THE ENVIRONMENTAL IMPACT OF ILLICIT NARCOTICS CULTIVATION IN SELECTED FOREST REGIONS OF LATIN AMERICA AND THE CARRIBEAN

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1.0 INTRODUCTION

It has been estimated that each year 11.3 million hectares of tropical forest are cleared and converted for other land uses. Where land can support sustainable agriculture, deforestation may be beneficial. But most of the tropics' remaining forest land cannot sustain continuous farming or grazing using current practices and is soon abandoned. This abandoned land has lost much of its inherent productivity - a loss tropical nations and the world can ill afford.

The loss of forest land has a range of consequences; degradation of site productivity, decreases in water quality, increased erosion and subsequent siltation, and a loss of biological diversity in both flora and fauna. Most narcotic crop cultivation takes place in the tropical latitudes. This illicit cultivation is now being recognized as a particularly deleterious aspect of tropical deforestation. Narcotic crop cultivators are usually new occupants to a region and less knowledgeable and concerned with local environments and suitable farming systems. Unlike many native populations they cultivate the same plots until the soil is exhausted.

The inherent nature of most illicit cultivation places it outside national planned development and control. Often as the illicit cultivators move from an exhausted site they select new areas removed from settlements and legitimate agriculture. This process exacerbates the impacts to the ecosystem, producing a series of degraded sites which have lost the ability to maintain productivity. The effects of degraded productivity are manifested throughout the surrounding area. Generally, tropical soils have low native fertility and the ecosystem these soils support are delicately balanced through the process of nutrient cycling. The disruption of this cycle can be studied and its effects measured, providing an understanding of the nutrient cycling process and the impacts of tropical forest clearfelling.

The following pages discuss the mechanisms controlling nutrient cycling, nutrient retention following disturbance, and a methodology to assess the impacts of clearfelling tropical forests for narcotic crop cultivation on site nutrient dynamics. While there are many potentially adverse impacts associated with clearfelling tropical forests for all agricultural purposes, degradation of site productivity is clearly of most concern. If site productivity is permanently degraded, all other adverse impacts are also permanent, such as loss of species diversity and degradation of water quality and soil properties. More importantly, permanent degradation of site productivity directly equates with loss of agricultural and forest resource potential. Matson et al. (1987) citing previous studies, estimated that $20-25x10^9$ Kg of nitrogen are lost annually from the $20-25x10^6$ ha cleared for shifting cultivation. A demonstrated loss of potential agricultural and forestry resources provides a most convincing argument for host governments. For these reasons nutrient cycling and productivity aspects of ecosystem functioning are stressed here rather than other ecosystem aspects.

The proposed methodology is designed to demonstrate loss of site productivity through the monitoring of nutrient stocks along a temporal sequence of disturbance history. Remotely sensed data are proposed as the tool necessary to identify the temporal sequence and, therefore, the appropriate sampling sites. In addition, remotely sensed data (specifically, Landsat TM) will be used to generate a spectrally classified vegetation cover type data base. The classification will identify permanently degraded sites, which will also provide an indication of loss of species diversity.

2.0 BACKGROUND AND PROBLEM STATEMENT

The first quantified, published findings concerning the environmental impacts of deforestation were conducted in the White Mountains of New Hampshire at Hubbard Brook (Likens et al. 1970). Selected sections of the watershed were clearcut and the remaining cut vegetation was sprayed with herbicide to prevent regrowth. Nutrient export from the cut site increased eighty-fold in some cases as compared to the uncut (control) areas, including increased export of potassium (K), calcium (Ca), sodium (Na) and magnesium (Mg). In addition to nutrient export, which decreases site productivity, increased soil erosion (partly responsible for nutrient loss) and increased stream temperature were observed. Increased stream temperatures have reduced dissolved oxygen content and result in unsuitable habitat for some aquatic species. For example, stream temperatures above 68° F (20° C) are no longer suitable for trout habitat.

The Hubbard Brook findings stimulated many subsequent investigations concerning nutrient cycling in environments throughout the United States and other ecosystems of the world, with nitrogen (N) cycling being the primary focus. Nitrogen is frequently a limiting nutrient, at least in temperate ecosystems, and nitrogen losses have increased more than any other element in most reported studies (Vitousek and Melillo 1979). Briefly, when an area is deforested, plant nitrogen uptake is eliminated and nitrification (conversion of NH_4^+ to NO_3^-, by microbial populations) increases as a result of increased forest floor temperatures (from removal of tree canopy). The excess microbial produced nitrate-N (NO_3-N) is lost through leaching and soil erosion. Moreover, denitrification (NO_3^- conversion to N_2 and N_2O through microbial respiration) is increased as a result of increased microbial populations (increased temperature) and reduced competition with roots.

The numerous studies conducted in the United States subsequent to the Hubbard Brook study all reported comparatively lower levels of nitrogen loss on disturbed forest sites. Corbett et al. (1978) examining the results of clearcutting investigations throughout the United States, found that nutrient loss increased with increasing latitude, and also that stream water temperature and sediment load decreased with increasing latitude. An often cited criticism of the Hubbard Brook investigation was that soil organic content (forest litter layer) was comparatively high due to slow decomposition in this temperature limited environment. Moreover, Hubbard Brook receives considerable annual input from weathering of parent material, which is not typical of all environments - especially deeply weathered tropical laterites and infertile, well drained sandy soils. Apparently, environmental differences among sites are important in controlling the magnitude of nutrient loss following deforestation. Vitousek and Melillo (1979) have suggested seven mechanisms of nitrogen retention following clearfelling; several of these, such as anion adsorption, immobilization, and denitrification, may be especially important in the tropics.

Cycling of nutrient stocks is often cited as one of the primary distinctions between temperate and perhumid (monthly precipitation values of at least 200 mm each month, with no dry season) tropical forests, with perhumid tropical forests characterized as being "tight" (Vitousek 1984). In other words, nutrients lost from the biomass are not lost from the ecosystem, but quickly reabsorped after decomposition. The most common evidence of this efficient nutrient cycling pattern is the lack of anion/cation concentration within the stream water of such ecosystems (Walter 1979). Conversely, temperate ecosystems are characterized as being open, a considerable part of the nutrient stock contained in the soil and litter layer. Thick litter layers are common to forest floors of temperate ecosystems. This is all very nice but so what!

The efficient nutrient cycling characteristic of perhumid tropical forests appears to be a response to nutrient deficient soils (laterites) common to this environment. Year-round high temperatures and abundant rainfall afford rapid decomposition of litter and intensified leaching of nutrients to lower soil profiles. Thus, while cold temperatures and/or lack of precipitation in subtropical, temperate and alpine environments limit productivity, perhumid tropical ecosystems are composed of species that have adapted strategies to increase productivity despite nutrient limitations.

✓ No, well yes but climate is the root of the issue

High root:shoot ratios and concentrations of fine roots at the soil surface appear to be the primary mechanisms which enable quick reabsorption of nutrients once they are introduced to the soil through litter fall. In the upper Rio Negro region of the Amazon Basin thick mats of roots in the upper soil surface layer (2 to 15 cm) were documented (Stark and Jordan 1978, Jordan 1985), which supports the assumption of an efficient reabsorption strategy. Another mechanism, increased carbon fixation per unit nutrient, has also been investigated, but empirical evidence gathered at one site does not support this theory (Vitousek 1984).

The general infertility of perhumid tropical forest soils stimulated the initial concern over adverse environmental impacts resulting from deforestation, largely slash and burn agriculture. Removal of standing vegetation and burning the resultant slash was thought to provide a flush of nutrients which would not be able to be retained on site and, therefore, would be permanently lost. This appeared to gain support from the continual declining productivity and eventual abandonment of the site, usually within three years.

Recent studies suggest other explanations to account for this quick decline in crop productivity. It appears that agricultural crops cannot make available the total nutrient stock. At a San Carlos, Venezuela site, cassava
Manihot esculenta, the principal crop species, was found to have a shoot:root ratio of 0.06. However, the average shoot:root ratio of successional species was 0.23 (Jordan 1985). It appears that crop productivity declines because of an inability to utilize potentially available nutrients, while successional vegetation is able to incorporate these nutrients and quickly restore the site's nutrient status to its original state. Anion adsorption to clays deep in the soil profile (previously mentioned) appears to be an important mechanism of nitrogen retention which the greater root mass of successional species is able to access.

The disturbed site, however, must be allowed sufficient time to recover if long term site productivity is to be maintained. The nature of the disturbance seems to be the critical factor which determines future site productivity. Slash and burn agriculture has been classified as a disturbance of moderate intensity and short duration (Jordan 1985) and does not appear to permanently degrade site productivity. However, shortening the duration of the fallow (successional) period eventually results in a nutrient stock which is depleted beyond its ability to recover. According to Walter (1979), after a series of exposures to shifting cultivation the soil can only support Pteridium spp. (tree ferns) or Gleichenia spp. and continued burning allows the domination of alang-alang, Imperata cylindrica. (Reference to Imperata cylindrica indicates observations were made in Africa; Imperata brasiliensis is the tropical America counterpart.)

In a study at Gran Pajonal, Peru (Scott 1978), replicating return to agricultural through burning, it was estimated that greater than 1200 years would be required for complete regeneration in the continually disturbed site (Jordan 1985). The vegetation expressed at frequently burned sites is commonly tropical grasses, which are better competitors under fire stress. This process of savannazation (conversion of forest to tropical grasslands) is widespread in Africa's seasonal evergreen and semi-deciduous tropical forests (Nye and Greenland 1964). Figure 1 provides an illustration of the impact of a too frequent disturbance cycle on site productivity.

This degradation in tropical America has been less, presumably a result of different land use practices, less population pressure and probably subtle but important climatic differences. The demand for narcotic crop products, though, can plausibly replicate the scenario evidenced in Africa. It is EarthSat's hypothesis that narcotic crop cultivation, as a result of its continually increasing demand and need to be free from detection, will result in a disturbance cycle that threatens long term site productivity.

As one progesses toward the margins of the tropics, away from perhumid regions, adverse impacts of forest clearfelling may be enhanced by climatic limitations on productivity. Productivity (rate of biomass accumulation) decreases poleward from perhumid regions to seasonal, wet/dry (and montane)

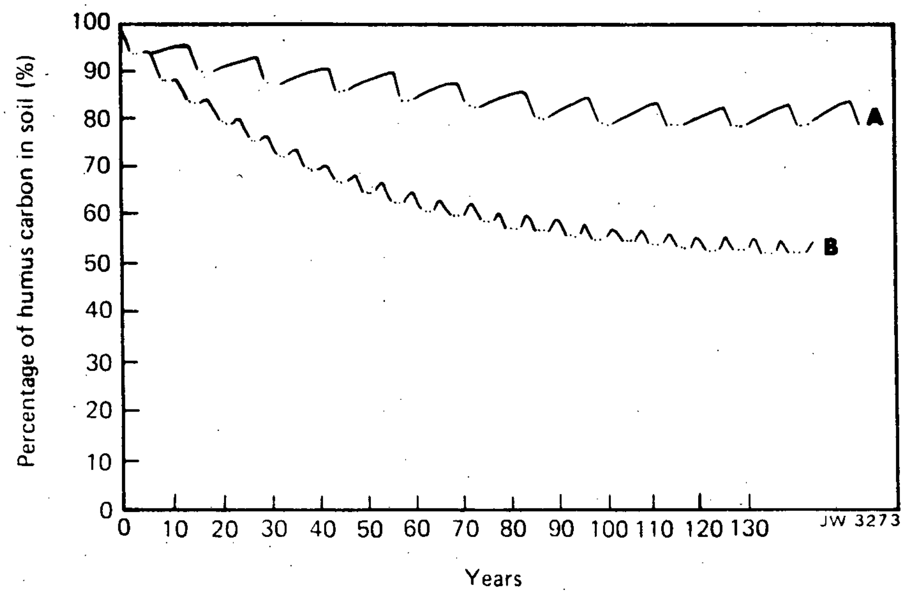

Figure 1: Fluctuation of humus carbon in the soil. Line A represents a two year crop cycle with a twelve year fallow cycle. Line B represents a two year crop cycle with a four year fallow cycle. Patterns of nitrogen decrease should follow carbon patterns (Jordan 1985). Original graph prepared from theoretical calculations by Nye and Greenland (1960), with this figure reproduced from Jordan (1985, p. 121).

tropical forests, as a result of the introduction of one or more dry periods and a general decline in annual precipiation. As productivity decreases, nitrogen incorporation into the biomass per unit time decreases and, therefore, the length of time required to return the nutrient stock to pre-disturbance levels is greater. Also, as the length of the dry season increases, the potential for fire is increased. Fire, which can be viewed as a rapid mineralization of nutrients, favors domination of grasses at the expense of woody vegetation. Grass cover prevents germination of woody species and grasses are better adapted to regeneration following fire, since their underground rhizomes are not destroyed (Jordan 1985). Assuming this scenario to be correct, the potential for permanent site productivity degradation in tropical wet/dry environments is greater than humid tropical environments, since a longer recovery or successional period (in terms of nutrient stock) is necessary, and the threat of fire arresting succession is increased.

Transecting an altitudinal gradient in the tropics also evidences change in ecosystem functioning and nutrient dynamics. As altitude increases, tree heights decline, temperatures decline and permanent cloud forests eventually develop. Decreasing temperatures limit microbial activity, likely causing nitrogen deficiencies. Alexandar and Pitchott (1979), studying carbon:nitrogen ratios along an altitudinal gradient in Colombia, found ratios to increase from less than 10 to greater than 15 as altitude increased from 600m to 3700m; high C:N ratios inhibit plant nitrogen uptake (Pritchett 1979). Tanner (1977) also found nutrients to be limiting in four distinct Jamaican montane forests. Decomposition rates were also less in the Jamaican montane forests than in lowland tropical rain forests, a result, in part, of lower temperatures (Tanner 1981). Tanner further suggested that reabsorption of nutrients prior to leaf abscission is important in the Jamaican montane forests studied. Clearfelling and burning would destroy this nutrient conservation mechanism.

In summary, investigations, to date, indicate that forest ecosystems in tropical environments are able to recover from clearfelling if sufficient time is allowed for regeneration, which is necessary to restore the nutrient stock. However, continual return to the same site at short intervals results in site nutrient loss which can take over one thousand years to restore. Futhermore, as one moves into tropical environments experiencing a dry season or temperature limiting, high altitude tropical environments, lower productivity and the increased threat of fire will likely cause an increase in the length of the successional period necessary

All very nice but so what!

to restore the site to its original productive state.

3.0 METHODOLOGY

The methodology proposed is designed around the collection of field data that supports the calculations of Figure 1, using watersheds or a complex of watersheds as the unit of investigation. The selection of watersheds, therefore, should be implemented according to the watershed's ability to replicate a chronic (shortened, quick return fallow period) disturbance history reflected in line B of Figure 1.

Remotely sensed data, in conjunction with client supplied information, is proposed as the mechanism necessary for identification of areas appropriate for investigation. Landsat MSS and any available photographic data sources will be used to identify areas with chronic disturbance cycles; Landsat MSS data provides a fifteen year chronosequence. The approach implemented by EarthSat for the Jamaica change detection study will be used to identify watersheds exhibiting a chronic disturbance cycle. Imagery should be acquired at a minimum of three year intervals for this analysis.

Within the watersheds identified as appropriate for field sampling (chronic disturbance cycle), sampling units (cultivated areas) will then be identified according to the number of disturbances experienced during the fifteen year period. Figure 1 suggests that a portion of these sample units should have experienced three cultivation cycles within the fifteen year temporal sequence to adequately reconstruct Figure 1 from empirical data.

Field sampling will be composed of foliar nutrient content, soil organic matter nutrient content and streamwater nutrient content analysis.

Nutrient concentration analysis will be restricted to nitrogen (N) and phosphorus (P), since these nutrients are most often limiting (productivity), with phosphorus especially critical in tropical ecosystems (Jordan 1985, Vitousek 1982). As illustrated in Figure 2, leaf production is a feature distinguishing tropical forest ecosystems from other forest environments (Jordan 1985). Coupling this feature with the "tight" or efficient nutrient cycling common in tropical wet forest ecosystems, provides one with the reasonable assumption that foliar nutrient content (concentration) is an adequate estimate of total biomass nutrient content.

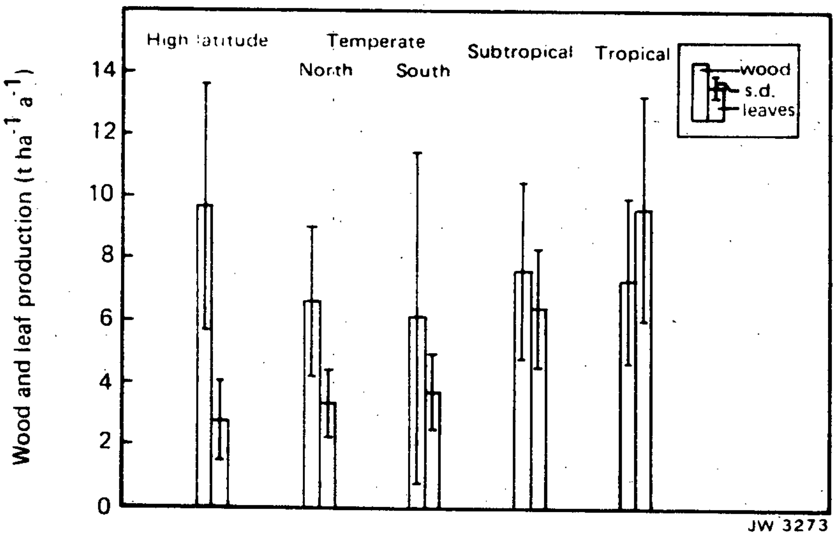

Figure 2: Average and standard deviations of wood and leaf production from mesic hardwood forest ecosystems of various latitudes. Data values are originally published by Jordan (1983). Figure reproduced from Jordan (1985, p. 9).

Combining foliar nutrient concentration estimates with soil organic matter nutrient content will provide an index of the total nutrients (N, P) available to an ecosystem. In fact, Vitousek (1982) suggests that litter dry mass/nutrient ratios (oven dried weight of total litter sample per weight of nutrients in sample) provide a good index of nutrient economy within the unit sampled. Combinations of foliar and organic matter nutrient concentrations will index total nutrient availability of the site and provide insight into nutrient cycling within the site.

A third necessary estimate is stream nutrient concentration, to provide an estimate of site nutrient export. The three estimates, in total, will provide an adequate, time efficient estimate of nutrient cycling and afford comparison of nutrient cycling mechanisms across an environmental continuum. Furthermore, measurement of stream nutrient concentration will provide a reasonable assessment of water quality. Phosphorus eutrophication is a frequently evidenced problem affecting water resources. The algal blooms of Lake Okeechobee (Florida) are a most recent and well publicized example. Schindler (1974) has experimentally demonstrated phosphorus eutrophication in small Canadian lakes.

It is hoped that sampling of undisturbed situations can be eliminated through compilation of related, previously published data. Vitousek (1984) has published in tabular form productivity/nutrient cycling data from other investigations conducted throughout the tropics. If this data can be further supplemented, field sampling of undisturbed situations may be able to be eliminated.

Upon completion of the field sampling, Earthsat will produce a classifiaction of vegetation cover types for the areas field sampled using 1987 Landsat TM data. As indicated in Section 2.0, areas "permanently" degraded can often be identified by the presence of particular species associations -- tree ferns and grasses, <u>Pteridium</u> spp. and <u>Imperata</u> spp. respectively. A classification of vegetation cover types reflecting disturbance patterns will provide a product identifying the spatial impact of repeated forest clearfelling and provide a "map" identifying areas of

Then why all this sampling Crap!

permanently degraded site productivity.

4.0 PROJECT PERSONNEL

The following resumes represent the type of interdisciplinary project team EarthSat would expect to utilize in implementing the described methodology. This type of environmental impact study requires expertise in a range of both investigative and practical disciplines. Candidate members are:

Dr. Charles Sheffield	-	Project Officer
Dr. Carl Jordan	-	Chief Scientist, Project Design
Dr. Vernon Meetenmeyer	-	Project Advisor
b5 Mr. James Durana	-	Environmental Impacts/Assessments
Mr. James Wickham	-	Tropical Ecosystems
Mr. Douglas Pool	-	Tropical Agronomy
b5 Ms. Nancy Anderson	-	Environmental Analysis
Mr. Dennis Hlavka	-	Agro-meteorology
b5 Ms. Kim Freed	-	Soils/Field Research

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