Assessing Deforestation in the Guinea Highlands of West Africa Using Remote Sensing

Peter T. Gilruth and *Charles F. Hutchinson*
Arizona Remote Sensing Center, College of Agriculture, University of Arizona, Tucson, AZ 85721
Bademba Barry
National Direction of Forest and Game, Ministry of Agricultural and Animal Resources, Box 624, Conakry, Guinea

ABSTRACT: Multiple remote sensing systems were used to assess deforestation in the Guinea Highlands (Fouta Djallon) of West Africa. Sensor systems included (1) historical (1953) and recent (1989) aerial mapping photography; (2) recent large-scale, small format (35-mm) aerial photography; (3) recent, large-scale aerial video imagery; and (4) historical (1973 and 1985) Landsat MSS imagery. Photographic and video data were manually interpreted and incorporated in a vector-based geographic information system (GIS). Landsat data were digitally classified. General results showed an increase in permanent (48 percent) and shifting (526 percent) agriculture over the past 35 years. This finding is consistent with hypothesized strategies to increase agricultural production through a shortening of the fallow period in areas of shifting cultivation. However, our remote sensing results also show that the total area of both permanent and shifting agriculture had expanded at the expense of natural vegetation along with an increase in eroded areas. Although sequential Landsat MSS imagery cannot be used in this region to map land cover accurately, the location, direction, and magnitude of changes can be detected in relative terms. Historical and current aerial photography can be used to map agricultural land-use change with better accuracy. Video imagery is useful as ancillary data for mapping vegetation.

INTRODUCTION

TROPICAL DEFORESTATION is a topic that has received considerable attention recently as a major theme in the global change initiative. Despite its importance, accurate statistics on current tropical deforestation rates are difficult to obtain (Booth, 1989; Grainger, 1983 and 1984; Green, 1983; Myers, 1988). In contrast to the large-scale felling of forests in the Amazon basin, removal of tropical forests in West Africa is much less dramatic. Here, forests are not being so much felled as they are being slowly degraded (Booth, 1989). As a consequence, the rates and extent of deforestation in West Africa are even less-well known than in other regions.

We report the results of a study of deforestation and land-use change in the Guinea Highlands of West Africa. The impetus for this research is the need to describe the types and rates of land-use change within the tropical environment and, ultimately, to understand how changes in land use and vegetation cover might affect the regional environment. The specific objectives of this study were (1) to determine types and rates of changes in permanent and shifting agriculture within the region; (2) to identify the types of land degradation that has accompanied these changes; and (3) to consider alternative combinations of sensors that might be used to achieve these ends.

STUDY AREA

The Fouta Djallon, the central mountain range of the Guinea highlands (Figure 1), gives rise to most of the major rivers that deliver water to the Sahelian Zone of West Africa. Because changes in land use and deforestation in the Fouta Djallon will have profound effects on the flow regimes of rivers that support agriculture, transportation, and energy needs throughout the Sahel, the management of lands within these headwaters is of regional importance. Downstream countries potentially affected by land degradation in the Fouta Djallon include Guinea-Bissau, The Gambia, Senegal, Mali, Mauritania, Niger, and Nigeria (Varady, 1983).

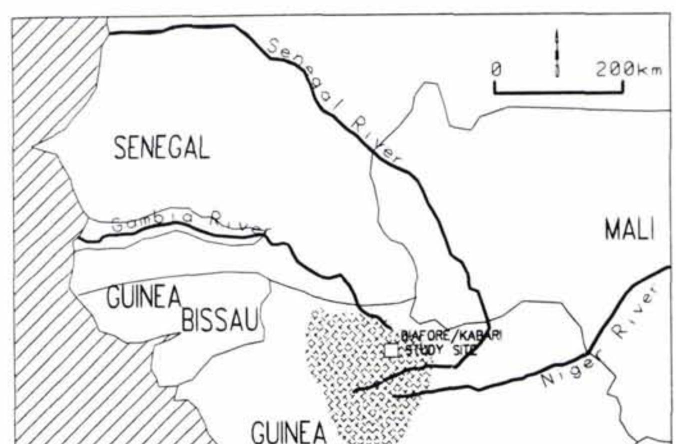

FIG 1. Location map of Diafore/Kabari study site and Fouta Djallon mountain range (cross-hatched).

PHOTOGRAMMETRIC ENGINEERING AND REMOTE SENSING,
Vol. 56, No. 10, October 1990, pp. 1375–1382.

0099-1112/90/5610–1375$03.00/0

PHYSICAL CHARACTERISTICS

The study was conducted in three neighboring watersheds located within the Fouta Djallon (Figure 2). The Tougue District, which encompasses the Diafore and Kabari River Basins, is on the gently sloping eastern face of the Fouta Djallon. The three watersheds are located between 12° 25′ and 12° 45′ North, and 11° 20′ and 11° 45′ West. The Diafore watershed has an area of $60km^2$, the Kabari $61km^2$. A small watershed located between the two, the Belakoure ($20km^2$), was also included.

Neither the Diafore nor the Kabari basin exhibits exceptional relief, with local topography ranging from 600m to 875m. The region is composed mostly of sandstones, which developed into rich, but easily eroded, soils (Heermans and Williams, 1988).

The main limitation on the distribution of both human population and vegetation is the presence of deeply dissected lateritic plateaus, which are either barren or veneered by a thin soil layer supporting a sparse woodland. These surfaces play a major role in the agro-ecological system and in the evolution of the landscape: they determine water flow, percolation, ground water dynamics, soil fauna, and have an effect on the local climate (Pascual, 1986). Local people generally do not settle on bare laterite because there is no possibility of growing crops.

The Diafore/Kabari landscape is also characterized by a dense stream network associated with multi-tiered gallery forests in the bottomlands. A dry woodland is often found on slopes[1], with the density and height of vegetation canopy a function of the most recent agricultural clearing. The Diafore/Kabari Basins receive about 1500mm annual precipitation, but this is 200 to 300mm/yr less rainfall than other parts of the Fouta Djallon to the south and west. Local farmers complain of a downward trend in precipitation (Heermans and Williams, 1988), and Isbecque (1985) reported an approximate decline of 300mm of annual rainfall in the Fouta Djallon over a 15-year period beginning in 1970.

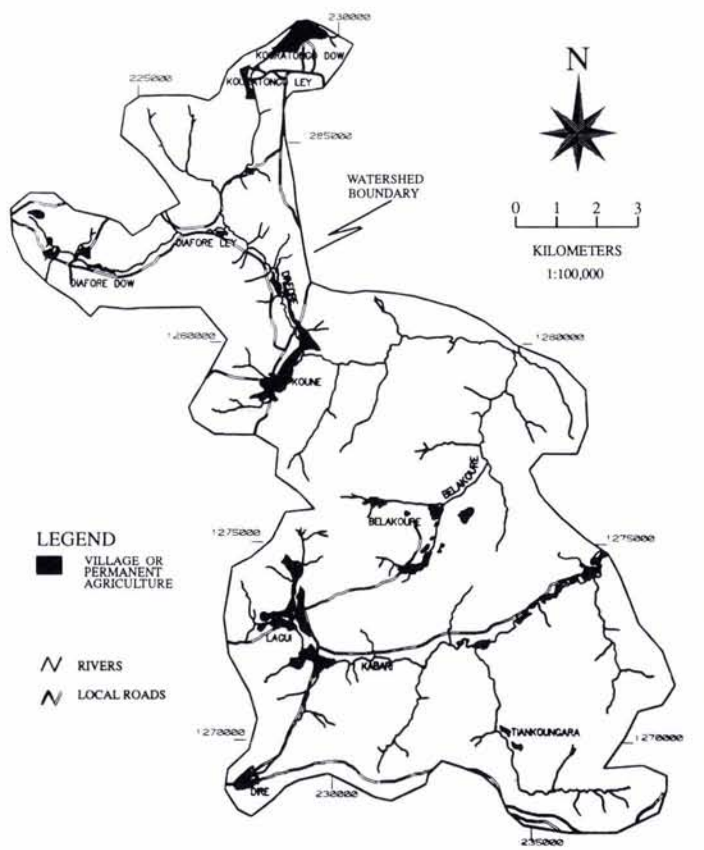

FIG 2. Diafore/Kabari 1989 village location map.

[1]The term "slope" is a direct translation of *versant* which French geographers typically use to describe this landscape unit.

CULTURAL PATTERNS

Traditional agriculture in the region is complex and utilizes each landscape element. The permanent agricultural unit is the home garden, a small field of about 0.5ha surrounding the living quarters. Although not always true in other areas of the Fouta Djallon, home gardens in the Diafore/Kabari basin are most often interspersed with gallery forests in the fertile bottomlands. Brush fences surround each garden to prevent entry of domestic or wild animals. The wood for these fences is gathered from surrounding forests, which contributes to deforestation.

Shifting cultivation of cereal crops is practiced on the wooded slopes and comprises a secondary agricultural unit (Figure 3). Individual families or entire villages may cultivate a piece of land for two or three years or until yields begin to decline. Until recently, normal fallow periods were typically between ten and fifteen years (Heermans and Williams, 1988; McGahuey, 1985).

Due to physical limits on the amount of arable land, the growth of permanent agriculture has not kept pace with the expanding population (Richard-Molard, 1949; Boulet and Talineau, 1986). Thus, to increase total production, villagers must intensify cultivation on valley slopes in two ways. One is to increase the total area under cultivation at any one time, thereby shortening the rotation period. This leads to a loss of soil fertility and lower yields. The other way is to establish new permanent home gardens on the lower portion of valley slopes just above the crowded bottomlands. However, these soils are generally shallower, rockier, and require more fertilizer inputs than traditional bottomland home gardens.

METHODS

A variety of methods have been used to determine rates of deforestation in several different regions. A few examples of these include the comparison of historical maps in a geographic data base for Costa Rica (Sader and Joyce, 1988), and remote sensing based surveys in (1) Brazil using a combination of aerial photography and land resource satellite imagery (Carneiro, 1985); (2) Nigeria using Side Looking Airborne Radar (SLAR) and aerial photography (Kio *et al.*, 1985); (3) Zaire using Landsat MSS imagery to assess deforestation around a rapidly growing urban environment (Soyer and Wilmet, 1983); and (4) Brazil using Ad-

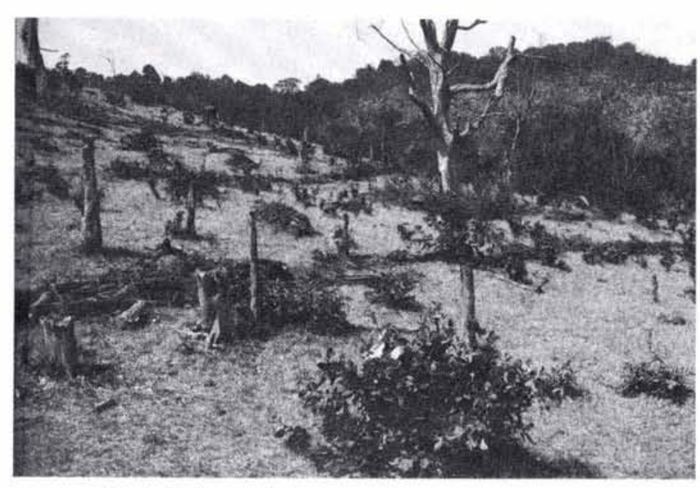

FIG 3. Deforested slope used for shifting agriculture.

vanced Very High Resolution Radiometer (AVHRR) satellite data (Malingreau *et al.*, 1989). In these efforts it was found that, generally, satellite imagery could be used to quantify large-scale changes in forest extent.

As already noted, deforestation in West Africa is more a case of degradation than large-scale felling. Due to the subtle nature of agricultural intensification that leads to degradation, changes in forest cover tend to be incremental and spatially dispersed. The coarse resolution of Landsat MSS and the short record of the higher resolution satellite systems (i.e., SPOT) limit their potential utility for mapping change. In fact, a study of deforestation in the region performed with Landsat MSS yielded mixed results (Westinga, 1987).

Our intent was to examine several different data sources for mapping deforestation and, where possible, to make qualitative comparisons among them.

Data

Four remote sensing data types from several dates were assembled to assess change in agricultural land use over the past 35 years (Table 1). Data were selected to give a variety of spatial and spectral resolutions. Fortunately, most of the historical data were collected near the end of the dry season when the land-cover classes are most easily distinguished.

1953 mapping photography. Black-and-white 1:50,000-scale photography flown by the French military before independence in 1953 served as baseline data. Although old and frayed through long use, these photos still allowed identification of agricultural classes.

1989 mapping photography. The 1989 HZ Aerial Survey and Mapping Company 1:30,000-scale photography, flown under contract to the Government of Guinea, is currently being used to develop large-scale topographic maps of the watershed study areas.

Landsat images. The 1973 and 1985 Landsat MSS scenes were selected to (1) encompass the longest time span possible within the Landsat MSS record, and (2) keep within seasonal requirements for data comparison.

35-mm photography/aerial video. A team from the Arizona Remote Sensing Center (ARSC) collected the most recent data set immediately prior to the onset of the 1989 rains. A combined 35-mm camera and bi-spectral video camera platform was mounted in the belly port of a locally rented aircraft. This system was developed at ARSC for mapping and assessing vegetation in rural environments (Hutchinson *et al.*, 1990). Meisner (1986) and Marsh *et al.* (1990) have described the advantages and disadvantages of using video imagery for mapping vegetation and land use.

Field Observations

The ARSC team gathered field data from 25 sites to establish land-cover classes and develop an interpretation key. Sample sites were representative of land-cover classes, problem areas in interpretation, and areas that showed change between 1953 and 1989. Ground observations included land use, vegetation density and structure, estimates of canopy cover, and any signs of land degradation. Aerial photos were used to locate sample points in the field.

Definition of Land-Use Classes on Air Photos

Five land-use/cover classes were mapped. Interpretation keys for each class follow.

Permanent agricultural units: Irregular honey-comb shaped villages interlaced with prominent fences constructed of live or dead brush.

Shifting agriculture: Rectilinear cuttings into the forested slopes, often with large, isolated trees left standing after brush is cleared for planting (Figure 3). Fallow fields of one or two years were also discernible, but were not included in this class; only active fields were mapped.

Bare laterite plateau: Typically devoid of woody vegetation and displaying a medium gray tone (on black-and-white photography) or dull reddish hues (on color photography) with a smooth texture.

Gallery forest (a multiple-canopy riparian forest): Differentiated from a dry forest type by density and size of tree crown; only large stands of gallery forests were interpreted. This class is characterized by dark tones and a very rough texture. On the larger scale 1989 photography, the band of forest along rivers was delineated in addition to the larger stands. Hence, the 1989 estimate for gallery forest area was inherently greater than that of 1953.

Vegetated slope: This class is actually covered by a dry forest characterized by medium gray tones and a rough texture on the black-and-white mapping photography. Fallow fields were included in this class.

From the 1989 ARSC photography, it was also possible to identify two subclasses of vegetated slopes and secondary agriculture showing signs of active erosion. These classes were derived from analysis of photography, discussions with Government of Guinea's Ministry of Forestry staff, and site visits. Eroded areas were identified by the accumulation of sediment at the foot of slopes or on the slope itself. It was more difficult to identify eroded areas on the 1953 photography with confidence, but a sample area was mapped to assess expansion of eroded areas resulting from intensified land use. It was not possible to estimate the degree (intensity or stage) of erosion with this data set; only spatial extent was considered.

Mapping Techniques

Aerial photographs were manually interpreted for land use/cover with a mirror stereoscope and plastic overlays. Interpretations were mosaicked onto a single map and digitized into Earth Resources Laboratory Application Software (ELAS) at

Table 1. Remote Sensing Data Collected Over Diafore/Kabari Study Site

Date	Sensor	Format	Scale at Interpretation (Spatial Resolution)	Source
March 1953	Aerial Camera	9″ × 9″ B & W Prints	1:50,000	National Direction of Forest and Game, Conakry, Guinea
7 March 1973	Landsat MSS	Computer Compatible Tape	1:40,000 to 1:125,000 (79m)	EOSAT/EROS Data Center
15 April 1985	Landsat MSS	Computer Compatible Tape	1:40,000 to 1:125,000 (79m)	EOSAT/EROS Data Center
April 1989	Aerial Camera	11″ × 11″ B & W and Color IR Prints	1:30,000	HZ Aerial Survey and Mapping Company, Conakry, Guinea
31 May 1989	Aerial Camera	35MM Color Slides	1:20,000	Arizona Remote Sensing Center, Tucson, Arizona
31 May 1989	Video Camera	780 × 488 Pixel VHS Image	1:6,000 (4m)	Arizona Remote Sensing Center, Tucson, Arizona

NASA Stennis Space Center. The photomap could not be registered to the best available topographic map (1:250,000-scale U.S. Army Map Service) because of scale differences and poor map quality. Instead, the 1985 Landsat MSS image was registered to the U.S. Army map and served as a reference base. Next, the 1953 photomap was registered to the satellite image. The ELAS map was then converted to Earth Resources Data Analysis System (ERDAS) format at the University of Arizona and transformed into vector format in pcARC/INFO[2].

The 1989 map was produced through the combined interpretation of the aerial color 35-mm photos and video imagery with interpolated interpretations from the HZ photography (*cf.* Table 1) on areas not covered during the ARSC aerial survey. The difficulty of mosaicking a series of video frames precluded the use of video imagery as the main data source (Marsh *et al.*, 1990). However, the infrared imagery the video provided was useful to distinguish between denser gallery vegetation and dry forest on slopes.

The HZ photography was interpreted first and used as a template upon which the ARSC photointerpretations were transferred with a reflecting projector. Field samples were used to check the final interpretations. The resultant land-use map was registered to the 1985 Landsat reference and digitized.

LAND-USE CHANGE ANALYSIS

We compared the extent of agricultural land interpreted from 1953 photography (Figure 4) with interpretations made from 1989 photography (Figure 5) to identify change. The two sets of photos were not comparable in scale or quality, so we concentrated on changes that were easily interpreted and unambiguous. This restricted analysis to changes in agricultural land use rather than deforestation. Moreover, it is unclear whether the vegetated slope class should be functionally identified with the gallery forest type for assessment of deforestation. Woody vegetation on slopes is not allowed to reach maturity, (i.e., become a forest) except in a few protected areas. On the other hand, from a satellite or airplane platform, it is often not possible to differentiate the two vegetation types. Hence, we concentrated on growth in the more easily observed agricultural land uses.

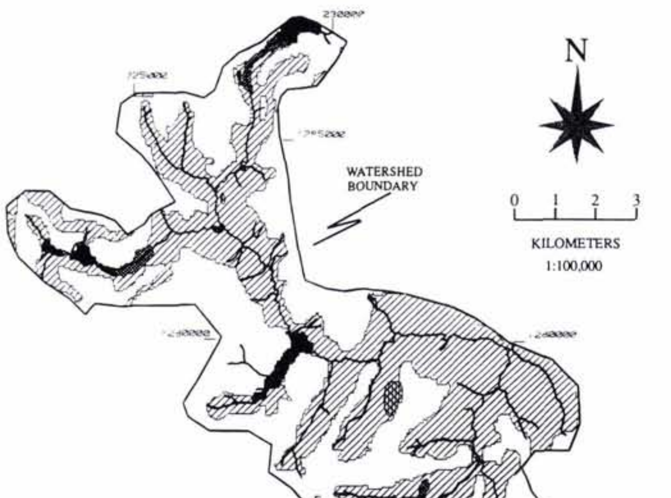

Fig 4. Diafore-Kabari land cover, 1953.

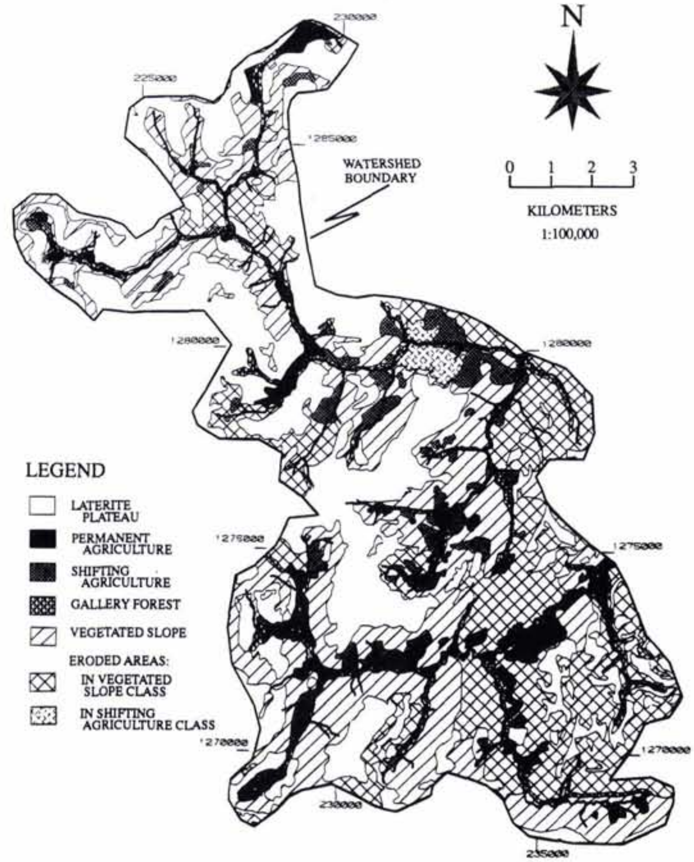

Fig 5. Land cover, 1989.

Change Analysis from Aerial Photography

A map of three land-cover classes (primary agriculture, shifting agriculture, and eroded shifting agriculture) was extracted within the GIS from the 1989 interpretation. A corresponding map from 1953 was logically subtracted from the 1989 map to create a new map depicting agricultural change. For display purposes, the original 1953 agricultural map was merged with the change map (Figure 6). Area measurements for each class for the two dates were summed using database capabilities to obtain estimates of changes in absolute area (Table 2).

Change Analysis from Landsat MSS Imagery

Landsat MSS images from 1973 and 1985 were registered to the 1:250,000-scale base map, and a scene subset (339 by 428 pixels) covering the project area was extracted for classification.

A hybrid multispectral classification approach (Fleming, 1975) was used for both dates. In the first phase, an unsupervised clustering algorithm derived ten spectral classes for the 1973 scene and eight for the 1985 scene. The spectral clusters were used to seed a maximum-likelihood classifier. Resultant spectral

[2]The use of trademarks is for the benefit of the reader and does not constitute an endorsement by the University of Arizona.

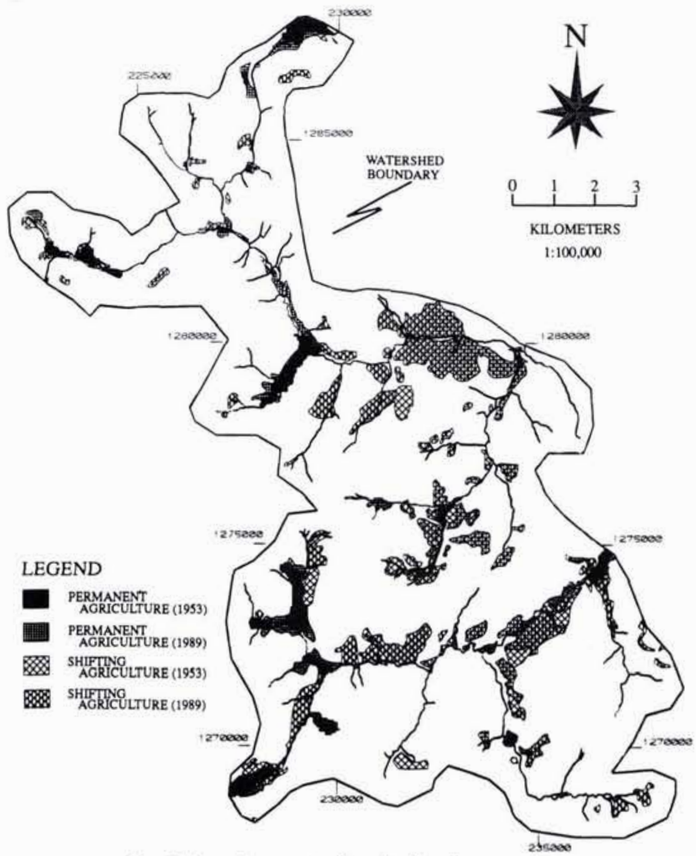

FIG 6. Location map of agricultural expansion.

TABLE 2. SUMMARY OF LAND-COVER AREA ESTIMATES FROM AERIAL PHOTO INTERPRETATION (HECTARES)

	1953 Photos	1989 Photos & Video
Laterite Plateau	5734	4661
Vegetated Slope	7902	4089 3204 (Eroded)
Permanent Agriculture	292	432
Gallery Forest	135	642
Shifting Agriculture	243	1125 153 (Eroded)
Total	14306	14306

classes were merged to four land-cover classes (agriculture, vegetated slope, laterite plateau, and riverine vegetation), smoothed with a 3 by 3 majority filter, exported to ARC/INFO, and registered to the common Landsat reference.

No aerial photography or field data existed for either the 1973 or 1985 data sets, so it was not possible to verify classification directly. Due to the rapidly changing nature of vegetated slopes, ancillary data from years other than the date of satellite image acquisition are less reliable than data collected in the same year. However, during photo interpretation we found that certain contiguous home garden groupings, gallery forests, and laterite plateau had remained constant in size and location between 1953 and 1989. These relationships were used to label spectral classes according to the defined land-use/cover classes. The area in land-use classes was summed for each date (Table 3).

TABLE 3. SUMMARY OF LAND-COVER AREA ESTIMATES FROM LANDSAT MULTI-SPECTRAL CLASSIFICATION (HECTARES)

	1973 MSS	1985 MSS
Laterite Plateau	2794	2766
Vegetated Slope	7658	7890
Permanent Agriculture	243	581
Gallery Forest	3611	3069
Total	14306	14306

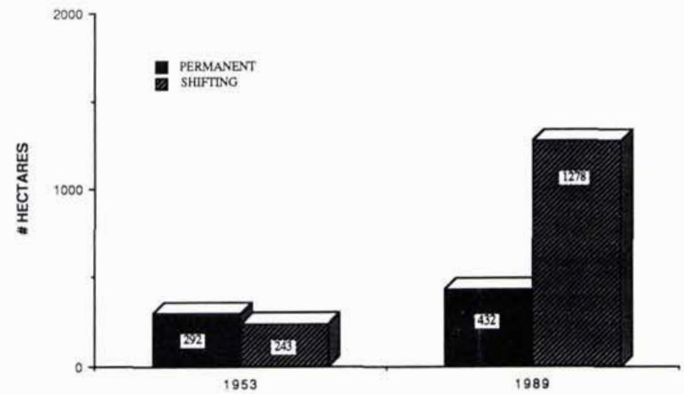

FIG 7. Agricultural expansion, 1953 - 1989.

RESULTS

AERIAL PHOTOGRAPHY

Between 1953 and 1989, the area under primary agriculture expanded from 292ha to 432ha, an increase of 48 percent (Figure 7). As expected, a comparison of Figures 4 and 5 suggests this growth occurred in bottomlands and on vegetated slopes.

The most striking result was a five-fold increase in shifting agriculture from 243ha to 1278ha. This change occurred almost entirely (98.7 percent) within the vegetated slope class. Although it is possible that secondary agriculture was underestimated to some degree in the 1953 photography, this change is still pronounced and impressive.

The extent of eroded area mapped on the 1989 photography was 3357ha. The area in this class is greater than in shifting agriculture, but the difference can be explained by the fact that signs of erosion persist after cultivators leave the slopes in fallow.

From the sample site mapped for erosion expansion, we found an increase in eroded area from 17 percent to 40 percent of the total vegetated slope area. This translates to an average increase of 0.66 percent/yr.

LANDSAT MSS

Our analysis of Landsat MSS data from 1973 and 1985 showed that agricultural land use increased from 228ha to 581ha (Table 3). Although the larger groupings of home gardens were detected (Figures 8 and 9), other areas fell into this class that were not permanent agriculture in either 1953 or 1989. Probably these isolated units corresponded to bare areas caused by shifting agriculture or naturally occurring barren surfaces.

The area of gallery forest on both data sets was greater than the total we found from analysis of the aerial photography and field data (*cf.* Tables 2 and 3). We feel that MSS data cannot consistently distinguish between gallery and dense stands of dry forest because of their spectral similarity. Despite this, the

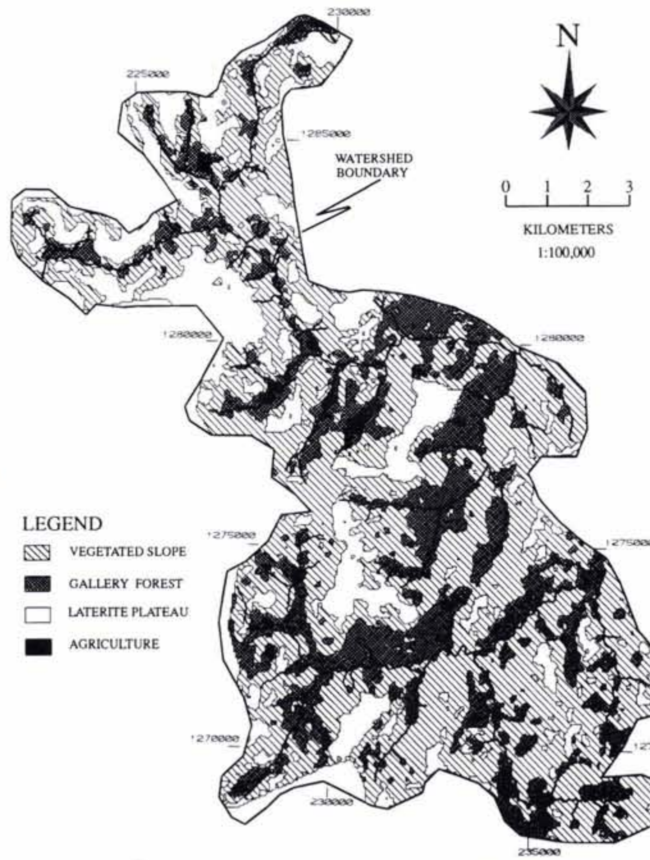

FIG 8. 1973 Landsat MSS classification map.

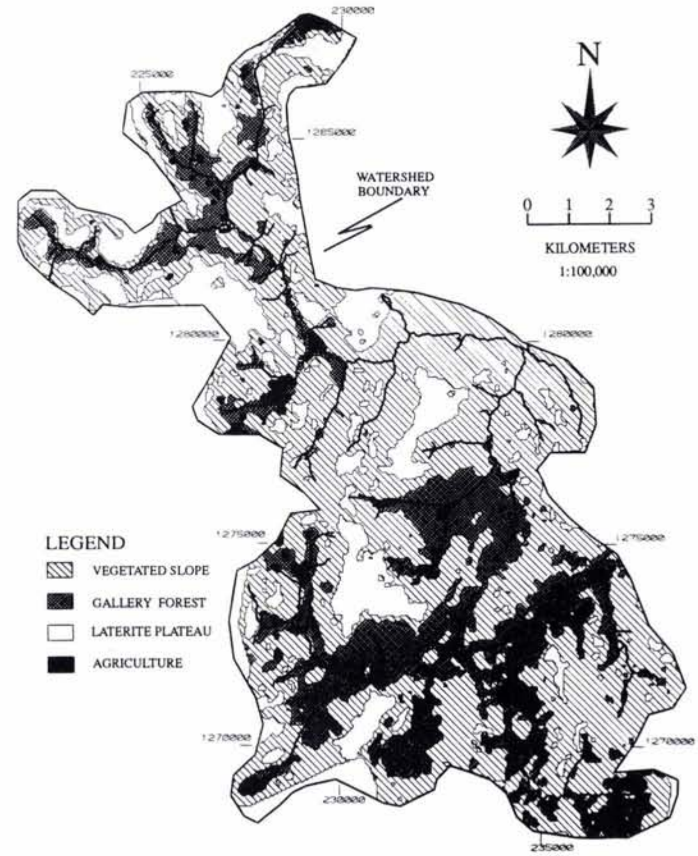

FIG 9. 1985 Landsat MSS classification map.

analysis shows a decrease in the amount of forested area, from 3611ha to 3069ha.

SENSOR PERFORMANCE

A qualitative comparison of the utility of each sensor type to map basic land-cover classes found in the Guinea Highlands is offered below (Table 4). These observations are based on our experience and knowledge of the project area.

Gallery forest. In the bottomland environment, removal of gallery forest is restricted because of the need to protect river banks from erosion. Nevertheless, local officials claim that the width of these gallery forests has diminished in recent times. It was not possible to substantiate this observation with the available data because the gallery forests on the 1:50,000-scale 1953 photography were too narrow to be mapped accurately. Both the color aerial photography and the video imagery were adequate for delineating this forest type. Working scales of 1:30,000 or larger are required to map the extent of the large trees bordering rivers.

Permanent agriculture. Both aerial photography and video imagery are excellent for mapping the extent of home gardens. Even with 1:50,000-scale black-and-white photography from 1953, it was possible to detect isolated dwellings surrounded by a permanent field.

It was not possible to map permanent agriculture accurately with Landsat MSS data. Isolated home gardens with their occasional fruit trees were not detected by MSS; only larger groupings were identified. Other areas, probably not permanent agriculture, were included in this class. This misclassification seemed to be consistent in magnitude and direction in both the 1973 and 1985 data sets, which suggests that MSS data might be used with some confidence to target areas in the Fouta Djallon that are undergoing change. For example, Figure 10 shows agricultural expansion assessed with Landsat MSS between 1973 and 1985. Once identified, these areas can be subjected to more intensive data collection with a combination of sensors (e.g., 35-mm photography; aerial video) and field work.

TABLE 4. QUALITATIVE ASSESSEMENT OF FOUR SENSOR TYPES FOR DETECTING LAND-COVER CLASSES WITHIN THE GUINEA HIGHLANDS

	Land-Cover Classes				
Sensors	Gallery Forest	Permanent Agriculture	Vegetated Slope	Shifting Agriculture	Laterite Plateau
Color 35-MM Photos 1:20,000	V. Good	Excellent	Good	Good	V. Good
B & W 70-mm Photos 1:30,000	Good	Good	Good	Fair	V. Good
IR Video Imagery	V. Good	V. Good	V. Good	Good	Good
Landsat MSS	Poor	Fair	V. Poor	V. Poor	Good

Shifting agriculture/vegetated slope. These critical areas were most easily detected with the 1:20,000-scale ARSC color photography, but could be seen with some difficulty on the smaller scale black-and-white photos.

Shifting agriculture and vegetated slope classes were difficult to separate with MSS data because of their high spectral variability. This variation is due to several factors: (1) mixed pixel problems with occasional large trees remaining in fields after clearing; (2) growth of underbrush in fields farmed for a second year after clearing; (3) variations in soil type; (4) seasonal variations in spectral reflectance; and (5) variations in canopy density within the vegetated slope class.

Plateau. Bare laterite surfaces were easily detected with all data types.

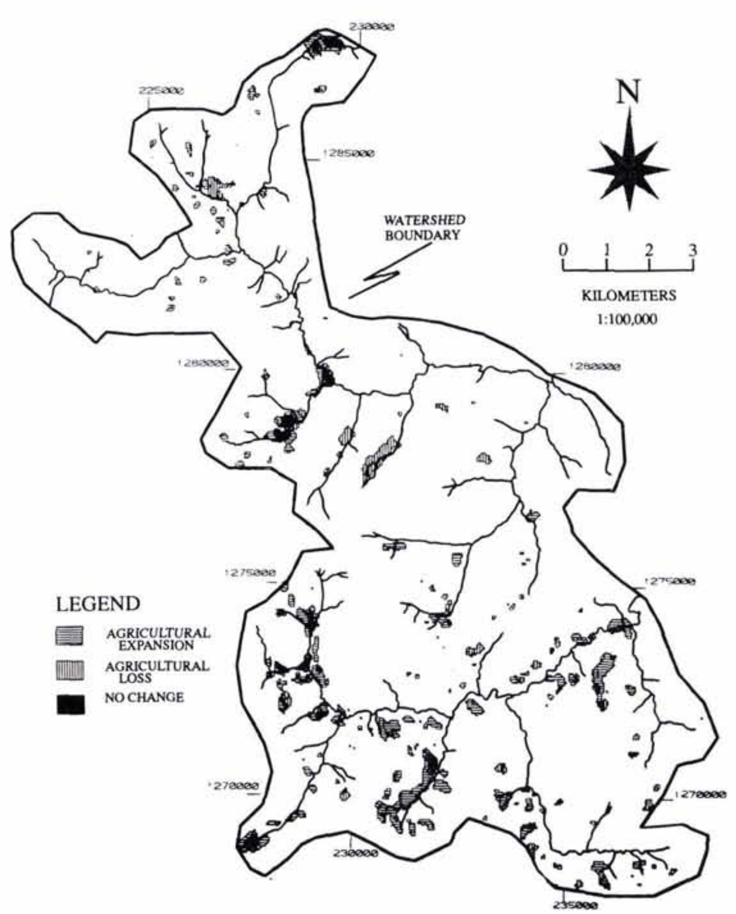

FIG 10. Landsat MSS agricultural change map, 1973-1985.

DISCUSSION

DEFORESTATION DYNAMICS

Our findings are consistent with earlier statements regarding land use change in the region. As suggested by Richard-Molard (1949), much of the best land for permanent agriculture was occupied prior to 1949. Thus, given that other land units (laterite plateau and most of the vegetated slope class) are less suitable for permanent agriculture, the main means of increasing production is by increasing the area under shifting cultivation. This simple strategy results in a decrease in the rotation period given that the available arable land is limited.

Richard-Molard's hypothesis assumes that no new land is developed. However, we found that permanent agriculture did expand along the river bottoms and, most significantly, up the lower valley slopes from existing villages. Thus, the intensification of cultivation involved both (1) expanding the area of shifting agriculture within a spatially fixed vegetated slope class and thus shortening the fallow period (*cf.* conceptual model below); and (2) increasing the area under permanent agriculture by extending into marginal slope areas. Both of these management practices accelerate erosion.

CONCEPTUAL MODEL OF ENVIRONMENTAL DEGRADATION

Based on the above results, it is possible to present a model that suggests future agricultural expansion and subsequent environmental degradation. The bulk of this expansion is a direct result of the 2.2 percent annual population growth (Varady, 1983). For this model, we assume (1) shifting agriculture occurs only within the vegetated slope class; (2) to maintain fertility, fields are cultivated for two years and left fallow for eight years (Heermans and Williams, 1988); (3) all the vegetated slope is assumed to be fertile (a best case scenario); (4) eroded areas are removed from production; (5) the increase in shifting agricultural area estimated from photointerpretation is constant at 2.5 percent/yr; and (6) expansion of eroded area in the vegetated slope class estimated from a sample site is 0.66 percent/yr. From Table 2:

Total uncultivated vegetated slope	4089 ha
Present shifting agriculture	+ 1125
Total hectares available for shifting agriculture	5214 ha

Given the eight-year fallow to two-year production ratio, only one-fifth of the total available area for shifting cultivation (5214/5 or 1043ha) would be used in any one year under present conditions. Because 1125ha are currently in use, the rotation must be shortened to maintain production. As more vegetated slope is eroded (0.66% * 5215ha = 34ha/yr), it is removed from potential production. Carrying the calculations forward in time, with shifting agriculture expanding at 2.6 percent or 29ha/yr, the fallow period must be shortened from eight to seven years after one cycle. As a consequence, crop yield should decrease due to a loss in soil fertility. Without any increase in inputs, more area would be brought into production and further accelerate erosion. Fallow periods must be shortened again and the resource base will continue its downward spiral.

CONCLUSIONS

This study was intended to assess the types and amount of deforestation in the Fouta Djallon region of Guinea, West Africa, using a variety of sensors coupled with geographic information systems technology. We found the greatest change in vegetative cover occurs on slopes where (1) shifting agriculture is expanding; as a consequence, (2) rotation periods are being shortened; and (3) permanent agriculture is being extended at increasing environmental cost and diminishing return. All of these factors reduce overall vegetation cover and increase erosion hazard.

Sequential satellite imagery can be used to identify areas showing overall increase in bare surfaces/shifting or permanent agriculture. After general areas (strata) of potential hazard are identified, large-scale photography/video imagery could be used to develop estimates of specific parameters of land degradation. In addition, historical aerial photography can provide a temporal dimension to environmental studies that is unavailable in any other data set.

ACKNOWLEDGMENTS

This research was funded by a grant from NASA (Grant No. NAGW - 1359). The authors wish to thank August Hartman and the U.S. Agency for International Development in Conakry, Guinea, for their training support, and Dr. Ourey Bah of the Guinean National Direction of Forest and Game for logistical support. Dr. Armond Joyce and the NASA Science and Technology Laboratory at Stennis Space Center provided technical support during the initial data preparation phase. We also wish to acknowledge the invaluable suggestions provided by Stuart Marsh, James Walsh, Chris Lee, and John Regan of the University of Arizona.

REFERENCES

Booth, W. 1989. Monitoring the Fate of Forests from Space. *Science*, (243): 1428–1429.

Boulet, J., and J. C. Talineau, 1986. *Contributions aux Etudes Socio-économiques: Rapport de Synthèse.* Project RAF/81/060: Aménagement Intégré du Massif du Fouta Djallon. Labé, Guinée: FAO Project Report, April. 26 p.

Carneiro, C. M. R., 1985. Monitoring the Modifications in the Forest Ecosystem of the Brazilian Amazon Region Through Remote Sensing Techniques. *Inventorying and Monitoring Endangered Forests* (Schmid-Haas, Ed.), International Union of Forestry Research Organizations Conference, Zurich, pp. 63–69.

Fleming, M. D., J. S. Berkebile, and R. M. Hoffer, 1975. *Computer Aided Analysis of Landsat-1 MSS Data: A Comparison of Three Approaches, Including a "Modified Clustering" Approach,* LARS Information Note 072475, Laboratory for Application of Remote Sensing, Purdue University.

Grainger, Alan, 1983. Improving the Monitoring of Deforestation in the Humid Tropics. *Tropical Rain Forest, Ecology and Management* (L. Sutton *et al.*, Ed.). Spec. Pub. #2 of the British Ecological Society. Blackwell Scientific Publications. pp. 387–395.

———, 1984. Quantifying Changes in Forest Cover in the Humid Tropics: Overcoming Current Limitations. *J. World Forest Resource Management*. 1984 (1): 3-63.

Green, K. M., 1983. Using Landsat to Monitor Tropical Forest Ecosystems: Realistic Expectations of Digital Processing Technology. In, *Tropical Rain Forest, Ecology and Management* (L. Sutton *et al.*, Ed.). Blackwell Scientific Publications. pp. 397–409.

Heermans, J., and P. Williams, 1988. *Natural Resource Management in the Fouta Djallon Watershed, Guinea: A Prefeasibility Study Conducted for the U.S. Agency for International Development*. Washington, D.C.: World Resources Institute. 49 p.

Hutchinson, C. F., R. A. Schwowengerdt, and L. R. Baker, 1990. A Two Channel Multiplex Video Remote Sensing System. *Photogrammetric Engineering & Remote Sensing* (in press).

Isbeque, J., 1985. *Exploitation des Données Météorologiques Disponibles Concernant l'Erosion Hydraulique du Fouta Djallon*. FAO: Rapport d'Activités auprès du GUI/82/003. 31 p.

Kio, P. R. O., B. A. Ola-Adams, J. O. Abayomi, 1985. Inventory and Monitoring of Tropical Forests: The Nigerian Experience. *Inventorying and Monitoring Endangered Forests* (Schmid-Haas, P., Ed.), International Union of Forestry Research Organizations Conference, Zurich. pp. 71–79.

Malingreau, J.-P., C. J. Tucker. N. Laporte, 1989. AVHRR for Monitoring of Global Tropical Deforestation. *International Journal of Remote Sensing* (10):855–967.

Marsh, S. E., J. L. Walsh, and C. F. Hutchinson, 1990. Development of an Agricultural Land-Use GIS for Senegal Derived from Multispectral Video and Photographic Data. *Photogrammetric Engineering & Remote Sensing*, (56): 351–357.

McGahuey, M. L., 1985. *An Investigation of the Soil, Forestry and Agricultural Resources of the Pita Region of the Republic of Guinea: Findings from a Field Investigation and Recommendation for Their Improvement.* Final Report: USAID Contract #675-0410-5-00-8402-00, Aid Affairs Office, Conakry, Guinea. 89 p.

Meisner, D. E., 1986. Fundamentals of Airborne Video Remote Sensing. *Remote Sensing of Environment*, (19): 63–79.

Myers, N., 1988. Tropical Deforestation and Remote Sensing. *Forest Ecology and Management*. 1988 (23): 2–3.

Richard-Molard, J., 1949. Les Densités de Population au Fouta Djallon et dans les Régions Environnantes. *Proceedings: XVI Congrès International de Géographie*, Lisbon, Portugal, pp. 192-204 (not consulted, cited in Boulet and Talineau, 1986).

Pascual, J. F., 1986. *Quelques Aspects Géomorphologiques des Cuirassements dans le Massif de Fouta Djallon*. FAO Seminar Report: RAF/81/060. 56 pp. Available from National Direction of Forest and Game, Box 624, Conakry, Guinea.

Sader, S. A., and A. T. Joyce, 1988. Deforestation Rates and Trends in Costa Rica, 1940 - 1983. *Biotropica* 20(1): 11–19.

Soyer, J., and J. Wilmet, 1983. Environmental Study of Lubumbashi from 1973 to 1981 Using Satellite Imagery: Urban Expansion and Deforestation. *Geo-Eco-Trop*. 1983 (7): 67–81.

Varady, R. G. (ed.), 1983. *Environmental Profile of Guinea*. Prepared by the Arid Lands Information Center, University of Arizona for the U.S. Man and the Biosphere Program, U.S. Department of State. Tucson. 229 p.

Westinga, E., 1987. *Landcover Change Detection in the Fouta Djallon Highlands with Multitemporal Landsat Images*. FAO Seminar Report: RAF/81/060. Available from National Direction of Forest and Game, Box 624, Conakry, Guinea.

(Accepted 7 June 1990)