Secondary Succession

EMILIO F MORAN, EDUARDO BRONDIZIO, & PAUL MAUSEL

Monitoring Secondary Succession and Land-use Change in Amazonia

Combining Landsat TM satellite data with ethnographic, botanical, and survey research allowed us to detect change between small areas of managed floodplain forest and unmanaged forest, and among 3 distinct age/growth classes of secondary succession following deforestation at both terra firme and estuarine sites in Brazilian Amazonia. Mechanized agriculture at one site has eliminated virtually all the mature upland forest. More diversified land use at another site shows a subtle cycling of flooded forest to managed palm forest in response to the price of palm fruit and cycling in the use of fallow land. A 3rd site, characterized by intensive colonization along the Transamazon Highway now consists largely of pastures degraded to various stages of secondary succession with crops constituting <4% of the total area. This study suggests how a balance between use and conservation in Amazonia may be achieved and the effectiveness of monitoring these types of land cover from satellite platforms.

Rates of deforestation in Amazonia reached a peak in 1987 when 8 million ha of forest were burned.[2:1428] Fortunately, rates have declined steadily since then, but observers fear that they still remain at levels higher than the ecosystem's restorative capacities. Much of the attention devoted to restoration ecology has overlooked the natural regrowth that follows deforestation of tropical moist forests. Amazonian farmers over the past 20 years often commented to me (EM) that natural regrowth was one of their biggest problems in maintaining productive fields. Particularly where soil is fertile, weed invasion rather than fertility decline make continued use of cleared land costly.

Over the past 2 years, in response to considerations such as these, a multidisciplinary team of U S and Brazilian scientists has studied factors that affect rates of secondary succession at 2 sites in eastern Amazonia: one in Amazonian terra firme, west of Altamira (Figure 4) on the 1st big bend of the Xingú River, and another in the lower Amazon estuary, at Ponta de Pedras, Marajó Island (Figure 2). Research activities have combined information from time-series Landsat thematic mapper (TM) satellite data (Figure 3) with detailed ethnographic, botanical, and pedological field research and georeferenced these data into geographic information systems for analysis. Through this nested data set it is possible to infer land-use dynamics taking place in time and space at the local level, and to scale upward to regional and global levels.

The 2 sites vary in a number of ways that highlight not only their environmental differences but also the differential impact of human activities on land-cover change. At the terra firme site land-use change has been affected by government-sponsored development projects *cf* [2,11] and here deforestation has been ≤49% of the total land cover, whereas land-use change in the estuary bears fewer but nevertheless visible scars. Instead of deforesting their habitat, the estuary inhabitants have taken advantage of the fertile floodplain forest and the proximity of a major market to implement agroforestry systems. The complexity of the ecosystem challenges both social and ecological researchers in Amazonia, particularly in assessing deforestation. Little has been done to recognize the spatial and temporal heterogeneity of land use and the impact of different forms of land use on regeneration. Thus, one of our concerns has been to link farm-level management to regional reforestation and deforestation.

Methods

Two TM Landsat scenes recorded land cover for 1985 and for 1991 for each site (Table 2). The 4 scenes are cloud-free. To facilitate the study of change, the scenes were overlaid pixel-to-pixel, resulting in a single multi-

Figure 1.
Fishbone pattern of colonization in Brazilian Amazonia. This pattern has been observed throughout the region and was observed earlier in Paraná as well.
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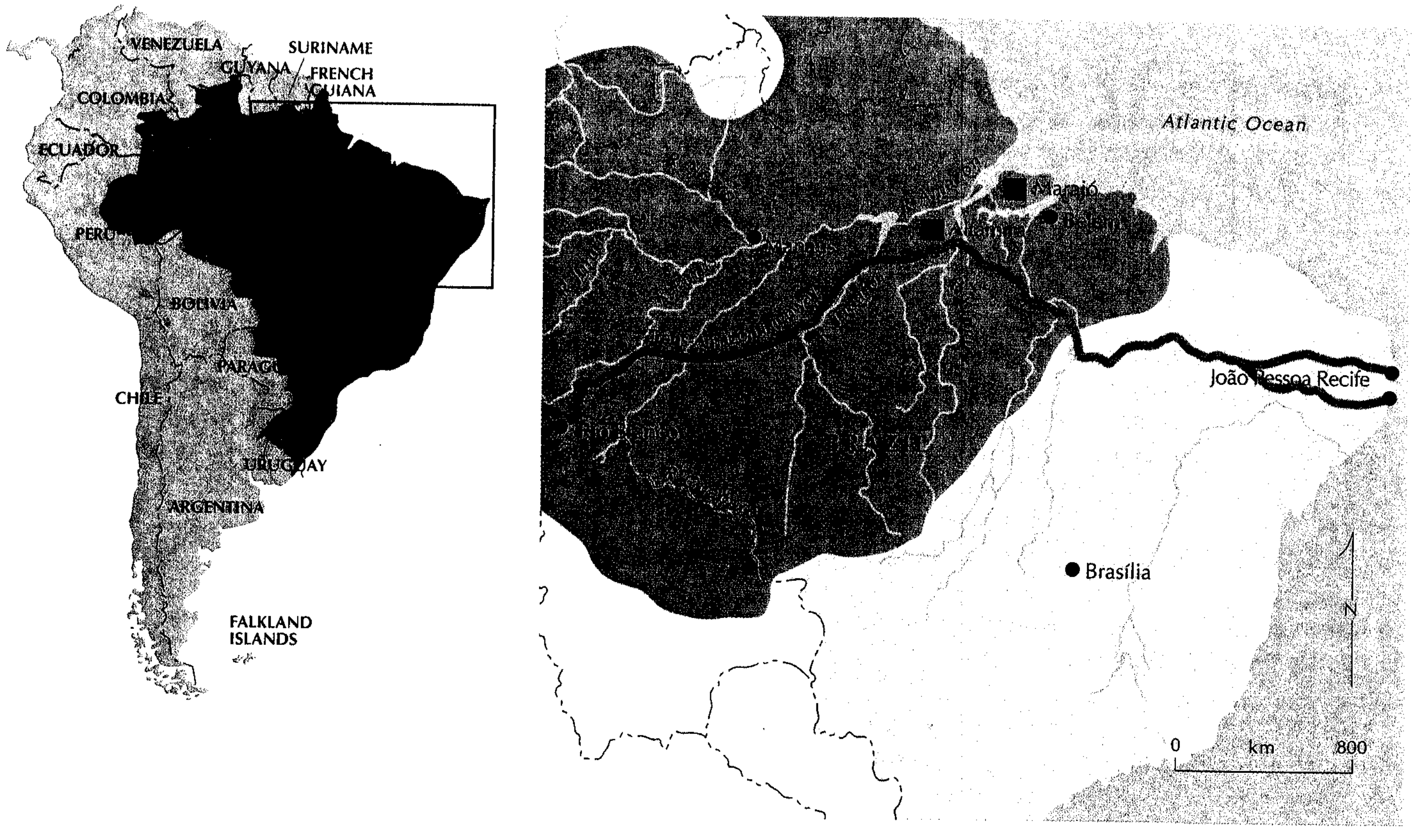

Figure 2.
Study areas include the estuary sites near Ponta de Pedras on Marajó Island, and the Altamira site, along the Transamazon Highway, near the 1st big bend of the Xingú River.

temporal image with 12 channels for each of the 2 study areas, the 1st 6 representing the 6 bands of the 1985 TM scene and the other 6, those for 1991. (The thermal band was omitted from both dates for this analysis because of its poorer spatial resolution.) To minimize atmospheric effects between dates, the 1991 image was adjusted to 1985 spectral values using distant intact forest in both years as controls for differences in spectral values between years. The images were spatially registered and geocorrected (or georeferenced) to a Universal Transverse Mercator grid using available base maps of 1:100 000 scale.[7] Ground observations during fieldwork were precisely registered with the collection of latitude and longitude coordinates for numerous areas obtained with a Magellan 1000 Pro Global Positioning System receiver. Household interviews were carried out to record the sequence of management steps in the sampling areas (eg, abandoned crop sites). In areas where vegetation was sampled, soil samples to 1-m depth were taken and analyzed both texturally and chemically.

Initial methods focused on the identification of land-cover classes, by developing representative statistics associated with a particular class of land cover (eg, mature moist forest). The spectral signature of a class is a term used to characterize the spectral behavior of a land feature in relation to a range of wavelength values. Representative clusters were saved for use as training statistics of that class in a supervised classification (classified by the computer analyst). The spectral statistics of each class were also evaluated for their congruence with known characteristics of the study sites. This led to the development of a conceptual spectral model with which we could define the land-cover classes and consider the reflection and absorption characteristics of the physical components that made up each class. For example, floodplain forest manifests the following spectral responses: low reflectance in bands 2 and 3 due to high chlorophyll

Emilio F Moran, professor and director, & Eduardo Brondizio, Ph D candidate, Anthropological Center for Training and Research on Global Environmental Change (ACT), Indiana University, Bloomington, IN 47405.

Paul Mausel, professor, Department of Geography and Geology, Indiana State University, Terre Haute, IN 47809.

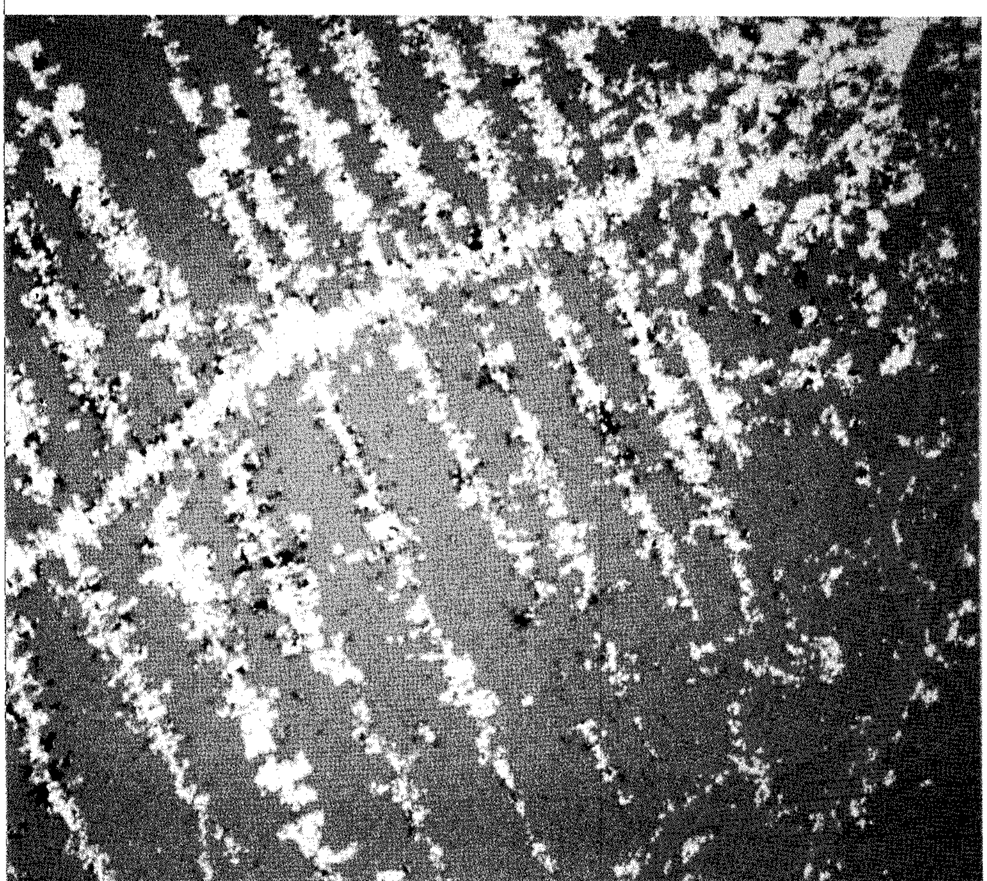

Figure 3.
Landsat TM image of Ponta de Pedras, Marajó island.
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Figure 4.
"Fishbone" pattern of deforestation west of Altamira, Pará, associated with Brazilian colonization.
ACT LAB

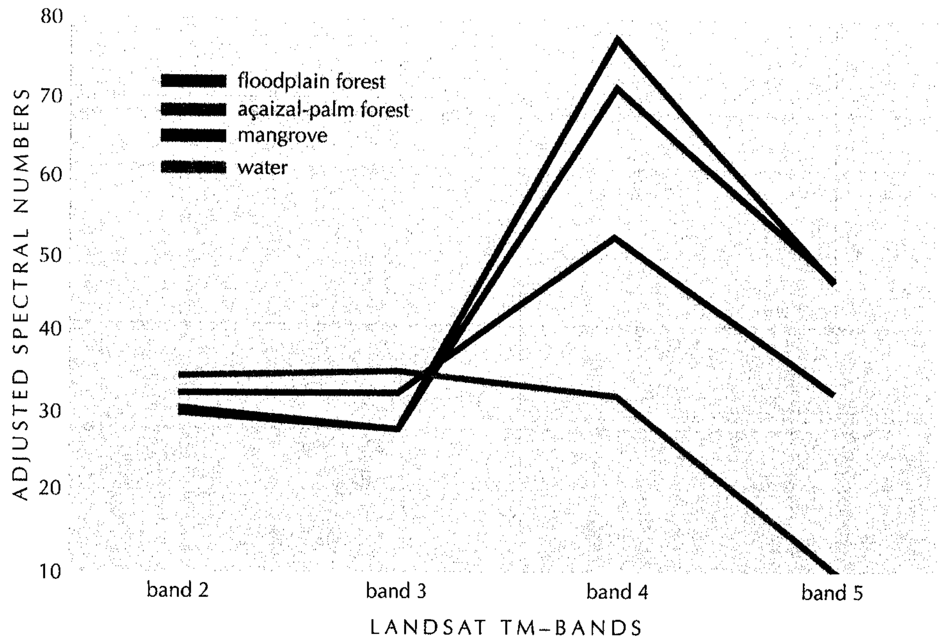

Figure 5.
Spectral signatures differentiating managed from unmanaged flooded forest.

Efforts in the 1970s to monitor secondary succession failed due to the poorer resolution of Landsat MSS (multispectral scanner) and many scientists gave up their efforts. The newer Landsat TM rewarded the efforts of our team.

absorption; high biomass and high water content are indicated by low values in band 5 and the resultant shadowing would be manifest in lower values of the near-infrared band 4 when compared with managed floodplain forest, eg, the *açaí* palm forest. For example, unmanaged flooded forest has a more irregular and higher canopy, a denser understory, and more stratification which created shadowing that depressed near-infrared and mid-infrared spectral values (Figure 5). This kind of procedure was carried out for each signature (spectral pattern) of interest.

Intensive botanical and environmental work was carried out in June and July 1992 and 1993. Representative samples of land-cover classes identified in the unsupervised classification (classified by the computer) results were taken during fieldwork, and some additional classes were added and sampled as a result of field studies. All vegetation classes present in the classification scheme of 1992 were sampled to determine species composition, frequency, density and dominance, basal area, percentage of ground cover, stem height, and total height. This data collection was further expanded and refined in fieldwork in 1993 using the supervised classification that resulted from the 1992 field study. In parallel, ethnographic data were collected about the history of land use, length of fallow periods, and management techniques.

Bands 2, 3, 4, and 5 proved best in combination for image classification. For example, water, bare ground, upland forest, flooded forest, and savanna have distinct reflective properties and, hence, spectral signatures. Other features of interest had more complex spectral characteristics because the mix of features varied considerably over small distances. The spectral definition of these classes is somewhat "noisy," as are any classes composed of a dynamic land-cover type. Late initial succession grades imperceptibly into an early intermediate succession (*cf* Figure 8) in spectral signatures except for the ability of the mid-infrared channel to distinguish among moisture levels (which reflect greater shadowing and stratification with time) (Table 1). Secondary succession occurs along a continuum that represents numerous factors such as land use, age of secondary growth, opportunistic colonization by pioneer and gap species, and landscape features such as soil quality and slope.

The basic elements of spectral modeling involve recognition of the visible bands' sensitivity to chlorophyll absorption, of the near-infrared to mesophyll reflectance, and of the mid-infrared to water and moisture absorption. The cross section of these elements helps discriminate among types of secondary succession, between flooded forest and managed flooded forest, and among a number of types of savannas. The detailed field data (such as types of crops, management, and soil) combined with the satellite data make it possible to discern among spatial patterns of land use, such as those created by mechanized and swidden cultivation.

Results

ESTUARY SITE—MARAJO ISLAND

Marajó Island, a delta island at the mouth of the Amazon, is a region characterized by a variety of vegetation types and land uses, including cattle ranching, mechanized agriculture, palm fruit–wood–oil extractivism, and swidden cultivation. It is an area with a large population of Amazonian *caboclos* (similar to Peruvian *ribereños*) among whom are a group who combines indigenous knowledge of land use with adaptations to the economic and cultural which the dominant national forces have imposed,[5,8,13,15,19] and another group who represents the most transformed economy in the estuarine area.

Changes brought about by demand for forest and cultivated products in nearby urban centers such as Belém (population, >2 million) have led to intensified extractivism and agriculture. Caboclos living in the productive forests of the floodplain and estuary have responded to increased demand by intensifying their exploitation of forests through agroforestry. This

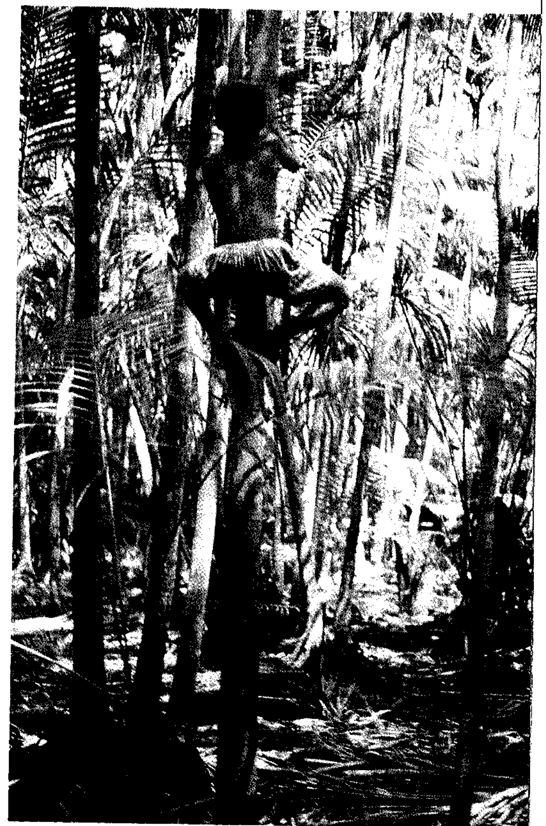

Figure 6.
Young caboclo climbing an açaí palm to harvest the fruit.
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Table 1. **Spectral Signatures of Land-use Classes**

CLASSES	*B 2	SD	B 3	SD	B 4	SD	B 5	SD
water	34.8	0.7	35.8	1.2	32.1	4.4	10.1	4.2
upland forest	30.5	0.5	24.8	0.4	81.7	1.6	55.4	4
floodplain forest	30.5	0.3	28.4	0.5	71	4.2	46.9	4.7
açaí palm forest	30.9	0.5	28.9	0.6	77.6	3.9	46.3	5
mangrove	32.8	0.9	32.9	1.6	52.36	8	32.6	0.4
bare soil	45.5	2.4	52.5	3.5	60.9	4.2	107.9	7.2
pasture	39	0.8	35.8	2.3	98	3.3	115	3.5
pasture with palms	37	0.2	34.1	0.6	96.7	2.6	112.5	4.1
initial secondary succession	36.1	0.2	33	1.1	95.9	6.3	100.9	4.5
intermediate secondary succession	35.9	0.7	31.8	1.3	93.6	3.8	92.6	5
advanced secondary succession	32.6	0.4	26.3	0.7	91.7	3.5	71.2	5.4
high savanna	31.7	0.4	33.9	0.2	44	3.7	69.8	3.8
low savanna	33.2	0.8	35	1.2	55.5	3.5	78.1	2.2
Imperata savanna	32.3	0.6	31.4	1.1	65.6	1.8	61.5	2.1

* B = band.
Values represent midpoints of a class, recognizing that for each class there may be some misclassified pixels that are closer to the endpoints of the range.

Figure 7.
An açaí palm stand near a riverine homestead, a typical pattern of settlement in the estuary. The high density of açaí is a product of intensive management of this naturally occurring species.
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intensification is subtle, since it involves underclearing to increase the frequency of individual trees that produce valued products (Figure 7). For example, the palm *Euterpe oleracea* occurs naturally in low-lying floodplain forest. The value of the fruit of this palm, *açaí*, has grown 4-fold in urban areas in the past 10 years, and increasing the production and productivity of this palm has become a major goal of estuary populations (Figures 6&18). The resilience of floodplain forest to this intensification may point to an effective way to achieve higher income without large-scale deforestation, and without reducing diversification of land-use practices.[1] Competing with agroforesters are traditional swiddeners, cattle ranchers, and mechanized agriculturalists. On the western part of the island, forest resource extraction and swidden cultivation persist. In the transitional area, a local bishop, in an effort to modernize the caboclo economy, has established internationally financed cooperatives on which he promotes mechanized farming on cooperative lands.

This site is in a transitional region between 2 macro-environments: the dense floodplain forest to the west and the natural grasslands to the east. Tidal floodplain forest[16] is internally diverse: Some areas flood only at high tide, others flood more frequently. The varied vegetation is rich in palms. Upland forest occurs at sites that date from the Tertiary period; they are dominated by sandy and acid (commonly, pH <5.0) Oxisols. This uniformly stratified forest consists of large trees whose canopy reaches ~40 m and a sparse herbaceous layer. Disturbed areas, whether floodplain or upland forest, fairly quickly become secondary forest at diverse stages of regrowth. Savannas consist mainly of 2- to 5-m-high trees, widely spread across a mantle of grasses such as *Aristida* and *Eragrostis*. Transitional forest occurs between forest and savanna. Arboreal formations of mangroves are dominated by *Rhizophora mangle* which reaches a canopy height of 25 to 30 m. It is preceded in the aquatic environment by marsh vegetation dominated by *Montrichardia arborecens* and *Drepanocarpus lunatos*.[17]

In this site at least 2 patterns of land use may be contrasted. One is illustrative of the "traditional" system of land use. The local population whose settlement pattern is characteristic of riverine peoples, has the most diversified resource-use strategies of the 2. Their land use focuses on swidden cultivation on both floodplain and upland forests, and on palm fruit extraction. The importance of shifting agriculture to this population distinguishes them from the majority of the caboclo population of the estuary, where this activity has been steadily decreasing.[18]

The second population, with the most transformed economy in the estuarine study area, is currently settled in an upland area, along a road rather than a river. With assistance from the local Catholic bishop the population has, since the 1960s, organized an agricultural cooperative based on mechanized agriculture producing corn, beans, rice, and coconuts. Mechanized preparation of land for pasture and cattle was also undertaken. A modest amount of extractivism continues, supplemented by fishing, shrimping, and other activities.[14]

Common to the 2 populations is that >90% of households engage in the extraction of açaí palm fruit, an important resource of the Amazon estuary and flood-prone areas in the interfluves. Over 50% of households in the traditional site are engaged in swidden cultivation while mechanized agriculture and cattle ranching are restricted to the second site, driven by subsidies provided by the church and a church-based cooperative that has virtually eliminated the practice of swidden cultivation, and all but 28 ha of upland forest.

Four major land-management practices influence vegetation cover in the study area: burning of vegetation, mechanized land clearing or weeding, palm forest management, and secondary succession. In slash-and-burn agriculture, gardens are not actively planted after 2 to 3 years and succession occurs fairly quickly. The areas used for this purpose are well-drained soils of upland forest or old-regrowth fallow. These are preferable because they require the least labor to slash. The average size of gardens is 2500 m^2. Mechanically cleared areas vary from 1 to 5 ha and involve both short-fallow management and fertilizer input. These areas are distinguishable from the slash-and-burn gardens by shorter fallow cycle, form (generally more square and rectangular), and distribution and rate of secondary successional regrowth. Because the mechanized areas are maintained in cultivation longer than swidden areas, regrowth is slower and soil fertility lower. Intensive weeding of pastures, whether through fire or tractor, slows the rate of regrowth of woody species. The importance value index was originally developed by S Curtis and R P McIntosh as a way to provide a logical arrangement of "dominant" species in a given stand. By taking into account relative frequency, density, and dominance, it balances the different characteristics of a species as they occur in a plant community. Density indicates the number of individuals of a species, showing the species significance in relation to the community as a whole. Frequency is an expression of the spatial distribution of a species within the stand. Finally, dominance indicates how much a species contributes to the stand in terms of biomass. Basal area, which is the cross-sectional area possessed

Importance value is a vegetation index that accounts for relative density, frequency, and dominance (basal area) of a species.

$$I\,V = \frac{\text{relative density} + \text{relative dominance} + \text{relative frequency}}{3}$$

Alternatives: Intensive agroforestry is an alternative to floodplain agriculture. Such a system might imitate the stages of secondary succession by starting with annual crops interplanted with a few slower growing species of fruit and native trees, whose density would be gradually increased until a high biomass forest would be in place, combining the functional characteristics of moist forest with the economic returns of agroforestry.

Figures 8–11.
Stages of development of an açaí palm stand from clearing (8) to its mix with fruit trees and annual crops (9) to the gradual aging of the bananas and other fruits (10) to its purer stand status (11).
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by the trunk of a tree species, is the most used indicator of species dominance. Therefore, importance value provides a practical classification of species in the plant community, especially in heterogeneous habitats, such as the case of tropical environments, where most species do not have a high level of importance in the stand.[6] Such areas are characterized by palm trees adapted to resist burning, chief among them *Maximiliana maripa* (*inajá*) and *Astrocaryum vulgare* (*tucumã*). Palm-forest management (*açaizal*) involves management of floodplain forest dominated by *Euterpe oleracea* (açaí). Data on palm-forest management indicate that the importance value of *E oleracea* increases from 0.2 in an unmanaged floodplain forest to an average of 0.6 in managed floodplain forests.[3] We can distinguish from satellite data a palm forest in which the average importance value of the species is at least ~0.6. The management techniques involved in this process can be broadly characterized by 5 steps: selective thinning of undesirable forest species; selective thinning of understory vegetation and vines; pruning of palm seedling, sapling, and trees; planting of palm seedling and seeds; and annual weedings. (Figures 8–11). Vegetation composition drops not only in terms of tree diversity, but also in the number of individuals per species in favor of *E oleracea* (açaí). The more managed the floodplain forest, the fewer the number of species with diameters >10 cm DBH (diameter at breast height), and the greater the dominance and importance value of açaí. Following changes in tree composition, there is a decrease in the average height of canopy and first stem height. Therefore, higher emergent trees still occur on managed forests. The vigor of biomass has similar average values in managed and unmanaged forests.[3] The reduced canopy height, and the virtual absence of understory vegetation in the managed areas facilitates spectral separation. Once this spectral difference is determined, it is possible to monitor changes in biomass of managed palm forest and to estimate yield.

Secondary succession was discriminated, using combined Landsat TM and botanical fieldwork, into 3 stages: initial, intermediate, and advanced. These categories roughly correspond to age classes 0 to 5 years, 6 to 10 years, and >11 years, respectively. While we have been able to differentiate with an accuracy of 92.2% between secondary growth of 11 to 15 years

Açaí is just one of many candidates in Amazonia for agroforestry management. Among the other obvious candidates are cupaçaú (Theobroma grandiflorum), cajá (Spondias lutea) , graviola (Anona cherimolia), *mango,* bacurí (Platonia insignis), burutí (Mauritia vinifera), *Brazil nut* (Bertholetia excelsis), muricí (Byrsonima crassifolia), piguí (Caryocar coriacrum), pupunha (Guilielma speciosa), sapotilha (Acharas sapota).

Table 2. **Land-cover Classes**

CLASSES	% 1985	% 1991
water	11.7	15.2
upland forest	13.6	13.2
floodplain forest	18.6	16.3
açaí palm forest	5.0	5.7
mangrove	3.8	2.9
bare soil	3.8	2.8
pasture	2.8	0.9
pasture with palms	0.7	0.6
coconut plantation	0.4	0.5
initial secondary succession	3.1	2.3
intermediate secondary succession	8.0	3.1
advanced secondary succession	6.0	12.2
high savanna	16.9	9.6
low savanna	2.7	13.4
Imperata savanna	3.0	1.2

from mature forest, we have not yet been able to differentiate a 20-year regrowth fallow from undisturbed forest.[9]

In the traditional site the amount of open area (bare soil) decreased from 35.2 ha in 1985 to 18.7 ha in 1991. The decrease implies that areas of bare soil in 1985 are now in different stages of secondary succession, which is most clearly demonstrated by the percentage contributed by this class to the 3 stages of secondary succession. Areas of advanced secondary succession increased from 99.7 ha in 1985 to 222.3 ha in 1991. Out of the total 1991 area in secondary succession, 23.8% (52.8 ha) was in an intermediate stage of succession in 1985. These changes in successional stages characterize agriculture based on long-fallow cycles. Upland forest increased by 14.2 ha, although minor deforestation was evident in the contribution of forest to other classes.

The most marked change in this landscape has been the increased management of flooded forest for açaí palm fruit, although it has had the least effect on land cover. The small area of açaí palm forest between 1985 and 1991 land-cover maps indicate that intensification of management is concentrated in floodplain and estuary forest resources without extensive forest conversion.

Besides progressive management of floodplain forest, local farmers use areas of higher elevation (only occasionally reached and fertilized by tides) to practice intensive agroforestry. Although the area is prepared in slash-and-burn fashion, trees of economic importance (eg, rubber trees, *Hevea brasiliensis*) are not cut. This agroforestry system (*roçado de várzea*) is a spatio/temporal association of short and perennial crops. During the first phase, rice, corn, and sesame are planted in alternate lines and shorter cycle species such as cucumber, pumpkin, and watermelon are spread out in the site. At the same time, banana, sugarcane, and pineapple seedlings are planted in homogeneous distribution, and palm species (eg, pejibaye, coconut, etc). Following the 1st year of production, the açaí starts to overtake the bananas in height and to dominate the area in a manner similar to a secondary succession. The açaí trees form a forest-like structure and start production after 3 years, however, coconut, pejibaye, rubber, banana, and other economic species continue to produce for years. When completely developed, the importance value of açaí in these areas may reach ≤1.0. The area in managed palm forest increased by <2% between 1985 and 1991 in the 2 study areas. More significant has been the mechanization of agriculture at one site which led to removal of much of the upland forest in the 1960s. Much of this area could not sustain productivity and is undergoing secondary growth. Advanced secondary succession went from 6.8% of total land cover in 1985 to 16.4% by 1991 at the mechanized site. Areas in pasture have decreased, as have those of low agricultural productivity.

In the floodplain, there is a small area of açaízal palm forest, and while some areas were abandoned between 1985 to 1991, 67% of the palm forests mapped in 1991 come from the management of areas classified as floodplain forest or mangrove in 1985. The area of palm forests indicated as abandoned (which is the area changed from açaízal in 1985 to floodplain or mangrove in 1991) is characterized by an increase in tree species and by higher density of understory vegetation. This is also common in older and less productive palm forests which have been recently subjected to reduced management.

The upland forests were largely destroyed to allow intensive mechanized agriculture and cattle ranching. By 1985 only 29.2 ha of upland forest remained. Considerable areas of advanced secondary succession had developed enough by 1991 from the deforestation of the 1960s so they had become indistinguishable from forest in the satellite imagery. The images reveal an increase in advanced secondary forest approaching biomass of upland forest cover to a total of 43.1 ha. The failure of cattle ranching in this region is evident in the decrease of pasture areas from 223 ha in 1985 to 54 ha in 1991. These areas are now in different stages of secondary succession—a process not unlike that taking place throughout the Amazon basin on a much grander scale.[cf 11] By 1985, 111.3 ha of pasture had already been abandoned as can be observed in the land-cover class "pasture with palms" (the vegetation result of pasture management based on burning). The dominant palms on these pasture areas are *Maximiliana maripa* and *Astrocaryum vulgare*. Similarly, large areas were used for crops in the 1970s and later abandoned due to low fertility and soil compaction which explains the large area observed in different stages of secondary succession in 1985 and 1991. Initial secondary succession went from 149.7 ha in 1985 to 178.6 in 1991, while advanced secondary succession went from 104.5 ha in 1985 to 251.7 ha in 1991.

The decrease in intermediate secondary succession may reflect the reclearing of areas for agropastoral activity in lieu of clearing primary forest. This situation indicates the failure of intensifying agriculture in areas of 1 limited soil fertility, as the church cooperative did. The result of that experiment led to the total removal of terra firme forest from 1 study area without any notable increase in income or sustainable yields. Instead, mechanized areas have become dominated by secondary growth because areas whose yields decline are abandoned. Earlier work in this study area[14] noted a significant shortage of manioc flour (*Manihot esculenta*), which is the main calorie source for the population. During 1993 fieldwork, numerous households reported a return to shifting cultivation in areas of intermediate and advanced secondary succession as an alternative to the low returns from the mechanized system. A project based out of the Federal University of Pará (Belém) has promoted the restoration of deforested area through agroforestry systems. Floodplain forests continue to play an important role in the subsistence of caboclos at the mechanized site. While upland forest deforestation and mechanized agriculture and pastures seem to be reverting to regrowth, the areas of palm forest have increased from 47.3 ha in 1985 to 71.7 ha in 1991, a change that shows the increasing participation of the population in the açaí economy, despite efforts by leaders of the cooperative to wean caboclos away from extractivism.

COLONIZATION SITE—ALTAMIRA, PARA

The Altamira area became a showcase of colonization in 1970 when the Transamazon Highway reached the town (Figures 12&13).[2] Nearby rich soils made the town a potentially successful site for colonization. The study area included in our study extends from the town of Altamira (population, 80 000) to ~140 km west of it, an area of ~6000 km^2. The site's local relief varies by as much as 120 m, with steep ravines throughout. Soils are diverse and, overall, more fertile than most in Amazonia. High quality Alfisols are found together with the poorer Oxisols, Ultisols, and Spodosols. The dominant vegetation is mature moist forest, most of it of

Alternatives: Horticultural production for the urban market in farms near the Altamira should be intensified. Most of the areas near town already are severely deforested and the low quality secondary successional areas could be turned to high-yielding vegetable production, poultry and swine production, and other intensive uses. Farther out, in already cleared areas, agroforestry combining cacao with mahogany and other high value timber could provide a steady income (cacao) and high value long-term returns (mahogany, cedar). Diversifying would reduce the economic impact of fluctuations in commodities now experienced by local producers.

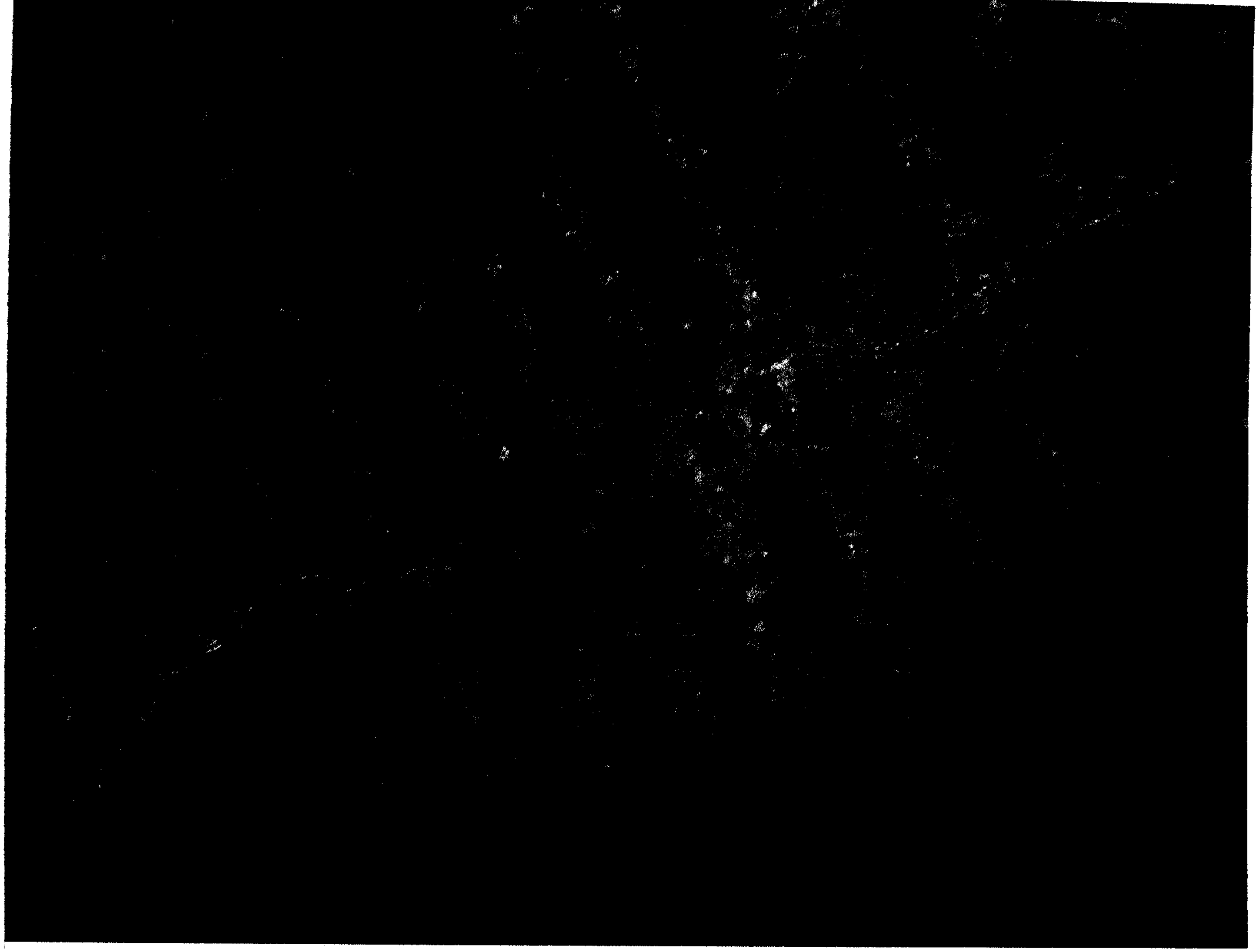

Figure 12.
With increasing distance, deforestation declines west of Altamira. This image is 70 to 140 km away. The forest at the bottom is an Arara Indian Reserve.
ACT LAB

Figure 13.
Close-up view of an area of intense colonization near Altamira (20 to 30 km), and higher deforestation than in Figure 12.
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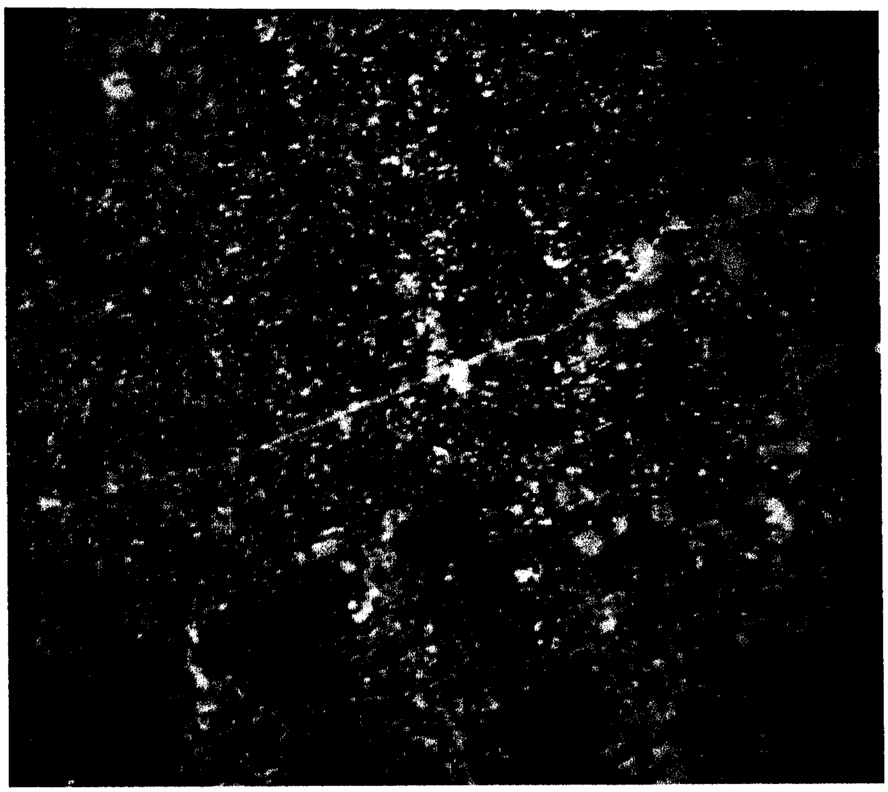

the liana forest variety. Annual precipitation is ~2000 mm, with a 4-month dry period between June and early September. There is a growing variability in rainfall, evident in the 1985 satellite data when 7.59% of the study area was "bare" due to pasture and cropland wilting. Rainfall in July 1985 was 10.8 mm, as compared with an average of 75 mm for that month.

Settlement of this area follows the "fishbone" roadside colonization pattern now well-known throughout the Brazilian Amazon (Figure 1). Beginning in 1971, land grants of 100 ha were given and properties have largely maintained the integrity of these boundaries, despite a degree of land consolidation in the 1980s. The majority of the population is comprised of farmers with limited resources who plant annual crops, followed by pasture or tree crops such as cacao and rubber (when commodity prices are favorable or credit subsidies given; Figures 14&15). Spectral signatures were arrived at with emphasis to date on 9 land-cover classes (Table 3).

Between 1971 and 1991, ≤1/2 of the moist forests had been converted to field crops, tree crops, and pastures (Table 4). Between 1985 and 1991, mature moist forest declined by 7%, a rate that if annualized is slightly higher than the basin-wide averages. The most striking finding at this site is the large increment in secondary successional land cover, ~32 000 ha in the 1985–1991 period, compared with the 19 000 ha of mature moist forest deforested for the same period. Of course, the bulk of the deforestation took place before 1985 during the initial occupation of the area in the 1970s. Much of the area now growing back is the proverbial "degraded

Table 3. **Mean Values and Standard Deviation of Altamira Classes**

MEAN					
CLASSES	B2	B3	B4	B5	B7
SS3	30.3	28.4	73.0	54.7	10.3
SS2	30.7	28.4	83.8	65.0	13.0
water	31.0	29.3	30.4	11.1	1.7
bare	39.5	48.0	61.9	96.2	41.4
forest	29.7	27.1	70.0	50.6	9.5
SS1	32.8	32.2	78.7	74.9	18.1
pasture	35.0	36.2	69.8	88.5	24.9
crop	31.0	28.5	94.9	70.6	14.8
wetland	31.0	30.0	53.9	42.5	9.0
STANDARD DEVIATION					
CLASSES	B2	B3	B4	B5	B7
SS3	0.9	1.3	5.3	5.7	1.5
SS2	1.1	1.5	5.4	4.5	1.6
water	1.2	1.3	3.3	4.3	1.6
bare	4.6	9.7	8.0	20.1	13.2
forest	0.9	1.1	4.8	4.9	1.3
SS1	1.3	2.1	8.0	7.4	3.3
pasture	1.6	2.7	5.0	8.4	4.3
crop	1.6	2.1	7.8	9.9	2.7
wetland	1.2	1.6	6.2	7.2	2.1

Table 4. **Land-cover Classes in the Altamira Study Area, 1985 to 1991**

LAND-COVER CLASS	PERCENT LAND COVER 1985 %	1991 %
mature forest	64.01	56.99
pasture	10.82	3.06
*SS1	5.58	10.90
SS2	4.91	15.47
SS3	0.91	5.93
bare	7.59	1.33
crop	1.16	0.64
water	4.87	5.29
wetland	0.87	0.39

ss = secondary succession

In recent interviews with original settlers of the Altamira Colonization Scheme, they commented, "If we had only known how vigorous regrowth was going to be, we wouldn't have cleared so much forest in the 1970s."

Figure 14.
View of a cocoa plantation along the Transamazon Highway. In an effort to develop more sustainable production, cocoa and rubber were promoted by favorable credit and these small-scale plantations thrived until prices collapsed in the mid-1980s and until disease struck the plantations thereafter.
E BRONDIZIO

Figure 15.
A farmer's cocoa crop.
E BRONDIZIO

pastures"—pastures which have become heavily invaded by woody species (initial secondary succession, in this area is commonly 1 to 5 years since pastures ceased to be dominant; Figures 16&17).

Advanced secondary growth is also evident in the area and refers to regrowth of 11 to 15 years. In these areas, canopies approximate the mean canopy height of mature moist forest (20 to 30 m) and are multilayered making spectral separation of these areas from mature moist forest difficult. These areas seem to be farthest from roads and suggest that farmers may have overcleared land in response to credit incentives in the 1970s.[11] Occasionally these areas represent patches that proved unproductive for agriculture and which have been left to grow back. It remains to be seen whether the areas that are currently at intermediate stages of regrowth will be left to grow into advanced stages of secondary forest, or will be cleared again for agropastoral production. We have seen evidence that an 8- to 10-year fallow is being practiced in response to the edaphic and economic conditions.

Pastures, which dominated the landscape in the 1980s, do not seem to persist as dominants beyond 2 to 3 years after being "reformed," the process through which land is cleared, vegetation burnt, and the area resown with pasture seed. Older areas are increasingly dominated by *babaçú* (*Orbignya phalerata*) which in areas where efforts have persisted to keep a pasture in production are now equally shared by pasture and this palm. In less fertile areas, the palm *inajá* (*Maximiliana maripa*) plays a similar role but less aggressively than *Orbignya*.

In the 1970s, this colonization site received large incentives to plant perennial crops, mainly cacao and black pepper, a program that motivated a large number of colonists. Although these crops are considered a sound alternative for economic and environmental problems in the area, lack of assistance, precarious infrastructure, and market constraints have limited

Figure 16.
Most pastures in the region remain dominated by grasses only briefly. They are soon invaded by pioneer species and woody sprouts that spell "degraded pastures," or the start of secondary succession of 1 to 5 years.
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Figure 17.
Secondary succession of 6 to 10 years. At the end of this period, the land would either be cleared again for crops or pasture, or continue its trajectory toward old fallow.
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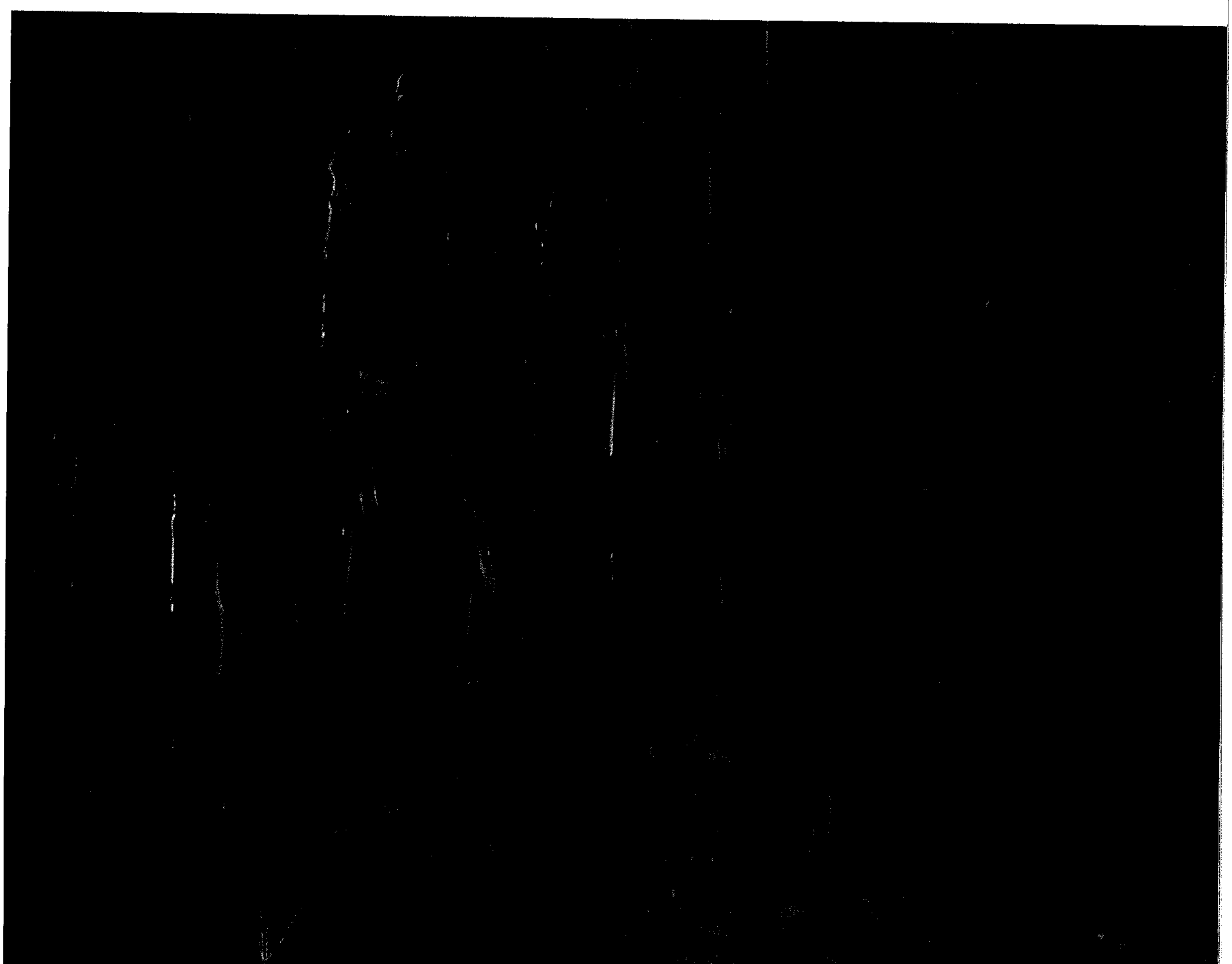

their success. The development of local-based enterprises to manufacture the raw product in the region prior to export, and the improvement of technical assistance to local producers could reverse such a picture. Some local farmers have already developed alternative strategies in these areas. This is the case of agroforestry that combines cacao and mahogany. During fieldwork, we had the opportunity to measure sites where 16-year-old mahogany has reached a DBH >40 cm. In addition to perennial plantations of cacao and black pepper, fallow vegetation could be enriched with valuable hardwood species. Management of secondary succession would decrease the pressure of logging in mature forest, while providing long-term economic security to local farmers.

Conclusions

Figure 18. (opposite page)
A proud young man with his açaí cacho.
E BRONDIZIO

This study gives no grounds for comfort. The evidence presented for the vigor of natural regrowth following deforestation gives ample reason to focus more attention on how we might be able to manage secondary succession to restore these areas in the future. The pace of deforestation continues at a steady 1% annually in one of our sites, despite the disappearance of 47% of the mature forest cover. Over the past 20 years, colonists experienced misinformed and poorly administered credit policies, infrastructure that was undependable in getting produce to markets, and insufficient extension support.[2] This slow-down has been made possible by economic recession, hyperinflation, and declining credit subsidies—not as a result of a greater conservation ethic. What colonists along the Transamazon Highway are only now just discovering, after 20 years of settlement—that the cost of keeping an area cleared of pioneer species is prohibitive to most farmers—is a lesson that the traditional Marajó caboclos in the estuary seem to know, appreciate, and live by. This lesson also escaped the church-based leaders who sought to transform the local economy through international assistance and virtually ended all mature upland forest in one area. Despite their best intended efforts much of that land has been reclaimed by secondary growth today.[10]

This study suggests the value and sustainability of the traditional system of diversified land use, a system that has left minimal impact on the native vegetation cover, can adjust to shifts in the value of commodities, and provides the human population with a diverse diet. In contrast, intensive mechanized agriculture, has scarred the landscape, has been costly in labor and capital, and has not proven sustainable as evidenced by the large areas abandoned to secondary growth despite the availability of tractors to control weed invasion. The estuary's conditions favor small-scale agriculture combined with extractive activities and fishing, rather than intensive mechanized agriculture. Deforestation has affected the estuary less than the interfluves because of the traditional caboclo's practices of a diversified system of land use appropriate to the daily flooding of the estuary. In those cases where "modern" forms of intensive land use are promoted, deforestation can be just as severe as in the interfluves. As has been the case in colonization areas of the interfluves, those deforested areas have often proven unproductive and are now undergoing secondary successional processes. The linkage between satellite data and field studies, within a geographic information system, has proven useful for analyzing land use.[4,10,11]

This study has demonstrated for the first time that it is possible to track stages of secondary growth and intensive management of forest vegetation by using satellite platforms with adequate spatial resolution, such as Landsat Thematic Mapper. The study of local systems of land use in regional and global context inform human and environmental concerns in the Amazon region. The traditional populations of the Amazon estuary give ample evidence of being capable of intensifying land use without leaving a deforested landscape in their wake, while externally induced strategies have been both environmentally costly and economically unsustainable to date. The caboclo strategies continue to be overlooked as an alternative for rural development in Amazonia. Continued monitoring of the differential impact of land-use strategies suggests ways to proceed in the years ahead. We need more modest strategies of land use that take into account the high costs of controlling weeds, the unpredictability of commodity prices, the need for social services of local populations (health, education, storage facilities, credit), and the high costs of transporting commodities to market.

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