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Landsat Assisted Forest Land-Cover Assessment of the Philippine Islands

The project provided the geographic distribution of forest resources and a measurement of land areas occupied by major forest-related land-cover types.

Abstract: *A nationwide forest land-cover assessment was performed for the Republic of the Philippines using Landsat digital data and aircraft photography. This forest cover assessment was the first phase of a national forest inventory program that will update the last intensive nationwide inventory conducted in the mid-1960's. The objective was to perform a rough estimate of the country's total forest resources and to identify the areas that have undergone the greatest amount of forest to non-forest land-cover change. Landsat multispectral scanner data for thirty 185 by 185 km scenes were classified into five forest related land-cover classes. Results were comprised of thirty 1:500,000 scale thematic overviews of the country showing the location of the five major forest-associated land-cover types, and of area measurements for each type for each major political subdivision and for the entire country.*

Introduction

The utilization of the forest resources of the Republic of the Philippines has increased substantially over the past ten years. Harvesting of these forests under concessions granted by the government has accelerated since the mid-1960's. Shifting cultivation as well as other activities of man are also claiming portions of the forest land and hampering reforestation of harvested areas. The Department of Natural Resources (DNR) of the Republic of the Philippines is responsible for monitoring these forest lands. In 1976, DNR undertook the task of identifying trends in land-cover changes caused by the increased utilization of the nation's forests. This task was the first phase of a national forest inventory program that will update the last intensive nationwide inventory taken in the mid-1960's. DNR's objectives for this first phase were to (1) perform a rough estimate of the country's total forest resources and (2) identify the areas that have undergone the greatest amount of forest to non-forest land-cover change since the mid-1960's.

DNR was required to perform this forest

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land assessment task within six months. In search of new tools to help assess the nation's forest resources, DNR identified Landsat technology, coupled with limited aerial reconnaissance, as a potentially cost-effective way to classify the major forest-associated land-cover categories.

The Republic of the Philippines is located in the tropics between 5°N and 20°N latitude. The country covers approximately 300,000 square kilometres, and is composed of over 7000 islands of extremely varied topography. Dipterocarp forests (Philippine mahoganies) cover the interior of many islands. The thousands of kilometres of shoreline sustain dense mangrove stands. Inland lowlands are often characterized by extensive wetlands and tropical swamps.

The country's variability in weather and climate parallels the diversity of the land cover. Characteristic weather conditions include high temperature, high humidity, persistent cloud cover, and tropical rainfall. All of these factors pose problems for any land-cover identification effort, particularly any effort that utilizes satellite and aircraft remote sensing.

DNR developed an approach in cooperation with the General Electric Company Space Division to test the utility of Landsat data in stratifying the land areas of the Philippines into five forest-associated land cover classes. These classes were full and partial canopy dipterocarps, mangrove, high elevation forests, and non-forest wetlands. Digital multispectral scanner data for thirty Landsat scenes were processed to yield results that provided (1) 1:500,000 scale thematic overviews of the country showing major forest-associated land-cover categories and (2) quantitative estimates of the area occupied by each category. The results were compared with the last forest inventory, and conclusions were presented to government officials to demonstrate how the forest-associated land-cover had changed over the past ten years.

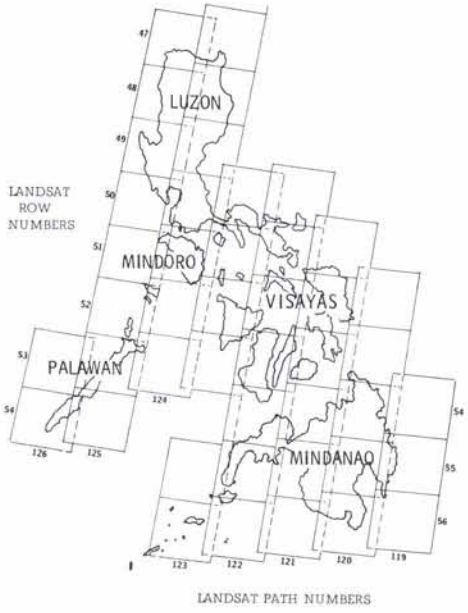

FIG. 1. Landsat coverage of the Philippine Islands.

METHODOLOGY

LANDSAT DATA

The land area of the Philippine Islands is covered by approximately thirty Landsat scenes. Figure 1 illustrates the distribution of Landsat frames over an outline of the major islands. These Landsat scenes were acquired by Landsats 1 and 2 between October 1972 and April 1976. The majority of the images came from late 1972 to early 1973. The data selected represented the most recent data available with workable cloud cover. Limited data were available for 1974-1976 because Landsat 1 had limited recording capabilities during that period and dense cloud cover often coincided with Landsat overpasses. Sun angle, cloud cover, the satellite, and the time between the first and last image of the series all introduced variation into the digital analysis. To account for these variations, the digital analysis of each scene had to be considered separately. A full description of the Landsat digital analysis techniques used in this project is presented later in this article.

Prior to the digital Landsat analysis, a Landsat color photographic mosaic of the Republic of the Philippines was constructed to serve as an index and ready reference during analysis. Photographic color composites of each scene (MSS bands 4, 5, and 7) were produced and pieced into a precision mosaic by the General Electric Photographic Engineering Laboratory in Beltsville, Maryland. The mosaic was not only a valuable reference during the entire study, but also a popular visual within the Philippine government.

SUPPLEMENTARY DATA

In order to accurately interpret or classify Landsat data, knowledge of the geographic area being analyzed is imperative. Detailed information about an area, such as its topo-

graphic and vegetative composition, provides an interpreter with the references needed to make intelligent land-cover classification decisions. To support this Landsat survey of the Philippines, a land and aerial "ground truth" mission was conducted by DNR and GE personnel. The objectives of the ground truth mission were to

- Familiarize the analysts with the variations in forest-associated land-cover types within the major ecozones and political regions of the Philippines,
- Collect a documented photographic record of land-cover types within representative test areas to be used for reference in the Landsat digital classification analysis, and
- Compile existing DNR maps (1:50,000 scale) and aerial photography (1:15,000 scale) of major areas of interest.

DNR personnel partitioned the country into five major timber producing regions that corresponded to the major islands or groups of islands. Three to six ground truth test sites were then selected within each of these major regions. The number and size of the sites selected depended on the size of the region and the vegetative cover complexity within the region. Flight lines for low-level reconnaissance by light aircraft were planned for each of these test sites. During the flights DNR and GE personnel compiled observations of forest types, density, crown closure characteristics, species, volume estimates, topographic features, and other forest-related observables. Observations were also made over non-forest areas. Thirty-five millimetre slides were taken from the aircraft with hand-held cameras in order to document each of the test sites. Several sites that were easily accessible were also visited on the ground in order to obtain another level of information. All observations, along with existing DNR maps and aerial photographs of selected areas, were thoroughly reviewed by DNR and GE personnel associated with the analysis of Landsat data. These supplementary data provided the analysts with the information necessary to make knowledgeable Landsat data classification decisions.

SELECTION OF FOREST-ASSOCIATED LAND-COVER CLASSES

The Landsat survey of Philippine forest resources was intended as a first step toward a comprehensive national forest inventory. The land-cover categories that can be discerned by a satellite are not equivalent to the detailed classes that are required in a conventional forest inventory. However, several forest-related land-cover classes can be defined by Landsat. Preliminary analysis of test site data indicated that five basic forest-related land-cover categories applicable to DNR's survey requirements could be uniformly identified. These categories were full canopy dipterocarps, partial canopy dipterocarps, mangrove, mossy (high elevation) forests, and wetlands in the proximity of forest areas. Other land-cover categories such as agriculture, range, and urban were also extracted over specific regions of interest to DNR, but a national inventory of these land-cover types was not attempted. The five identified forest-related categories met DNR's requirement to identify the major trends in the utilization of the nation's forest resources.

ANALYSIS OF LANDSAT DATA

The primary goal of digital processing was to classify the data from the thirty Landsat scenes that cover the Philippine Islands into major forest-related land cover types and to compute the total land area occupied by each forest type.

All digital processing was performed at General Electric Company's Digital Image Analysis Laboratory (DIAL) in Beltsville, Maryland. DIAL processing capabilities rely primarily on a minicomputer-based, man-machine interactive processing system. Due to the variation in Landsat source data as described previously, the spectral nature of the forest-related land-cover classes had to be addressed on an individual scene basis. No attempt was made to extend signatures between scenes. For a typical scene, four to six identified subscenes (9 by 9 miles each) associated with ground truth test areas were extracted from the Landsat computer compatible tapes. The subscenes were then displayed on the DIAL color TV monitor and interactively analyzed to obtain multispectral signatures for each land-cover class. Individual class signatures were normally consistent within a scene. However, when substantial atmospheric or ecozone variations existed within a scene, multiple sets of signatures for the same land-cover class were required. Developing the best multispectral signature set for a scene was an iterative process. DIAL interactive computer processing capabilities facilitate this iterative process because they allow the analyst to evaluate his classification immediately and to modify results as appropriate to obtain the most meaningful and accurate classification. The qualitative accuracy of each class in this study was evaluated by the analysts against

the available ground truth. Upon completion of the digital analysis, classification accuracy tests were performed by DNR for selected areas.

The multispectral signature sets established on the subscenes were then applied to classify the entire Landsat scene using DIAL bulk, or large area, processing. Political boundaries and other polygons can be introduced into the bulk processing in order to calculate and output results for selected areas within the full scene. The polygon inputs provide the capability to account for Landsat scene overlap, cloud cover, and other spatial considerations. Bulk results also include printouts of picture element counts documenting how much land area in each scene was occupied by each forest-related land-cover class. The pixel counts were readily converted to hectares and appropriately combined to yield the final area measurements.

The final step was to transfer the classification results from digital form to photographic form by means of a digital film recorder. Information for the entire Landsat scene was transferred onto a film transparency, which in turn was enlarged to a paper print at desired scale. This individual scene analysis technique was repeated 30 times until scenes covering the entire nation were processed.

Results and Discussion

This cooperative Philippine DNR and General Electric Company project provided two important parameters relative to the forest resources of the Republic of the Philippines: (1) the geographic distribution of forest resources and (2) a measurement of land areas occupied by major forest-related land-cover types.

The geographic distribution of the major forest cover types was presented in the form of thirty 1:500,000 photographic prints covering the entire country. Each print covered an area equivalent to one Landsat scene (185 by 185 km). The forest-related cover types that were classified and mapped included

- Full canopy closure dipterocarps
- Partial canopy closure dipterocarps—reproduction areas and brush
- Mangrove forest
- Mossy or high elevation forest
- Non-forest land—wetlands, marshy areas, and small water bodies in the proximity of forested areas.

Each of the above classes was represented on the photographic prints in a unique color. Areas that were not classified (i.e., agricultural areas, urban, etc.) were retained in their original false color rendition, similar to Landsat color composites. This provided scene background for easier geographic orientation. Where possible, areas that were obscured by clouds on the selected Landsat images were analyzed using supplementary Landsat images from different dates when that area was cloud-free.

The area measurements for the major forests types were compiled for each Landsat scene, and then appropriately combined for the following political subdivisions: Mindanao, Luzon, Mindoro, Palawan, and Visayas. The overlap between the Landsat frames was accounted for during the bulk classification process by properly selecting only a portion of each 185 by 185 km frame.

The results were verified by DNR personnel by comparing selected portions of Landsat thematic maps with corresponding recent aerial photographs and with conditions on the ground at several of the previously selected test sites. DNR personnel concluded that the overall accuracy of classification of the major forest types was between 85 and 95 percent, depending on the complexity of the area. Areas with more homogeneous forest cover and not in mountainous terrain exhibited high classification accuracies. The major item contributing to misclassification was high relief and its associated shadow areas, especially in Landsat data acquired during winter (low sun elevation). The use of Landsat data from many different dates also contributed to some inconsistencies in classification in the overlap region between scenes.

The final area measurements for this forest-associated land-cover classification are summarized in Table 1. The area totals for each forest type are listed by region, and for the entire nation. The results show that 38 percent of the country is covered by forest. The largest portion of these resources is composed of the full canopy dipterocarp forest.

The pictorial and numerical results together make up a synoptic view of the forest situation in the Philippines. This approach provided the DNR with a unique view of the entire country. Even though this information is of limited value for the intensive day-to-day management of forest resources, it provided several facets of great importance to the Philippine government. Most important, when compared with the previous inventory, it indicated numerous areas, especially

TABLE 1. FOREST-ASSOCIATED LAND-COVER AREA MEASUREMENTS SUMMARY, BY REGION AND FOR THE PHILIPPINE ISLANDS

Island or Region	Total Land Area	Land-Cover Category/ Area Measurements in Hectares						Forest Coverage By Region**	
		Forest Full Closure	Forest Partial Closure	Forest Obscured By Clouds	Forest Mangrove	Forest Mossy	Non-forest Wetlands	Hectares	%
Mindanao*	10,199,840	2,411,869	1,135,765	721,685	39,810	2,622	36,408	4,311,751	42.27
Palawan	1,489,626	675,681	312,324	87,030	34,853	30	92	1,109,918	74.51
Luzon	11,625,410	2,177,671	1,406,442	578,837	10,924	52	213,160	4,113,926	35.39
Mindoro	1,024,457	272,190	187,412	30,877	6,701	4,516	35,418	501,696	48.97
Visayas	5,660,622	474,356	775,698	101,474	13,845	—	67,806	1,365,373	24.12
TOTALS									
In Hectares	29,999,955	5,951,767	3,817,641	1,519,903	106,133	7,220	352,884	11,402,664	
%		19.84	12.73	5.07	0.35	0.02	1.18	38%	

* Area measurements include Basilan and Sulu Archipelago
** Forest coverage does not include non-forest wetlands

in Mindanao and Mindoro, where forest cover gave way to other land uses. In addition, the forest-related land-cover area measurements by region and for the entire country, when compared with similar numbers from previous years, highlighted trends in forest utilization (deforestation) in the Philippines.

The entire project was performed in a period of six months. The computer processing of Landsat data (classification, area measurements, and generation of output products) was performed in three months. The labor necessary to perform all the tasks was approximately two manyears. This does not include the time spent by Philippine DNR personnel.

The use of satellite multispectral scanner data is a new and unique way to survey forest resources for an area as large as the Philippines. The results of this project represent a useful pictorial and numerical base that can be used as a guide to formulate national forest utilization policies and to plan more intensive forest inventories. Images that are relatively cloud free can serve as base material for overlaying political boundaries and forest concession boundaries, and for overall assessment of the condition of forest resources on a regional basis.

ACKNOWLEDGMENT

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Forum

ISP Commission IV Symposium

IN HIS EXCELLENT review of the Symposium of Commission IV, Ottawa, October 1978 (*Photogrammetric Engineering and Remote Sensing*, April 1979, p. 491) Dr. James B. Case says that in my paper, "Some Constraints in Orthophotography," I "emphasized flight planning (flying height three to four times elevation differences, timed to avoid shadows)." Sir, I have been sadly misquoted for I said no such thing! It is true that I emphasized flight planning, but the other two statements are not mine. What I actually wrote was "an enlargement from photo to orthophoto of 3× to 4× is by far the most common" and "it is vitally important to avoid the hot-spot effect . . . (but) shadows should not be excessively long."

I am sure Dr. Case will agree that elevation differences of 25 percent to 33 percent of the flying height are not common in orthophoto production (though we have produced orthophotos with elevation differences over 30 percent). As for shadows, an orthophoto without shadows should be, I suspect, a dull, lifeless thing even if it were possible to achieve it.

—P. B. Stewardson
Wild Heerbrugg Ltd.