary experimentation with the geometrically registered 1976 "non-defoliated" and 1977 "defoliated" Landsat subimages of the Harrisburg area has shown that accurate isolation of areas of defoliation is enhanced by subtracting the corresponding MSS bands of these "before" and "after" images to yield "difference" images (figure 5.2). The areas fluctuating from high to low leaf canopy biomass between 1976 and 1977 appear as significantly lighter shades of gray in the MSS band 4 and band 5 difference images and as substantially darker shades of gray in the MSS band 6 and band 7 difference images. Color composites created by superimposing 3 of the 4 possible "difference" images can depict the areas of change in unique color tones which are even easier to interpret than the individual black and white displays (figure 5.3) Unfortunately, leaf biomass changes in agricultural crops are similarly represented in the difference images and are therefore potential sources of commission errors. However, many Landsat investigators utilizing digital classification techniques have reported the ability to accurately delineate areas of "forest" from "non-forest" using Landsat imagery representative of healthy forest conditions. Therefore, a hybrid classifier combining parallelepiped and maximum-likelihood algorithms was used to classify the 1976 "non-defoliated" Landsat subimage into "forest" and "non-forest" categories (figure 5.4a). This forest cover classification map was used to create a binary mask of "1's" for forested areas and "0's" for non-forested areas. This binary mask was then applied cell by cell to the 1977 Landsat subimage of defoliated conditions in order to eliminate all non-forest cells (figure 5.4b). In simple mathematical terms, all 1977 pixel values multiplied by "0's" become zeros, while those cells multiplied by "1's" (i.e., forested areas) are unchanged in value and their measured radiances are still available for further analysis to determine the amount of change in forest canopy biomass (i.e., severity of defoliation). This masking approach eliminates the potential of errors of commission when delineating forest insect defoliation damage because all non-forest land areas have been removed from the data set.

Similar techniques could be utilized to isolate and monitor the various types of forest alteration discussed in the other sections in this report. The major advantage of this type of approach is that only the particular land use(s) of interest is maintained within the data set. Therefore, future processing costs are reduced as less image data remain to be analyzed. Also, as demonstrated, the potential of commission errors is often reduced or eliminated.

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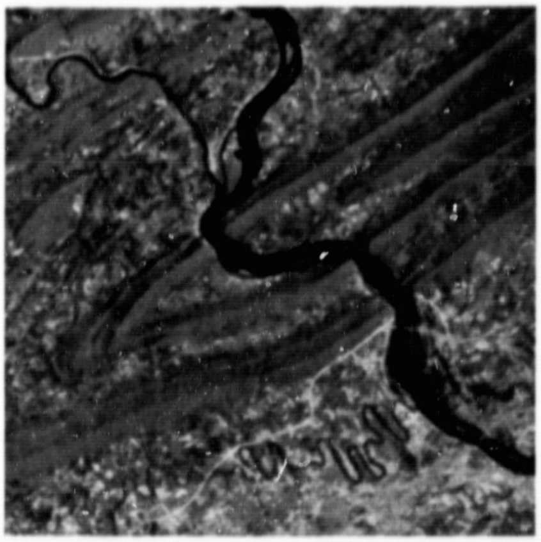


(a) 19 July 1976

(b) 27 June 1977

Figure 5.1. Landsat subimages of central Pennsylvania showing increase in gypsy moth defoliation between 1976 and 1977. These 30 by 30 kilometer Landsat subimages of the Harrisburg, Pennsylvania study site have been contrast stretched and geometrically registered to one another to provide a multitemporal data set of "non-defoliated" and "defoliated" forest canopy conditions. Note the heavily defoliated areas in (b) which occur along the forested ridges and appear to be "brownish" in color.

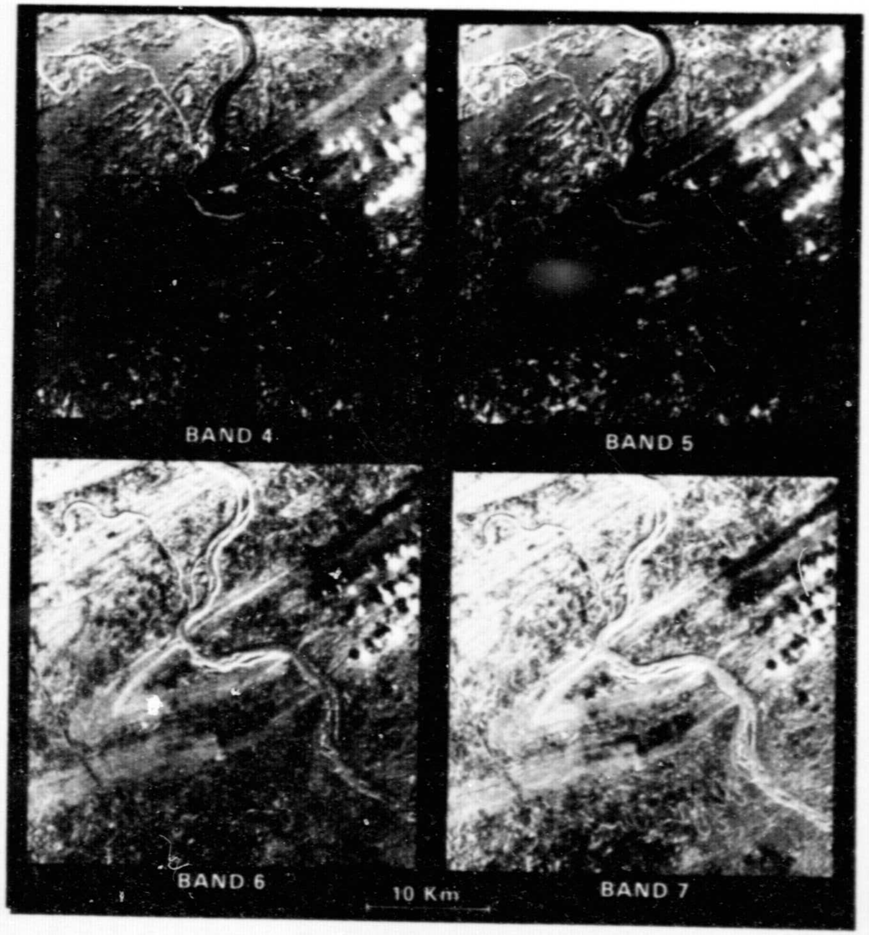
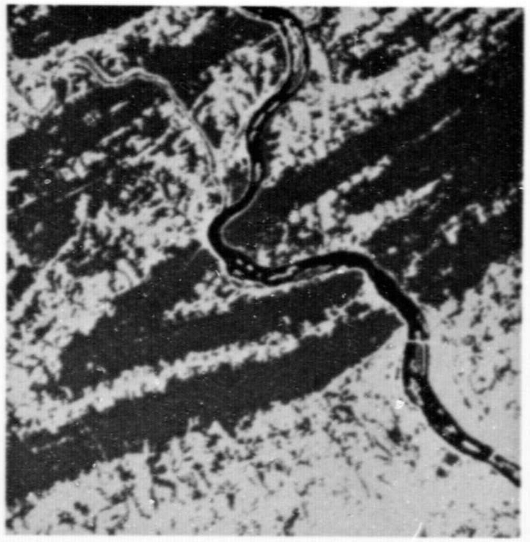
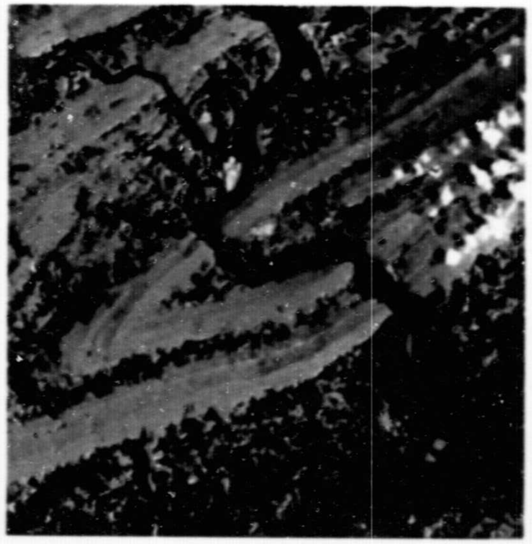


Figure 5.2. Difference images created by subtracting corresponding MSS bands of the "before" and "after" image set. By subtracting the corresponding MSS bands of the registered "before" and "after" images shown in figure 1, "difference" images are created which highlight areas of change. Note how the areas of change along the forested ridges appear as lighter shades of gray in MSS bands 4 and 5, and as darker shades of gray in MSS bands 6 and 7.

Figure 5.3. Color composite rendition of "difference" images. Color composites created by superimposing any 3 of the 4 possible "difference" images with various combinations of red, green, and blue filters can render the areas of change in unique color tones which are easier to interpret than the individual black and white displays in figure 5.2. This color composite rendition was created using "difference" bands 5, 6, and 7, and color filters blue, green, and red, respectively. Note how the areas of drastic change are enhanced, appearing as purplish-blue.



(a) simple land cover classification of July 1976 data



(b) application of the 1976-based binary mask to the June 1977 image shown in Figure 5.1b.

(c) application of the 1976-based binary mask to the "difference" image shown in Figure 5.3.

Figure 5.4. Classification map obtained by digital analysis and its application as a binary mask to isolate forest areas. The simple land cover classification map (a) portrays non-forested land cover in yellow, forested areas in red, and water in blue and was derived via maximum likelihood classification of the 19 July 1976 Landsat digital image shown in Figure 5.1a. A binary mask of "0's" for non-forested areas and water, and "1's" for forested areas was created from this classification map and has been applied cell by cell to the 27 June 1977 Landsat digital data shown in Figure 5.1b to yield a new display (b), where only those cells classified as "forest" remain. This procedure eliminates commission errors with non-forest cover types when delineating forest insect defoliation damage because all non-forest land areas have been removed from the data set. Also note that the same binary mask can be applied to other image products such as the color composite difference image (c), previously shown in Figure 5.3.

FOREST SITE INDEX MAPPING IN NORTH CENTRAL COLORADO

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BACKGROUND AND OBJECTIVES OF THE TEST

Forest site productivity expresses the combined influence of the biotic, climatic, and edaphic conditions on the timber-growing capacity of a given tract of land. Site productivity is commonly designated by a site number which relates tree height to age. That is, site productivity is defined as the average height of dominant and codominant crown classes in well-stocked stands at specific ages, usually 50 or 100 years. For example, site index 125 on a 100-year base means that the dominant and codominant trees will average 125 feet or 38 meters in height at 100 years of age.

While foresters can manipulate timber density, species composition, quality, and size distribution through cutting, the potential productivity is determined by the site. However, site "value" determinations are currently derived through expensive and time-consuming field measurements of tree height/age relationships. It was hypothesized that the application of statistical pattern recognition techniques to Landsat multispectral scanner data, combined with overlays of map-derived ancillary landscape data, would offer particular promise for site index mapping over large areas.

STUDY SITE

The Eaton Reservoir 1:24,000 scale U.S.G.S. topographic map quadrangle was designated as the study area for the site productivity mapping study. This test area was imaged on the 15 August 1973 Landsat-1 frame designated as path 36, row 32. The site is situated in the Colorado Front Range approximately 80 kilometers by road northwest of Fort Collins, Colorado. The site area is rectangular in shape, with dimensions of 10.5 kilometers east-west and 13.8 kilometers north-south, and an area of approximately 145.6 square kilometers. An abundance of diverse landscapes with a variety of landforms and vegetation types occur within the small test site. The elevation ranges from 2,341 meters to 2,999 meters above mean sea level. The climate is characteristic of the Colorado Rockies. Abundant sunshine, cool summers with frequent showers, heavy winter snows, low relative humidity, and wide temperature fluctuations are normal. Annual precipitation ranges from 25 to 38 centimeters, with over half of this precipitation falling during the winter months. Major tree species include lodgepole pine (*Pinus contorta* Dougl.), ponderosa pine (*Pinus ponderosa* Laws), quaking aspen (*Populus tremuloides* Michx.), Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco), limber pine (*Pinus flexilis* James.), subalpine fir (*Abies lasiocarpa* (Hook) Nutt.), and white fir Hook (*Abies concolor* (Gord. & Glend.) Lindl.).

APPROACH AND RESULTS

Ground control efforts consisted of initial field inventory and subsequent image registration activities. Field inventory crews of the Colorado State Forest Service visited 37 plots within the study area and compiled statistics for timber type, stand size class, stocking class, site area class, stand area, and site index. The site indices ranged from 25 through 65 and constituted the training data employed in the subsequent analysis.

The 15 August 1973 Landsat subimage was geometrically corrected and resampled to yield 137 rows and 102 columns of 1.01 hectare (2.5 acre) square cells for all four MSS bands (figure 6.1). A nearest-neighbor algorithm with correction for earth rotation, scan line skew, nonlinear mirror velocity, frame rotation, and pixel resampling without ground control points was used to generate the data set. The boundaries of the subimage were adjusted to the USGS quadrangle map with the use of an MSS band 7 graymap. This geometric rectification allowed the spatial registration of Landsat data with ancillary elevation, slope, aspect, and airphoto-derived vegetation data planes (figure 6.2). A fifth ancillary variable, Landsat image insolation, was calculated from the slope and aspect variables, and other information, to yield the incident solar radiation on the terrain at the time of the Landsat overpass (figure 6.2d). Thus, the original four MSS bands were registered with five ancillary map variables and overlayed as 1.01 ha. (2.5 acre) cells.

Stepwise linear discriminant analysis was applied to these nine variables using the site indices previously measured at the 37 training sets as "ground truth". The classification of these individual test plots using the four Landsat MSS bands and the five ancillary variables yielded 34 correctly classified plots out of 37, for an average training set accuracy of 92 percent (figure 6.3). A reclassification was performed to determine the training set accuracy which could be achieved using only the five map-derived variables (elevation, slope, aspect, vegetation and insolation). The resultant accuracy was 68 percent (figure 6.3). Using a similar approach, the optimum combination of five variables was selected from the total of nine available. The five optimum variables in order of decreasing importance were elevation, MSS band 6, slope, MSS band 4, and vegetative cover, and they yielded a training set accuracy of 81 percent (figure 6.3). Thus, the substitution of two easily obtained Landsat variables (MSS bands 4 and 6), for two tediously obtained map-derived parameters (aspect and insolation), increased the accuracy by an absolute 13 percent, which represents 41 percent of the remaining improvement possible in the range of 68 percent to 100 percent.

These results indicate the feasibility of spatial site index mapping in mountainous terrain. Five ancillary map-derived variables achieved 68 percent accuracy, but the incorporation of easily obtainable Landsat data significantly improved the accuracy of predicting forest site index and potential productivity. Existing forest inventory plots could be used for a practical application of the technique in lieu of the special training set plots employed in the test. The synergistic combination of

Landsat image and ancillary map data strongly suggests that additional information systems development could provide complete, objective, and consistent information and analysis. The versatility of a unified, multivariate resource data base can be employed to address a wide spectrum of management, planning, and research problems.

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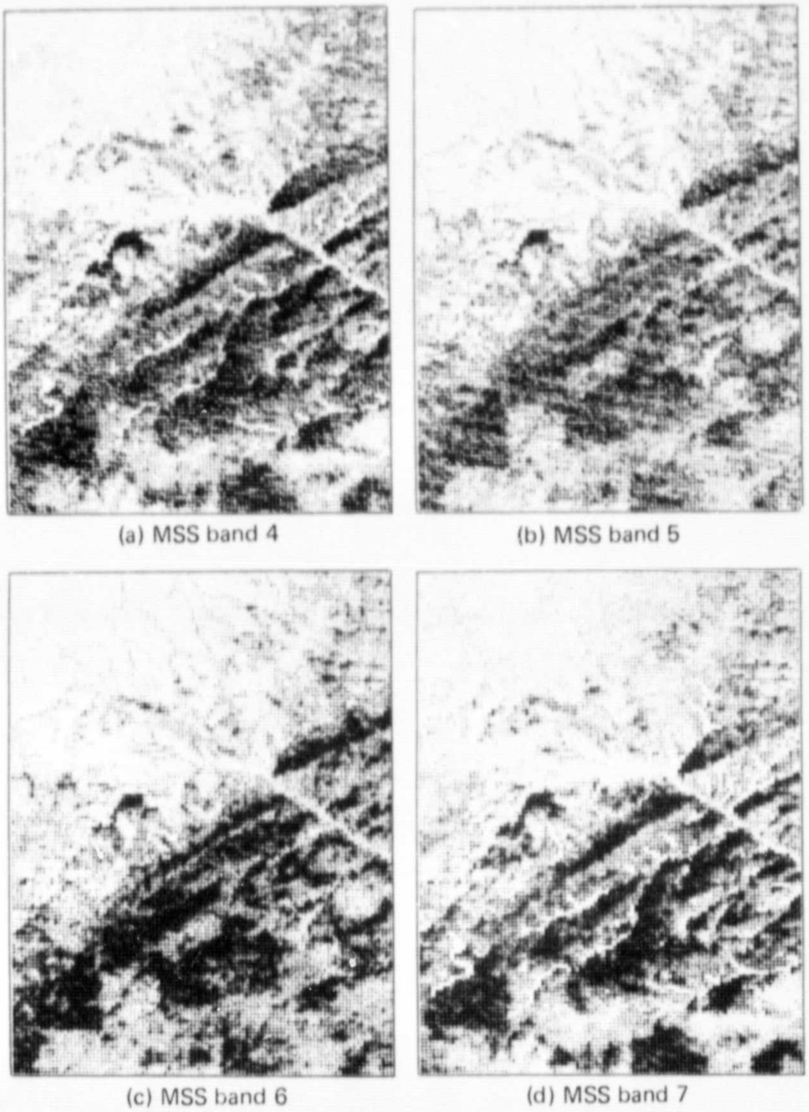
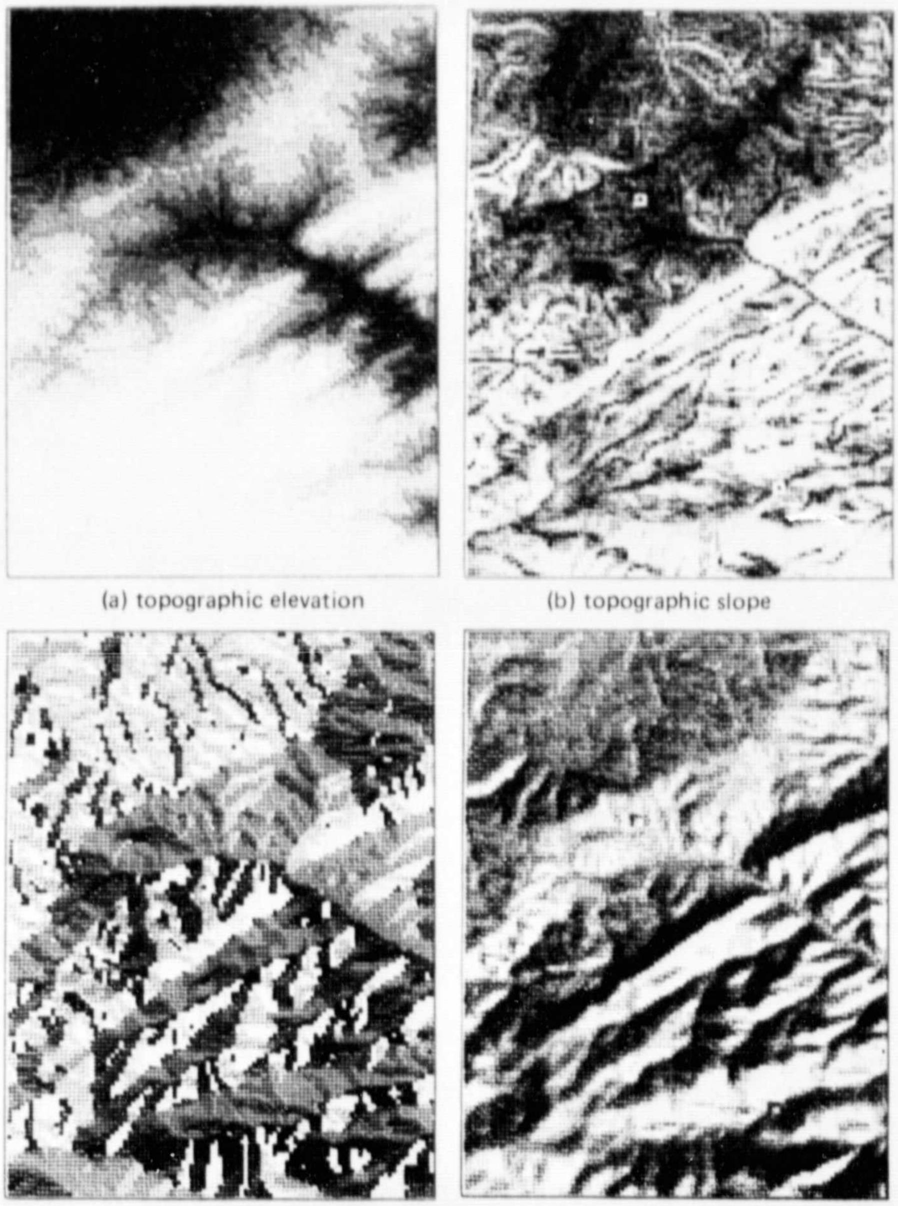


Figure 6.1. Landsat subimage depicting the U.S.G.S. 7½-minute Eaton Reservoir Quadrangle in North Central Colorado. These graymaps were extracted from a 15 August 1973 Landsat image and geometrically rectified and resampled to 1.01 hectare square cells. Note the lack of spatial and tonal variation in these four spectral bands due to the dominance of terrain-induced radiance variation.



(a) topographic elevation (b) topographic slope

(c) topographic aspect (d) solar radiation

Figure 6.2. Graymaps of the physiographic and insolation data planes overlaying the Landsat MSS bands. The elevation data plane (a) was sampled cell-by-cell from the 1:24,000 scale U.S.G.S. topographic map. Slope (b) and aspect (c) were computed from the elevation data plane. The near-instantaneous incoming insolation (d) was computed for the time of the Landsat overpass using the slope and aspect data planes.

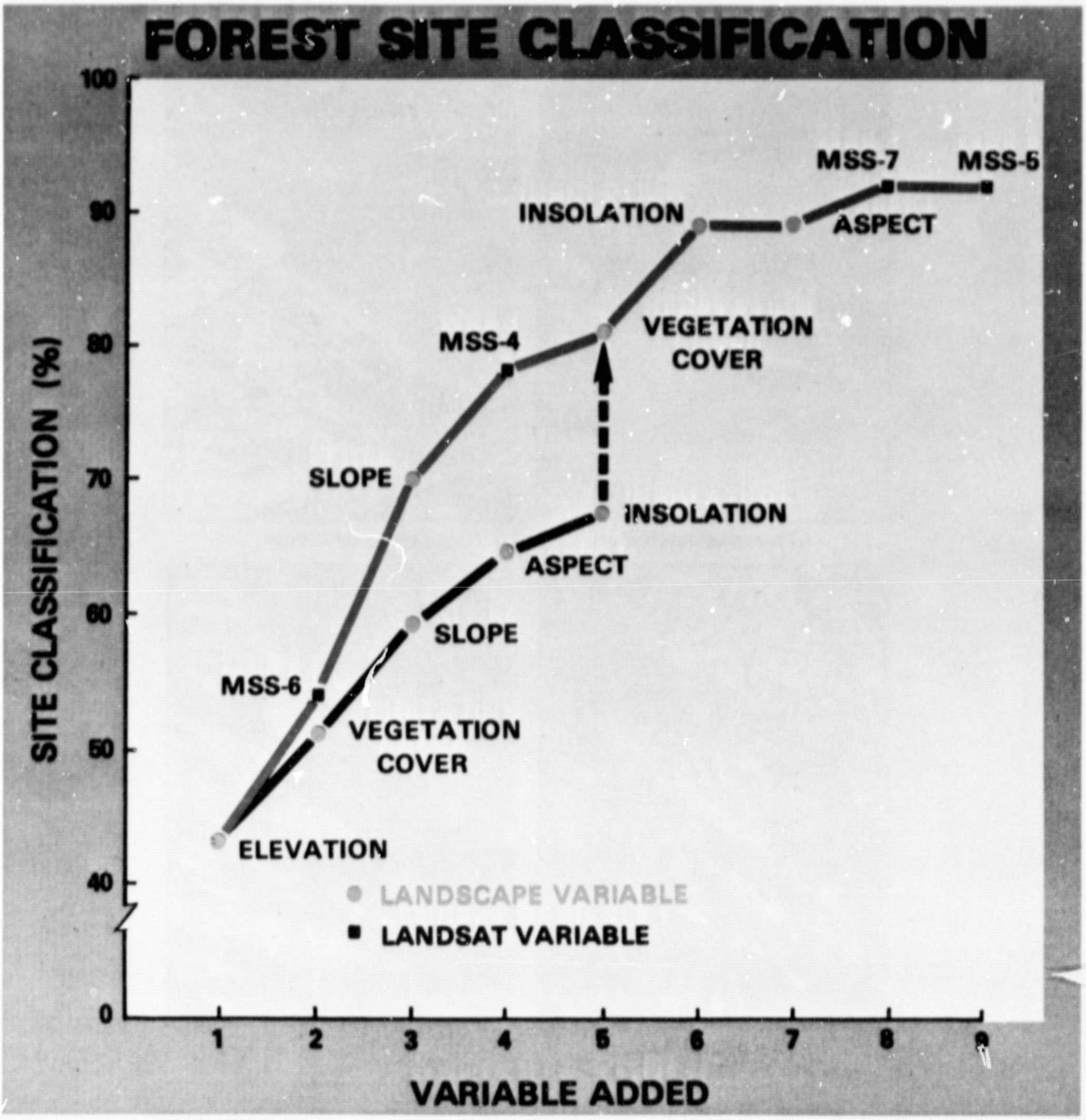


Figure 6.3. Training set accuracy of site index classification with and without Landsat imagery. The vertical axis represents the percentage of 37 training sets correctly reclassified into their one of ten site index classes. The lower curve represents the training set accuracy achieved when the classification is restricted to the five map-derived variables. The upper curve represents the improved training set accuracy obtained when five variables are selected by stepwise discriminant analysis from among the nine variables formed with the addition of the 4 Landsat bands.

SHIFTING CULTIVATION IN THE FORESTS OF NORTHERN THAILAND

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BACKGROUND AND OBJECTIVES OF THE TEST

The area of the Golden Triangle at the corner intersection of China, Burma, Laos, and Thailand has traditionally been a rugged, inaccessible terrain covered with tropical forest. Shifting cultivation, swidden or cut and burn agriculture, as it is variously called, has always been a permanent feature of this rugged forest landscape. Subsistence agriculture with some small amount of intermixed cash crops consisting primarily of opium and dry land rice have been historically grown on small newly cleared forest sites. Two or three years of cultivation usually exhausts the residual soil nutrients and the field locations are shifted by clearing new forest plots. The small, abandoned fields regrow into forest and in twenty years can not readily be discerned from old growth stands except for the size of tree stems. Historically, shifting cultivation did not occur in all forest types. The earlier practitioners preferred certain types of forests that indicated the presence of more desirable soil types. Thus, certain types of forests were only minimally impacted by the process. Originally these selected old growth forests and those allowed to regrow sufficiently between shifting cultivation cycles contained valuable quantities of teak.

Continually increasing international demand for illicit opium, coupled with the increasing pressure of population growth in this area, has substantially decreased the cycle time of shifting cultivation while simultaneously increasing the area under cultivation at any given time. The process is no longer in an ecological balance over time. All forest types are being cut and burned on cycles of something like six or seven years, replacing the past process which selectively used more resilient forest types on cycles of greater than 20 years. Suddenly all of the forests are disappearing and the abundant tropical rainfall and unavoidable erosion of these large non-forested areas is making the process irreversible. Large scale examples of the results of this disastrous process already exist in the extensive desert areas which have been created in the northeastern portion of the Amazon Basin.

The research reported here has been underway for approximately seven years to determine the application of remote sensing to the measurement, monitoring, and projection of spatial patterns of shifting cultivation in this region. The specific objectives of the research discussed here concern: (a) tests of the various methods for computer classification of the forested areas subjected to shifting cultivation and (b) the use of these results and related information collected from airphotos and existing maps to model the occurrence and spread of shifting cultivation so that its causes and control may be more clearly understood.

Fortunately, a persistent dry season occurs in the area during January, February, and March and excellent Landsat imagery and airphotos have been collected during these months. The work reported upon here has not been directly sponsored, although various peripheral aspects of it have been underwritten by Colorado State University, the Mekong Secretariat of the UN/ESCAP, Kasetsart University, and NASA/GSFC. However, the interpretation of the causes and implications of the shifting cultivation process noted above were purely those of the authors.

STUDY SITE

The particular study site selected for detailed analysis is located about 65 kilometers north of Chiang Mai, one of the major cities in the northern region of Thailand, and lies just south of the Burma border. Approximately 12 good Landsat images exist for the site which lies within the Landsat frame designated as path 36 and row 47. Five scenes* which represent annual, anniversary coverage of the site have been employed in the analysis to date. The specific forest area to be mapped and modeled is enscribed in a rectangle of 432 square kilometers (24 km E-W and 18 km N-S) which was cellularized with a resolution of one hectare (approximately 2.5 acres) yielding 43,200 cells. The closed, irregular bounded study site within this rectangle was limited to an area common to all of the special maps made available from earlier field analysis of the site by others. It consisted of an area of 292.9 km^2 or 29,290 square cells of 1 ha. resolution and is an anti-watershed bounded by major water courses or drainages on all sides with a mountain ridge in the center.

APPROACH AND ANALYSIS

The landscape model of this site consists to date of 102 image and map variables overlaid such that each constitutes a cellular data plane of 1 ha. resolution covering a common area of 29,290 ha. (figure 7.1). Utmost care was exerted to ensure that each of these data planes registers upon all others to the nearest 1 ha. resolution cell. Input into the landscape model of those data planes derived from existing maps and airphotos was completed entirely by a manual dot sample method. Area planes, such as topographic elevation and geology, were directly sampled cell-by-cell from 1:50,000 scale maps. Additional area planes, such as topographic slope and aspect, were computed from the elevation data plane. Point feature planes, such as the location of temporary huts and permanent dwellings, were interpreted using four different dates of low altitude, black and white aerial

*Landsat scenes of 27 January 1973, 22 January 1974, 13 February 1975, 26 February 1976, and 2 February 1977.

photography. These planes were then computationally transformed into minimum distance area planes. Linear features, such as drainage, roads, and trails, were similarly interpreted from each set of airphotos. They were also converted by computation into minimum distance area planes.

Airphoto interpretation maps depicting nine forest and agricultural land cover types were prepared for the four different dates of airphoto coverage and overlaid onto the model via the area dot sampling procedure. All four of these forest cover maps were interpreted by a single individual in a consistent fashion. The nine types of land cover interpreted from the photos for each of the four dates (figure 7.2) include the forest cover types of:

- dry dipterocarp
- dry dipterocarp forest with pine
- mixed deciduous forest with teak
- hill evergreen forest
- dry evergreen forest
- teak plantations

together with three agricultural cover types of:

- shifting cultivation
- irrigated rice paddies
- tea plantations.

The direct visual inspection of the resultant forest cover maps illustrates the marked increase in the area occupied by active shifting cultivation over the past 20 years (figure 7.2). This comparison illustrates that the nominal 20-year cycle from forest to shifting cultivation and back to forest has been drastically shortened.

The assumption that future changes in forest cover can be measured in terms of those which occurred in the past allows a simple projection of the fate of the future forest cover within the site. Cross-tabulation of each pair of consecutive forest cover data planes available in the landscape model (e.g., 1968 with 1972) provides a probability transition matrix. This matrix is applied in a Markov process to the distribution of forest cover recorded in the second or more recent data plane to project future forest cover trends in the test site (figure 7.3)*. Only a few years of validity may be assumed for these projections, as the processes controlling the observed forest cover changes during the training period (i.e., 1968 to 1972) can only be assumed to persist for a few years into the future (i.e., beyond 1972). A much more complex model has been developed which is capable of projecting the future *spatial behavior* of the forest cover of the site based upon the controlling landscape features represented in the overlaying data planes. Essentially, the spatial projection model takes all the specific changes in forest cover as tabulated between two consecutive forest cover data planes, groups them together into like changes, and correlates their occurrence with the corresponding landscape parameters also available in the landscape model (i.e., slope, distance to roads and trails, etc.). Details on this approach and its results can be found in the references provided.

The Landsat imagery existing for the site represented five consecutive anniversary dates which were geometrically rectified and resampled to the one hectare square cells (figure 7.4). Difference images

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*Land cover trend models have also been computed for the following pairs of dates: 1954 with 1972, 1954 with 1966, 1966 with 1968 and 1968 with 1972.

were formed between like spectral bands for consecutive pairs of dates. Displays of these easily obtained image analysis products provide a mechanism for quick reconnaissance-level detection of areas of change between consecutive years. The areas of change which were detected represent both shifting cultivation (figure 7.5) and annual shifting crop-type patterns where permanent agriculture is practiced (figure 7.6).

Landsat land cover classification in areas of significant relief is limited in accuracy by that portion of the radiance variation created by the terrain which is independent of the surface cover type. Overlaying slope, aspect, and elevation data planes (figure 7.7a) in the landscape model provided a basis for several approaches designed to minimize this impact. Overlays of cultural features (figure 7.7b) as data planes were also evaluated to determine their contribution to the accuracy of the classification of the 8 cover types noted above*.

The value of combining these various types of ancillary landscape data planes with the Landsat MSS bands was tested using stepwise linear discriminant analysis as the classifier (Table 7.1). Three types of training sets were evaluated. These consisted of rectangular representations of each cover type, rectangular areas selected to represent sun-facing and opposite topographic aspects, and grid sampled training sets assembled for a 1/9 sample of the test site consisting of every third row and column of 1 ha. image cells. Tests were also completed to assess the value of having apriori knowledge of the composition of the area to be mapped (i.e., using proportional apriori probabilities), in comparison to having no knowledge of the composition of the area (i.e., using equal apriori probabilities).

The overall performance of the various classifiers and training set approaches tested were directly evaluated on the 27 January 1973 Landsat image. A complete classification map of the 29,290 cells common to all data sets was prepared for each case and checked cell by cell against the 1972 airphoto-derived forest cover map†. The accuracies achieved (Table 7.1 and figure 7.8) do not appear very high but this will always be the case when dealing with map verification accuracy rather than the commonly employed training set accuracy. The latter verification scheme is much more subjective or even operator manipulated. The verified map classifications achieved the best overall accuracy of 55.4% with grid sampled training sets and proportional apriori probabilities. It should be noted that the percentage of correctly mapped points in such a complete map verification scheme cannot be expected to approach 100%, as the airphoto interpretation maps of land cover have their own inherent inaccuracy. For example, assume that the land cover map derived from the airphotos is 70% correct; that is, if 10 random cells were checked on the ground, 7 of the 10 would have been assigned by photointerpretation to the correct cover type. This 70% accuracy is a reasonable assumption in such a complex tropical forest canopy. The Landsat image classification map may also be 70% correct relative to ground conditions. Thus, verification of the Landsat classification map against the airphoto map will produce a 70% times 70% verification accuracy, or 49% which is reasonably close to the results reported above (i.e., 55.4%).

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*Teak was omitted in the Landsat classification as it occupied only 40 ha. of the entire site.

†Note that December 1972 airphotos were used in preparing the 1972 forest cover type map and are separated by about one month from the Landsat scene classified.

FURTHER INFORMATION

References

Miller, L. D., K. Nualchawee and C. Tom. 1978. Analysis of the dynamics of shifting cultivation in the tropical forests of northern Thailand using landscape modeling and classification of Landsat imagery. Proc. Twelfth International Symposium on Remote Sensing of Environment (also NASA/ Goddard Space Flight Center, Tech. Memo. 79545, Greenbelt, Maryland). 19p.

Wacharakitti, S., L. D. Miller and C. Tom. 1975. Tropical forest land use evolution/twenty year landscape model with inputs from existing maps, historical airphotos and ERTS satellite imagery. Colorado State University, Environmental Engineering Technical Report 1, Ft. Collins, Colorado. 217 p.

Nualchawee, K., L. D. Miller and C. Tom. 1978. Spatial land-use inventory, modeling, and projection in northern Thailand with inputs from existing maps, airphotos, and Landsat imagery. Texas A&M University, Remote Sensing Center, Technical Report, College Station, Texas. 220 p.

Experimenters

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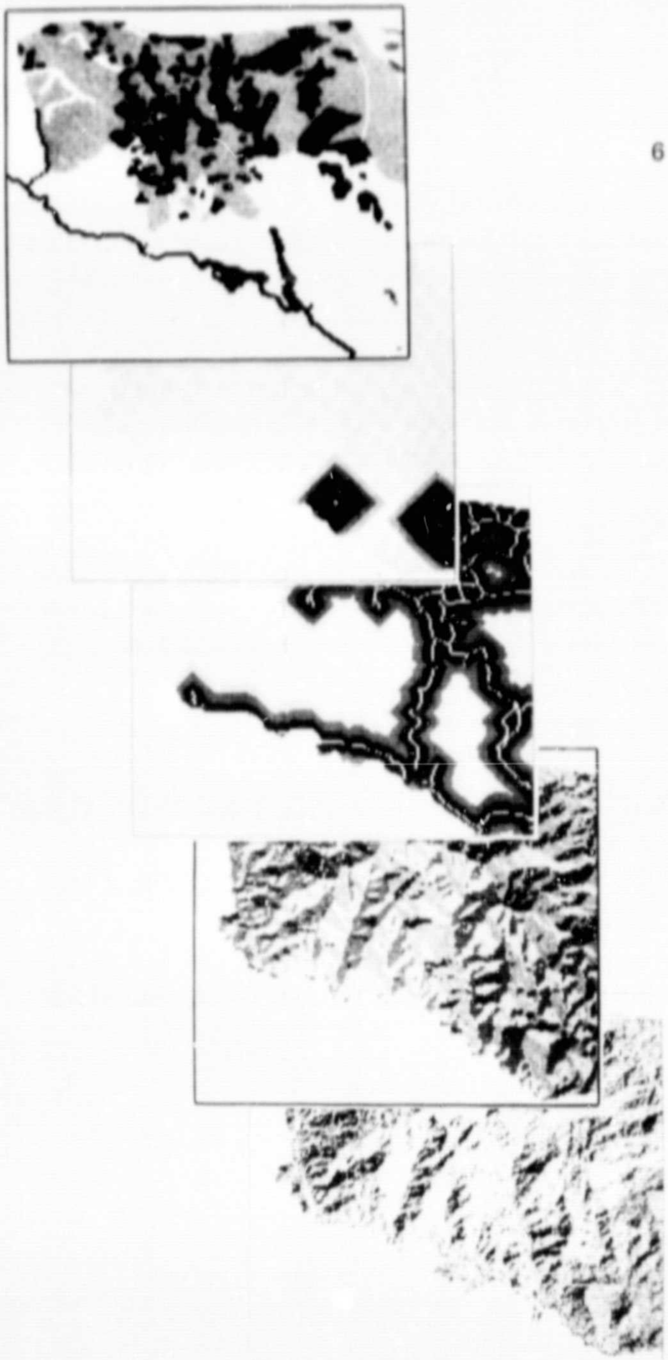


6 LAND USE SUBMODEL VARIABLES:

- 1954
- 1966
- 1968 Forest Types and Related Land Use
- 1970
- 1972
- Potential Natural Vegetation

9 CULTURAL FEATURES SUBMODEL VARIABLES:

- 1954
- 1966 Minimum Distances to Temporary Structures
- 1968
- 1970
- 1954
- 1966 Minimum Distance to Permanent Structures
- 1968
- 1970
- 1972 Minimum Distance All Structures

5 TRANSPORTATION SUBMODEL VARIABLES:

- 1954
- 1966 Minimum Distances to Roads and Trails
- 1968
- 1970
- 1972

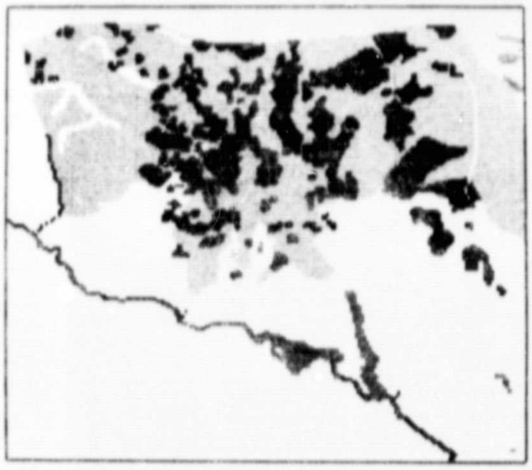
9 PHYSIOGRAPHIC SUBMODEL VARIABLES:

- Topographic Elevation
- Topographic Slope (2 versions)
- Tropographic Aspect
- Drainage (2 versions)
- Geology (2 versions)
- Landsat Image Insolation

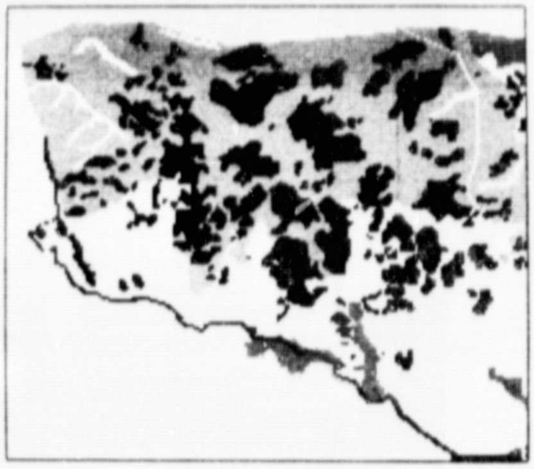
73 LANDSAT IMAGE VARIABLES:

- MSS-4 Visible Green
- MSS-5 Visible Red
- MSS-6 Solar Infrared For 5
- MSS-7 Solar Infrared Anniversary
- 6 MSS Channel Ratios Dates
- 4 MSS Insolation Ratios
- Photo Interpretation MSS-5
- Photo Interpretation MSS-7 1 Date
- Photo Interpretation MSS Color IR Only

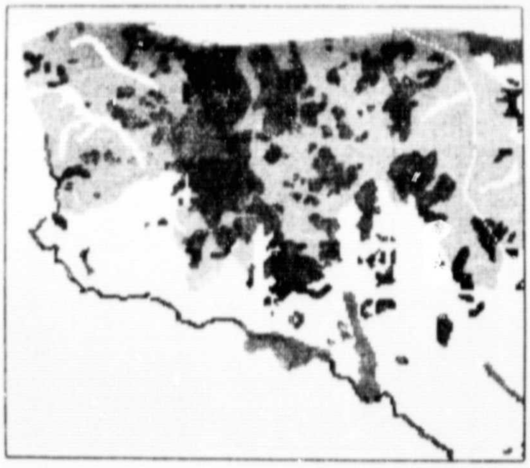
Figure 7.1. Conceptualization of the landscape model constructed for the study area. Listed are the 102 variables which were overlaid as individual data planes in the form of 29,290 square cells of 1 ha. resolution. Each of these data planes contain 43,200 cells within the inscribing rectangular area but the information content is limited to the irregularly bounded area common to the special maps made available by other studies of the area. This irregular site consists of an anti-watershed bounded by major watercourses or drainages on all sides with a mountain ridge in the center.



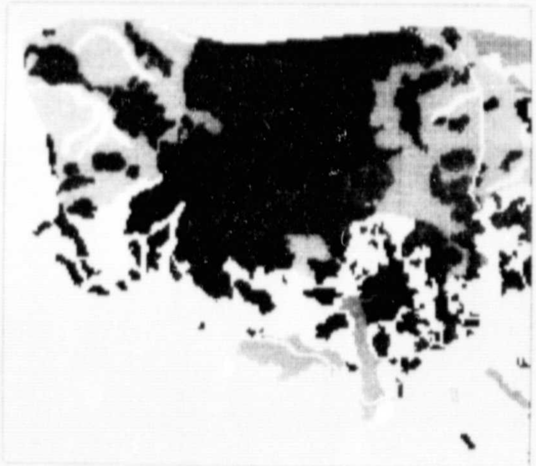
(a) 1954 forest types



(b) 1966 forest types



(c) 1968 forest types



(d) 1972 forest types

Figure 7.2. Forest cover data planes illustrating the marked increase in cycle time in the transition of forest cover to shifting cultivation. Each displav emphasizes the areas of shifting cultivation in black. All 4 of these cover type maps were compiled for 9 cover types by very careful, detailed interpretation of low-altitude, black-and-white airphotos.

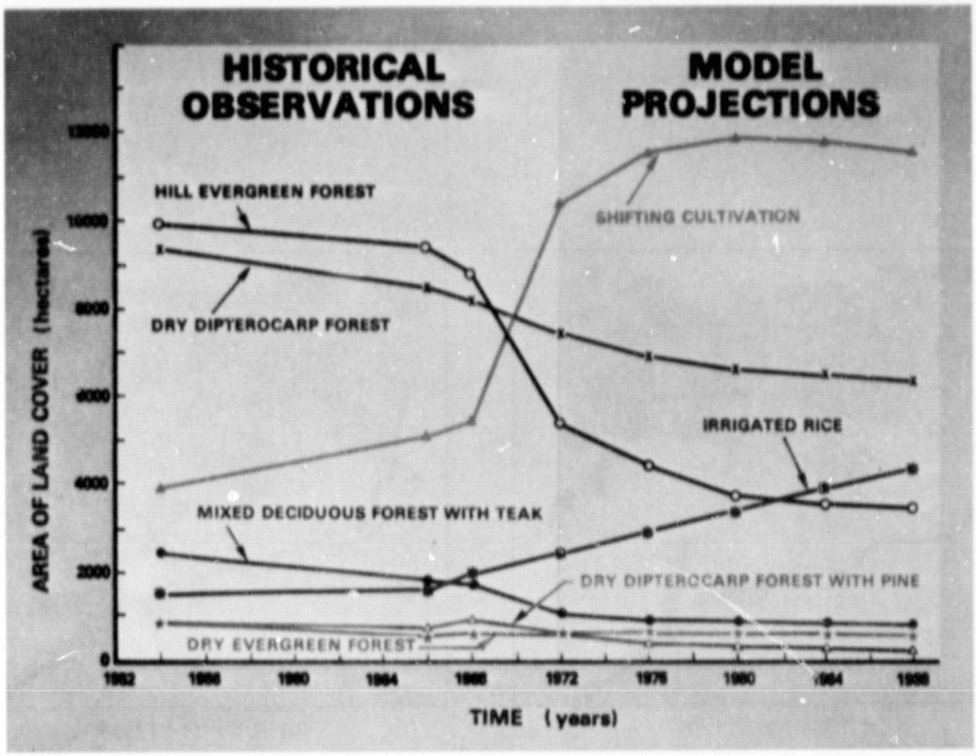
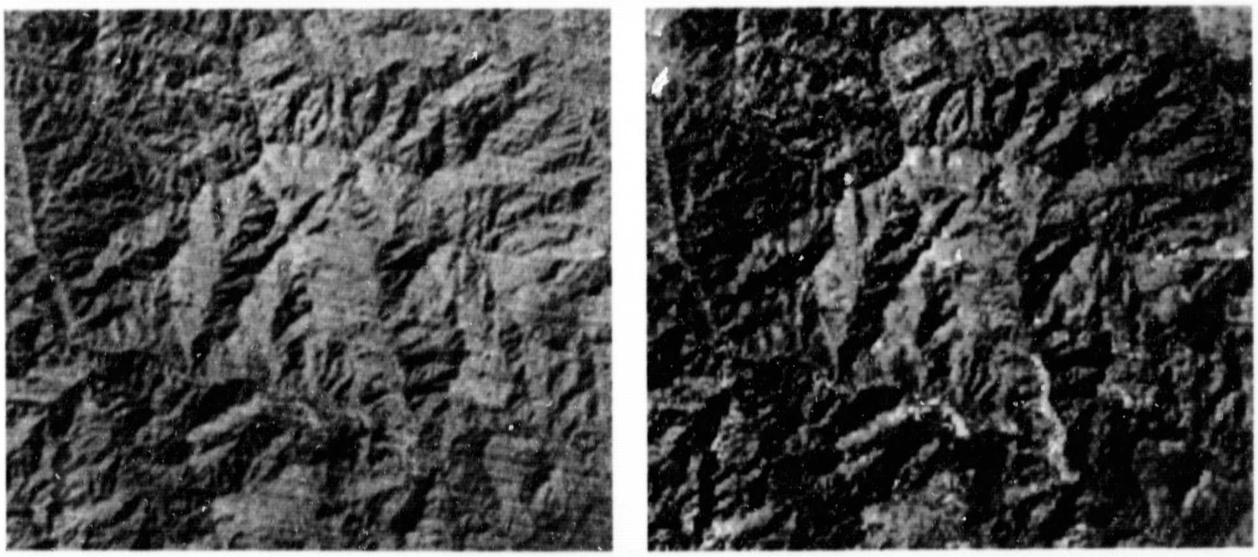


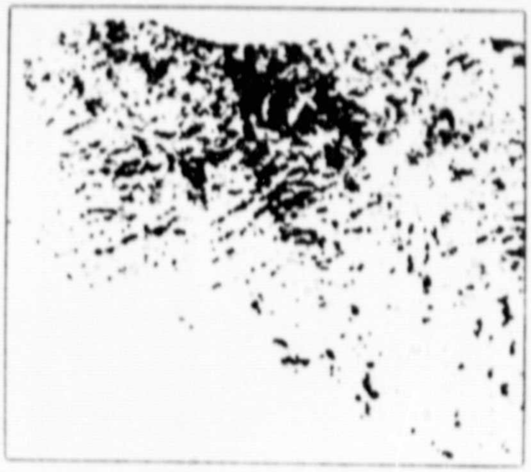
Figure 7.3. Observed forest cover depletion and prediction of future trends. The first four data points of each curve (1954, 1966, 1968, and 1972) represent tabulations of the area of the cover types from the 29,290 cells of air photo interpreted data planes illustrated in figure 7.2. The model projections were simulated using a Markov process and the probability transition matrix computed from the comparison of the 29,290 cells of the 1968 and 1972 cover type maps.



(a) original color IR image (b) contrast stretched color IR image

Figure 7.4. Comparison of the Landsat color products of the northern Thailand forest site. The original color IR image (a) was extracted photogrphically from the standard Landsat color IR photographic transparency. The contrast stretched subimage (b) was extracted from the digital tapes for the same scene, geometrically rectified and resampled to 1 hectare resolution, contrast stretched and MSS bands 4, 5, and 7 superimposed and displayed on a digital film recorder.

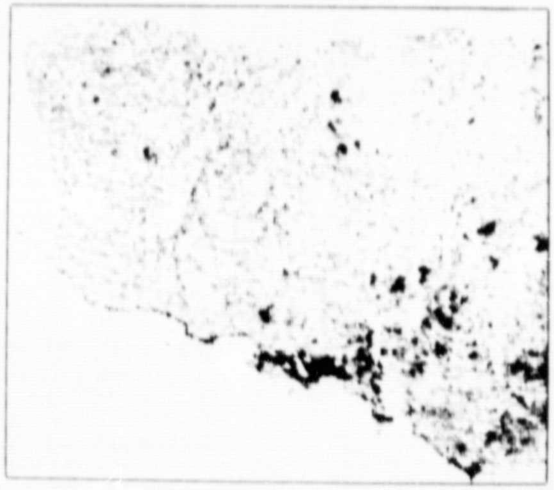
(a) airphoto comparisons of 1968 to 1972



(b) MSS-7 Landsat difference of 1975 to 1974

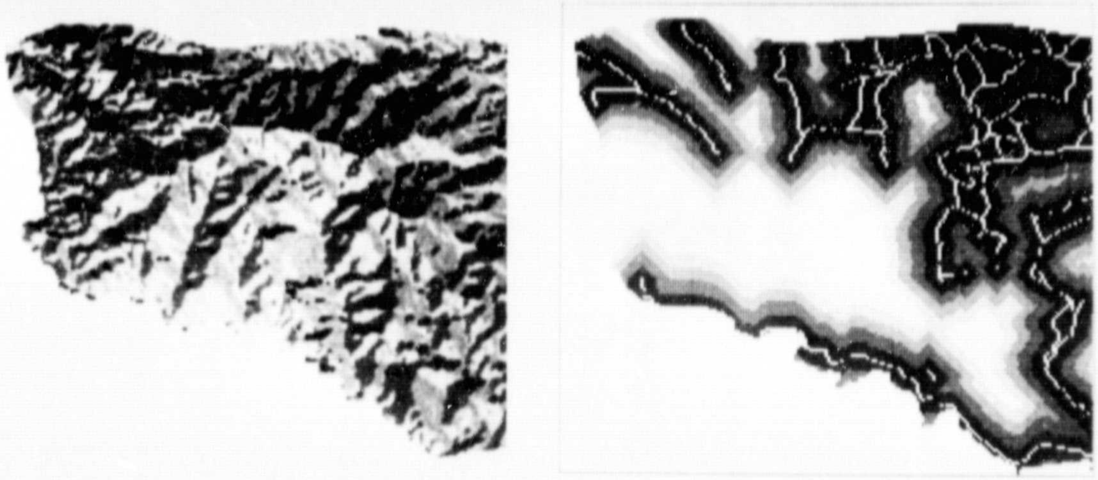
Figure 7.5. Comparison of forest depletion maps computed from airphoto land cover maps and Landsat difference images. The displays both represent the 1 hectare resolution. The Landsat images were taken 13 February 1975 and 22 January 1974 and represent a solar angle difference of +1°.

(a) airphoto comparisons of 1968 to 1972



(b) MSS-7 Landsat difference of 1974 to 1973

Figure 7.6. Comparison of forest regeneration maps computed from airphoto land cover maps and Landsat difference images. The displays both represent the 1 hectare resolution. The Landsat images were taken 22 January 1974 and 27 January 1973 and represent a solar angle difference of -1°.



(a) topographic aspect (b) M.D. to roads and trails

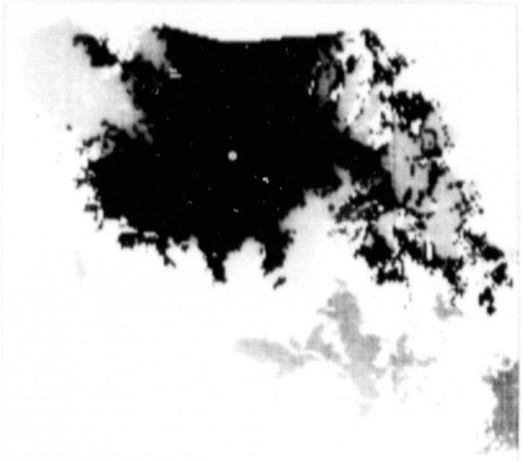
Figure 7.7. Representative graymaps of the physiographic (a) and cultural features (b) data planes overlaying the Landsat MSS bands. M.D. = minimum distance. The topographic aspect data plane (a) was computed from the topographic elevation data plane at the 1 hectare resolution. The minimum distance data plane (b) was computed from an airphoto interpretation of cultural features.

Table 7.1. Comparison of the verified accuracies for the Landsat forest cover classifications with ancillary data overlays. The numbers represent the percentage of the total number of the 29,290, 1 ha. cells which were correctly classified into their respective cover type when checked against the 1972 land cover map. The second set of percentages in parentheses represents only those cells correctly classified as shifting cultivation. These percentages for shifting cultivation fluctuate widely as the various classification approaches were optimized to achieve the best overall accuracy for all 8 land covers and not optimized for this specific cover type.

2 variables used = MSS-5 and 7,
4 variables used = those above plus MSS-4 and 6,
8 variables used = those above plus topographic slope, aspect, elevation, and distance to drainage,
11 variables used = those above plus distance to roads and trails, permanent housing, and temporary housing.

	TYPE OF TRAINING SETS					
VARIABLES USED	RECTANGULAR		ASPECT		GRID	
	Equal	Proportional	Equal	Proportional	Equal	Proportional
2	26.0 *(15.8)*	43.6 *(67.6)*	19.0 *(14.1)*	41.4 *(61.9)*	22.1 *(13.5)*	41.7 *(66.7)*
4	26.2 *(16.6)*	44.5 *(64.8)*	33.6 *(87.9)*	39.0 *(99.0)*	28.0 *(27.4)*	48.8 *(83.3)*
8	33.4 *(34.9)*	43.9 *(47.4)*	22.6 *(34.7)*	29.6 *(54.4)*	32.9 *(35.6)*	52.2 *(79.7)*
11	36.0 *(37.4)*	46.2 *(48.2)*	38.0 *(36.2)*	47.8 *(46.8)*	36.3 *(34.9)*	55.3 *(74.0)*

(a) using rectangular training sets



(b) using aspect oriented rectangular training sets

(c) using grid sampled training sets

Figure 7.8. Land cover classification maps computed using three types of training sets and 11 Landsat and map-derived variables. Each display emphasizes the area of shifting cultivation in black. All 3 classifications were computed using stepwise linear discriminant analysis with proportional apriori probabilities of land cover occurrence. The 11 variables were the 4 Landsat MSS bands, the 4 physiographic variables, and the 3 cultural feature variables.