"A GOOD, A BETTER OR THE BEST REMOTE SENSING APPLICATION SYSTEM" FOR TROPICAL RAIN FOREST SURVEY IN THE AMAZON REGION.

by

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ISPRS Commission VII

ABSTRACT:

A historical review based on personal experience is presented of forest surveys executed in the Amazon region. For this account two remote sensing application techniques were selected, using: trimetrogon aerial photograps (Brazil, 1942; scale 1.:40,000) and Side Looking Airborne Radar (Colombia, 1973; scale 1:40,000). Some remarks are made, regarding the latest types of satellite images. The conclusion is drawn that "a good, better or the best remote sensing system" depends on the object of the survey and the availability of field information.

Keynotes in this account are: Remote Sensing, Tropical Rain Forest, Amazon Region.

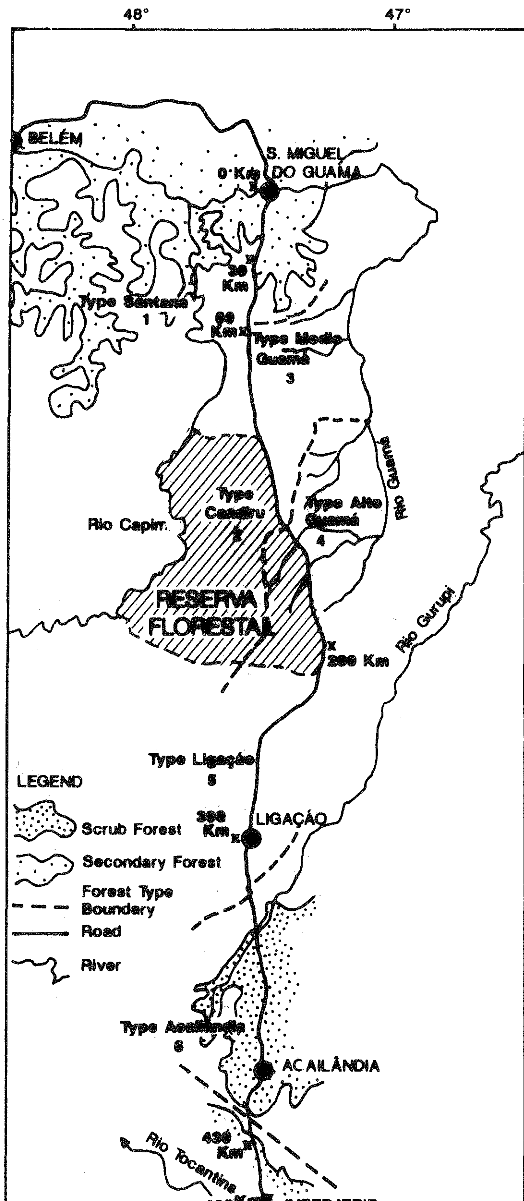
INTRODUCTION

The growing concern about the dwindling of the tropical rain forests in the Amazon region merits a historical review of forest surveys using remote sensing techniques to prepare base maps. Usually, the tropical rain forest is heterogeneous in species composition and tree diameter distribution. Of all the species measured in the field, only few have actual commercial timber value. The commercial species can be either dispersed throughout the forest or more or less concentrated because of special growing conditions. Such conditions are mostly related to topography and the presence of stagnant water and impermeable or sandy soils. Interpretation of remote sensing images for forest type classification is more suited to the needs than a technique based on recognition of individual trees. Small scale images in combination with ground truth are therefore preferred over only large scale images. To emphasize the importance of field data acquisition and as examples of the application of remote sensing tools trimetrogon aerial photographs and side looking airborne radar images are discussed.

TRIMEGON AERIAL PHOTOGRAPHS

At the time of the combined forestry-soil survey (Glerum D.B.and Smit G., 1962) along the road BR 14 now called BR-010, see map 1, (Belém-Brazilia) from São Miguel to Imperatriz over a distance of 460 km took place in 1959/60, aerial photographs constituted a widely accepted tool for forest type classification and mapping. A recent photo coverage of 1958 at scale 1:25,000 was the only one available for the northern and southern 30 kilometer sections of the road, which were excluded from the survey because of shifting cultivation and the presence of secondary forests.
A reconnaissance flight with a DC-3 was made along the road and a map at scale 1:500,000 was compiled of the main forest types: dense natural rain forest from km 30 to km 320 and a dryer forest type consisting of shrubs and bamboo from km 320 to km 420. Swampforersts were not observed.
Fortunately, 9 strips of trimetrogon (see for explanation the Manual of Photogrammetry, 1980) aerial photographs were available, taken during World War II (1942?) by the US Air Force. The scale of the vertical photographs was 1:40,000. On the oblique photographs on both sides of the vertical one, it was possible to identify the main drainage channels and the divides down to a scale of less than 1:100,000. Because of continuous adjustment of the eyes to the scale variations in the obliques caused considerable eyestrain. Stereoscopic observation was possible for only 20 minutes at a stretch.
The heterogeneous rain forest could not be classified into types according to timber volume and/or species composition. In the high oblique parts it was sometimes possible to follow a river course by looking under the clouds which was impossible on the vertical photographs. The vertical photographs covered approximately 60 kilometer of the 400 kilometer of the road, consequently, 360 kilometer had to be covered by interpretation of the oblique photographs. In one case, a gap of more than 100 kilometer between the vertical runs had to be bridged by the obliques. The selection of tie points was cumbersome. Mapping of the interpretation was done using an oblique sketchmaster. Here too eyestrain necessitated breaks every 20 minutes.

ROAD BR-14 (BR-010)



To collect the required inventory field data in the dense rain forest, a system was used of 10 kilometer long transacts perpendicular to the overall north/south direction of the road at six-kilometer intervals. In the shrub/bamboo forest, the interval was 12 kilometer. In the transects three sample plots of an area of 1.0 hectare (100 x 10m) were taken at km 2 to 3, km 5 to 6 and km 9 to 10. The total area covered by the inventory was 1.280.000 hectare. In each sample plot all trees with a diameter at breast height (D.B.H.) of 25 cm and more were enumerated with the species name and commercial height of the bole.

In addition, ecological and botanical information was obtained. A soil survey was also carried out along the transacts and the road. The distribution of the number of trees per species per sampling unit of one hectare was either a Poisson or Normal distribution, with the exception of the commercial species "Pau amarelo" (*Tecoma serratifolia; Bionomiaceae)* in the foresttype Candiru and Ligação.

To obtain more detailed information on the distribution of "Pau amarelo", eight 100 hectare blocks were selected at random for 10% and 100% surveys. In these blocks two subregions occurred with different ecological factors. Here the distribution of Pan Amarelo was according to the Normal distribution for the sloping high parts and a Poisson distribution for the flat lower part.

A crew of 50 field-workers, travelling four to nine weeks at a stretch, required 185 days to complete the entire survey during the period November 1959 - September 1960. All food, materials and gasoline had to be brought in by car and once food was dropped by the Brazilian air force. Alcohol was prohibited to staff, labourers and even visitors. In addition to the 10% and 100% survey blocks, 620 kilometers of 10 km transects were cut, 177 plots of 1 hectare were sampled.

A "good" classification of forest types was obtained by statistical calculation of 1)the mean volume and 2)the species volume per species with distribution, the emphasis being on commercial important timber.

A "better" classification was arrived at by including the soil survey data and divides between the main basins delineated on the trimetrogan photography. This approach allowed sharper classdelineation as a result of improved sampling along the class boundaries. A total of five rain forest types and the dryer vegetation/shrub forest type Açailandia could be mapped with data as follows:

a) area in ha
b) number of samples of 1 ha
c) number of trees/ha
d) volume in m³
e) number of species

Forest *type:*	*a*	*b*	*c*	*d*	*e*
1 Santana	135,000	16	106	152.5	139
2 Candiru	315,000	34	124	191.6	153
3 M. Guamá	132,000	13	108	161.2	132
4 U. Guamá	200,000	26	94	121.1	137
5 Ligação	398,000	62	101	138.0	156
Açailandia	100,000	26	51	61.6	118
total	1,280,000	177			

The overall sampling density is 0.014%

The "best" forest-type classification using all available modern techniques cannot be attained because actually considerable parts of this forest region suffer from human interference! Consequently, the better aproach is the best we can do.

SIDE LOOKING AIRBORNE RADAR

The main advantage of radar as an active remote sensing system is that for large areas, where climatic conditions hamper coverage by even small scale aerial photographs, full coverage of the terrain can be obtained independant of the weather in a short time. To monitor the cutting and burning of the tropical forest, it is important to have up-to-date images.

To obtain images the radar is installed in an aircraft as a "side looking airborne radar" (SLAR). The antenna emits a narrow beam of radio waves in a selected band and polarization. The echo returns are recorded in time sequence and provide the cross-track component. The SLAR image has a line-perspective geometry. Linear features such as drainage patterns, forest type limits with abrupt differences in vegetation height, and topographic variations can be observed more clearly in the direction parallel to the flight line than perpendicular to it. SLAR strips can be interpreted, but beware of pseudoscopic vision. A modern technique is to record SLAR strips with 60% overlap in such a way that the terrain imaged in the near and far ranges, can be interpretated under a stereoscope.

The interpretation elements tone and texture must be used with utmost care. The tone will be lighter if the reflection towards the antenna is strong and also depends on the depression angle, the angle of slope towards the radar beam and the dielectric constant of the object. Large bodies of water, lakes and main rivers are easily detected by their black tone and smooth texture. Swamps, former river courses and oxbows in the wetland, pattern of "gallery" forests along streamlets in natural or man-made grassland are easily detected.
The straight line pattern caused by human activities is visible if tonal differences are present. If the abrupt change in height between lower vegetation and higher forest is towards the radar beam, it shows up as thin line of high reflection ("corner reflection"), and away from the radar beam as a thin dark line ("radar shadow"). In the dryland region of the tropical rain forest, human influence can be delineated if the disturbed area is large enough and its limits are straight lined. The problem is the detection of small areas of agriculture classified as part of the shifting cultivation system and the differentiation between man-made secondary forest and natural low forest types. In areas with high hills and mountains, delineation of forest types becomes difficult because of the high reflection from the slope towards the beam and the presence of radar shadow.

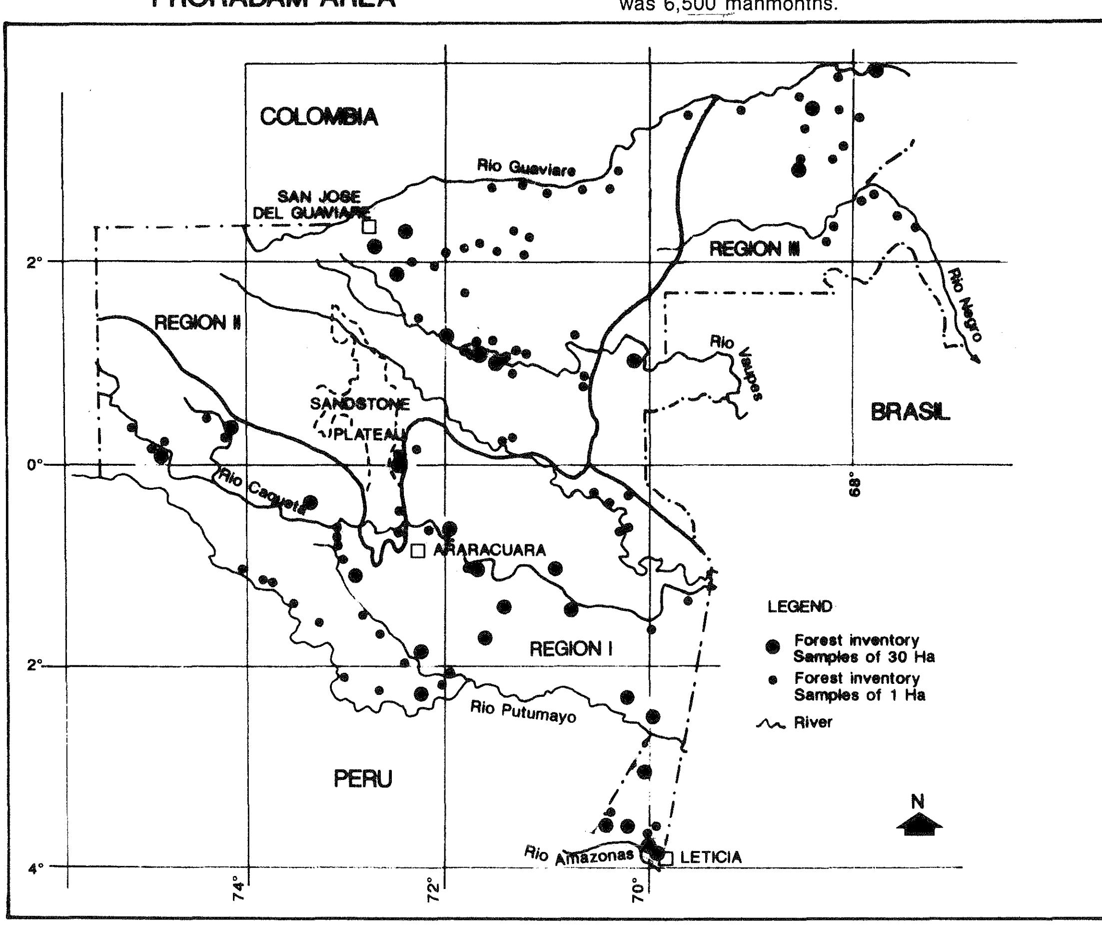
Mapping of forest types in the tropical rain forest with radar in Colombia started in 1968 with the radar mosaic of the Darien area at the border between Colombia and Panama. The legend consisted of 4 dryland forest types, 4 wetland forest types and 3 types of human interference. This means that in addition to the important distinct between dry and wetland forests, subdivision was possible on the basis of topography. On the other hand, information on human influences was superimposed on the radar images because areas with, e.g., timber exploitation could not be identified directly on the images. There was no field control.
The importance of field control was demonstrated by the following example. In June 1969, radar images were produced using the Westinghouse real aperture system AP/APQ-97 (Ka-band, 0.86 cm, 34.9 GHz) at scale 1:220,000 of 10 million hectares of the Pacific coastal region of Colombia. Approximately 70% of this area consists of tropical rain forest of which large parts have never been mapped before. A company suggested that on 1:50,000 scale enlargements the following two forest types could be delineated without field verification or collateral sources:
type 1 - trees 20 to 25 m tall, heavy underbrush, spacing approximately 8 m, bole diameter 0,2-0.5 m.
type 2 - trees 30 to 40 m tall, contains canopy, spacing approximately 13 m, bole diameter 0,5 - 1,0 m.

This suggest that without field data it would be possible to measure or estimate tree height, undergrowth, closure of the tree canopy, number of trees and bolediameter. In other words, the volume of the standing timber.
First of all, such a delineation system would be more applicable for a homogeneous even aged plantation forest in the temperate zone than for the heterogeneous tropical rain forest. Secondly, based on an existing interpretation system developed in Colombia (Sicco Smit, G. 1969) and adjusted to interpretation of Radar images (Sicco Smit, G. 1971), an area of 1,300,000 ha was mapped. In the map, 13 vegetation and forest types were delineated and checked by plane, boat and fieldwork. The conclusion was drawn that single trees could not be identified on the Radar images.

PRORADAM- COLOMBIA AMAZON

The "Projecto Radargrammetrico del Amazonas" (1979) in Colombia is an excellent example of the practical application of Radar for forest type mapping of a vast tropical rain forest area of which no accurate maps were available. This area (see map 2) of 38,000,000 ha is covered mainly by dense natural rain forest and some savannas and savanna forest types in the northeastern part, shrub vegetation types on sandstone rock outcrops in the central part, areas disturbed by settlers in the western part and scattered small Indian tribal settlements along the rivers. The terrain consists of broad floodplains along the main rivers, flat to low hill areas in the dryland, and zones with higher hills and low mountains. It was a multidisciplinary project, incorporating forestry, geology and pedology and was completed in 93 months. The total amount of work was 6,500 manmonths.

PRORADAM AREA



In 1973, the Aeroservice Corporation covered the area using their synthetic aperture radar (SAR) system in the X-band (3.13 cm). The flight line was N-S with a west-looking direction and a 60% overlap for coverage in the near and far ranges. The 104 radar strips covered each an area of 37 kilometer in width and up to 1000 km in length at scale of 1:200,000. A total of 69 semi-controlled (scale 1:200,000) radar mosaics were prepared. The interpretation system for the forest type mapping was based on the differentiation between wet and dryland types, physiographic features such as topography and drainage patterns, and differentiation between dense forest, savanna types and shrub forest types.

A reconnaissance forest field inventory was carried out to verify the accuracy of these interpretations and obtain field information (not visible on the radar images) related to species composition and standing timber of the various forest and vegetation types.

Taking into account the logistics, for an inventory in such a vast forest area a system of 30-hectare cluster samples in 30 pilot areas was selected. Each sample consisted of a base line 5 kilometer with at both sides 5 perpendicular lines of 1 kilometer not unlike a fishbone. Each subsample of one hectare was 20 m wide and 500 m long. All trees with a diameter at breast height of 25 cm and more were measured for DBH, commercial bole length and total height, and the species, local and scientific names were listed.

Only the one-hectare subsamples of the dry land free of human influence were used for statistical calculation of volume per hectare and listing of species composition. A total of 874 hectare of subsamples were used for the calculations. In addition, a reconnaissance was executed of 174 individual one-hectare plots of forest types in the floodplain area. The sampling density was 0.0036%.

The final classification (published in 11 maps at scale 1:500,000) of the main forest and vegetation types and their respective areal extent in percentages contained in this region of 38 million hectare was as follows:

Region A:	Floodplain: 8.95% 4 subtypes and 6 combinations based on inundation characteristics
Region B:	Dry land of terraces and low hills: 84.25% I. Dense and heterogeneous forest: 69.20% 6 subtypes and 6 combination based on topography II. Savanna and savanna forest: 15.20% 5 subtypes based on vegetation differences and topography
Region C:	High hills and outcrops: 3.85%
All regions:	Special types of human influence and non-forest: 2.95%

An overall map at scale 1:1,000,000 presents information on the standing timber volume in combination with the topographic ruggedness and forest types, statistically grouped as exploitable an non-exploitable.

SATELLITE IMAGES

From 1972 onwards satellite images became available as an additional tool for "small scale" interpretation and mapping application of the tropical rain forest. During the past years the pixel size improved from 60 m x 80 m (Landsat MSS) to 30m x 30m (Landsat TM) to 10 m x 10m (SPOT). Landsat TM provides the most favorable resolution. The individual trees however in the heterogeneous tropical rain forest can not be identified, and even subdivision into forest types according to volume and/or species composition of the dry land main forest types is highly inaccurate. For monitoring recent human interference by cutting and burning the forest, the climatic conditions of continuous cloud cover impede up to date acquisition.

The launching of radar satellite ERS 1 on 16 July 1991 has created the theoretical possibility to obtain radar images of the tropical rain forest area several times per year (10 x near the equator, 35-day sequence). For monitoring human influence, one image a year is more than enough.

Addition data has to be obtained to find out if satellite radar images will enable reliable estimation of the timber- and/or biomas volume. Identification of individual trees and species composition will probably remain impossible.

CONCLUSION

Depending of factors such as climatical conditions, area of survey, accuracy of timber volume, monitoring changes over shorter or longer periods, inundation by rivers, etc., there are several good remote sensing systems available for application in a forest survey. It is better to combine the selected remote sensing tool and additional collateral information from topographic and geomorphologic maps, and pedologic data. The best system is the "remote sensing as a tool", information and groundtruth control; Let us hope that in the future there will be enough tropical rain forests left to apply the best method.

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