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# Forest Area Estimates from Landsat MSS and Forest Inventory Plot Data

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## **SUMMARY**

Forest area estimates for Puerto Rico from Landsat multispectral scanner data were compared with area estimates derived from black and white aerial photographs. Area estimates were adjusted according to a field check at 141 sample plot locations. Adjusted Landsat area estimates differed from adjusted photo area estimates by 1.7 percent. The sampling error for Landsat data was nearly twice the sampling error for photo-interpreted data.

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## INTRODUCTION

Forest area estimates are used worldwide for resource evaluation, monitoring, and planning. Recent concern about deforestation in the tropics has revealed the lack of current, reliable forest area estimates in many developing countries (UNESCO 1978). Many countries do not have the financial and technical resources at hand to conduct large scale forest inventories.

Landsat multispectral scanner (mss) data has, in recent years, been considered for its potential contribution to forest resource evaluation. Computer-processed satellite data can be substituted for data previously obtained from time-consuming photo interpretation. A recent study has documented the feasibility of applying Landsat technology to forest inventory (Nelson and Hoffer 1979). Landsat imagery has been used in the tropics to monitor forest cover alteration (Williams and Miller 1979), and in Costa Rica, Landsat data was incorporated into a geographic data base to develop cover type estimates for resource analysis (Sader 1980). In the most recent World Forest Inventory, visually-interpreted Landsat images were the only sources of information for some remote regions in Latin America (Lanly et al. 1982).

In general, the most successful projects have combined Landsat with ground truth or other geographic information. Some studies have explored the possibility of merging Landsat data with forest survey field data gathered by the U.S. Forest Service (Langley et al. 1980; Mroczynski et al. 1980). These pilot studies have established the feasibility of incorporating Landsat data into a sampling framework and demonstrated the usefulness of a geographic information system for accurately registering forest survey plot data with the Landsat data.

This study was initiated after a recent inventory of Puerto Rico highlighted the limitations of existing aerial photography (Birdsey and Weaver 1982). The inventory data was used to assess the potential benefits from combining Landsat data with forest survey data in Puerto Rico.

## OBJECTIVES

The project goal was to develop rapid, efficient survey techniques for mountainous tropical regions. Specific objectives were:

1. Develop an area stratification based on terrain and Holdridge's ecological life zones (Holdridge 1969).
2. Compare forest area estimates from Landsat data with estimates from black and white aerial photography.
3. Evaluate potential benefits from combining Landsat data with forest survey data.
4. Explore usefulness of a geographical data base for combining the various data sources.

## STUDY AREA

A search for Landsat data covering Puerto Rico found only one usable scene with cloud-free coverage of the northwestern third of Puerto Rico (fig. 1). Two ecological life zones account for most of the area: the subtropical moist forest zone receives between 1,000 and 2,000 mm of annual rainfall, and the subtropical wet forest zone receives between 2,000 and 4,000 mm of annual rainfall (fig. 2). Mean annual biotemperature ranges from 18° to 24° C.

The moist forest zone includes the coastal plain, interior valleys, and a wide band of limestone hills. Crops, pasture, and urban land uses are common in the plains, valleys, and lower slopes. Secondary forests are developing on the less productive, steeper slopes which are no longer farmed. Portions of the limestone hills are virtually inaccessible due to extremely rugged topography. The hills support a complex forest vegetation on varied slope positions. Tall forests in the sinkholes, bottoms, and lower slopes grade into scrub vegetation or bare soil on the xeric upper slopes, ridges, and cliff faces. Steep, forested slopes, sensitive to disturbance, have little commercial forest management potential.

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The wet forest zone includes most of the higher, wetter sites in the central mountains. Active and abandoned coffee plantations are common, interspersed with pasture, cropland, and secondary forest. The steep slopes and high rainfall quickly cause soil erosion and reduced soil productivity when the land is cultivated. Coffee grown under shade trees reduces the exposure of bare soil to intense storms. A portion of this life zone receives high rainfall (more than 2,500 mm/year) on slopes greater than 60 percent. Some forested areas are critical water catchments and should remain under protective forest cover.

## METHODS

### Forest Survey

An initial estimate of forest area was made from a dot-count on black and white 1:20,000 aerial photographs taken in 1977. Forest area estimates obtained from the dot-count were adjusted according to a ground check of land use at each sample location. Data on species composition and timber volume were obtained by establishing permanent sample plots at all forested sample locations. A detailed site description was made for each forested location. Fieldwork was done in 1980 and included land cover checks at 437 locations.

### Landsat Image Processing

The Landsat scene was processed at the Mississippi Remote Sensing Center (Miller et al. 1982). The digital Landsat data were classified using a technique which combined elements of both supervised and unsupervised classification procedures. This technique consisted of selecting several training fields from the study area, with each field including a dominant cover type and a variety of other cover conditions. Statistics (reflectance values) from each training field were pooled for clustering into spectrally similar classes (Lockheed Engineering Co. 1977). Clusters were then assigned cover classes based on ancillary information, including panchromatic 1:20,000 stereo aerial photographs, topographic quadrangle maps, half of the ground truth information from the 1980 forest survey, and some additional field observations. Once the clusters were assigned the appropriate cover classes, the entire scene was classified using the maximum likelihood approach.

Prior to image processing, the survey area was stratified into two regions using the life zone classification. The two life zones have different land use patterns and produce different spectral responses in similar vegetation. In order to improve classification accuracy, each life zone had to be classified separately. To accomplish this, the entire scene was classified twice using unique sets of training statistics from each life zone. Only data which fell inside the life zone from which the statistics were taken was valid.

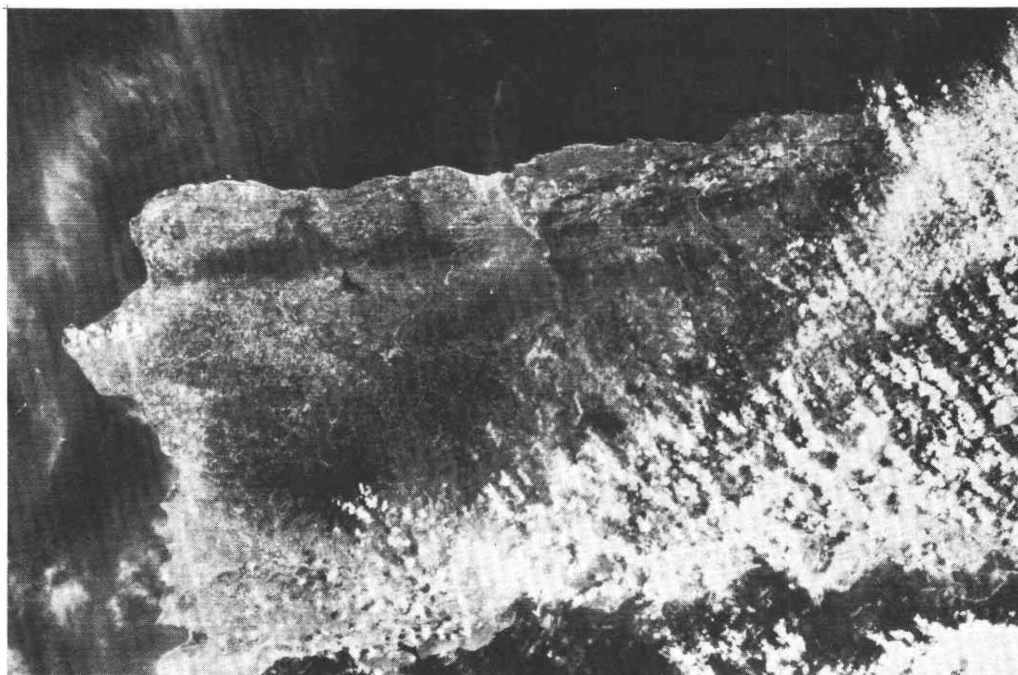


Figure 1.—Landsat MSS coverage and atmospheric conditions, Western Puerto Rico, March 30, 1978.



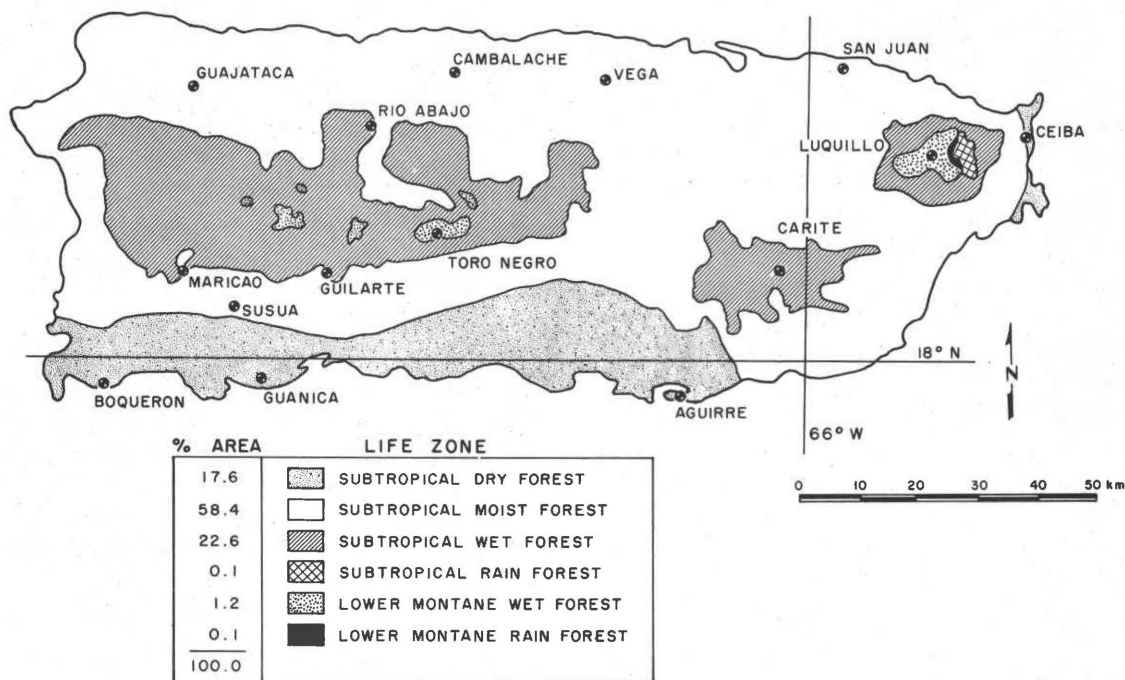


Figure 2.—Ecological life zones of Puerto Rico.

In order to stratify the Landsat data, classify each stratum separately, recombine the strata into a single product, and make use of ancillary data, a geographic data base was constructed. The data base employed a grid or cell-based system and an arbitrary set of coordinates. The data base allowed access of all data types or classes from one cell, or a group of cells, simultaneously.

A visual interpretation of a black and white print of the Landsat data revealed the presence of variable atmospheric haze over the study area. Reflectance values were elevated in the haze regions to an extent that varied with the density of the haze. In order to eliminate classification errors due to haze, only the haze-free portion of the Landsat scene was used in this analysis. The haze region was delineated on a 1:250,000 scale print of the data, then digitized and added to the data base.

### Merging the Data

The two classified Landsat data sets, digitized life zone boundaries, and the digitized haze boundaries were input to the data base for merging. By using the life zone map as a mask, the valid portion of each classification was extracted and the two portions were merged to produce one valid land cover map.

Each forest survey plot location was digitized within a particular 4-ha cover type cell (fig. 3). The 4-ha resolution ensured that most plots were correctly

registered within the identified cover type cell. The Landsat classification results were treated as an initial estimate of forest area, just as the aerial photos provided an initial estimate of area for the forest survey. The Landsat estimate was then adjusted according to actual ground cover at the forest survey plot locations. The adjusted estimate explains misclassified data cells and changes in land use between the date of image acquisition and the collection of ground truth. Sampling errors were estimated using random sampling formulae, as in the forest survey.

## RESULTS

To allow fair comparison of the three area estimation procedures, the region covered by atmospheric haze in the cloud-free portion of the Landsat scene was eliminated from the study area, leaving 205,000 ha or 23 percent of the land area of Puerto Rico. This area included 141 field plot locations from the forest survey for ground truth.

### Forest Survey

Area estimates based on 1980 forest survey data were computed for the haze-free portion of the study area for each of the two life zones (table 1). A total of 5160 photographic classifications were made, and 141 sample locations were visited in the field. The

adjusted proportion of forest area for the moist forest zone was 31 percent, and for the wet forest zone, 52 percent.

These area estimates can be further subdivided by land use categories based on photo and field observations (table 2). Results are similar to area estimates for the whole island since the study area represents the range of conditions found in Puerto Rico, excluding the dry southern coast. Forest cover is more prevalent in the wet forest zone, especially active and abandoned coffee shade. Nonforest land uses occupy more than two-thirds of the moist forest zone, with pasture and cropland together occupying 57 percent of all land.

Table 1.—Forest cover estimates for the haze-free study area from 1980 survey data

Forest life zone	Total area <i>hectares</i>	Proportion of forest land		Sampling error <sup>1</sup>
		Unadjusted	Adjusted	
Moist	122,484	51.9	30.5	3.1
Wet	82,888	71.9	52.1	3.7
Total	205,372	60.4	39.2	

<sup>1</sup>By random-sampling formula, 67 percent probability level.

The proportion of photo misclassification exceeded 25 percent for each life zone (table 3). In the moist forest zone nearly all misclassifications were due to difficulty in distinguishing forest from pasture in transition areas where trees and shrubs begin encroachment. Because of shadows and poor photography, pasture often appeared as non-stocked or young secondary forest.

In the wet forest zone, misclassification occurred when bananas, bamboo, fruit trees, and other vegetation common to rural residences appeared as forest in the photographs. Some plots were misclassified due to the presence of a new "shadeless" coffee variety. Land clearing between the photography date and the fieldwork also contributed to misclassifications. A land classification scheme which could yield better results with black and white photography has been developed (table 4).

#### Landsat Classification

Uncorrected Landsat forest area estimates for the haze-free region were similar to unadjusted forest survey estimates in both life zones (table 5). Active and abandoned coffee shade could not be distinguished from secondary forests; however, several

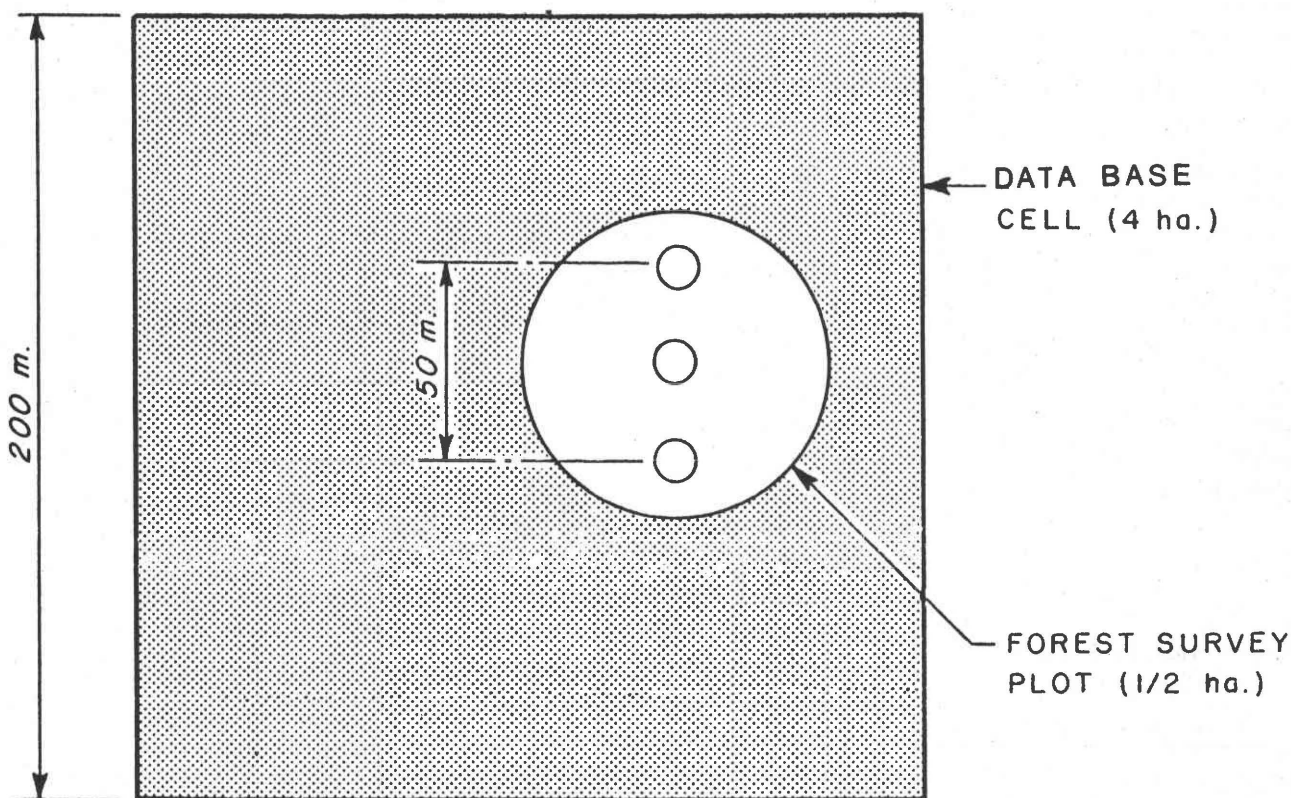


Figure 3.—Relative sizes of a Landsat data base cell and a forest survey plot area.

subdivisions of secondary forest and distinct agriculture/forest transition classes were found for each life zone (table 6). The classification scheme and the reflectance values for identical cover types were different for each life zone, indicating that treating each separately improved the overall results.

During processing an evaluation area was selected in each of the life zones, and land cover mapped by photo interpretation. Evaluation areas were selected with good photographic coverage to minimize photo-interpretation errors. The Landsat results were then compared to this "known" cover classification. This preliminary test indicated a fairly accurate forest/nonforest detection capability, with more variable results among specific cover classes (table 7). Detailed cover classes could not be distinguished due to the high proportion of "edge effect" between cover types. Many small farms are used for a variety of purposes, including fruit production, shade, vegetable gardens, etc. These mixed land uses were confused with non-stocked forest land in the moist-forest evaluation area, and agriculture/forest transition in the wet forest evaluation area.

Table 2.—Area by land use for the haze-free area from 1980 survey data

Land use	Forest life zone	
	Moist	Wet
	percent	
Forest:		
Nonstocked	5.2	0.0
Secondary	17.4	21.7
Abandoned coffee shade	6.7	17.8
Active coffee shade	1.2	12.6
Total forest	30.5	52.1
Nonforest:		
Inert <sup>1</sup>	12.4	14.8
Cropland <sup>2</sup>	27.8	18.6
Pasture <sup>3</sup>	29.3	14.5
Total nonforest	69.5	47.9
All land	100.0	100.0

<sup>1</sup>Urban and industrial areas, roads, rights-of-way, residential, water, other.

<sup>2</sup>Includes shadeless coffee and idle farmland.

<sup>3</sup>Includes unimproved pasture.

Table 3.—Photo classification results for 141 field plots

Land cover	Photo classification		Plots mis-classified	
	Moist forest	Wet forest	Moist forest	Wet forest
	number of plots			
Forest	40	56	18	18
Nonforest	34	11	1	0
Total	74	67	19	18

Table 4.—Land classification capabilities of black and white aerial photography for secondary forest cover in Puerto Rico

Cover class	Class description
Inert	Includes urban, residential, and industrial areas; rights-of-way; water; roads; other non-forest and non-agriculture uses.
Cropland	All cropland and orchards, shadeless coffee, and idle farmland.
Pasture <sup>1</sup>	Grassland with less than 10 percent tree and shrub crown closure.
Transition	Grassland with 10–50 percent tree and shrub crown closure.
Young secondary	Fine-textured appearance, occasional scattered large crowns, with crown closure more than 50 percent.
Secondary	Uniform intermediate crown texture, with occasional gaps or emergent trees.
Abandoned coffee shade	Coarse texture of large-crowned trees, with occasional gaps or emergent trees.
Active coffee shade	Large-crowned trees form an incomplete upper canopy layer; small trees and other vegetation visible between crowns.

<sup>1</sup> Will include some nonstocked forest land.

Several image processing problems were investigated during the classification procedure. Atmospheric haze partially covered the study area, raising the reflectance values of all land cover types. A test area in the haze region was successfully classified when treated separately. However, since haze conditions were not uniform, numerous classifications would have been necessary to apply this to the entire study area.

Shadowing and variable reflectance in the mountainous terrain also caused problems. Adding digital terrain data to identify additional strata was considered but rejected due to resolution incompatibility. Aspect and elevation change so rapidly in the complex terrain that National Cartographic Information Center digital data resolution excludes microtopographic relief, and an individual data cell would likely show only an average terrain reading.

### Merged Cover Estimate

Adjusted Landsat area estimates were nearly identical to adjusted aerial photo dot-count area estimates (tables 1, 8). When ground truth was used to correct Landsat area estimates, similar results were

Table 5.—Area by land use for the haze-free area from Landsat data<sup>1</sup>

Land use	Forest life zone	
	Moist	Wet
	percent	
Forest:		
Nonstocked	8.6	0.0
Young secondary	8.5	25.7
Intermediate secondary	19.0	16.8
Older secondary	10.3	27.6
Total forest	46.4	70.1
Nonforest:		
Inert <sup>2</sup>	21.4	0.2
Agricultural <sup>3</sup>	32.2	29.7
Total nonforest	53.6	29.9
All land	100.0	100.0

<sup>1</sup>Shadowed areas were distributed proportionally among other categories.

<sup>2</sup>Urban and industrial areas, roads, residential areas, water, other.

<sup>3</sup>Pasture, cropland, and agriculture/forest transition (idle farmland and unimproved pasture).

obtained despite a high percentage of misclassified data cells. The sampling error was higher than from photography due to a higher percentage of cell misclassifications, especially in nonforest cover types (table 9). The most common misclassifications occurred in distinguishing small agricultural plots and rural homesteads from forest land, much of which is in transition from the nonforest to forest category.

## DISCUSSION

During project execution, some problems surfaced regarding merged forest survey and Landsat data. For example, the field plots were too small, and photo interpretation too unreliable to extend the point sample cover class to a larger area which could be used for training. Also, the field plots were widely dispersed over the study area, and usable plots near identifiable features did not represent the full range of cover diversity. Several additional training sites were visited to complete the Landsat classification.

Certain processing techniques showed promise and will be tested in future projects. Preliminary data stratification, including haze level and detailed terrain classification, would effectively partition the data into relatively uniform subsets within each life zone. Each strata would then be classified separately using internal training statistics. Disadvantages to this approach are the additional time needed to perform the classification and extra ground truth requirements.

Some problems could be avoided if a better selection of aerial photographs or Landsat data were avail-

able. Persistent cloud cover, common in mountainous tropical areas, makes complete, cloud-free photographic coverage difficult to obtain. This also reduces the likelihood of the Landsat satellite passing overhead on a clear day. Puerto Rico's location outside a Landsat data receiving station compounds the problem; only a single year of data was available.

In sum, the study has identified some opportunities and problems associated with using remote sensing for forest area estimation in Puerto Rico. Both Landsat data and aerial photography gave roughly

Table 6.—Cover classes discriminated from Landsat data

Forest life zone	Cover class	Class description
Moist	Inert	Includes all highly reflective areas; construction, urban, residential, bare soil, clouds.
Moist, wet	Agriculture (crop and pasture)	Land primarily used for cropland or pasture with less than 10% brush cover or stocking; scattered trees are common.
Wet	Agriculture/forest transition	Low density brush/pasture, and forest/pasture edge.
Moist	Non-stocked forest (early transition)	Degraded and fallow cropland or pasture; small brush and ferns may predominate with scattered large trees common.
Moist, wet	Young secondary forest	Pasture or cropland with moderate to dense brush cover, reverting to forest, although occasional grazing may occur. Young growth is generally less than 5 m tall with or without larger old field trees scattered throughout or in clumps.
Moist, wet	Intermediate secondary forest	An intermediate stand structure where younger trees have reached the height of older trees; generally a relatively smooth canopy texture.
Moist, wet	Older secondary forest	Scattered larger dominant stems cause coarser canopy texture; considerable variation in individual crown tones.
Moist, wet	Shadow	Heavily shadowed areas, generally terrain shadowing; shadow/forest transition pixels; cloud shadows; and shadow/water transition.
Moist, wet	Water	All turbidity classes were grouped.



comparable area estimates. Each data source has unique classification problems originating with the difficult terrain and intermixed land uses found in many mountainous tropical regions. The study has demonstrated that Landsat MSS data is a viable alternative to panchromatic photographic data for area estimation in forest surveys. Where cloud- and haze-free Landsat data is available, photographic missions under difficult atmospheric conditions are unnecessary. Unfortunately, clear conditions are rare for many tropical mountain regions, and Landsat data availability is often sporadic. Complete digital cover classification under clouds or severe haze would require additional imagery, such as radar, which is not significantly affected by atmospheric conditions.

Table 7.—Comparison of photo interpreted land cover and Landsat solution for two evaluation areas

Forest life zone	Cover class	Photo results	Landsat results
		—percent—	
Moist	Forest:		
	Nonstocked	3	14
	Young secondary	1	9
	Intermediate secondary	78	55
	Older secondary	7	17
	Total forest	89	95
Wet	Nonforest:		
	Agriculture and inert	11	5
		100	100
	Forest:		
	Nonstocked	3	0
	Young secondary	6	18
	Intermediate secondary	80	18
	Older secondary	4	43
	Total forest	93	79
	Nonforest:		
	Agriculture and inert	7	1
	Agriculture/Forest transition	0	20
	Total nonforest	7	21
		100	100

Table 8.—Forest cover estimates for the haze-free study area from merged forest survey and Landsat data

Forest life zone	Total area	Proportion of forest land		Sampling error <sup>1</sup>
		Unadjusted	Adjusted	
	hectares	percent		
Moist	122,484	46.4	30.0	5.3
Wet	82,888	70.1	57.0	6.0
Total	205,372	55.9	40.9	

<sup>1</sup>By random-sampling formula, 67 percent probability level.

Table 9.—Landsat classification results for 141 field plots

Land cover	Photo classification		Plots mis-classified	
	Moist forest	Wet forest	Moist forest	Wet forest
	number of plots			
Forest	39	46	25	19
Nonforest	35	21	9	11
Total	74	67	34	30

## LITERATURE CITED

- Birdsey, R. A. and P. L. Weaver: The forest resources of Puerto Rico. U.S. Dept. Agric. Resour. Bull. SO-85, Southern For. Exp. Stn., New Orleans, La., 59 p. 1982.
- Holdridge, L. R.: Life Zone Ecology. Tropical Science Center, San Jose, Costa Rica, CA. 1969.
- Langley, P. G., J. van Roessel, C. Sheffield, and M. C. Place: Multiresource inventory methods pilot test (phase I): final report. Earth Satellite Corporation and USDA Forest Service, Houston, TX. 39 p. 1980.
- Lanly, J. P. et al. (ed.): Los recursos forestales de la America Tropical. Informe Tecnico 1, UN 32/6. 1301-78-04, ISBN 92-5-301066-5, 343 pp. Rome. 1982.
- Lockheed Engineering Co: User documentation, EOD-LARSYS, Earth Observ. Div. version of the LARS system. EOD, JSC, NASA. Houston, TX. 1977.
- Miller, W. F., J. Clark, R. Smith, and R. Birdsey: Resource evaluation techniques for mountainous tropical forests: Landsat capabilities. The Mississippi Remote Sensing Center, Miss. State, MS. 1982.
- Mroczynski, R. P., R. M. Hoffer and R. F. Nelson: Evaluation of Landsat data analysis for forest survey. Dept. of For. and Nat. Re. LARS. Purdue Univ. Submitted to: North Central For. Exp. Stn., U.S. Forest Service, St. Paul, MN. 1980.
- Nelson, R. F. and R. M. Hoffer: Computer-aided processing of Landsat MSS data for classification of forestlands. LARS Technical Report 102679. Purdue University, Indiana. 102 pp. 1979.
- Sader, S. A.: Renewable resource analysis and monitoring in Costa Rica. In: Proceed. of the Fourteenth Int'l Sympos. on Rem. Sens. of Environ. Vol. II. April 23 - 30, 1980. Environ. Res. Inst. of Mich., Ann Arbor, MI. pp. 1251 - 59. 1980.
- UNESCO: Tropical Forest Ecosystems: A State-of-Knowledge Report. UNESCO/UNEP/FAO. France. pp. 17 - 32. 1978.
- Williams, D. L. and L. D. Miller: Monitoring forest canopy alteration around the world with digital analysis of Landsat imagery. NASA. Greenbelt, Maryland. 45 p. 1979.

**Birdsey, R. A., W. F. Miller, J. Clark, R. H. Smith. Forest area estimates from Landsat MSS and forest inventory plot data. Research Paper SO-211, New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station; 1984. 7 p.**

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**Additional Keywords:** Tropical forest inventory, remote sensing, forest resources.