Strategies for Amazonian Forest Restoration: Evidence for Afforestation in Five Regions of the Brazilian Amazon

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Amazonia at the Crossroads

The Challenge of Sustainable Development

edited by

Anthony Hall

Introduction

Studies of secondary succession have become an important subject on the research agenda of the global change community.[1] Ecologists noted as far back as 1685 the tendency of plant communities to change through time, a process that is referred to as succession.[2] The way that the term is used in this chapter is that secondary succession refers to the vegetation that grows back naturally following the cutting of primary mature forest. It represents a gradient from pioneer species, which grow quickly when an opening in the canopy occurs and which provide an environment for the slower growing, mature forest species that eventually replace the pioneers.

Thus, this chapter focuses on the natural regrowth of vegetation following deforestation, rather than managed processes of succession or those resulting purely from natural gaps in the forest canopy when large individuals fall and leave openings. While this chapter focuses on natural or non-directed vegetation regrowth, what is learned from studying this process can provide insight into directed and managed succession. As Luken (1990) notes, the principles of management tend to be most successful when they mimic the trajectories of natural secondary succession. A few suggestions in that direction are made throughout the chapter.

The study of succession also draws attention to the human dimensions of global and regional analyses, which have tended to focus largely on basin-wide deforestation rates[3] and on the impact of deforestation on climate change and atmospheric trace gases.[4] Rates of deforestation in Amazonia have been alarm-

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[1] See, for example, Dantas (1988); Brown et al. (1989); Uhl (1987); Saldárriaga et al. (1988); Nepstad et al. (1991); Hall et al. (1991); Lugo and Brown (1992); Alves et al. (1997).
[2] See Clements (1916); Luken (1990).
[3] See, for example, Skole and Tucker (1993); Instituto Nacional de Pesquisas Espaciais (INPE) (1988, 1989, 1997); Lean and Warrilow (1989).
[4] See Salati (1985); Dickinson (1987); Shukla et al. (1990).

ing in their absolute magnitude, which reached a peak in 1987 and which are returning to these high levels according to recent assessments by Brazil's National Institute for Spatial Studies (INPE), particularly those for 1995. In contrast, succession studies draw attention to local-level trajectories of land-use change,[5] to differences in post-deforestation processes of forest regrowth,[6] and to the contribution of secondary succession in carbon sequestration and emissions.[7] In the tropics, it is estimated that 40 per cent of extant forests are secondary forests.[8] Given the still high proportion of people practising field rotation, their growth is significant in global terms as well as being an essential component in the subsistence of millions worldwide.

The process of succession reflects differential agro-pastoral activity impact on a landscape.[9] Succession plays a key role in soil restoration through the accumulation of biomass, the build-up of litter and organic matter and other beneficial soil/plant interactions. Among traditional populations, secondary forests are selectively managed to keep them useful as sources of food and fibre and, in some cases, are rich in pharmacologically valuable plants.[10] At the local level, regrowth dynamics are closely correlated to such factors as the way the forest was cut and burnt and the land used in different crops and/or pasture; the length of use; the technology used; the presence or absence of surrounding forest vegetation; area size and shape; soil fertility; and the presence or absence of species whose dispersion pattern relies on wind and/or animals that frequent fallow.[11] At the regional level, differences in soil fertility and physical structure and the original vegetation cover are the most significant aspects explaining differential rates of vegetation regrowth in different areas of the Amazon. At basin-scale, studies tend to suggest that the culprit is population growth, or external forces such as capital penetration and road-building schemes.

The research presented here is part of a long-term project, which aims to explain differences in rates of vegetation regrowth. To achieve this, it will look at regions distributed along a fertility gradient representing nutrient-poor to nutrient-rich ecosystems of Amazonia, as well as associated differences in land-use history and landscape patterns.[12] Five regions are examined as representative of different soil fertility conditions and land-use in the region: Altamira (Xingu Basin); Ponta de Pedras (Marajó Island); Igarapé-Açú (Bragantina re-

[5] Brondízio et al. (1994).

[6] Mausel et al. (1993).

[7] Lugo and Brown (1992); Skole et al. (1994); Moran et al. (1994a); Dale et al. (1993); Fearnside (1997a).

[8] Brown and Lugo (1990).

[9] Nepstad et al. (1991); Uhl et al. (1988).

[10] Posey and Balée (1989).

[11] Uhl (1980); Howe and Smallwood (1982); Salomao (1994); Vieira et al. (1996).

[12] Moran (1993); Moran et al. (1994b, 1996); Brondízio et al. (1994, 1996); Tucker et al. (1998).

gion); Tomé-Açú (central Pará State); and Yapú (Vaupes Basin-Rio Negro). See Figure 8.1 for the distribution of research locations.

The goal of this chapter is to explore the process of secondary succession in these five regions by examining basin-wide patterns and inter- and intra-regional differences as follows:

- Basin-wide patterns of forest regrowth, focusing on the relationship between structural and floristic features associated with regrowth stages. All study areas are combined in this analysis and compared to data from available literature. Stand height, basal area, density of trees and saplings and family diversity are compared across sites representing fallow of different ages.

- Inter-regional differences in rates of regrowth appear to be associated with differences in soil fertility. The study areas are compared in terms of vegetation structure, particularly average stand height, while controlling for soil fertility. Regrowth rates based on stand height increment for each region are presented and compared.

  Intra-regional differences in rates of regrowth seem to be associated with the differential impact of land-use history on forest recovery. This section focuses on examples of one particular region (Marajó) where fallow sites of the same age, but which differ in land-use history, are compared in terms of stand height and biomass.

Study areas

Five study areas representing different scenarios of soil fertility and land use are presented in this study:

(1) Altamira in the Xingu Basin is characterised by patches of nutrient-rich alfisols and less fertile ultisols.

(2) Ponta de Pedras in Marajó Island is located in a transitional environment composed of upland oxisols and floodplain alluvial soils.

(3) Igarapé-Açú in the Bragantina region is characterised by both nutrient-poor spodosols and oxisols

(4) Tomé-Açú (south of Bragantina) represents a mosaic of oxisols and ultisols.

(5) Yapú, located at the Vaupés tributary of the Rio Negro, is composed of large patches of nutrient-poor spodosols interspersed with stretches of oxisols.

Figure 8.1   Secondary Succession in Amazonia: ACT Research Sites

1 Altamira, Xingu Basin, Pará, Brazil

2 Ponta de Pedras, Marajó Island, Pará, Brazil

3 Igarapé-Açú, Bragantina, Pará, Brazil

4 Tomé-Açú, Pará, Brazil

5 Yapú, Vaupes Basin, Colombia

Land use varies amongst these areas but, in most cases, these are variations of swidden cultivation, agroforestry and pasture management. The site at Altamira, situated on the Transamazon Highway, was first colonised by settlers in 1971 and has experienced high rates of deforestation and secondary succession associated with the implementation of agropastoral projects. In contrast, the Marajó site has historically been occupied by *caboclo* populations (mixed-race descendants of Amerindian and white settlers, with some black influence). These traditional groups practise mainly agroforestry activities in the floodplain and swidden agriculture in the uplands, although the upland oxisols are also used for pasture and mechanised agriculture. Land use in the Bragantina region has gone through several phases, and today the dominant form is short-fallow swidden cultivation and pasture development, given the proximity of the Belém market. Cultivation of secondary growth areas has been common for decades, and islands of mature forest are rare. The Tomé-Açú site has experienced the most intensive agriculture of the sites studied

and is associated with monocrop production, followed by agroforestry development during the past two decades carried out by Japanese colonists, and more recently by pasture formation. Finally, the Vaupés site at Yapú is populated by Amerindians who practise traditional, long-fallow, swidden cultivation based on bitter manioc. Each, however, has a very distinct landscape and land-cover pattern that reflects human uses in time and space.

Strategies of data collection and integration

For the purpose of site selection during fieldwork and further analysis of the impact of land use and history on regrowth, age classes were used as a baseline. Sites were aggregated at five-year intervals and preliminarily divided into structural classes. Initial secondary succession encompasses fallows of zero to five years, intermediate secondary succession fallows of five to ten years and advanced secondary succession represents fallows above ten years. One stage merges almost imperceptibly into another, thus creating periods that blend characteristics of both stages. For this reason, sites in the middle of each class range and those between classes were selected for sampling in order to examine unique and overlapping structural features. Age classes will be dismissed as an organising principle of regrowth stages later in this chapter, although they will be used to study the impact of land-use history on fallow sites of the same age.

Plots and subplots were randomly distributed, but nested inside each other to provide a detailed inventory of trees (DBH>10 cm),[13] saplings (DBH 2–10 cm), seedlings (DBH<2 cm) and herbaceous vegetation. In the plots, all the individual trees with DBH >10 centimetres were identified and measured for DBH, stem height (height of the first major branch) and total height. In the subplots, all individual trees were identified and counted, and diameter and total height were recorded for all individuals with a DBH greater than two centimetres.

Experienced botanists carried out the species identification in the field and borderline identifications were checked at the Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA) herbarium in Belém, Pará. Botanical samples were collected from half of all species identified to ensure accuracy of taxonomic identification. Identification included family, genus and species and common name when known. In each site, soil samples were collected at twenty-centimetre intervals to a depth of one metre. Soil samples were analysed for chemical and physical properties at the CEPLAC and EMBRAPA soil laboratories in Belém.

Above ground dry biomass was derived from inventory data using allometric equations from the literature. Two different biomass equations were used to differentiate between trees and saplings. The equation used by Brown et al. (1989) was used to estimate tree biomass (DBH>10cm). Another equation from Uhl et al.

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[13] DBH = Diameter at Breast Height.

(1988) was used to estimate sapling biomass (DBH 2–10). The equation taken from Brown et al. was selected for its focus on forest biomass. This equation was developed from a large number of forest inventories from different areas of the tropics, focusing on adult trees and mature stands. The equation formulated by Uhl et al. was developed from data collected from different stages of secondary succession sites in eastern Amazônia, derived mainly from sapling data. Uhl's generic species equation was selected for to its applicability to a wide range of species. Sampled areas were located on the satellite image, and their coordinates were obtained with a Global Positioning System (GPS) device, the Magellan Nav 1000 Pro receiver. In areas of closed canopy which obscured GPS signal reception, ground control points were collected on the fringes of the vegetation and, when possible, at its corners.

The data was subjected to statistical analysis to provide a structural comparison between sites. One-way analysis of variance (ANOVA) was performed. Each inventoried site was subdivided into plots (ten plots at each site of SS2, SS3 and forest, and five plots at each SS1 site). This data arrangement increased the number of samples to be analysed and facilitated comparison of sites on the basis of standard deviation and variance. Early work using ANOVA to compare the significance of structural parameters to discriminate regrowth stages found that average height is the most significant indicator of structure.[14] For this reason, only average height was used to test for differences in rates of regrowth between and within sites. First, ANOVA ($p/=.05$) was used to compare the five regions in terms of average height across age classes. This made it possible to reorganise age classes into structural classes. Second, ANOVA ($p>/=.05$) was repeated, but this time the test was controlled for soil fertility differences between sites. The soil fertility index was used as an indicator of regional-level fertility.

A soil fertility index to summarise differences between regions was used.[15] The index uses pH, organic matter, phosphorus, potassium, calcium and magnesium and aluminium (inverse value). The index was prepared for each depth (0–20 cm, 20–40cm, 40–60cm, 60–80cm and 80–100cm) and an average index was prepared across depths (see the discussion of inter-regional differences for data analysis resulting from the above).

Using a similar statistical analysis, data from the Marajó region was used to analyse the impact of land use on regrowth (see discussion on intra-regional differences in succession). Land-use was divided into four categories of intensity: abandoned pasture ($n=15$); swidden cultivation on abandoned mechanised field ($n=15$); traditional swidden cultivation ($n=30$); and no use (upland forest) ($n=20$). These classes represent four intensities of use: heavy (abandoned pasture); moderate (swidden cultivation on abandoned mechanised field); light (traditional swidden cultivation); and no use (upland forest).

[14] Brondízio (1996)
[15] Alvim (1974).

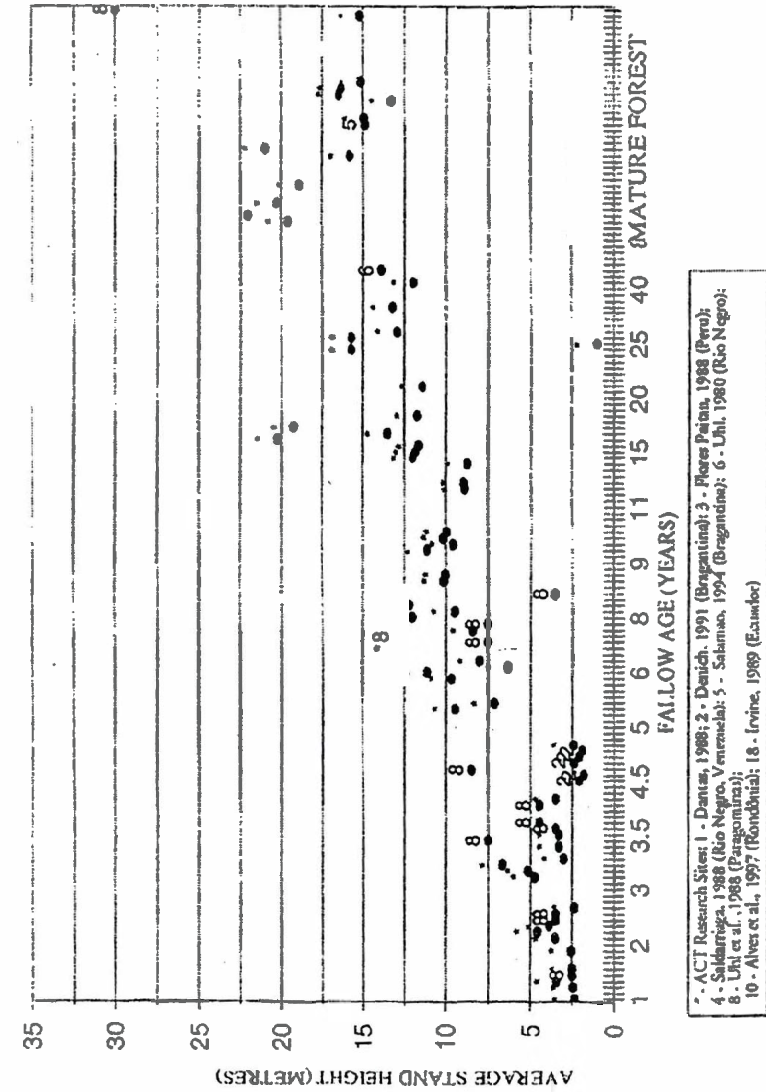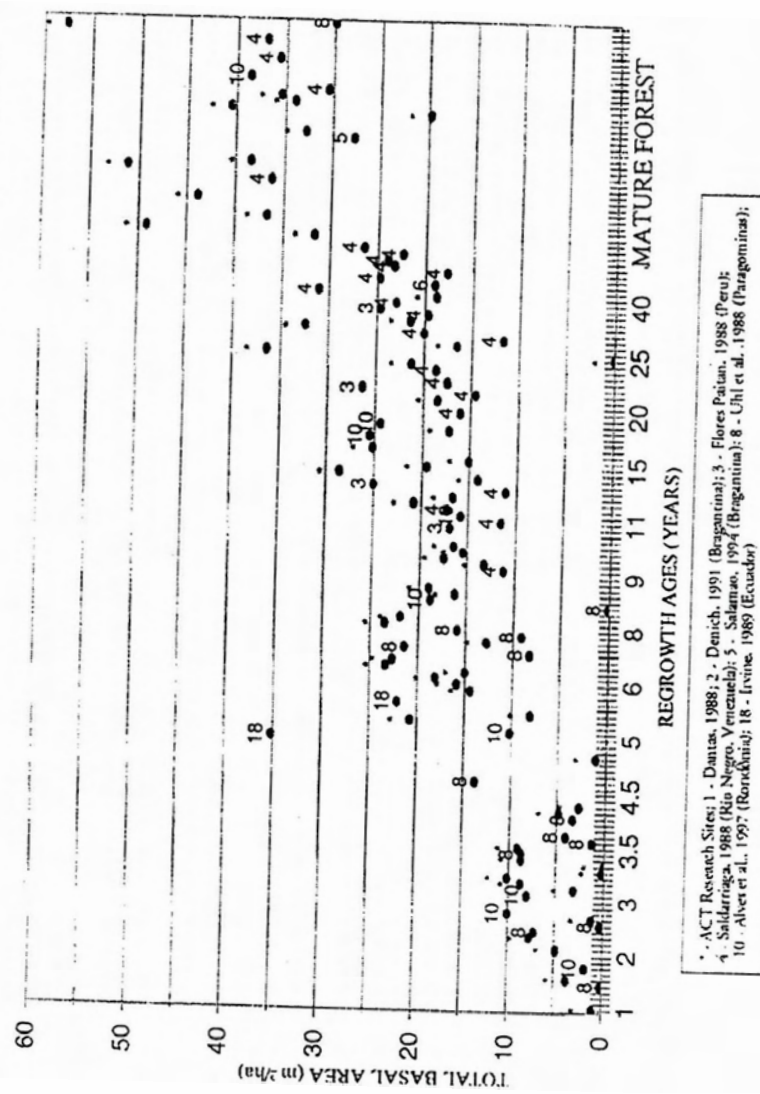Figure 8.2 Regrowth Stages by Stand Height : ACT Research Sites and Literature Data

Figure 8.3 Regrowth Stages by Basal Area : ACT Research Sites and Literature Data

Basin-wide patterns of rates of regrowth: defining stages of regrowth in Amazonia

One of the most difficult challenges to basin-wide analyses is differentiating between mature forest and secondary succession. That is why it is common for basin-wide work to focus on deforestation rates based on fire occurrence monitored daily by satellites such as the National Oceanic and Atmospheric Administration (NOAA).[16] Even when monitoring of secondary succession is undertaken on this scale, it is commonly focused on distinguishing secondary succession from forest,[17] but it has not been possible to achieve any greater discrimination on this scale. To do so requires extensive and intensive field studies. An important result of this five-region study is the characterisation of basin-wide stages of regrowth based on the analysis of average stand height and basal area of our study sites.

Figure 8.2 provides a comparison of stand height data for our five study sites (referred to as ACT research sites)[18] and of nine other study areas examined by other investigators. The data from our sites is consistent with that of other locations. The data on basal area from our sites is also consistent with that of these other study areas (see Figure 8.3). Stand height proves to be a statistically significant indicator of regrowth stages at this level (with a R-square = 0.7068). Although less significant, basal area can also be used to define structural stages of regrowth. Three structural stages of regrowth can be delimited from our inter-regional comparison: initial (SS1); intermediate (SS2); and advanced (SS3) regrowth stages. Each of these stages can be broadly associated with age classes, but more importantly, they have display clustering that allows for basin-wide comparison (see Figure 8.4).

Initial secondary succession (SS1) is associated with a period of establishment that includes herbaceous and woody species. Saplings are the main structural element in a SS1 landscape and represent the majority of the vegetation biomass. This stage ranges in average height from two to six metres, depending on regional characteristics and land-use history. Most individuals have a height equal to or less than two metres during the first two years, whereas individuals between three and six metres are more commonplace after that. In terms of basal area, this stage has a range of one to ten square metres per hectare. The vast majority of individuals at this stage have a DBH ranging from two to five centimetres. In age terms, this phase encompasses the first five years of fallow.

Intermediate secondary succession (SS2) is characterised by thinning of the herbaceous and grass species, and by a rapid increase in saplings and small trees. During this stage, saplings are still a major contributor to total

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[16] Instituto Nacional de Pesquisas Espaciais (INPE) (1988, 1989, 1997).
[17] Skole et al. (1994).
[18] ACT is the Anthropological Centre for Training and Research on Global Environmental Change.

basal area and biomass, and young trees dominate canopy structure. It is at this stage that vegetation begins to differentiate canopy from understorey individuals, but stratification is still subtle. The increase in shade during this stage is an important element in species selection. This stage (SS2) ranges in average height from seven to 13 metres. Overall, the majority of individuals are four to nine metres high, while DBH is between five and 15 centimetres. A small number of individuals can reach a height ranging from ten to 15 metres. In terms of basal area, this stage ranges from ten to 25 square metres per hectare. It encompasses fallows of five to 15 years.
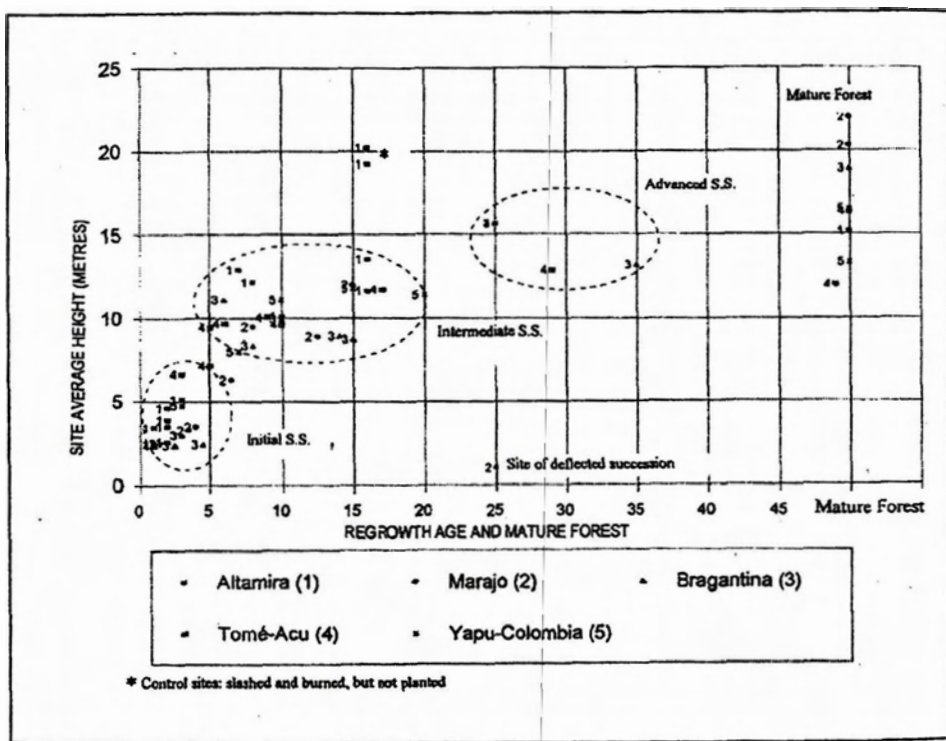
Figure 8.4 Regrowth Stages by Average Stand Height: Distinct Ranges for Amazonia

Advanced secondary succession (SS3) is characterised by a subtle stratification between understorey and canopy and by the decreasing contribution of saplings to total basal area and biomass. This stage ranges in average height from 13 to 17 metres, with a considerable number of individuals only six to 13

metres high. Individuals with a DBH of ten to 15 cm are still of major importance at this stage, but a considerable number of larger individuals are present. Basal area has a similar range to the intermediate stage, although sites with a larger basal area are likely to occur at advanced age. One of the reasons for the similarity in basal area is related to the process of species selection that occurs between SS2 and SS3. Fast growth trees in SS2 (e.g. *Cecropia* spp.) are replaced by forest tree species during SS3. Thus, instead of a progressive increment in basal area from SS2 to SS3, there is a replacement of the species and individuals contributing to it. Since forest tree species tend to have a slower rate of diameter growth in relation to height development, increment in basal area tends to be slower during this stage. Thus, advanced secondary succession (SS3) can be termed a period of transition towards mature forest structure that includes thinning of the understorey and increasing dominance of tree species. In age terms, this stage covers fallows older than 15 years.

Mature forest vegetation varies widely within the Amazon Basin. Average height varies from less than 15 metres to around 24 metres. However, distinguishing between forest and advanced regrowth can be achieved by taking into account additional features that characterise mature forest vegetation. First, species composition needs to be considered a discriminator of forest environment. Mature forest will have a higher canopy and greater understorey diversity characterised by the presence of particular species not found elsewhere. Emergent trees with very large diameter are also distinctive. Most emergents have a DBH of over 30 cm and a height greater than 15 metres. Basal area in mature forest (upland) ranges from 25 to 50 square metres per hectare, thus providing a distinct structural difference from advanced regrowth. In summary, establishment accounts for pioneer colonisation of grass, vines, shrubs and seedlings, followed by a selection that favours young trees and saplings. This, in turn, is followed by a transition in which large trees shade an understorey composed of fewer saplings and a larger number of species with fewer individuals.

These distinguishing parameters of regrowth stages (see Figure 8.4) can be applied to the Amazon region. Land-use intensity, landscape diversity and soil fertility variables are likely to speed up or slow down structural development of vegetation, thus influencing any model relying exclusively on age. For example, dominance of grasses in abandoned pasture specifically controls colonisation by seedlings, whereas in an area of traditional swidden cultivation, a larger number of species are expected to enjoy more equal opportunity for colonisation. The nature of this process is closely connected to the future structure of intermediate and advanced stage secondary vegetation. The faster establishment of tree species during initial and intermediate stages is likely to speed up regrowth towards an advanced structural stage. The proposed regrowth classes and characteristic range of variation provide a baseline for remote sensing analysis and other large-scale studies of land use and deforestation dynamics in the region.

Inter-regional differences in rates of regrowth

Soil fertility proves to be the key element that in discriminating between rates of secondary succession on a regional scale. Two basic patterns of nutrient cycling can be distinguished. First, in nutrient-poor areas, nutrient stocks are largely concentrated in the vegetation and in the organic horizon rather than in the mineral soil itself. This is a process well described for the Rio Negro area and is frequently associated with physiological mechanisms developed by the vegetation to prevent the loss of the limited nutrients within the vegetation-soil complex. [19] Second, in nutrient-rich areas, such as Altamira's alfisols, nutrients tend to be less concentrated in the biomass itself and soil nutrient stocks are more important.

Nutrient cycles in these two types of region present different degrees of susceptibility to anthropogenic impacts. In nutrient-poor areas, nutrients are more susceptible to leaching than in nutrient-rich areas, due to mechanical erosion and its volatilisation through burning. Thus, factors influencing the pace of ground cover and successional vegetation establishment — such as root sprouting and species colonisation from neighbouring vegetation — are crucial to avoid nutrient losses following disturbance. In nutrient-rich areas, factors affecting species colonisation, such as areal extent, neighbouring vegetation and micro-climatic conditions, are likely to be more limiting to succession establishment and development than soil chemical and physical conditions alone.

Amazonian upland soils can be typified by a fertility gradient in which extremes are represented by nutrient-rich alfisols and the very poor spodosols, while nutrient-limited oxisols and ultisols characterise most of the region in terms of areal extent. However, it is important to note that these broad-scope soil categories also encompass large internal variations, especially in terms of soil horizon differences and particular differences in colour associated with particular elements, such as the presence of iron-magnesium compounds.

Differences in soil types need to be understood in terms of nutrient availability and other related factors such as pH, organic matter and cation exchange capacity, and by differences in soil texture. [20] However, textural differences also need to consider parent material. This is especially true for differentiating alfisols and spodosols. While both soil types are characterised by a clayish B-horizon and similar amounts of sand in the A-horizon, spodosols differ from alfisols due to a characteristic spodic horizon composed of hydromorphic clays. Although oxisols and ultisols present small differences in fertility that favour the latter, ultisols are distinguished by increasing clay content with depth.

The soil structure and texture of the study regions — as represented by the percentage of fine sand, coarse sand, silt and clay at five depths (20 centimetre intervals) — were analysed. Of the textural components in a soil included in analysis, coarse sand and clay provide greater contrast between soils studied (as opposed to silt, loam or fine sand). Four major textural groups can be distinguished in the study regions. Altamira soils have a low content of fine and coarse sand at all depths (averaging around ten per cent) and a clay content above 45 per cent at all depths. Although the Yapú region presents a similar textural pattern, it differs in the presence of a spodic-B horizon with low permeability and penetrability, often characterised as groundwater humic podzols. [21] Marajó and Bragantina soils are similar in terms of sand and clay content at all depths. In both cases, the average fine and coarse sand content is above 25 per cent and the average clay content is below 20 per cent at all depths. Tomé-Açú soils, although similar overall to those of Marajó and Bragantina, are distinct because of their lower content of fine sand (below 25 per cent) and higher clay content (between 30 to 40 per cent) at all depths. Thus, while the first two are typical examples of oxisols, Tomé-Açú presents a soil type closer to ultisols.

Differences in soil fertility are small but significant between the study regions. Altamira stands alone in terms of soil fertility, while differences are subtle between Marajó, Bragantina, Tomé-Açú, and Yapú, as shown in Figure 8.5. An average pH of over five in Altamira contrasts with a pH of below five in the other regions. A pH above 5.5 is viewed as necessary for most domesticated cultigens, except for a few such as manioc, cowpeas and sugarcane, which are adapted to low pH conditions. However, lower pH is found in Marajó and Yapú (below 4.4 at the first 20cm) when compared to Bragantina and Tomé-Açú.

The combined analysis of aluminium and calcium/magnesium offers additional elements to distinguish fertility between regions. Yapú has the highest aluminium concentrations and also the lowest concentrations of calcium and magnesium. This nutrient-poor and acidic profile is reinforced by the low availability of phosphorus. Higher concentrations of aluminium tend to limit absorption of other nutrients, especially that of calcium and magnesium, which are closely related to root growth and plant development. [22] Phosphorus is considered the to be the scarcest nutrient in Amazonia, [23] frequently found only as a trace element (below 1 ppm). Although phosphorus content is low at all sites, Altamira displays larger amounts when compared to the other regions. Only traces of phosphorus are present in Yapú and Marajó. No difference is found in the amount of organic matter between the different regions. The analysis of these elements reveals that soil fertility is significantly different between Altamira and the other regions, but on the whole similar in the other four regions. This similarity is further demonstrated by looking at particular elements such as pH and aluminium (see Figure 8.5).

[19] Jordan and Herrera (1981).
[20] Moran and Brondízio (1998).

[21] Sombroeck (1984).
[22] Lathwell and Grove (1986).
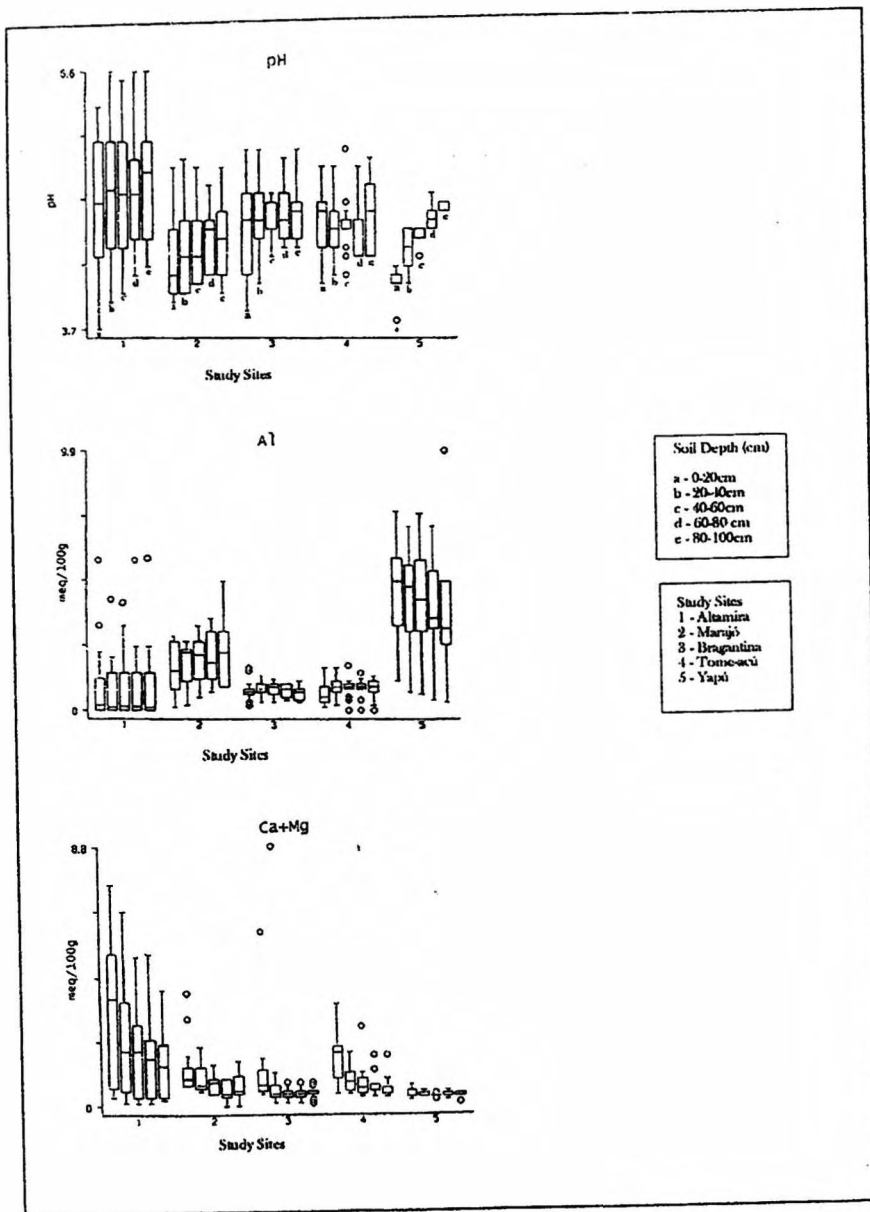[23] Cochrane and Sanchez (1982).

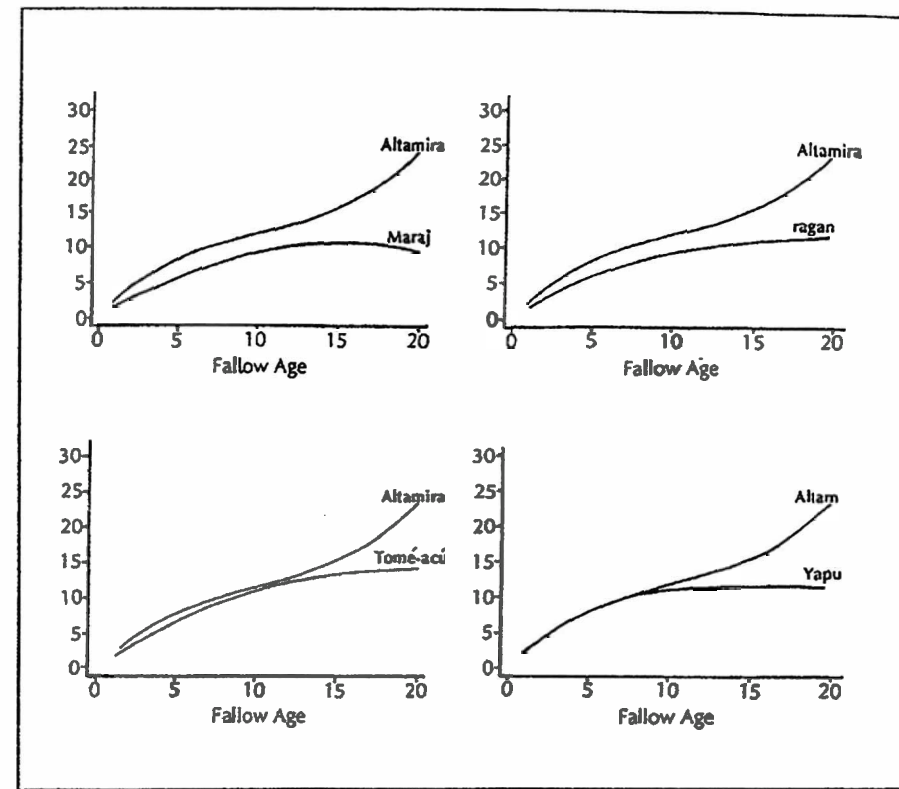Figure 8.5 Supply of Calcium and Magnesium, Aluminium and Level of pH in the Soils of the Five Study Sites

Figure 8.6 Growth Rate of Secondary Forests, by Average Height in Metres, at Five Study Sites

Analysis of variance shows that soil fertility is a significant index of differences in secondary succession between regions (Adj $r^2=0.69$) when average stand height is used as a parameter to indicate rates of regrowth. Differences in fertility clearly favour faster regrowth in Altamira and distinguish it from the other regions. Similar regrowth rates in Marajó, Bragantina, Tomé-Açú and Yapú are consistent with their similarity in soil endowments. These differences are illustrated in Figure 8.6, where each site is compared to the average growth for all regions. Altamira is the only region presenting above-average rates of regrowth. During the first five and ten years, Altamira fallows are a metre higher than the average fallow of all other regions. This difference increases twofold after 15 years of fallow. Such an increase may be linked to the faster development of trees in relation to saplings in Altamira. On the whole, Altamira tends to reach a lower understorey density at a faster rate than other sites, indicating a faster pace of tree development and forest structure. A 15-year fallow in the

nutrient-poor Bragantina region has typically reached only 17 per cent of the tree basal area of the mature forest of the region. However, in the nutrient-rich Altamira region, secondary forest of the same age has already, on average, reached 45 per cent of the tree basal area of mature forest.[24] This pattern is reinforced by the differences in family diversity between Altamira and the other regions. On the whole, family diversity in the understorey is higher during the first five years, decreases during the following ten years and increases again as vegetation reaches a mature, forest-like structure. In the canopy, family diversity displays a progressive rate of increase in line with age.

However, significant variations in these patterns can be noted. Whereas Altamira has lower understorey diversity than other regions (especially Bragantina), it has the highest diversity of tree families. The Bragantina region in particular presents a higher degree of understorey family diversity that is associated with its land-use history. The Bragantina landscape is dominated by fallows and a land-use strategy that emphasises short-fallow swidden cultivation. The greater diversity of saplings and the herbaceous components in this region may be closely associated with the adaptation to disturbance of a specific group of families and species. [25]

### Intra-regional differences in rates of regrowth

The variation in land-use practices in the Marajó region provides an interesting example of the impact of land-use history on regrowth. Land-use strategies in the region include traditional swidden cultivation, agroforestry, mechanised agriculture and cattle ranching; therefore offering a mosaic of land-use types that is representative of Amazonia in general. These land-use types are analysed here in relation to average stand height and biomass. Analysis of variance examining the relationship between age and regrowth structure (i.e. average stand height), shows that land-use type has a significant impact on regrowth (R-square=0.9387).

Analysis of average stand height indicates that fallows following traditional swidden cultivation increase in stand height by increments of 1.5 metres/year, while fallows in areas of abandoned pasture and abandoned mechanised fields, increase respectively by 0.62 metres and 0.45 metres less (see Figure 8.7). However, this is not a linear increment. Height increments are larger during the first eight years and tend to decrease after that.

Figure 8.7 The Impact of Land Use on the Rate of Secondary Forest Regrowth (by Average Height Increment in Metres) at Plots Studied in Marajó
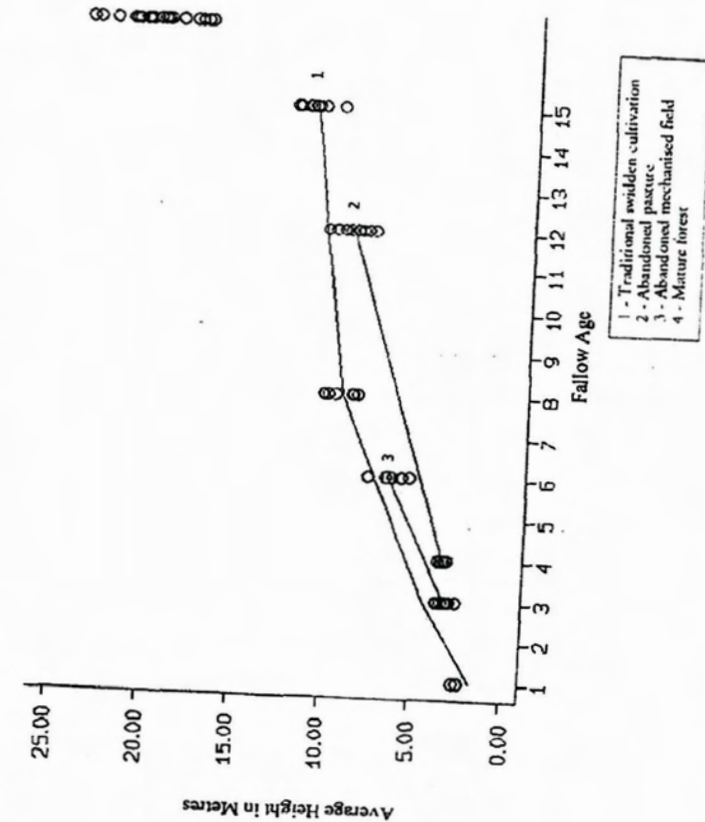
The contribution of understorey and canopy to total biomass is a good indicator of the changes that characterise vegetation development in relation to land-use impact. As succession proceeds, there is a progressive increase in the importance of canopy over understorey vegetation. In other words, while for initial secondary succession, the understorey accounts for the majority of biomass at the site, at intermediate and advanced stages, the importance of canopy individuals increases. There is a positive correlation between age and canopy biomass and a negative correlation between age and understorey biomass. Overall, fallows following traditional swidden cultivation have a higher total biomass in all the cases examined. Fallows following traditional swidden cultivation have a higher dominance of canopy biomass by the eighth year of fallow. Understorey vegetation tends to be dominant for a longer time in sites more heavily used, which is indicative of the slower pace of tree development and the higher density of saplings. Variations in the process of structural transition, evident in the interplay between saplings and trees in relation to height, density and biomass, reinforce the value of using land-use history as a variable in succession studies.

Final considerations

This chapter has sought to identify the variables responsible for differences in rates of secondary successional regrowth in Amazonia. Whereas soil fertility is particularly important in explaining inter-regional differences in rates of regrowth, land-use intensity and landscape diversity are more important in intra-regional analysis. A further objective of this chapter has been to outline a basin-wide association between total height and regrowth stages derived from inter-regional comparisons but which appears to be applicable to large-scale analysis of land-use and deforestation dynamics in Amazonia. If confirmed by further studies, this structural pattern will assist with environmental monitoring of secondary vegetation and the estimation of carbon sequestration by secondary forests. This task will become all the more feasible with the successful launch of a new satellite in 1999 that provides height-of-canopy estimation, thereby making the application of the above height criteria to large-scale estimation of biomass and carbon in forests even more relevant.

Secondary successional forests have socioeconomic and ecological importance at local, regional and global levels. They are products of human activity and continue to have value even during so-called fallow periods as sources of food, fibre and medicine. They have prodigious rates of growth that even in nutrient-poor areas can exceed four tons per hectare per year of biomass.[26] In more favourable areas, rates of biomass regrowth can be three to four times this level. While poorer in species diversity than mature forests, they can be quite

[26] Nepstad et al. (1991).

rich in species depending on the forms of land use prior to their existence. Uniform plantations and mechanisation have been noted to lead to lesser species diversity and slower rates of regrowth than swidden cultivation practices.[27]

Strategies will differ from region to region, as well they should. Regions with greater soil patchiness, for example, will require no less patchy development strategies in order to take full advantage of productive areas and avoid the high costs that are incurred when trying to impose inappropriate resource management practices in poor areas. This is particularly true in regions such as Altamira, which are rated as superior. At the farm level, Altamira is very patchy, with both very rich and extremely poor soil patches. Local people have, for example, put in place productive plantations of mahogany intercropped with cocoa, in order to take full advantage of the fertile patches in Altamira, while relegating poorer soils to rotational systems. In Marajó, an estuarine site, soils vary not only along a fertility gradient but also along a hydrological gradient. This chapter has only examined the upland soils, but the area has adjacent flooded forest areas where the potential for agroforestry is very high, and which fundamentally require the manipulation of native species frequency and spacing.[28] If we have learned anything from the literature on indigenous management,[29] it is that indigenous people have routinely managed secondary forests as sources of medicinal plants, fruit and fibre during long fallow cycles. Attention to these uses, particularly in poor soil regions, can lead to a significant extension of the economic value of fallows, rather than the impoverishment that we commonly see in colonisation areas due to the absence of clear management strategies.

While many of us would wish to see an end to Amazonian deforestation, this is an unlikely scenario. Amazonian forests have always felt the forces of storms, senescence and the human axe, which have all created gaps in the forests. Human impact has only increased with time and the use of technology that make forest clearing faster and less thoughtful. The deliberate and complex ways in which traditional populations have made use of forest products and have managed their fallows can still be restored. Indigenous strategies of fallow enrichment with valuable species of timber, fruit trees and plants with medicinal and fibre value, extend the value of these forests while ensuring their restoration by stimulating reseeding by fauna and weather forces.

These practices can be integrated into the overall small farmer economy, greatly enhancing their long-term success on the land by assuring their food security and a more varied set of resources to provide them with income over time, rather than be subjected to single commodity market fluctuations.

[27] Brown and Lugo (1990).
[28] Brondízio et al. (1994, 1996).
[29] See, for example, Denevan and Padoch (1987); Posey and Balée (1989).

tions. In the way stand incentives that favour short-term extraction rather than long-term stewardship of resources and a balance between population and resources. Our studies suggest that traditional populations have more of their forests standing than colonisation areas. They point out that secondary forests tend to remain standing for less than ten years in many colonisation areas, while they are given longer fallow time in traditional areas.

However, this is only true where population growth is not explosive, and where tenure arrangements favour a communal or common pool resource approach to access to forest resources with rules of access derived from community decision-making processes. In the Amazon, one sees a growing concentration of land in the hands of a few. Even small-farm colonisation areas experience land concentration within less than a generation, resulting in extensification of agriculture through expansion of pasture at the expense of forest. It is generally in the best interest of pasture managers to prevent the natural restoration of vegetation cover known as secondary succession. Repeated use of fire not only increases carbon emissions, but it also leads to floristic impoverishment, loss of organic matter from soils and a decreased capacity of those areas to avoid long-term degradation. Strategies of land use that provide food and fibre to local populations, and that are consistent with creating a favourable environment for both agriculture and forest landscapes, need political support and the mobilisation of civil society. The future of Amazonian forests, both primary and secondary, depends on the political will to manage and conserve them. However, it will also require understanding of how human uses of the landscape accelerate or retard the regrowth process, and how to use knowledge of these differences to restore deforested areas by taking advantage of the natural restorative capacities of the environment.

ACT Publications 1999

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