# Integrating Field Data and Remote Sensing to Identify Secondary Succession Stages in the Amazon

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Abstract - Secondary succession (SS) of tropical forest ecosystems follows disturbances such as deforestation. Sharp distinctions between SS stages are often artificial, but useful in Land-Use/Land-Cover (LULC) classifications. In this paper, results for vegetation structure in Rondônia, Brazilian Amazon, are presented as a basis for discussing the reflectance of SS stages when using Landsat TM imagery. Vegetation structure data were collected through 32 surveys encompassing initial SS (SS1), intermediate SS (SS2), advanced SS (SS3), and forest. The results informed the classification of a TM image acquired in 1998. Statistical analyses were performed. SS1, SS2, SS3, and forest were well separated when using solely the data for vegetation structure ($p<0.001$). However, analyses of reflectance on selected TM bands allowed the separation of only three of these classes (SS1 and SS2 mixed together, SS3, and forest). These findings contribute to the spatial-temporal monitoring of Amazonian landscapes and their LULC dynamics.

## I. INTRODUCTION

Secondary tropical forests originate from some source of disturbance. Sharp distinctions between successional stages are often artificial, but useful to differentiate between forest or secondary formations. The most common distinction within forest species is between two contrasting ecological groups: pioneers (short- and long-lived) and climax species (Whitmore 1998). Climax species can germinate and establish seedlings below a canopy, whereas pioneer species require full light. Therefore, succession is the process where pioneer (light-demanding) species establish themselves in big canopy gaps, climax (shade-tolerant) species follow, pioneers die creating small gaps, and mature forest species grow up.

The physiognomic outcome of this continuous process of restoration is a change in vegetation structure, analyzed in this article for an area in Rondônia, Brazilian Amazon. Brown and Lugo (1990) enumerate five main structural characteristics typifying secondary forests: high total density but low density of trees > 10 cm diameter at breast height (DBH); low basal area; short trees with small diameters; low woody volume; and high leaf area indices. These characteristics change with time giving place to different stages of vegetation features toward a forest structure.

Recently, remote sensing and GIS have improved significantly the capability to monitor processes of LULC change (Turner 1995). Land-cover classifications using these tools became fundamental to understand and monitor processes of deforestation and SS, particularly in the tropics (Foody et al. 1996; Steininger 1996). The integration of these methods of analysis, field data about vegetation structure and composition, and ecological research provide new opportunities for the study of dynamic processes such as forest disturbance and recovery. For regional and landscape assessments, the study of vegetation structure in tropical forests is even more effective than floristic composition because of general spectral responses to vegetation communities at resolutions such as those in Landsat TM images.

In this study, the results for vegetation structure in Rondônia are presented as a basis for discussing the spectral response of secondary stages when using Landsat TM images. The rationale behind this approach is to follow an itinerary from the continuous vegetation variability found in the field to specific categories of SS useful for LULC classifications.

## II. DATA AND METHODS

Rondônia has called attention for its high deforestation rates in the Brazilian Amazon during the last twenty years (Dale and Pearson, 1997). Colonization projects initiated by the Brazilian government in the 1970s played a major role in this process (Schmink and Wood, 1992). Research has compared distinct settlement strategies implemented in the early 1980s (Batistella, 2001), calling attention to the need for multi-temporal LULC assessments to understand the history of occupation and the trends for the future. The accurate classification of vegetation classes responds to this demand. The data used in this study were collected in Machadinho d'Oeste, northeastern Rondônia. Settlement began in this area in the mid-1980s creating a mosaic of cultivated crops, pastures, and fallow land. The climate in Machadinho d'Oeste is equatorial hot and humid, with tropical transition. The well-defined dry season lasts from June to August, and the annual average precipitation is 2,016.6 mm. The annual average temperature is 25.5° C and monthly averages for air moisture ranges from 80 to 85 percent (Rondônia, 1998). The terrain is undulated, ranging from 100 to 450 m above the sea level. Several soil types were identified, mainly alfisols, oxisols, ultisols, alluvial soils, and other less spatially represented associations (Bognola and Soares, 1999). Settlers, rubber tappers, and loggers inhabit the area, transforming the landscape through their economic activities and use of resources.

Fieldwork was carried out during the dry seasons of 1999 and 2000. Preliminary image classification and band composite printouts indicated candidate areas to be surveyed, and a flight over the areas provided visual insights about the size, condition, and accessibility of each site. The procedure used for surveying vegetation was a multi-level technique adapted from CIPEC (1998). After defining the area to be surveyed (plot sample), three sub-plots were randomly installed to cover the variability within the plot sample. A sub-plot is composed of three nested squares: one for sampling ground cover and tree or woody climber species seedlings (1 $m^2$); one for sampling sapling information (9 $m^2$); and one for sampling trees and woody species (100 $m^2$). The center of each sub-plot was randomly selected. Seedlings were defined as young trees or shrubs with a maximum stem diameter less than 2.5 cm. Saplings were defined as young trees with DBH between 2.5 cm and 10 cm. Trees were defined as woody plants with a DBH greater than or equal to 10 cm. Height, stem height, and DBH were measured for all trees in the 100 $m^2$ areas. Height and DBH were measured for all saplings in the 9 $m^2$ areas. Ground cover estimation and counting of individuals were carried out for seedlings and herbaceous vegetation in the 1 $m^2$ areas. Every plot was registered with a Global Positioning System (GPS) device to allow further integration with spatial data in Geographic Information Systems (GIS) and image processing systems. In-depth interviews with landowners were conducted at each sample location to investigate land-use history. In total, 32 plots, 96 sub-plots, and 288 nested squares were surveyed encompassing land-cover classes such as forest, SS1, SS2, and SS3. From the number of individuals, total height, and DBH, other variables were calculated, i.e. density, basal area, biomass, and ratios (Kent and Coker, 1994). For the purpose of image analysis, each plot sample became a training sample. The mean reflectance for the training samples was extracted for each TM band as well as the value for the Normalized Difference Vegetation Index (NDVI). A database was built to integrate all the vegetation data and the spectral data. Descriptive statistics, correlation coefficients, and analyses of variance were performed (Gujarati 1999).

## III. RESULTS AND DISCUSSION

Six sites were sampled to represent SS1. Pioneer species such as light-demanding herbaceous plants, grasses, vines, seedlings, and saplings dominate SS1. Some tree species become important after the second or third year of regrowth. Besides palms, species commonly associated with this period include *Vismia sp.* and *Cecropia sp*. An important characteristic of this stage is the much higher density of saplings (7460.3 individuals/ha) compared to the density of trees (266.7 individuals/ha). High sapling competition in SS1 is also expressed by its twofold basal area compared to trees. The average DBH for trees is just 1.4 cm above the minimum sampling size (10 cm), indicating the early stage of vegetation recovery. The mean tree height of 7.8 m is relatively high compared to other sites in the Amazon (Tucker et al. 1998). This is due mainly to *Cecropia* trees competing for light and emerging to form the canopy. Despite the high density of saplings, trees are responsible for the greatest part of total stand biomass, which is 29.2 t/ha (metric tons per hectare).

The sample for SS2 included ten sites with ages of six, eight, nine, and ten years. The physiognomic difference of this stage in relation to SS1 is evident. In SS2, the density of saplings is still high (4,814.8 individuals/ha), but the density of trees is three times greater than in SS1 (763.3 individuals/ha). DBH for trees increased to an average of 13.8 cm. Total basal area is 11.5 $m^2$/ha and the mean height of trees (10.1 m) is now two times greater than for saplings. Biomass increased twofold in relation to SS1. During SS2, a closer canopy alters the microclimate, improving conditions for shade-tolerant tree species and creating an unsuitable environment for pioneer species.

Eight sites with ages of twelve and thirteen years represented SS3. There are clear differences in vegetation structure in this stage. Although large *Cecropia* are still present, most pioneer species gave way to slow-growing, shade-tolerant forest species. Tree density increased to 920.8 individuals/ha while density of saplings decreased to 3,750.0 individuals/ha. Average DBH for trees is 17.1 cm. Total basal area increased to 13.6 $m^2$/ha with a tree contribution of 51.1%. The mean height for trees is 3 m greater than in SS2 stands. Increases in DBH and height doubled the aboveground biomass in relation to SS2. The general appearance of this vegetation type in terms of canopy layers is similar to a forest. However, trees are still not as high or thick as found in forest stands.

Seven sites represented the sample for open tropical forest. A clear understory and larger trees characterize these areas. The vegetation formation comprises relatively widely spaced tree individuals, sometimes including palms, bamboo, and lianas. The structure of the tropical open forest is quite different from SS stages. The average height is 15.2 m. The density of saplings is the lowest of all vegetation classes sampled (2.407,4 individuals/ha). The density of trees (772.1 individuals/ha) is lower than in SS3, certainly because large *Cecropia* individuals and other pioneer species died off during the transition to forest. The mean DBH of trees (22.8 cm) is five times greater than the mean DBH for saplings (4.5 cm) indicating the dominance of trees in these sites. This characteristic is also depicted from values of basal area. Basal area for trees (12.5 $m^2$/ha) represents 69.4% of the total basal area. An ultimate indication about the developed structure of the sampled forests in relation to the SS stands is given by their total biomass of 269.2 t/ha.

A complementary way to understand differences and similarities between SS stages and forests in the study area is to analyze structural variables in a comparative fashion. Overall, the comparative analysis indicates a significant separation between the classes sampled in the field. Although the process of vegetation recovery happens on a continuous basis, the decision to choose three categories of regrowth was appropriate to characterize distinct structural phases. It is obvious the trend in increasing DBH from SS1 up to forest. The difference between DBH of trees for all classes is statistically significant at $p<0.001$. Basal area, total height, density, and biomass are also well differentiated in SS1, SS2, SS3, and forest at significant levels.

While structural vegetation variables seem to be good indicators of SS stages, the question remains about how spectral Landsat TM bands respond to their variation. SS1 and SS2 spectral curves have a higher variability for the mean reflectance in bands 4 and 5 than SS3 and forest. These latter classes have a smaller and well-defined range of reflectance in the near infrared (band 4) and mid-infrared (band 5). Band 3 shows poor distinctions in reflectance between SS1 and SS2. NDVI does not separate any of the vegetation classes ($p<0.502$). A tridimensional graph of total height and DBH of trees, and reflectance in band 4 also suggests that SS1 and SS2 are not well spectrally separated (Fig. 1). Therefore, the integration of spectral data with the analysis of field vegetation structure can support the decision-making process when defining classes of land cover during image classifications.

## IV . CONCLUDING REMARKS

The study of vegetation structure presented in this paper confirmed expected trends about secondary succession of tropical forests in Rondônia, which include: increase in density of trees with decrease in density of saplings; increase in DBH of trees and total basal area; increase in total height of trees; and, consequently, increase in total aboveground biomass. In addition, the results obtained for selected vegetation structure variables were depicted by spectral responses in Landsat TM bands, particularly within the infrared portion of the spectrum. This is due to chlorophyll absorption in the visible TM bands (1-3); mesophyll reflectance in the near infrared (band 4); and for both plant and soil water absorption in the mid-infrared bands (5 and 7) (Moran et al. 1994). The balance within and between these three groups of bands permits the differentiation of stages of succession, tropical forest, and other land-cover classes.

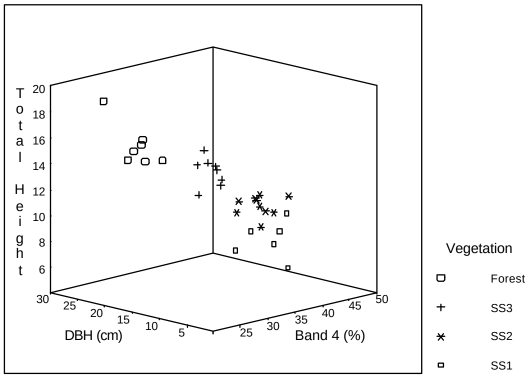

Fig. 1. Total height, DBH, and mean reflectance in Landsat TM band 4 within vegetation classes sampled in Rondônia, Brazilian Amazon.

The applicability of these findings surpasses the understanding of vegetation recovery processes at local scales. It allows the spatial-temporal monitoring of Amazonian landscapes regarding their land-cover dynamics. The use of remote-sensing techniques has improved this capability by ensuring the investigation of SS in larger areas on a multi-temporal basis. However, such an enterprise is not an easy task, mainly because it artificially reduces the continuous process of vegetation recovery to a selected number of categories.

The sample variability allowed the comparison of vegetation structure and spectral responses within and across classes. In general, height and DBH of trees, density of saplings, total basal area, and total biomass were good indicators of vegetation regrowth stages. All of them were significantly separated among SS1, SS2, SS3, and forest classes. The advantage of choosing height or DBH of trees instead of basal area or biomass is the relative simplicity of directly measuring them during fieldwork and perhaps in the future using Light Detection and Ranging (LIDAR) to estimate canopy height for large regional areas.

Despite the clear separation among classes of succession and forest, when graphed against mean reflectance in infrared TM bands, only three clusters of samples were well differentiated (SS1 and SS2 mixed together, SS3, and forest). These results supported the decision of grouping SS1 and SS2 into a single class of regrowth. In doing that, the accuracy increases in relation to the classification system. Also, the confusion between SS1 and pasture or SS2 and perennial agriculture tends to be minimized. In addition, two classes of succession are still maintained, allowing studies of LULC dynamics and landscape transformation in the Amazon. The authors are engaged in improving the performance of SS classifications by using other techniques, such as the implementation of image transform based on ground-truth data, canonical discriminant analysis, linear mixture models, and spatial-spectral classifiers.

## REFERENCES

M. Batistella, "Landscape change and land-use/land-cover dynamics in Rondônia, Brazilian Amazon," Ph.D. diss., Indiana University, Bloomington: Indiana, 399 p., 2001.

I. A. Bognola and A. F. Soares, 'Solos das glebas 01, 02, 03 e 06 do Município de Machadinho d'Oeste, RO," Pesquisa em Andamento, n.10, Campinas, Brazil, EMBRAPA Monitoramento por Satélite, 7 p., 1999.

S. Brown and A. E. Lugo, "Tropical secondary forests," Journal of Tropical Ecology, vol 6, p.p. 1–32, 1990.

CIPEC (Center for the Study of Institutions, Population, and Environmental Change), "International Forestry Resources and Institutions (IFRI) Research Program, Field Manual," Bloomington, CIPEC, Indiana University, 1998.

V. H. Dale and S. M. Pearson, "Quantifying habitat fragmentation due to land-use change in Amazonia," In "Tropical Forest Remnants: Ecology, Management, and Conservation of Fragmented Communities," ed. W. F. Laurance and R. O. Bierregaard Jr., Chicago, The University of Chicago Press, p.p. 400–409, 1997.

G. M. Foody, G. Palubinskas, R. M. Lucas, P. J. Curran, and M. Honzak, "Identifying terrestrial carbon sinks: classification of successional stages in regenerating tropical forest from Landsat TM data," Remote Sensing of Environment, vol. 55, p.p. 205–216, 1996.

D. N. Gujarati, "Essentials of Econometrics," Boston, Mass., McGraw-Hill, 534 p., 1999.

M. Kent and P. Coker, "Vegetation Description and Analysis: A Practical Approach," Chichester, N.Y., John Wiley and Sons, 1994.

E. F. Moran, E. S. Brondizio, P. Mausel, and Y. Wu, "Integrating Amazonian vegetation, land-use, and satellite data," BioScience, vol 44(5), p.p. 329–339, 1994.

Rondônia, "Diagnóstico sócio-econômico do Estado de Rondônia e assistência técnica para formulação da segunda aproximação do zoneamento sócio-econômico-ecológico – Climatologia," vol.1, Porto Velho, Brazil, Governo de Rondônia/ PLANAFLORO, 401 p., 1998.

M. Schmink and C. H. Wood, "Contested Frontiers in Amazonia," New York, Columbia University Press,1992.

M. K. Steininger, "Tropical secondary forest regrowth in Amazon: age, area and change estimation with Thematic Mapper data," Int. J. Remote Sensing, vol. 1, p.p. 9–27, 1996.

J. M. Tucker, E. S. Brondizio, and E. F. Moran, "Rates of forest regrowth in eastern Amazônia: a comparison of Altamira and Bragantina regions, Pará State, Brazil," Interciencia, vol. 23(2), p.p. 64–73, 1998.

B. L. Turner II, D. Skole, S. Sanderson, G. Fischer, L. Fresco, and R. Leemans, eds., "Land-Use and Land-Cover Change Science/Research Plan," Joint IGBP and HDP Publication, Stockholm, Sweden, International Geosphere-Biosphere Programme; Bonn, Germany, Human Dimensions Programme on Global Environmental Change, 1995.

T. C. Whitmore, "An introduction to tropical rain forests," Oxford, Oxford University Press, 282 p., 1998.