Secondary Vegetation
Ecological, Social, and Remote Sensing Issues

Report on a workshop organized by the project group for "Measurement and Modeling of the Inter-Annual Dynamics of Deforestation and Regrowth in the Brazilian Amazon." David Skole (Principal Investigator), Robert Walker, William Salas, and Charles Wood.

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Participating Projects

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"Biogeochemical cycles in degraded lands," Eric Davidson, Tatiana Deane de Abreu Sá, Ima Guimaraes Vieira, Paulo Moutinho, and others.

"Human and physical dimensions of LUCC in Amazonia: Forest regeneration and landscape structure," Eduardo Brondizio, Emilio Moran, and others.

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I. **INTRODUCTION**

Recent results from NASA's Landsat Pathfinder project indicate that 30% of once cleared land in the Brazilian Amazon is now in secondary regrowth.[1] Such widespread succession clearly impacts carbon flux over the basin, given the sequestration potential of secondary vegetation. Indeed, basin-scale assessments that do not recognize regrowth sequestration miss a key component of the carbon cycle. The balance of atmospheric carbon in Amazonia depends nearly as much on succession in the wake of disturbance as on deforestation.

Despite this centrality, key aspects of successional ecology have been overlooked by the LBA Ecology project For example, there are limited studies addressing critical elements of the disturbance environment associated with logging and fire. Moreover, patterns and processes of vegetation recovery are outcomes of human behavior interacting with the environment, a circumstance calling for interdisciplinary research. For reasons such as these, a workshop was convened at The Florida State University on February 25 and 26, 1999 to identify program-related issues regarding secondary vegetation, to integrate the discussion along ecological, social, and technical dimensions (i.e., measurement via remote-sensing), and, when possible, to state research questions of importance to LBA ecology.

This document, a product of the FSU workshop, is meant to function as a resource for LBA scientists. In particular, we provide brief overviews of pertinent issues that arose in discussion. In order of presentation, these overviews (with appropriate bibliographic materials organized at the end) address (1) terminological issues, (2) measurement from both ecological and remote sensing perspectives, and (3) the human dimensions of regrowth generation, utilization, and abandonment.

II. **WHAT IS SECONDARY VEGETATION?**

The Farmer's Terminology: Farmers throughout the Amazon basin have different names to indicate different types and stages of secondary growth. Evidently, these terms indicate farmers' perceptions about differences in structure and species dominance. Terms may be site specific or of common usage throughout the region. In some cases, they reflect actual stages of succession, from shrubby regrowth to more mature stands of successional trees. It is important to keep in mind that farmer terminology is not based on measurement or ecological categories. The following list enumerates a few of the more common terms. Clearly, this list is not an exhaustive one, since terms may be highly specific to place or vegetative complex.

- *Quiçassa, Juquira, and Massega*: Theses are three names widely used for roughly the same type of secondary growth where herbaceous weeds and shrubs dominate.

- *Capoeirinha*: This term indicates a slightly more advanced stage than *Quiçassa, Juquira, and Massega.* In *Capoeirinha*, saplings of pioneer and successional trees

[1] Brown and Lugo (1990) note that 40 percent of New World tropical forest is secondary forest. Allan (1965) claims that the Congo basin is entirely in secondary growth.

are also present, with a slight dominance of tree species over herbaceous weeds and shrubs.

- *Capoeira*: This term indicates a stage in which pioneer trees are present. This category can include a broad array of ages, height, and structural features.

- *Capoeirão, Mata Fina*: These terms are used to indicate a stage where successional species dominate the composition of the secondary growth. In this stage it is almost impossible to differentiate secondary growth from primary forest using current remote sensing approaches.

The Ecologist's Terminology: Ecologists understand secondary vegetation to be the successional plant community that occurs in the wake of disturbance. Such disturbances, both anthropogenic and natural, alter the structure of vegetation and modify microclimate and soil characteristics. Typical anthropogenic disturbances in the tropical forest biome include agriculture, logging, and fire, each of which shows different vegetative impact. Agriculture often eradicates the original species, and post-agricultural regrowth begins with a highly modified set of ecological actors. Logging may leave much of the original vegetation intact, which allows succession to start with a forest community already in place. Fire has variable impacts that range from minor damage to complete obliteration as a function of intensity.

Early stages of post-agricultural secondary succession are usually dominated by grasses (Poaceae), sedges (Cyperaceae), and herbaceous dicots. Over time, pioneer tree species arrive and exclude the early-successional vegetation. In general, key pioneer genera in secondary growth include *Vismia* (Clusiaceae), *Cecropia* (Cecropiaceae), *Miconia* and other Melastomataceae, *Piper* (Piperaceae), *Croton* (Euphorbiaceae), and *Ochroma* (Bombacaceae). Pioneer species typically have short lives (3-15 yrs) and are replaced by heliophiles, sun-loving hardwoods from many different families that appear early during succession. Only after several decades do primary forest tree species become a significant part of the vegetation. The quintessential Amazonia sequence may be summarized as a "forest" dominated by *Cecropia* progressing to hardwoods as the forest matures. This pattern varies, however, and in certain areas unique species such as the Babassú palm (*Attalea racemosa*) is a prominent element of secondary growth.

II. MEASUREMENT

Ecological Issues and Questions: Summaries of biomass estimates for mature and secondary forests have been provided by Cairns et al. (1997) and Johnson et al. (1999).[2] Cairns et al. (1997) assemble data on biomass and disaggregate it to aboveground and root components. They then explain the magnitude of root biomass in a regression framework using as independent variables the aboveground biomass, age of stand, and a set of dummy variables capturing boreal, temperate, and tropical locations (n=151). Johnson et al. (1999) descriptively address the relationship between above ground biomass and temperature adjusted age (growing-season degree-years), stratified for sandy/non-sandy soils, and for tropical/non-tropical sites (n=283). There is no

[2] The focus of the report is on biomass and Carbon, as is the LBA-ecology program.

difference in the relationship for tropical and non-tropical sites, although age is truncated for the tropical sample. The relationship is flatter for sandy than for non-sandy soils, as would be expected with nutrient or water limitation.

Despite worldwide measurements of biomass accumulation, observations for tropical sites are relatively few, which inhibits specification of functional relationships between regrowth rates, age, and environmental conditions.[3] Early work by Uhl and colleagues in the Rio Negro basin provides a well-known account of biomass accumulation in the Amazon region. Uhl (1987) measured regrowth at about 6.77 T/ha in the early stages of succession. Saldarriaga et al. (1988) found a steady increase for older secondary vegetation, but even after eighty years biomass remained substantially less than primary forest.[4] In a similar vein, Brown and Lugo (1990) show the most rapid rate of accumulation occurring during the first thirty years, after which it slows considerably. For sites in northeastern Para, secondary forest appears to recover only thirty five percent of mature forest biomass after twenty years (Vieira 1996).

Many factors contribute to the regeneration of secondary vegetation, and it should come as no surprise that growth rates are highly variable. In some settings, a field abandoned for two years can have woody specimens 4 m tall, while elsewhere a similarly aged plot could still be dominated by grasses and sedges. Soils, nutrients, and mycorrhizal associations play important roles in vegetative regrowth outcomes, as do ecological processes such as decomposition and herbivory (e.g., by ants; see Nepstad et al. 1995). Land use history is critical in this regard (Salomão et al 1996; Moran et al. 1996; Denich and Kanashiro 1998). Long periods of intense use cause the greatest changes to soils and their components, thereby slowing the process of regrowth. Since many secondary forest species reproduce vegetatively, root destruction following mechanized agriculture favors succession by plants such as grasses that reproduce from seeds (Denich and Kanashiro 1998). In abandoned pastures where soil has been compacted and leached, the period of biomass accumulation by secondary vegetation is prolonged. Invasion by woody species is inhibited by root destruction, soil compaction, diminished nutrient stocks, and loss of the mycorrhizal community. Salomão et al. (1996) show that biomass varies as a function of prior land use from 3.5 to 33.4 T/ha for secondary vegetation aged five years, from 22.3 to 62.8 T/ha for vegetation aged ten years, and from 48.1 to 131.5 T/ha for vegetation aged twenty years. The same soil degradation that causes farmers to abandon their land also affects the growth rate of secondary vegetation.

Ecological Research Needs: Although accounts of biomass accumulation exist for sites in the Amazon basin, the sample is insufficient to provide statistical descriptions linking rates of succession to environmental conditions and ecological processes. In addition, research has generally considered the full process stemming from agricultural clearance to restoration of closed, high biomass forest. A notable gap involves disturbances associated with logging and fire. Although previous research has addressed the magnitude of related effects, such as the amount of collateral damage that occurs

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[3] For example, in the study by Johnson et al (1999), 20 of 283 sites are in Brazil or Venezuela.

[4] Secondary forest aged 80 years ranged from 160 to 213 T/ha in four stands, while mature forest ranged from 268 to 335 T/ha in another four stands. Measures were of total living biomass (Saldarriaga et al. 1988).

under selective logging (Uhl et al. 1991), studies aimed at assessing regeneration after logging or fire are limited. Finally, successional studies tend to focus on gross measures of biomass and have paid little attention to nutrient recovery in either biomass or soils, with a few exceptions (e.g., Denich 1991; Hondermann 1995). This linkage is key to understanding the behavior of shifting-cultivators who depend on recycled nutrients. Indeed, social scientists hypothesize that the rate of fertility recovery is a key piece of ecological information assessed by shifting-cultivators in deciding when to slash secondary vegetation (Barret 1991; Walker 1999).

In sum, the following questions are pertinent to the ecology of secondary succession in the basin, and expand upon the LBA Ecology questions elaborated in our Experiment Plan:

- How is rate of regrowth affected by environmental conditions such as soil types and precipitation?
- How is the rate of regrowth affected by changes in ecological processes such as decomposition and herbivory?
- How is rate of regrowth affected by prior land use?
- What form does succession take in areas disturbed by logging or fire?
- How is the rate of soil nutrient recovery linked to biomass recovery? For that matter, does nutrient build-up in biomass exactly track the rate of biomass accumulation? (The interaction of soil nutrient recovery and land use management is discussed further in Section III.)

Remote Sensing of Secondary Regrowth: Optical remote sensing has been used extensively to map the extent and rates of deforestation in Amazonia (e.g. Tucker et al. 1984, Malingreau and Tucker 1988, and Skole and Tucker 1993). Recently, several studies have mapped the extent and temporal dynamics of secondary vegetation at site level (e.g. Alves and Skole 1996, Mausel et al. 1993, Skole et al. 1994, Adams et al. 1995, Steininger 1996, Foody et al. 1996). Optical remote sensing identifies post-disturbance forest regrowth by analysis of patterns of spectral reflectance, a function of vegetative structure, not biomass.[5] As abandoned pastures develop into young secondary forest stands, reflectance in the visible and mid-infrared regions diminishes with increased canopy density, chlorophyll absorption, and canopy water content; near-infrared reflectance initially increases due to increased mesophyll reflectance of the new green biomass (Mausel et al. 1993, Moran et al. 1994, Steininger 1996, Foody et al. 1996). With continuing maturation, the ratio of visible reflectance in the green and red regions of the spectrum declines, as does near- and mid-infrared reflectance due to inter-

[5] Conceptual models of secondary forest recovery have focused on either forest biomass (e.g. Bormann and Likens 1979) or structure (e.g. Oliver 1981).

canopy shading. Eventually, reflectance characteristics become indistinguishable from those of mature, undisturbed forest (Mausel et al. 1993, Boyd et al. 1996).

Secondary vegetation formation and dynamics can also be monitored using multi-temporal remote sensing. There have been several multi-temporal studies mapping age and dynamics of secondary vegetation in various regions of Amazonia (e.g. Alves and Skole 1996 in Rondonia, Lucas et al. 1993 near Manaus, and Sant'Anna et al. 1995 near Tapajos National Forest). For example, Alves and Skole (1996) used multi-temporal Spot XS imagery for a site in Rondonia, Brazil to show that 42% of the areas in secondary vegetation in 1986 remained in secondary vegetation over the following 6 years and approximately 14% of the total area in secondary vegetation in 1992 was older than 6 years.

Several studies have focused using Landsat TM data to separate age classes of forest regrowth. Results indicate that regrowth stands can be spectrally separated into at most 4-5 spectrally distinct age classes, remaining spectrally distinct until an age of roughly 14 years (Boyd et al. 1996, Foody et al. 1996, and Steininger 1996). Working near Manaus, Foody et al. (1996) have demonstrated that intra-site differences in land use history (short term agriculture versus pasture use) can also have a significant impact on the spectral properties of regrowth stands. A pilot study (Salas and Zarin, unpublished) conducted using Landsat data from Amazonas and Mato Grosso further suggests that the seasonality of precipitation has a significant influence on the rate at which regrowth stands recover mature forest spectral reflectance characteristics in Amazonia.

Over the past few years there have been several studies on the use of synthetic aperture radar (SAR) for mapping deforestation and secondary vegetation in Amazonia. Nevertheless, the absence of a spaceborne multi-frequencey or polarimetric SAR system has limited applications. Studies to date have focused on using single frequency and single polarization spaceborne (e.g. JERS-1 and ERS-1) or mission-based systems of opportunity (e.g. SIR-C; See Rignot et al. 1997, Luckman et al. 1997, Saatchi et al. 1997, and Yanasse et al. 1997).

There has also been considerable research on the use of long wavelength SAR systems for estimating above ground biomass, since changes in radar backscatter are related to biomass. Unfortunately, backscatter data saturates beyond certain biomass levels. Estimates of the saturation point for L-band backscatter from tropical forests vary from 40 tons/ha (Imhoff 1995) to 60 tons/ha (Luckmann et al. 1997). Ranson and Sun (1997) and Rignot et al. (1995) have shown that multipolarization, P-band backscatter can be used to estimate biomass for forest stands ranging from 150 tons/ha (temperate forest) to 200 tons/ha (tropical forest), respectively, the expected range of biomass for secondary regrowth in the tropics. Yanasse et al. (1997) used C-band and L-band SIR-C data to discriminate secondary forest stand ages up to 6 years old for a site in Amazonia, but Luckman et al. (1997) showed that biomass in secondary forest in central Amazonia is likely to exceed the saturation cutoff for L-band backscatter.[6] Despite the promise of

[6] Luckman et al (1997) considered 13 stands of secondary forest. Eight of them had biomass exceeding the L-Band saturation point. However, in no case did biomass exceed the saturation point for longer wave, P-Band backscatter.

SAR in monitoring land-cover change, a longer wavelength SAR system is needed to systematically map secondary vegetation biomass in the region.[7]

Remote Sensing Research Needs Quantitative estimates of the net biotic flux on a decadal average suffer from lack of quantitative data on pre- and post-disturbance biomass and on the actual fate of disturbed lands which may be logged, dedicated to perennial or annual crops, converted to pasture, or abandoned to fallow. Now that the spatial extent and rates of tropical deforestation are being measured with some degree of accuracy, techniques are needed for measuring rates of secondary vegetation formation, turnover, and accumulation (under a variety of disturbances) in order to more accurately estimate carbon fluxes. In this regard, the following questions are relevant:

- Given that secondary vegetation is detectable through remote sensing, to what extent can classes of regrowth be disaggregated and identified? Can we separate logging disturbances and fire disturbances?

- Can remote sensing stratify or characterize classes of secondary vegetation based on structure, and can we obtain information on biomass using such classes?

- Can remote sensing stratify rates of change in secondary vegetation structure, and possibly biomass?

- How do spectral signatures for secondary vegetation vary across space? Can we develop basin-wide classifications?

- Are there general rules for multi-temporal analyses with optical (e.g. Landsat and Spot) sensors in defining landcover class membership?

III. SOCIAL SCIENCE EXPLANATION

The Social Sciences and Secondary Vegetation The social sciences have addressed secondary vegetation from a variety of perspectives, both explicitly and implicitly. Field research, much of it by anthropologists, has long considered the manipulation of fallow and use of associated plants in the household economies of indigenous peoples (Posey 1984; Denevan and Padoch 1987; Irvine 1987; Padoch 1987; Unruh 1988; Unruh 1990). Some of this research explicitly incorporates elements of regrowth and forest structure by addressing links between product type, understood as *plants* providing some utility to the household or community, and fallow ages (Denevan and Treacy 1987; Unruh and Alcorn 1987; Unruh and Paitan 1987; Balée and Gély 1989). Salick (1989), Salick and Lundberg (1990), and Coomes and Burt (1997) broaden this stream of analysis by attempting to explain characteristics of farming systems (numbers of fields, crop types,

[7] For LBA, the only suitable SAR system for mapping secondary vegetation biomass, *at site level*, is an aircraft based, multi-frequency (C,L, & P), multipolarization SAR, such as the TOPSAR/POLSAR instrument on the DC 8. Of course, aircraft cannot hope to provide the regional coverage of a spaceborne platform.

associated fallow lengths) in terms of household variables such as size of workforce and wealth position of families or kinship groups. Balée (1989) notes that a large percentage of the Amazonian forest is really an artifact of human use, given the extensive fallow improvements made by pre-colombian inhabitants over hundreds and even thousands of years.

The system of shifting cultivation has also been an object of long term interest to agronomists, anthropologists, and agricultural economists, given its apparently inefficient use of land (Spencer 1966; Ruthenberg 1971; Watters 1971; Peters and Neuenschwander 1988).[8] Shifting cultivation, of course, utilizes secondary vegetation as a means to restore soil fertility; in particular, *shifts* from swidden fields to newly cleared regrowth occur with declining fertility and weed invasions (Ruthenberg 1971; Peters and Neuenschwander 1988; Unruh 1988).[9] Boserup (1965) provides one of the earliest systematic accounts of shifting cultivation from the perspective of the social sciences, and in so doing elaborates an explicit model of vegetative change. (See Turner et al 1977). According to Boserup (1965), increasing population density explains the historic shift that occurs in land-covers, from old growth forest under long rotations, to younger forms of secondary forest, and ultimately to shrubby regrowth cycled every few years.

Recently, economists and geographers have extended the explanation of shifting cultivation beyond the demographic factors identified by Boserup (1965). One aspect of the literature addresses farmer control over soil loss (McConnell 1983) and develops a modeling frame based on pulsing models from the renewable resource literature (Lewis and Schmalensee 1977 and 1979). Krautkraemer (1994) argues that shifting cultivation may be understood as a sequence of farming episodes broken into intervals of soil fertility recuperation during which farming ceases. In this framework, the farmer controls the rate of soil loss (or fertility decline) to maximize net benefits. The approach by Barrett (1991) is similar in that a periodic sequence of farming and fallow is determined to be optimal for the farmer. The farmer's behavior is fundamentally different, however, in that no control over soil loss is exercised. Instead, the farmer chooses fallow and farming periods that will provide the most income over the planning horizon. Walker (1999) develops a model in keeping with the subsistence requirement of shifting cultivators, who must insure a yearly supply of food from their own farming systems in the absence of capital markets for borrowing. Walker's approach predicts the fallow times of secondary regrowth as well as the areas of regrowth associated with each regrowth cohort, as a function of family size (Walker 1999).[10]

Social Science Needs The importance of secondary vegetation has been well-elaborated for indigenous groups, but not for colonists, the majority population in the forest frontiers of Amazonia. In particular, little is know about how these farmers actually utilize

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[8] For an opposing view, see Dove (1986) who notes that inefficient use of land is likely to generate high labor productivity, highly desirable to those who do the work, namely the farmers.

[9] Shifting cultivation in our usage is a term of broad definition including sedentary farmers rotating a fixed number of fields (the Amazonian colonist case) and nomadic groups that shift their residential base with soil depletion. A "swidden" is Old English for "burned clearing (Peters and Neuenschwander 1988)."

[10] Our account is not exhaustive. Dvorak (1992) states a model incorporating weed clearing costs. Jones and O'Neill (1993a, 1993b) present an adaptation of the von Thunen/Alonso land allocation model to shifting cultivation. Such aggregate models focus on regional characteristics as opposed to farmer behavior, the focus of our discussion.

secondary regrowth in their farming systems. In addition, the existing model frameworks suggest that vegetative fallow provides natural re-fertilization and soil protection, but the work remains abstract, with little empirical grounding in the knowledge base of ecology. This shortcoming inhibits behavior-based models of carbon flux, given that regrowth sequesters carbon and is a function of farming activity. Finally, logging and fire disturbances in the tropical forest biome have not been systematically addressed by social sciences, excepting cost-benefit analyses of harvesting programs and plantation forestry for the case of logging.[11] Thus, questions that remain to be answered include:

- What are the retention times of secondary vegetation, and how large are areas of regrowth on individual properties? What products, if any, do colonists take from their secondary vegetation?

- How do farmers decide what age of regrowth to clear for agriculture? Do they recognize the rate at which soils recover nutrients, and if so, how?

- To what extent does regrowth represent a long-term feature of colonist farming systems, or a transient phase in the conversion to pasture or perennials plantations?

- How does logging open forest areas to shifting cultivation and fire? What long-term vegetative *succession* emerges from the social *succession* involving early exploitation by loggers, and forest penetration by shifting cultivators using fire? How does the risk of accidental fire affect farming decisions?

IV. CONCLUSION

Secondary vegetation is a form of land-cover, but it is also a conceptual focal point that unites information from the ecological, physical, and social sciences. As such, it is an inherently interdisciplinary concept. Ecologists describe the structure of secondary vegetation, its rate of biomass accumulation, and the environmental conditions, including those of ***human origin***, that impact its trajectory of change. Remote sensors measure the areal extent of succession, while social scientists explain why people find it advantageous to manage fallows, to slash their regrowth, and to abandon fields to ***natural processes*** of nutrient recovery. Consequently, the dynamics of secondary succession cannot be comprehended without interdisciplinary effort. For the purposes of modeling, this effort must be placed in a conceptual framework that allows for integration across disciplines.

In particular, a composite regrowth function needs to be developed in which biomass accumulation is explained by age, on the basis of *both environmental and land-*

[11] Beside these explicit shortcomings in the social science literature, little is known about how land uses themselves impact the prospects for succession, with some notable exceptions (Moran et al 1996; Denich and Kanashiro 1998).

*use controls***.** This function, in turn, must be linked to the land management actions of shifting-cultivators, who assess *ecological information* regarding nutrient recovery and prospects for *weed* invasions in taking their decisions. The exogenous effects of logging and fire must also be introduced into the model formulation, because these affect ***both successional and decision-making processes***. And finally, upon integration, such a model must be stated with sufficient empirical detail that remote-sensing can be used to test, calibrate, and extend its predictions to regional and basin scale. Only in this way can carbon flux be predicted in a manner sensitive to both the natural and human dimensions of land-cover change.

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