PSR Eaton White Paper

ENVIRONMENTAL IMPACT OF ILLICIT NARCOTICS CULTIVATION: AN ECOLOGICAL STUDY USING REMOTE SENSING TECHNOLOGY

R. W. Podmilsak and W. A. Hallada

July 1987

Submitted to:
Lloyd Armstead
U.S. Department of State
International Narcotics Matters
Washington, D.C.

PACIFIC-SIERRA RESEARCH CORPORATION
1401 Wilson Boulevard, Suite 1100 • Arlington, Virginia 22209 • (703) 527-4975
A Subsidiary of Eaton Corporation

PSR Eaton White Paper

ENVIRONMENTAL IMPACT OF ILLICIT NARCOTICS CULTIVATION: AN ECOLOGICAL STUDY USING REMOTE SENSING TECHNOLOGY

EATON

R. W. Podmilsak and W. A. Hallada

July 1987

Submitted to:
Lloyd Armstead
U.S. Department of State
International Narcotics Matters
Washington, D.C.

CONTENTS

Section Page

Appendix

PROGRAM OBJECTIVES

This paper outlines a research program designed to evaluate and quantify the extent of tropical rain forest destruction by the cultivation of narcotics in three specific regions of Latin America and the Caribbean, namely Jamaica, Northern Colombia, and Peru's Upper Huallaga River Valley. As a minimum, the program will have the following specific objectives:

1. Assess both the short- and long-term environmental impact of extensive clearing of tropical forests for the purpose of narcotics cultivation
2. Estimate the extent of deforestation that is a result of narcotics cultivation
3. Scientifically quantify the extent of environmental damage caused by narcotics cultivation
4. Extrapolate data to predict future damage.

To begin this investigation, the PSR Eaton team will conduct a comprehensive and current review of related environmental studies. Building on the results of this review, we will investigate the environmental effects of deforestation, such as loss of forests, fishery resources, soil nutrients, watershed, and agriculture, and determine how much damage results from narcotics cultivation. Two major techniques will be used: field sampling and remote sensing. To aid in collecting and handling data, we propose to use a unique transportable computerized data collection and processing system, which we have used successfully since early 1986.

BACKGROUND

Significant narcotics cultivation of marijuana and coca is occurring in the Caribbean country of Jamaica; in the Central American countries of Mexico and Belize; and in the South American countries of Colombia, Peru, and Bolivia. In these countries there has also been an alarming increase in the cutting down of the tropical forests. It is not known how much of this deforested land is being cut down to cultivate narcotics, but for some areas it is suspected to be substantial.

To assess the extent of damage from cultivation of narcotics, it is necessary to understand (1) the tropical forest environment and (2) the combined environmental impact of deforestation and cultivation of both marijuana and coca.

Tropical Forest Environment

Because of abundant rainfall and warm temperatures, countries such as Peru, Colombia, and Jamaica are characterized by growth of tropical forest or selva, a vegetation type unexcelled for luxuriance of tree growth and number of species. Broadleaf trees rise to heights of 30 to 45 m forming a dense leaf canopy through which little sunlight can reach the ground.

Unique species of small forest animals make their homes in the tropical forests, taking advantage of the continuous forest canopy for living and traveling. Birds, too, are numerous in species. Actually, the lushness is deceptive. Created only by the abundance of moisture, it belies an essential poverty of the soil.

The dampness and high temperature combine to produce a rich growth of bacteria, insects, earthworms, and other organisms that break down the organic material and also aerate the soil. In these warm temperatures, the vigorous bacteria in the upper soil layer consume virtually all dead vegetation. Therefore, humus is almost entirely absent on well-drained sites.

With copious rainfall and high temperatures, chemical processes are continuously active on the rocks and soils in these regions. Leaching out of all soluble constituents from the deeply decayed rock results in a distinctive type of soil, termed latosol. It is reddish or yellowish and often contains irregular nodules of reddish iron hydroxides. These have been left behind in the soil after the soluble minerals have been carried down through the soil and into the streams and rivers. Large concentrations of iron, manganese, or aluminum minerals occurring as layers in the soil are termed laterite. Laterite soils are not fertile once cleared of the forest cover. The complex interaction of living and decaying forest plant matter is what maintains the soil's fertility in these ecosystems.

Marijuana Cultivation

Cultivating marijuana is similar to cultivating alfalfa. The crop is grown in plots and is harvested many times. These plots are often small with uniform plant cover. Unlike coca, marijuana provides complete surface cover during its growth cycle. Because of its high density, it has the potential to deplete the soil's nutrients very fast, particularly on the tropical lateritic soil that is common in Jamaica and northern Colombia. Some experts contend that marijuana cultivation in some of the mountainous areas of Jamaica and northern Colombia can be done for a limited number of years before the ground is depleted of nutrients. More than half of the marijuana smuggled into the United States originates in Colombia and Jamaica.

Marijuana Cultivation in Jamaica. Jamaica is judged to be the third largest U.S. supplier of marijuana, after Colombia and Mexico. In 1984--the most recent estimate---approximately 14 percent of the U.S. marijuana supply originated in Jamaica. At this time over 3000 hectares were used for cannabis cultivation. The crops are usually planted in January and June and peak harvesting takes place in May and October. Because of the favorable climate, some cultivation and harvesting occur year-round. Field sizes range from a high of 5 hectares on broad slopes to a low of .2 hectares on rugged terrain. Although commercial grade cannabis is cultivated throughout Jamaica the most extensive plantings are believed to be in the parishes of St. Elizabeth, Westmoreland, and Cornwall.

The cultivation of marijuana has been extensively expanded in the more remote areas of Cornwall county in western Jamaica. Some of the largest expansion of marijuana cultivation is occurring in the Cockpit Country of Westmoreland Parish. The Cockpits are large, steep-sided hollows, which are common wherever limestone bedrock occurs. The Cockpits of Jamaica receive between 250 and 500 cm of rain a year. Therefore, these areas have a complex forest ecosystem. The limestone is very porous and highly soluble in rainwater. Carbon dioxide and other acids in the water dissolve the limestone and wear it away, carving out deep hollows separated by sharp ridges. This creates a wild and very distinctive landscape, which is called karst. Since the porous nature of the limestone causes rainwater to sink immediately into cracks and sink-holes, surface streams are almost completely absent.

The rugged broken nature of the Cockpit Country makes communications almost impossible. These remote areas now offer protection to narcotics growers from government eradication efforts.

Deforestation of the Cockpit Country could have devastating effects on the Jamaican ecosystem. The cutting down of forests has already had a bad effect on farming in many areas. The roots of trees bind the soil together, and the leaves stop the rain from falling directly onto the soil. When there are no trees, the rain falls directly onto the soil and erodes it more easily. Water also runs more quickly over the exposed soil into streams and rivers to cause more frequent floods. The silted water can also destroy the fisheries and reefs along the coasts of Jamaica. Such advanced stages of environmental degradation have already occurred in Haiti. If left to continue on its present course, Jamaica could be the next Haiti.

Marijuana Cultivation in Colombia. The Santa Marta and Perij Mountain area of northeastern Colombia has traditionally been the major marijuana growing region. Colombia has two major harvests: from March to May and from September to November. The latter crop is more abundant since it follows the rainy season. Peak harvesting generally lasts 2 to 3 months because of staggered planting and maturation. Commercial-scale cannabis fields are planted on mountain sides and in canyons generally at an altitude of 900 to 2200 m. Thick jungle growth camouflages illicit cultivation, and growers also conceal cannabis among legitimate crops.

The Drug Enforcement Agency (DEA) estimated that in Colombia about 10,000 to 13,000 hectares were under cultivation in 1984. Each hectare can produce about 1/2 ton per year based on two harvests. Although as already indicated, there are distinct growing seasons, harvesting marijuana is becoming almost continuous, with the highest level still occurring in the fall.

In Colombia, usually the land used to grow marijuana is owned by individual farmers who are paid a price for the harvest; however, some marijuana smugglers own their own land.

Coca Cultivation

Growing coca is in essence like growing grapes. Because the roots need to be well aerated and cannot tolerate high soil moisture conditions, coca is grown on slopes at the higher and drier elevations in the tropics. It is probably a safe assumption that nearly all cultivation on Andean mountain slopes is almost certainly coca. Coca producers select remote mountainous slopes, cut down the timber with chain saws, and burn the toppled trees. About a year later the coca producers return to the slopes and plant their coca seedlings, which are already about 6 months to 1 year old. In the meantime, the mountainous slopes--comprised of lateritic soils--are laid bare to the erosion and nutrient depletion caused by heavy rains. The coca is planted in rows in holes the size of coffee cans about 1 meter apart down the mountain slope. The coca plants are very hardy. Grasses grow between the plants, holding the soil in place; fertilizers are increasingly used by the local growers to maintain the soil fertility. There are about 10,000 plants per hectare that will produce about 1 metric ton of coca leaves per year. Harvesting can vary from 3 to 4 times per year, but usually will not begin for at least the first 18 months after transplanting. For some areas in Peru, there is evidence that if a coca field is properly managed, it can be productive for as long as 30 years. If cultivation is not properly managed, the devastation in these areas can be significant, resulting in irreversible damage to the environment.

Peru is one of the two major producers of coca leaves. Estimates of coca under cultivation range as high as 120,000 hectares. This occurs mainly in the Departments of Huanuco and San Martin in the Upper Huallaga Valley of the Andes. The potential growing areas for coca in Peru are immense, stretching nearly 1600 km north to south in a belt of land on the eastern slopes of the Andes about 80 km in width. This may be the biggest coca growing zone in the world.

Most of the processing of coca into cocaine still occurs in Colombia; however, processing in Bolivia is increasing. Apparently little or no processing of coca into cocaine occurs in Peru because of the unavailability of chemicals to refine the coca paste into cocaine. Therefore, Peru must transport its processed coca paste to Colombia for refining.

APPLICATIONS OF REMOTE SENSING TO TROPICAL DEFORESTATION

A number of remote sensing investigations have been conducted to assess the potential of using satellite-acquired data to monitor the world's forest resources. Most of these investigations concentrate on the tropical rainforests of the Amazon Basin (R. Nelson et al., 1987; Woodwell et al., 1987, Woodwell, 1984). As is well known, current estimates of deforestation applicable to large areas are notoriously variable (J. Allen and D. Barnes, Annals of the Association of American Geographers, 1987).

The objectives of past remote sensing investigations have been the development of techniques to estimate the rates of deforestation in selective regions through the use of satellite imagery. The long-term objective of this proposed study is to estimate how much the cultivation of narcotics is contributing to tropical deforestation in Jamaica, Colombia, and Peru.

Past investigations have shown that the rate of deforestation can be measured using Landsat Multispectral Scanner (MSS) and Thematic Mapper (TM) data, Space Shuttle Imaging Radar (SIR-A and -B), Large Format Camera, and NOAA Advanced Very High Resolution Radiometer (AVHRR). Another sensor with high potential for investigating tropical deforestation is the French SPOT multispectral sensor.

There are many problems that make the identification of coca or marijuana using remote sensing technologies a difficult task. The variation in harvesting times of coca farmers makes the use of single-data analysis extremely inaccurate and the development of spectral/temporal profiles nearly impossible.

In addition to temporal problems associated with coca identification, the spatial resolution of the Landsat-type MSS and TM instruments (80 m and 30 m respectively) is inadequate for the field sizes typically found. Another problem is cloud cover. The regions used for marijuana and coca cultivation are often obscured by clouds. The pointability of SPOT increases the sensors revisit times to frequencies of every 4 days, much better than the 16 days needed for Landsat.

There is some reason for optimism, however. The row spacing of coca in particular is similar to that of vineyards. Given the higher spatial resolution (10 m) of the SPOT panchromatic band, some experts assert that the row direction of coca could aid the identification process. By using digital enhancement techniques and by coupling the spatial information with the multispectral and multitemporal imagery, terrain data, and field surveys, an accurate inventory of coca cultivation via remote sensing could become a reality.

METHODOLOGY

This section describes PSR Eaton's approach to the proposed study. It details our plans and already completed work toward the literature survey. It describes the proposed teams, preparation, and field work. It details how we plan to use multispectral imagery to assess the extent and causes of deforestation. Finally, it explains how we will use--in the field and elsewhere--a transportable computerized data collection and evaluation system. It gives a tentative schedule and tells what we propose as final deliverables.

Literature Review

The literature review will cover the following topics:

- Narcotics Cultivation of
  - Coca
  - Marijuana
- Tropical Deforestation
  - Remote sensing measurement
  - Ecological changes
    - soil fertility
    - watersheds
    - hydrology
    - wildlife
    - meterology/microclimatology
  - Economic impact
    - agriculture
    - lumbering
    - river transportation
- Country specific studies
  - Jamaica
  - Peru
  - Colombia

Library Services. PSR Eaton's senior technical librarian Ms. Celia Griffin, will perform a comprehensive literature search. She regularly uses several on-line computer databases--both government and commercial: DROL's produced by the Defense Technical Information Center (DTIC), covering government-sponsored research in all technical fields since 1953; and DIALOG, ORBIT, and NEXIS, which together access over 250 separate databases. Recently she has compiled bibliographies on such subjects as multispectral image processing, narcotics traffic in South America and Latin America, narcotics legislation , narcotics and drug detection by dogs.

For the proposed project, the search will concentrate in DROLs and on several DIALOG files, such as Environmental Bibliography and AGRIS International. Ms. Griffin has already begun work on compiling a select bibliography (See Appendix B).

All of the databases allow reference searches under single or multiple-word subject term, author, or title. Many of the databases allow searching via corporate author, publication date, or journal title. The data bases primarily index journal articles, but some index books, conference papers, patents, government-sponsored reports, or congressional documents.

Additional Sources. We will draw heavily upon the extensive library holdings in various private, government, and international organizations. The libraries at the Agency for International Development, the World Bank, the Smithsonian, and the United Nations are especially rich in data on tropical forests. An excellent source of data in each host country to be studied will be the U.S. State Department Narcotics Assistance Unit. For example, the narcotics unit in Lima, Peru, is quite active in collecting and studying the coca phenomena in Peru. Useful data already collected, mapped, and automated could be made available to PSR Eaton. This data includes recent aerial surveys of the narcotics growing region.

The Peruvian aerial survey includes 10,000 km^2 of the Upper Huallaga Valley mapped at 1:10,000 and 1:25,000 courtesy of the National Photographic Survey Unit of the Peruvian Air Force. None of this data has been correlated with Landsat TM or SPOT imagery, which of course would be one of our objectives.

Within each country resident DEA personnel would also be excellent sources of information. The DEA country office in Lima, Peru, for example is comprised of seven individuals.

We will also make full use of local national sources. For example, in Peru the University de Selva (Jungle University) in Tingo Maria is a source of much data concerning narcotics cultivation. Sources there are known to have gathered much data relevant to our study.

Each host country also maintains scientific research stations dedicated to understanding the tropical rain forest and the economic and sociological costs of their destruction. Key among such institutions is the La Selva Biological Station for Tropical Studies in Costa Rica.

Scientific Study

PSR Eaton proposes that a 6-month study be conducted to assess the environmental impact of large-scale narcotics cultivation.

The problem of quantifying the long-term ecological effects of narcotics-related deforestation can be divided into two parts. The first is to determine the environmental effects of deforestation on the ecosystem through time for the types of ecosystems in which marijuana and coca are grown. The second is to access the amount of deforestation caused by the expansion of narcotics cultivation and, thus, determine the contribution of narcotics cultivation to the rates of deforestation in each country. Our approach will lay the necessary ground work to predict the environmental impact caused by current rates of deforestation in areas of narcotics cultivation and any future expansion of narcotics cultivation in each country for the next, 5, 10, or 15 years.

We will carry out an ecological study to assess the environmental impact of the cultivation of marijuana in Jamaica, marijuana in Colombia, and coca in Peru. The most immediate effects are the contribution to the destruction of tropical forests, the removal of valuable land from potential agricultural production, and the destruction of the natural ecosystem of a tropical forest. Other effects include the destruction of fisheries, coral reefs, sedimentation, and flooding.

Field Work

Field Teams. PSR Eaton has tentatively identified a team of experts in tropical ecology, field data collection, and remote sensing technology. This unique combination of skills will be used to evaluate the effects of tropical deforestation for the purpose of narcotics cultivation. Our team will consist of outside consultants who are experts in the ecology of tropical forests and problems associated with deforestation in Jamaica, Colombia, and Peru. Each team member brings special knowledge or experience doing field work and remote sensing investigations in these countries. State Department, DEA, and Central Intelligence Agency (CIA) experts on marijuana and coca cultivation will be used to help focus the investigation to key problem areas.

Each of our three field teams will consist of two to three experts who together will conduct the investigation within each country. Each team will consist of (1) an expert on the ecology of the particular country; (2) a remote sensing expert; and (3) a narcotics expert. The first team members will vary for each country; however, the second and third team members may well be the same for all three countries. Two visits to each country are anticipated.

<u>Preliminary Work</u>. To lend efficiency to the process of gathering field data, a number of operations will be initiated before actual field activities begin. These preliminary activities include the preselection of sample sites by use of satellite and aerial photographs, stratification of the study areas into unique ecosystems, notation of prominent surface features for location of sample sites within each strata, concentration of sites whenever possible, use of locally available aerial photographs or maps, and assembling of sample site packages consisting of questionnaires. (See sample questionnaire in Appendix A.) Doing such preliminary work will permit better use of time in the field and ensure that similar quality and quantities of data are gathered in each country.

<u>Field Travel</u>. The first trip to each country will be of 10 working days duration and will be used for site selection and familiarization. This trip will be designed to understand the logistics of each location, to select study sites, and to meet with key government, university, and scientific experts on tropical deforestation, land use planning, agricultural expansion, remote sensing, and narcotics control. PSR Eaton will bring to the country a

portable, digital Landsat image display system to aid in the study site selection (see Computerized Data Collection Compilation section). PSR Eaton will copy digital Landsat imagery and available SPOT imagery onto optical disks for transport to the country. The data will be provided by the International Narcotics Matters (INM).

Three weeks will be spent in Washington, D.C., before the second trip to analyze the information collected on the first trip, study the information available at the Department of State and finalize the field sampling approach.

The second trip to each country will be of 10 to 15 working days duration for data collection and on-site analysis. On each team the ecologist will work in conjunction with the remote sensing expert and local officials to collect data to answer ecological questions.

The State Department will coordinate the arrival, local logistics, and familiarization of the teams with local resource personnel within each country. Issues of security and local transportation into the field will be coordinated with the State Department and the local governments.

Ecological Data Collection. To quantitatively measure the environmental impact of narcotics cultivation, PSR Eaton's selected ecologists will conduct an extensive survey of each sample site. For each sample site the field ecologist will characterize the ecosystem before deforestation in detail and current ecosystem after deforestation. Sites will be selected and stratified by age using the following criteria:

- A mature tropical forest equivalent to the one that would be existing in a sample area of narcotics cultivation
- A recently burned or cleared sample site
- Sites with 1 to 2 years of narcotics cultivation
- Sites with 2 to 5 years of narcotics cultivation
- Sites under narcotics cultivation for more than 5 years
- Sites that have been abandoned or where eradication efforts have taken place.

The length of time a previously forested area in the tropics is under cultivation and the size of the area are important factors in the area's recovery back to a forest. Large areas of tropical deforestation recover only secondary forest growth (Office of Technology Assessment, 1984).

Sample sites will be visited on the ground whenever possible. If it is not possible, information will be gathered by photographing the sites from low-flying aircraft or helicopters and writing down field notes on prepared forms. PSR Eaton will provide at least two experts to be available for any overflights: a remote sensing expert to do the photography and an ecologist to record elaborate field notes.

The PSR Eaton selected ecologists will classify what the soil, water, and vegetation ecosystem was like before deforestation. This will be done by studying nearby stands of mature tropical forest and comparing this ecosystem to the one after deforestation. Changes in forest soils follow major changes in the vegetation cover. Changes in vegetation cover can be measured by remote sensing from aircraft, Landsat, and SPOT imagery. While direct measurements of changes in soils are not usually possible using satellite imagery, indirect appraisals of the environment from direct measurements of changes in major types of vegetation are clearly possible.

Land Surface Characterization

The first step on gathering ground truth data for remote sensing investigations is to determine and define the major information categories that relate to objectives of characterizing the environment. To ensure that the land cover categories are compatible with the data acquisition and processing technique, those factors that influence reflected energy, as measured by Landsat, must be addressed. The environmental variations anticipated in areas of narcotics cultivation must be listed so that sample sites can be established to represent each source of variation.

We will design our ecological survey of a site to take into consideration such variations in reflected energy so that observables made on the ground can be extrapolated to the aerial photographs and finally to the Landsat data. The areas selected are to contain a uniform, homogeneous land cover type (i.e., a coca field that is uniform with respect to planting date, density, vigor, slope, etc.). To be used with Landsat data, the selection of sample sites must address four basic factors: (1) the categorization of surface features (i.e., slope, exposure, the crop of interest versus other crops of noninterest, etc.); (2) the size and shape of the sample site; (3) the number and distribution of sites; and (4) the homogeneity and uniformity of the surface cover.

Three general categories of land surface features significantly affect the reflected energy as measured by Landsat. These categories are the vegetation cover, land surface without vegetation, and the topography.

Vegetation Cover. Various elements of vegetation cover influence the reflected energy as measured by Landsat. These include plant species or species association, plant age and vigor, plant density, and understory (or background) vegetation. Such factors as the size of the plants, leaf arrangement on the stem, the pigments present, the thickness and shape of the leaves are all important. To characterize narcotics cultivation, some selected areas may be mixtures of plant species. For example, marijuana may often be mixed in with other agricultural crops such as bananas and coconuts. For some of these areas it may be impossible to detect any sign of growing narcotics. Furthermore, the environmental impact will be insignificant in comparison to areas where deforestation has occurred solely for the cultivation of narcotics. It is these area that will be the target of our investigation.

Land Surface without Vegetation. In the tropics the surfaces that are devoid of vegetation are those on which soil has been temporarily exposed, those that are permanently covered with water, or those that are devoid of soil at high altitudes. After deforestation and before the planting of the first crop, most areas are in some stage of soil preparation. Consequently, we will use critieria to establish the condition of the exposed soil.

For remote sensing purposes the three main variables to be considered are the physical state of the surface, soil moisture, and soil type. At a minimum, sites will be sampled that represent extremes--should they exist--and the various combinations of the three variables. For example, the extremes for the state of the surface would be a rough surface with the charred remains of the forest after a recent burning and a smooth surface just before planting. Another common condition in areas of marijuana cultivation is the stubble remaining after harvesting operations. These sites need to be established to characterize the impact on the environment through time of the cultivation methods employed.

Topography. The topography (slope and aspect) is also a factor in establishing uniform, homogeneous sample sites for remote sensing study if there is pronounced topographical variation. Marijuana is grown in flat, hilly, and mountainous terrain. Coca is grown on slopes in hilly and mountainous terrain because the crop needs very good drainage. It is recommended that slope categories be established for 0 to 10 percent slopes, 10 to 30 percent slopes, and greater than 30 percent slopes. It will also be determined if there is a preference for certain aspects of slopes in the regions investigated.

Computerized Data Compilation

PSR Eaton proposes to use a unique transportable computerized data collection and processing system to aid in the collection of the above field data. This system can be transported to each country to aid in data compilation and sample site selection. PSR Eaton has been transporting such hardware and software into the field since April 1986.

PSR Eaton proposes using the following hardware and software.

Hardware

- COMPAQ Portable III computer with
  - 640 Kb RAM
  - 80287 math coprocessor
  - 12 MHz clock
  - 40 Mb hard disk
  - 1.2 Mb floppy disk drive
  - Add-on expansion box with two slots
  - RS-232 serial communications ports
  - Parallel printer port
  - LED crystal display
- Image processor board
  - 512 rows by 512 columns by 32 bits per pixel
  - Hardware roam and zoom

  - 13 inch high-resolution color monitor

- Optical disk drive and board
  - Uses five 1/4 inch optical disks
  - 230 Mb storage capacity
- Image digitizer board (512 by 512 by 8 bit black and white video image digitizer)
- Video camera (Black and white with 3 color filters for generating color images)
- Digitizing tablet
  - GTCO Corp. model 1111A
  - 11 by 11 inch work space
  - 16-button cursor
  - Power supply
- Voltage converter

Software

- Earth Resources Data Analysis Sytems (ERDAS) modules
  - Multispectral image processing
  - Geographic Information Systems (GIS)
  - Polygon digitizing
  - Video digitizing
  - Enhanced Graphics Package (EGP)
- dBase III Plus
- Clipper
- Word processing

The COMPAQ Portable III computer along with the optical disk drive is small enough to be carried onto the airplane and stored under the seat. The digitizing tablet, camera, and monitor will be transported in specially constructed transport boxes. This system will provide the ability to carry the most recent Landsat, SPOT, or AVHRR digital imagery into the country of interest. The available imagery of the regions will be copied from tape onto optical disks using PSR Eaton's in-house hardware and software.

The system can be set up in the Embassy or the hotel room. For the first trip, only the computer, optical disk drive, and monitor will be taken to the country. The system will be set up in the Embassy office where the aerial photographs and maps of the regions to be investigated are available.

Displaying the imagery on-site will provide local officials and INM investigators the ability to better select representative sample sites (see Figure 1). As mentioned earlier, it is important that the sample sites be locatable on a display of the digital data so that satellite image observations can be extrapolated to ground measurements and observations. Sensor band combinations can be chosen interactively that best highlight and bring out the details of the study sites. In addition, the ERDAS software allows the analyst to enter training sites for computerized multispectral categorization. Such training sites will be entered during the second trip after a visit to the field.

Having the digital multispectral image processing and GIS on-site during the second trip will provide many other opportunities to collect data about the sample sites. Spatial information from maps and aerial photographs that may be available only in the country of interest can be digitized and brought back to the United States for later analysis. The tablet digitizer will be used to trace data off aerial photographs and maps into the system. For example, a PSR Eaton analyst can use the 1:17,000 scale aerial photographs provided by the Department of State Narcotics Assistance Unit in Lima, Peru. The analyst would digitize the following data off the aerial photography for each sample site:

- The boundaries of the deforested areas
- The boundaries of the narcotics cultivation areas
- The boundaries of abandoned deforested areas
- Ground control points that can be found in the Landsat TM image and the aerial photograph
- Major access routes to the deforested areas and narcotics cultivation area
- The boundaries of areas near the coca cultivation field that have been affected by the deforestation (e.g., land slides, increased sediment deposits down stream, etc.).

For any feature that is digitized, additional descriptive information will be entered into an on-line database. The variables to be

Figure 1. Digital merge of 1:500,000 map produced by the Bolivian government with Landsat TM bands 4, 2, and 1 in red, green, and blue. Note how inaccurate the map is compared to TM image.

entered into the database will be defined after preliminary discussions with the local experts on ecology, narcotics cultivation, and deforestation.

Locations of the aerial photographs will be plotted on top of the digital TM images. Furthermore, selected aerial photographs can be video digitized and referenced to the TM data. Any data that can be spatially referenced by location in the TM image can later be recalled for display using the ERDAS EGP.[1] By pointing to a sample site on the screen, the analyst will be able to call up any data acquired for that site (see Figure 2).

The locations of the sample sites will be annotated on the digital image, and field data describing the site can be entered into an on-line database that is keyed to the site's location in the image. This field data will be entered into a dBase III database for further analytical and statistical analysis after returning from the country during the last months of the investigation.

Stratified Multistage Sampling Approach

The statistical frameworks useful for inventorying and monitoring land surface cover over large areas have existed for decades. Countrywide assessments of vegetation change necessitate the use of Landsat MSS or TM as a sampling tool. Colwell (1983) reports that "regional inventories covering areas the size of many Landsat frames are sometimes difficult to achieve using Landsat MSS data, for reasons of data availability and cost." He recommends using coarse resolution satellite data (e.g., AVHRR, Coastal Zone Color Scanner [CZCS]) for primary enumeration. The Landsat MSS or TM data are used to "correct" or adjust the estimates made from coarse resolution.

---

[1] This package is currently used by utility companies to monitor power lines, switching stations, and transformers located in the field. The military uses the same package to enter data about installations and units and to plot the locations on background maps and imagery in different overlays.

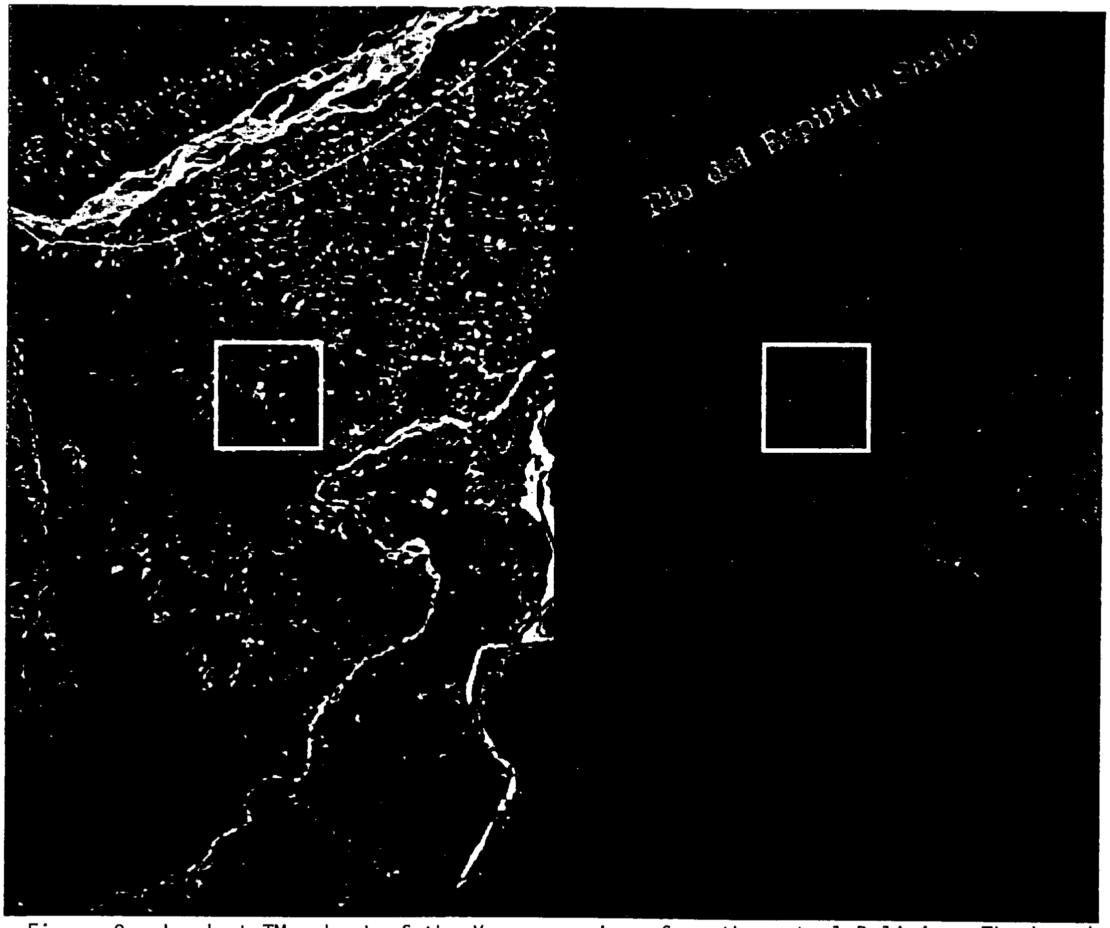

Figure 2. Landsat TM subset of the Yungas region of north central Bolivia. The boxed area reveals indications of probable coca cultivation. Left image is TM band composites 3, 2, and 1; right image is bands 4, 3, and 2 in red, green, and blue.

PSR Eaton will evaluate various sampling designs that are available for consideration: simple random sampling, ratio estimation, stratified random sampling, double sampling with regression, systematic sampling, and probability sampling. The most appropriate will likely be a combination of stratified random sampling combined with multistage variable probability sampling (W. G. Cochran, 1963).

Landsat MSS and TM imagery will be used to delimit an ecosystem strata. If Landsat data are not available, the AVHRR imagery will be used to stratify the region. Once the area of interest is stratified, the strata boundaries will be entered into a GIS for later analysis. We will identify at least three sample sites within each strata, using available medium- and high-resolution color aerial photographs.

A stratified multistage sampling approach will be used to collect the necessary environmental data to characterize the effects of deforestation due to narcotics cultivation in these countries. The parishes, departments, or provinces will be stratified into forested versus deforested areas. The deforested areas will be further stratified into physiographic regions (i.e., mountainous, limestone bedrock, coastal plains, valley bottoms, etc.). The purpose of the stratification is to get a good sample of each type of ecosystem in which narcotics are grown, without doing a complete survey. Stratifying the areas into ecosystems will, thus, save time and effort and still provide a scientifically sound estimate of the environmental impacts of deforestation. The stratification will be done after consulting with authorities on the regions' ecology and with narcotics experts. For example, most of the coca cultivation occurs on well-drained slopes in Peru.

After stratifying the area into ecosystems, a multistage approach will be used to pick sample sites using satellite imagery with aerial photography at scales of 1:80,000 to 1:60,000 and high resolution scales of 1:10,000 to 1:17,000 used in a secondary sampling stage. Between 8 and 15 aerial photographs (depending upon scale) will be allocated across the region in a stratified random sample, to identify study sites for field data collection. For example, the U.S. Department of State Narcotics Assistance Unit in Lima, Peru, has available over 10,000 aerial photographs of coca growing areas in central Peru at scales of 1:17,000.

PSR Eaton experts will evaluate these aerial photographs to select sites to visit or fly over. Potential sites will be delineated in such a manner that their locations are referenced to prominent surface features that can easily be found in the field and detectable on a CRT display of the Landsat imagery. Any road networks, trails, rivers, or landing strips will be observed and identified whenever possible to locate potential sample sites to facilitate access and take best advantage of the existing transportation network. The objective will be to lessen field work by reducing time spent walking or flying to and over multiple sites.

A final means of attaining efficiency consists of establishing potential sample sites in concentrated groups distributed throughout the area encompassed by a particular Landsat scene of interest. This will be accomplished by selecting 8 to 12 aerial photographs, depending upon scale, from all the photography available for the area encompassed by a particular Landsat scene. We will make selections so that each photograph encompasses a variety of cultivation and surface conditions. The net effect of delineating potential sample sites in concentrated groups distributed throughout the Landsat scene is the reduction of travel time between sites during field data collection and the reduction in time to locate the sample sites in a CRT display of the data.

DELIVERABLES

We anticipate furnishing the following deliverables:

- Briefings as needed
- A final summary report
- An annotated pictorial report for each country

SCHEDULE

Table 1 shows the proposed schedule of work.

Table 1. Proposed schedule.

Task	Oct	Nov	Dec	Jan	Feb	Mar
1. Search and review literature	●—	—	—	—	—	—●
2. Select sites, prepare for field work, pre-process Landsat data	●—	●				
3. Work in field		●—	—	●		
4. Analyze data				●—	—	—●
5. Deliver final report						●

RESUMES OF PROPOSED TEAM

PSR Eaton Staff

This section contains brief resumes of the proposed team. All are highly qualified and genuinely enthusiastic about the project.

RONALD W. PODMILSAK — Program Manager

M.A., Russian Studies, City University of New York (1966)
B.A., Geography, University of Pittsburgh (1961)
Mr. Podmilsak has completed course requirements for a Ph.D. in Soviet and Environmental Studies at the University of Maryland.

Mr. Podmilsak will be program manager for the proposed study. His work for PSR Eaton focuses on technical and requirements studies to support national and defense systems and programs. He is a company focal point for development of new concepts for design and operation of intelligence collection systems. Recently he collaborated with another division of Eaton on a successful proposal to U.S. Customs Service to use data collected by both low and high-level aircraft and other reconnaissance methods to track narcotics smuggling activities. The proposed model predicts movements and locates chokepoints for interdiction. His multispectral work includes plans for a terrain reduction project over the U.S. Southwest border in support of Project Alliance using Landsat imagery. He is currently program manager on a comprehensive multispectral utility study.

Mr. Podmilsak's 18 years with CIA and the Intelligence Community Staff (1966-1985) covered a broad range of agency intelligence activities. For over 2 years Mr. Podmilsak has worked closely with the narcotics intelligence community. Recently, he was granted a Top Secret clearance by the Drug Enforcement Administration to facilitate work with Eaton Corporation's Text Analysis System and Communications Processor located at the El Paso Intelligence Center. Mr. Podmilsak has developed and briefed his concept of a near-real-time all-source approach to narcotics interdiction to intelligence officers in CIA, DIA, DEA, Customs, the Coast Guard, the National Narcotics Border Interdiction System, and the El Paso Intelligence Center.

WAYNE A. HALLADA Senior Research Analyst

M.A., Geography, University of California at Santa Barbara (1980)
B.S., Geography and Mathematics, Carroll College (1977, magna cum laude)

For the proposed project, Mr. Hallada will be in charge of all multispectral image processing and field data collection. He will take advantage of 9 years of experience in remote sensing and 10 years in the field of geography and field work in Jamaica. As PSR Eaton's senior analyst in the multispectral image processing work, Mr. Hallada is expert on a wide variety of image processing software and hardware.

Mr. Hallada's experience includes a wide range of multispectral image processing: (1) support to the Tactical and Military Multispectral Requirements Evaluation Group (TaMMREG) within the Defense Intelligence Agency; (2) studies to determine future image processing requirements for the national security community; (3) technical research support to compare Landsat Thematic Mapper (TM) with the German MOMs imaging system, to determine the noise characteristics of TM, and to generate bathymetric maps from TM; (4) research on changes in spatial and spectral resolution on digital image texture analysis and image sharpening using simulated mixed spatial and spectral resolution images; (5) study of Landsat Thematic Mapper spectral band combinations for land cover classification hydrologic investigations; (6) research and supporting software development on geographic and agricultural remote sensing projects and (7) preparation of a vegetation map from aerial photographs and ground survey information for the Rocky Mountain Arsenal, U.S. Army.

TERRENCE H. HEMMER Research Analyst

B.S., Physics, University of Dayton (1979)
Graduate work in Chemical Physics, Kent State University (1979-1980)
Graduate work in Mathematics and Engineering, Wright State University, (1982-1983)
Ph.D., Candidate, Chemical Physics, University of Maryland (1984-present)

For the proposed project, Mr. Hemmer will assist Mr. Hallada in multispectral image processing and field data collection. He will analyze and evaluate available imagery to select specific sites in geographic areas being studied and coordinate that imagery with ground truth data, which is either already available or obtainable through field work.

Mr. Hemmer has been with PSR Eaton since 1981. His work in the Technical Systems Division is currently to identify new potential application areas for multispectral image data; to assess the feasibility of using an multispectral sensor to satisfy information requirements; and to specify collection requirements using the number and position of bands. He has performed studies to glean intelligence from multispectral landwakes and to assess the use of multispectral sensors in defeating command, control, and deception.

Consultants

The following individuals have been tentatively identified as possible PSR Eaton consultants for this research project. We have contacted each individual, and each is willing to perform field work. All have tentatively agreed to participate. We would expect to make our selection from among these and other candidates we have identified. All candidates are experts in some aspect of tropical forests. We have identified experts who have conducted extensive field work in each of the areas to be studied.

ROBERT J. BUSCHBACHER PSR Eaton consultant

Ph.D., Ecology, University of Georgia (1984)
B.A., Biology (concentration in Ecology), Cornell University (1976)

Dr. Buschbacher is currently the director of the Tropical Forest Program for The Conservation Foundation and World Wildlife Fund. His work includes research and publication on policy issues related to tropical forest management and initiation and implementation of forest management field research. Since 1980 he has investigated changes in biological and physical pathways of phosphorus cycling during pasture management in a converted rainforest in Brazil; studied ecosystem recovery following abandonment of pastures formed from Amazon rainforest; and researched changes in productivity and nutrient cycling following conversion of Amazon rainforest to pasture.

FRANK W. DAVIS PSR Eaton Consultant

Ph.D., Geography and Environmental Engineering, The Johns Hopkins University (1982)
B.A., Biology, Williams College (1975)
B.A., Pathobiology, The Johns Hopkins School of Hygiene and Public Health (1978)

Since 1983, Dr. Davis has been Assistant Professor, Department of Geography, University of California, Santa Barbara. He is a specialist in plant ecology and demography, vegetation remote sensing, and ecological applications of geographic information systems. He has traveled extensively to Jamaica to study the vegetation and ecosystems of the Cockpit country.

ROBIN B. FOSTER PSR Eaton Consultant

Ph.D., Botany, Duke University (1974)
A.B., Biology, Dartmouth College (1966)

Dr. Foster has extensive field experience in Peru and in other countries of Central and South America. Among his many publications are several relating to the ecology of tropical rain forests.

Dr. Foster presently holds the following positions: Research Associate in the Department of Botany with the Field Museum of Natural History in Chicago; Research Associate, Smithsonian Tropical Research Institute in Balboa, Panama; and Research Associate with the Missouri Botanical Garden in St. Louis. He held earlier positions with the University of Chicago, where he was on the Committee on Latin American Studies (1972-1980); the Organization for Tropical Studies, Board of Directors (1973-1980); the Institute for Botanical Exploration (1974); and the International Society for Tropical Ecology (1976).

ALWYN H. GENTRY PSR Eaton Consultant

Ph.D., Washington University of St. Louis (1972)
M.S., University of Wisconsin (1969)
B.A., Physical Science; B.S., Botany/Zoology (1967)

Since 1967, Dr. Gentry has engaged in field work funded by National Science Foundation grants in many different South and Central American countries, including Peru, Colombia, and Bolivia. He is a specialist in the flora of Amazonian Peru and in the structure and composition of tropical forests. In 1980 he did field work in Jamaica. He is currently Curator for the Missouri Botanical Garden.

FREDERICK C. MERTZ PSR Eaton Consultant

B.A., M.A., Geography, University of California, Santa Barbara
(1977-1984)

Specific experience relevant to the proposed project includes extensive image processing for applied research (in particular, database development) for agricultural applications and for vegetation communities in mountainous terrain; and image processing procedure development for high resolution sensors (TM, SPOT) on satellite and/or aircraft platforms. Mr. Mertz has traveled extensively within Latin America, including visits to coca-producing regions of Bolivia (Cochamamba/Santa Cruz), Peru (Tingo Maria), and Colombia (southeastern and northern) and to marijuana-producing regions of Mexico.

ROSS NELSON PSR Eaton Consultant

M.S., Forestry/Remote Sensing, Purdue University (1979)
B.S., Forest Management, University of Maine (1974)

Mr. Nelson works as a physical scientist at NASA's Goddard Space Flight Center in the Earth Resources Branch, Laboratory for Terrestrial Physics. He is an expert in the use of satellite digital data, specifically AVHRR, MSS, and/or TM data, and airborne laser data for large area assessment and monitoring of tropical and subtropical forest conversion. He has written many articles in his field, for example: "Monitoring Tropical Deforestation in Mato Grosso, Brazil, Using Landsat MSS and AHVRR Data" (1986); and "Deforestation in the Tropics: New Measurements in the Amazon Basin Using Landsat and NOAA Advanced Very High Resolution Radiometer Imagery" (1987).

GEOFFREY GRAHAM PARKER PSR Eaton Consultant

Ph.D., Ecology, University of Georgia (1985)
M.S., Environmental Sciences, University of Virginia (1981)
B.S., Biology, McGill University (1976)

In a significant project with the University of Georgia (1980-1985), Dr. Parker studied changes in hydrology and nutrient loss as a function of degree of disturbance in a clearfelling experiment in a tropical rainforest of Costa Rica. He also developed standard procedures and managed the laboratory for chemical analyses of water, plant, and soil samples from field sites in tropical America. He has published extensively in his field and has numerous articles relevant to the proposed project, such as "Effect of Disturbance on Water and Solute Budgets of Hillslope Tropical Rainforest in Northeastern Costa Rica" (1985); Hydrologic Changes Following Tropical Deforestation" (1985); "Tropical Deforestation and Evapotranspiration" (1985); and "Percolation and Nutrient Leaching from Soils From Intact Forest; "Artificial Tree-fall Gaps, and Small Clearcuts in a Tropical Rainforest in Northeastern Costa Rica" (both to be submitted).

THOMAS A. STONE PSR Eaton Consultant

M.A., Geology, Dartmouth College (1982)
B.A., History, Bates College (1970)
Additional studies, University of Southern Maine (1976, 1980) and Northeastern University (1978-1979)

Mr. Stone's experience combines field work in environmental studies with work using remote sensing for data collection. He has done a significant amount of field work in Brazil and the Amazon Basin. Relevant articles include studies of tropical deforestation measured by Landsat. Mr. Stone is presently a research associate at the Ecosystems Center of Woods Hole, Massachusetts, where he has worked since 1982.

CORPORATE CAPABILITIES AND FACILITIES

The proposed project will be handled by PSR Eaton's Advanced Concepts and Technology Division in Arlington, Virginia, conveniently located in Rosslyn. Well equipped to handle all aspects of the project, we have a secure facility, library research services, image processing equipment, and a publications department.

Security

The Washington office has a Top Secret Facility with a secure computer and a large secure work area. In addition, it has a large sensitive compartmented information facility (SCIF). All members of the proposed staff hold all necessary clearances.

Library Services

Library services are described under Methodology. See page 7.

Image Processing

PSR Eaton's image-processing center offers broad capabilities in the fields of digital image-processing and GIS.

Our resources include two ERDAS-PC systems, image-processing systems developed by Earth Resources Data Analysis Systems, leaders in small-system technology. Based on the IBM PC-AT, the ERDAS-PC is a complete image processing and geographic information system with full-color display, 105 Mb disk storage, digitizing tablet, 6250 bpi tape drive, a Tektronix 4696 color ink jet printer for input of satellite image data tapes, and color film recorder. The ERDAS-PC supports our multispectral training course and demonstration projects.

PSR Eaton uses the ERDAS EGP for additional PSR Eaton display graphics and geographic data base development. The EGP contains software that can tie display graphics (e.g., symbols, line segments, etc.) to an on-line dBase III database of geographic information.

PSR Eaton also subcontracts out to local companies, such as Earth Satellite Corporation and EOSAT, for the more advanced processing capabilities not available within ERDAS.

Publications

The PSR Eaton publications staff comprises of technical editors, graphic artists, and technical typists, is able to produce top quality documents. Support equipment includes word processing systems, reproduction and binding machinery, extensive graphic art equipment, and computerized plotters.

Appendix A

FIELD DATA SAMPLE FORM FOR MARIJUANA CULTIVATION AREA

This sample copy of the field record sheet is representative of the type of form that may be used to record field observations. Different forms will be required for marijuana and coca cultivation, and possibly different environments.

Taken by: ______________________________ Date: __________

Sample Site Identifier: ______________________________

Air Photo Index # ____________ Landsat Scene ID: ____________

Landsat Column: ______ Row: ______ Site Elevation: __________

Estimated Field Size: _____ meters by _____ meters or _____ hectares

Location: ____
Country Parish/Department Latitude Longitude

35 mm Frame Numbers: ______________________________

Kind of Surface Cover:

(check one)
( ) Natural forest
( ) Secondary forest
( ) Brush vegetation
( ) Harvested marijuana
( ) Growing marijuana
( ) Mature marijuana
( ) Recently burned
( ) Bare soil

(check one)
( ) Dense (65% to 100%)
( ) Sparse (10% to 65%)

Marijuana Conditions: Age: ____________ Height: ____________
Health: ( ) Good ( ) Poor
Row Direction: ____________________

Soil Type: ______________________________ Slope: ______
Slope Ascent: ______________ Soil Texture: ______________
Soil Wetness: ______________ Estimated Thickness: __________

Soil Conditions:

(check one)
( ) Highly eroded nonfertile
( ) Moderately eroded nonfertile
( ) Moderately eroded with some nutrients
( ) No erosion, nonfertile
( ) No erosion, fertile, good humus in A horizon

Other Soil Conditions: ______________________________
Estimated Age of Cleared Site: ( ) under 6 months
( ) 6 months to 1 year
( ) 1 to 2 years
( ) 2 to 5 years
( ) over 5 years

Appendix B

SELECT BIBLIOGRAPHY

Allen, J. C., and Barnes, D. F., "The Causes of Deforestation in Developing Countries," Annals of the Association of American Geographers, Vol. 75 (1985), pp. 163-184.

Bohn, H. L., "Estimate of Organic Carbon in World Soils," Soil Science Society of America Journal, Vol. 40 (1976), pp. 468-470.

Cochran, W.G., Sampling Techniques, 2d ed. (New York: John Wiley and Sons, 1963).

Colwell, J.E., Regional Inventory by Joint Use of Coarse and Fine Resolution Satellite Data Proc., 17th International Symposium on Remote Sensing of the Environment, Ann Arbor, Michigan (1983), pp. 1077-1083.

Fearnside, P.M., "Deforestation in the Brazilian Amazon: How Fast is it Occurring?" Interciencia, Vol. 7, No. 2 (1982), pp. 82-88.

Gentry, A.H., and Lopez-Parodi, J., "Deforestation and Increased Flooding of the Upper Amazon," Science, Vol. 210, No. 4476 (1980), pp. 1354-1356.

Grainger, A., "Quantifying Changes in Forest Cover in the Humid Tropics: Overcoming Current Limitations." Journal of World Forest Resources Management, Vol. 1 (1984), pp. 3-63.

Hallum, C.R., Sampling, Stratification, and Aggregation Approaches for Global Vegetation/Biomass Monitoring. Report No. JSC-18922, Johnson Space Center, Houston, Texas, 1984.

Houghton, R.A., et al., "Net Flux of Carbon Dioxide from Tropical Forests in 1980," Nature, Vol. 316 (1985), pp. 617-620.

Joyce, A. T., Procedures for Gathering Ground Truth Information for a Supervised Approach to a Computer-Implemented Land Cover Classification of Landsat-Acquired Multispectral Scanner Data, NASA Reference Publication 1015, Johnson Space Center, Houston, Texas (1978).

Kirby, C.L., and VanEck, P.I., A Basis for Multistage Forest Inventory in the Boreal Forest Region, 4th Canadian Symposium on Remote Sensing, Loews le Concorde, Quebec, Canada (1977), pp. 72-94.

Langley, P. G., New Multistage Sampling Techniques Using Space and Aircraft Imagery for Forest Inventory. Proceedings of the 6th International Symposium on Remote Sensing of the Environment, Ann Arbor, Michigan (1969), pp. 1179-1191.

Mares, M. A., "Conservation in South America: Problems, Consequences, and Solutions," Science, Vol. 233 (1986), pp. 734-739.

Nelson, R., and Holben, B., "Identifying Deforestation in Brazil Using Multiresolution Satellite Data," International Journal of Remote Sensing, Vol. 7, No. 3 (1986), pp. 429-448.

Nelson, Ross, et al., "Determining the Rate of Forest Conversion in Mato Grosso, Brazil, Using Landsat MSS and AHVRR Data," submitted to International Journal of Remote Sensing.

Raj, D.E.S, Sampling Theory (New York: McGraw Hill, 1968).

Rensberger, B., "Scientists See Signs of Mass Extinction," Washington Post (29 Sept. 1986), pg. A1.

Scheaffer, R.L., Mendenhall, W., and Ott, L., Elementary Survey Sampling, 2nd Ed. (Boston, Massachusetts: Duxbury Press, 1979).

Simon, J. L., "Disappearing Species, Deforestation and Data," New Scientist (15 May 1986), pp. 60-63.

Stone, T. A., and Woodwell, G. M., et al., Deforestation Measured by Landsat: Steps Toward a Method, Technical Report to the Department of Energy, TR005, Washington, D.C., 1983.

Titus, S., Gialdini, M., and Nichols, J., A Total Timber Resource Inventory Based Upon Manual and Automated Analysis of Landsat-1 and Supporting Aircraft Data Using Stratified Multistage Sampling Techniques, Proc., 10th International Symposium on Remote Sensing of the Environment, Ann Arbor, Michigan (1975), pp. 1093-1099.

Woodwell, G. M., et al., "Deforestation in the Tropics: New Measurements in the Amazon Basin Using Landsat and NOAA Advanced Very High Resolution Radiometer Imagery," Journal of Geophysical Research, Vol. 92, No. D2 (20 February 1987), pp. 2157-2163.

Woodwell, G. M., et al., The Role of Terrestrial Vegetation in the Global Carbon Cycle: Measurement by Remote Sensing (New York: John Wiley an Sons, 1984).