Settlement Design, Forest Fragmentation, and Landscape Change in Rondônia, Amazônia

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Abstract

Deforestation and colonization in Amazônia have attracted substantial attention. This article focuses on an area of 3,000 km^2 within the Brazilian State of Rondônia. Two adjacent settlements were compared to assess the role of their different designs in landscape change. Anari was planned following an orthogonal road network. Machadinho was designed with attention to topography in laying out roads and farm properties, while including communal reserves. Field research was undertaken in conjunction with multi-temporal classifications of remotely sensed data (1988, 1994, and 1998) and landscape ecology methods. The results indicate that large patches of communal reserves play an important role in maintaining lower levels of fragmentation. Analyses of landscape structure confirmed that forest patches in Machadinho are less fragmented, more complex, and preserve more interior habitat. By comparing the effects of different settlement designs on landscape change and forest fragmentation, this article contributes to the debate about colonization strategies in Amazônia.

Introduction

The interest of naturalists and ecologists in landscape spatial patterns is extensive. This approach, responsible for an ecological perspective about the geographic space, is today represented by landscape ecology (Forman and Godron, 1986; Urban *et al.*, 1987; Turner *et al.*, 1995). Landscapes became objects of scientific analysis and synthesis, being understood as a spatially heterogeneous mosaic to be studied from the reciprocal effects among spatial patterns and ecological processes (Turner, 1989; Pickett and Cadenasso, 1995; Forman, 1997). The human dimension underlying landscape changes has also been highlighted (Naveh and Lieberman, 1994). The study of these relationships confers a practical perspective to landscape ecology, through the establishment of scientific bases for planning, management, conservation, and development of territories (Leser and Rodd, 1991).

The applicability of these concepts to spatially explicit ecological studies is clear. In a world where human-altered landscapes are increasingly created, processes of disturbance need to be spatially quantified and understood (Pickett and White, 1985; Baker, 1995). Several methods based on the concept of landscape structure have been developed to address processes of disturbance within landscapes. Landscape metrics have been widely used for this purpose (Baker and Cai, 1992; McGarigal and Marks, 1995; Riitters *et al.*, 1995; Gustafson, 1998), and the integration of spatial data and methods in geographic information systems (GIS) has improved this approach (Turner and Gardner, 1991; Sample, 1994; Haines-Young *et al.*, 1996; Frohn, 1998).

One of the most frequent examples of landscape disturbance in the tropics is derived from land-use/land-cover (LULC) change of forested environments (Dale *et al.*, 1993; Dale *et al.*, 1994). Landscape heterogeneity can either increase or decrease, depending on the parameter and spatial scale examined (Krummel *et al.*, 1987). In general, the disturbed landscape has more small forest patches and fewer large, matrix patches than the intact landscape (Mladenoff *et al.*, 1993; Malcolm, 1994).

Taking this assertion as a hypothesis, this research examines landscape structure in Rondônia, Brazilian Amazon, through derived LULC classifications. The adjacent settlements Machadinho d'Oeste (Machadinho) and Vale do Anari (Anari) are analyzed in terms of their composition and configuration on a multitemporal basis to assess the role of their different designs in forest fragmentation and landscape change. Anari was planned following an orthogonal road network, a scheme used to colonize the majority of Rondônia. Machadinho was designed with attention to topography in laying out roads and farm properties, and included communal forest reserves. Results for both sites (Figure 1) are compared, trends are described, and methodological issues are discussed.

Study Area

Rondônia has experienced the highest deforestation rates in the Brazilian Amazon during the past twenty years (INPE, 2002). Following the national strategy of regional occupation and development, colonization projects initiated by the Brazilian government in the 1970s played a major role in this process (Moran, 1984; Schmink and Wood, 1992). Most colonization projects in the state were designed to settle landless migrants. Previous analysis of the settlement strategies implemented in the region have shown the need for multitemporal LULC assessments to understand the history of occupation and the trends for the future (Batistella *et al.*, 2000). Settlement began in this area in the mid-1980s and represents an important type of human impact on the Amazonian landscape.

The climate in the study area is classified as equatorial hot and humid. The well-defined dry season lasts from June to August, and the annual average precipitation is

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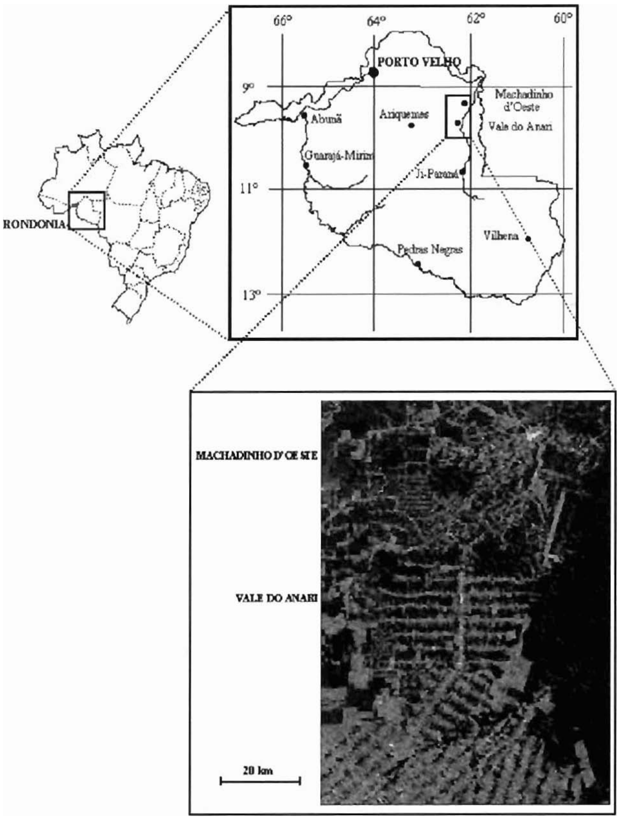

Figure 1. Location of Machadinho d'Oeste and Vale do Anari in the State of Rondônia, Brazilian Amazon.

2,017 mm (Rondônia, 1998). The annual average temperature is 25.5°C, and monthly averages for relative humidity range from 80 to 85 percent. These characteristics make the monthly potential evapotranspiration very constant, and the real and potential evapotranspiration are coincident with exception for the dry months (Shuttleworth, 1998). The terrain is undulating, ranging from 100 to 450 m above sea level. Several soil types were identified, mainly alfisols, oxisols, ultisols, alluvial soils, and other less spatially represented associations (Bognola and Soares, 1999). Settlers, rubber tappers, and loggers inhabit the area, transforming the landscape through their economic activities and use of resources.

Methodological Approach

Landscape change is the alteration in the structure and function of the ecological mosaic over time (Forman and Godron, 1986). This article does not focus on the function of landscapes or patch mosaics within the study area, although its findings may be used for this purpose. Instead, it concentrates on the structure of those landscapes and how they have changed since the settlements were implemented in Rondônia. Additionally, this research is not an empirical test about the behavior of metrics measuring landscape structure, but a comparison between agroecological processes and spatial patterns in Machadinho and Anari through the use of quantitative methods. LULC change is the most important variable affecting structure and function of landscapes in the study area. Other variables, such as topography and soils were assumed to be similar at this scale of analysis.

Based on Silbernagel (1997) and Gibson *et al.* (2000), the following definitions are used. Scale is the temporal or spatial dimension of an object or process, characterized by both grain and extent. Resolution is the precision of measurement (grain size, if spatial), and grain is the finest level of spatial resolution possible within a given data set (pixel size for raster data). Extent is the size of the study area or the duration of time under consideration. These parameters were controlled to allow the comparative analyses in Machadinho and Anari. LULC was determined from classified Landsat TM images, with both settlements in the same scene, so grain size is equivalent. The extent of each landscape was defined by the settlement's boundary.

The objective of this study was to compare the two different designs of colonization in terms of landscape structure and change using spatial metrics: fishbone design encompassing only private properties versus topography-based design including private properties and communal forest reserves. A multitemporal approach was used for the comparison. Dry season images dated June 1988, 1994, and 1998 were classified according to the following LULC categories: mature forest, advanced secondary succession, initial secondary succession, pasture, agriculture, bare land, built-up land, and water.

Prior to classification, TM imagery was radiometrically and atmospherically calibrated to surface reflectance using an improved image-based dark object subtraction (DOS) model (Chavez, 1996; Lu *et al.*, 2002). The imagery was also geometrically rectified into a UTM projection. Extensive fieldwork was carried out during the dry seasons of 1999 and 2000, and ground truthing included approximately 1,000 georeferenced observations on land cover distributed in both settlements. Forty sample plots and 120 subplots were inventoried for collection of vegetation structure data, and correlation between these data and reflectance data was computed to improve the classification accuracy of mature forest and classes of secondary succession (Batistella, 2001). Use of the Global Positioning System (GPS) allowed us to match data from the classified images with the features observed in the field, and an aerial survey was carried out to better examine the landscape patterns in the region. Landowners were interviewed about their current production systems and land-use history on their properties. Classification was performed using maximum-likelihood algorithms supported by separability and contingency analyses. The overall accuracy was 79.5 percent for 1988, 76.8 percent for 1994, and 81.1 percent for 1998 when including the eight classes.

The LULC classifications were similarly recoded for both settlements to facilitate interpretation of landscape pattern and change. Four recoded classes—forest, secondary succession (initial and advanced), production (pasture, agriculture, and bare land), and other (water and built-up land)—were based on the main processes occurring in the study area and affecting landscape transformation, i.e., forest fragmentation through deforestation, vegetation recovery through succession, and land occupation through pasture and agriculture conversion. The overall accuracy reached 87.7 percent in 1988, 84.7 percent in 1994, and 86.3 percent in 1998 when including just four classes. The authors are currently engaged in testing different approaches and classifiers to achieve even better accuracies (Batistella, 2000; Lu *et al.*, 2003).

The settlement boundaries were assigned as landscape limits. However, due to the lack of satellite data for the southern portion of Anari in 1988 and 1994, the boundary of the smaller subset (1994) was used to clip the classifications for other dates. The procedure left 11 percent of the

Anari settlement out of the analysis but allowed consistency during calculation and comparison of metrics. For Machadinho, metrics were calculated for the entire settlement for two cases: including and excluding the communal reserves. For the latter case, the reserves were considered as background with no class value.

Metrics were computed for classes and patches, and each settlement was assigned as one landscape. Thus, the study differentiates the landscape of Anari, with its orthogonal design of roads and parcels, and the landscape of Machadinho, following topographic features. Class is the patch type: forest, succession, production, or other. Patch corresponds to each polygon of the vector layers. Areas smaller than 900 m^2 were not computed so we could be consistent with the 30- by 30-m pixel size of Landsat TM images used for LULC classifications. The edge width for core metric calculations was 90 m.

Landscape fragmentation is the process where a landscape matrix is progressively subdivided into smaller and more isolated patches, mainly as a result of human land-use activities. Selected metrics were chosen for the comparative analysis of settlements in Rondônia (Table 1). Metrics quantifying fragmentation were highlighted. To some extent, all metrics except AWMSI (area-weighted mean shape index) are measuring fragmentation. At the patch level, additional descriptive statistics were computed for the population of patches. Tables and graphic outputs allowed comparisons between landscape patterns and changing processes. Landscape ecologists have recently pointed out the need for new developments and standardization for quantitative analysis of landscapes (Wiens and Moss, 1999). With this study in Rondônia, we intend to contribute to the rain forest fragmentation debate through a better understanding of spatial pattern and process by using a set of comparable metrics.

Results and Discussion

This article presents results for landscape metrics in a multitemporal approach for two distinct settlement designs in Rondônia, Brazil. The following sections present the results for selected metrics for both classes and patches within the studied landscapes. Results for forest are emphasized, as they play an important role in defining landscape structure and fragmentation within the study area.

Class-Level Findings

Patch size and variability metrics allow a general characterization of the structure of landscapes. Other metrics (e.g., edge, nearest neighbor, shape, and core area) have important applications for the study of edge effects and interior habitat. The sizes, the amount of edge, and the shapes of patches dictate the interactions between distinct patch types and, consequently, the flow of species throughout the landscape (Malcolm, 1994; Laurance and Bierregaard, 1997).

Percentage of Landscape

The percentage of landscape (PLAND) provides results in terms of percentage of total landscape covered by all patches of a class. PLAND of forest in Machadinho dropped from 88.4 percent in 1988 to 65.7 percent in 1998, while in Anari these values were 86.8 percent and 52.9 percent, respectively. When excluding the communal forest reserves from

Table 1. Metrics Used to Assess Landscape Structure in Rondônia, Brazilian Amazon

Metric Type	Metric	Formula	Definition	Range
Area Metrics	Percentage of Landscape (%)	$PLAND = Pi = \frac{\sum_{j=1}^{n} a_{ij}}{A}(100)$	Percentage of landscape comprised by a class	$0 < PLAND \leq 100$
Patch Size and Variability Metrics	Largest Patch Index (%)	$LPI = \frac{\max_{j=1}^{n}(a_{ij})}{A}(100)$	Percentage of comprised by the largest patch	$0 < LPI \leq 100$
	Mean Patch Size (ha)	$MPS = \frac{\sum_{j=1}^{n} a_{ij}}{n_i}\left(\frac{1}{10{,}000}\right)$	Average patch size for a class	$MPS > 0$, without limit
	Patch Size Standard Deviation (ha)	$PSSD = \sqrt{\frac{\sum_{j=1}^{n}\left[a_{ij} - \left(\frac{\sum_{j=1}^{n} a_{ij}}{n_i}\right)\right]}{n_i}}\left(\frac{1}{10{,}000}\right)$	Population standard deviation for patch sizes of a class	$PSSD \geq 0$, without limit
Shape Metrics	Area-Weighted Mean Shape Index	$AWMSI = \sum_{j=1}^{n}\left[\left(\frac{p_{ij}}{2\sqrt{\pi o'. a_{ij}}}\right)\left(\frac{a_{ij}}{\sum_{j=1}^{n} a_{ij}}\right)\right]$	Average shape index for a class, weighted by patch area	$AWMSI \geq 1$, without limit
Core Area Metrics	Mean Core Area Index (%)	$MCAI = \frac{\sum_{j=1}^{n}\left(\frac{a_{ij}^{c}}{a_{ij}}\right)}{n_i}(100)$	Average percentage of patches of a class that is core area	$0 \leq MCAI < 100$

Legend: a = total landscape area (m^2); $n=n_i$ = number of patches in the landscape of patch type (class) i; $i = 1, \ldots, m$ or m' patch types (classes); $j = 1, \ldots, n$ patches; a_{ij} = area (m^2) of patch ij; a_{ij}^{c} = core area (m^2) of patch ij based on specified edge width (m); p_{ij} = perimeter (m) of patch ij; Pi = proportion of the landscape occupied by patch type (class) i (adapted from McGarigal and Marks (1995)).

the analysis, Machadinho shows the same rate of deforestation as Anari. Areas in succession increased about 11.9 percent in Machadinho, 16.7 percent if the reserves are excluded, and 15.4 percent in Anari during the period of study. Production areas increased 10.7 percent, 15.4 percent, and 18.3 percent, respectively. PLAND for other areas (water and built-up land) stayed roughly stable over time (Figure 2).

The classes used for this research have distinct functions within the landscapes. Although this article focuses on landscape structure, further studies may be more specific about the role of different patch mosaics in flows of materials, energy, and species within landscape elements. PLAND is a useful metric when comparing the same classes between landscapes of different sizes, such as Machadinho and Anari. The results indicate the importance of communal reserves in maintaining a higher percentage of forest cover in Machadinho. Without them, the rate of deforestation is similar in both landscapes (Figure 2).

Largest Patch Index

The largest patch index (LPI) provides a measure of the size of the largest patch of a given type as a percentage of the total landscape area. The LPI for forest decreases with time down to 10.7 percent in Machadinho, 4.5 percent in Anari, and only 2.6 percent in Machadinho without reserves (Figure 3a). Ecologically, the largest forest patches often are the most important; therefore, the LPI can be one of the most effective metrics for measuring a landscape's resistance to fragmentation (Dale, personal communication, 2001). LPI for forest decreases in all cases over time (Figure 3a). The relatively large size of the largest communal reserve in Machadinho is affecting LPI results positively for this landscape. Certainly, the reserve itself and contiguous private forest areas make up the LPI value for forest in Machadinho. Interestingly, because of this communal reserve, this metric tends to remain stable in Machadinho, while it keeps decreasing in Anari. The largest forest patch in Machadinho has 22,892 ha and includes the largest communal reserve, which has 18,100 ha. Assuming that the areas adjoining the reserves will be cleared, the reserve will become the largest patch itself, stabilizing the LPI at about 8.5 percent.

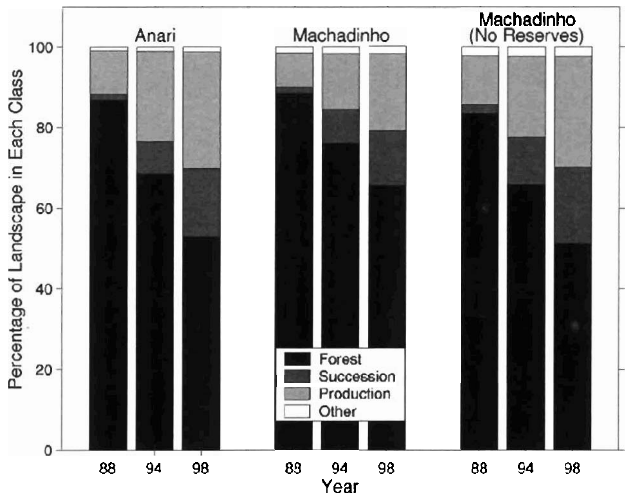

Figure 2. Percentage of landscape (PLAND) for each class in Machadinho d'Oeste and Vale do Anari in 1988, 1994, and 1998.

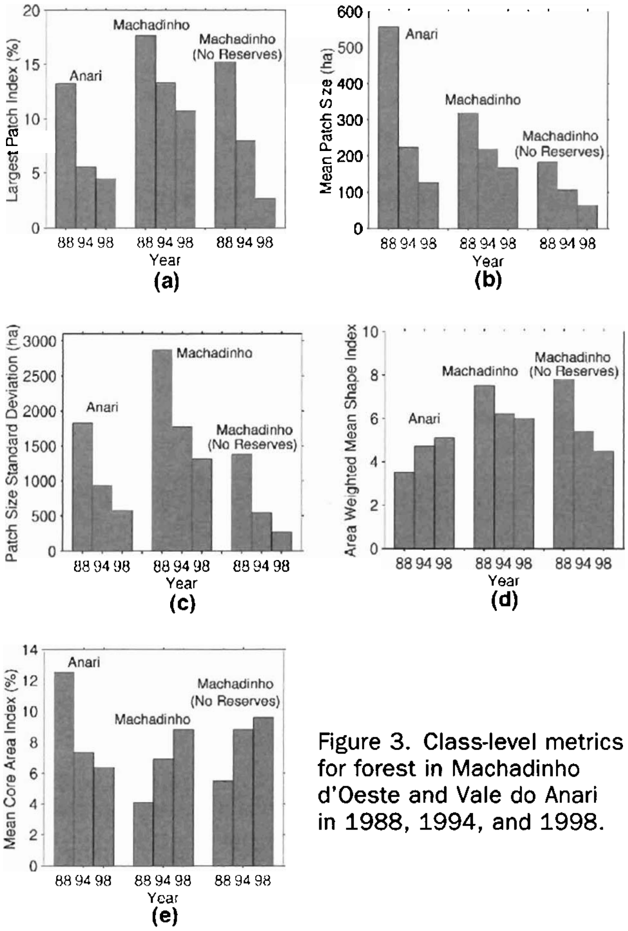

Figure 3. Class-level metrics for forest in Machadinho d'Oeste and Vale do Anari in 1988, 1994, and 1998.

Mean Patch Size

Patch size metrics are important quantitative measurements to assess landscape transformation and fragmentation because the total amount of energy and nutrients in a patch is proportional to its area (Forman and Godron, 1986). In Machadinho, mean patch size (MPS) of forest fragments dropped from 319.0 ha ($n=592$) in 1988, to 219.1 ha ($n=741$) in 1994, and to 167.4 ha ($n=838$) in 1998. In Anari, these metrics were 556.4 ha ($n=170$) in 1988, 224.9 ha ($n=332$) in 1994, and 126.7 ha ($n=455$) in 1998. In Machadinho without reserves, MPS of forest is considerably smaller in all dates (Figure 3b). MPS of succession areas in all landscapes is similar in 1988 and 1994, but larger in Anari in 1998. MPS of areas in production are always larger in Anari.

In general, MPS decreases for forest and increases for all other classes. Moreover, a lower pace of forest fragmentation is indicated for Machadinho when compared to Anari. Although MPS of forest was smaller in Machadinho in 1988, it ended up larger after fifteen years of landscape transformation. This occurred because MPS of forest decreased 1.9 times in Machadinho and 4.4 times in Anari during the period of study. The fishbone scheme tends to show lower levels of fragmentation during the early stages of colonization due to the large elongated patches of forest located between roads. However, when forest clearing advances, these patches are subdivided into several smaller patches. In Machadinho, communal forest reserves combined with private property forests produced a better outcome. If the reserves are excluded, MPS of forest drops abruptly, suggesting a much more fragmented class than even the fishbone design (Figure 3b). Although the exclusion of reserves in Machadinho was a hypothetical exercise and may have synthetically increased landscape fragmentation, it does offer an alert for further initiatives trying distinct settlement designs in the Amazon.

Patch Size Standard Deviation

The behavior of patch size standard deviation (PSSD) follows the trends observed for MPS. PSSD of forest decreases through time in all cases. In Machadinho, the exclusion of reserves from the analysis causes an abrupt drop in PSSD values for forest (Figure 3c). PSSD of succession areas is greater in Anari in 1998, while PSSD of production areas is always greater in all dates. In general, this dispersion metric decreases as MPS for forest decreases and increases as MPS for the other classes increases over time (Figures 3b and 3c). In other words, the variability in patch size of forest is decreasing, evolving to a more uniform distribution of forest patch sizes. Conversely, PSSD of production and succession classes increases over time, indicating that these areas are becoming larger and have varying sizes.

Area Weighted Mean Shape Index

The area weighted mean shape index (AWMSI) quantifies the amount of edge present in a class relative to what would be present in a class of the same size but with a circular shape. In other terms, AWMSI provides a relative measurement of shape complexity. Of particular importance is that AWMSI weights larger patches more heavily than smaller patches in calculating the average patch shape.

AWMSI of forest shows opposite trends within the two landscapes, decreasing in Machadinho and increasing in Anari over time. When Machadinho reserves are excluded, AWMSI also decreases, but at a higher rate than when the landscape is complete (Figure 3d). AWMSI of succession areas increases similarly in both landscapes. Production areas otherwise have higher AWMSI values in Anari in all dates. AWMSI results for other features (water and built-up land) are notably stable and higher in Anari, while they increased in Machadinho during the period of study.

Patch shape and size dictate perimeter extent and edge with neighbor patches. These perimeter-area relations are intricate to quantify concisely in a metric and often are difficult to interpret (Frohn, 1998). When weighted by areas of patches, not only the magnitude but also the trends of shape metrics are different within the settlements. AWMSI for forest decreased in Machadinho and increased in Anari during the period of study (Figure 3d). The size and perimeter-to-area relationship of forest patches within the landscapes is certainly affecting the results, because AWMSI increases similarly for all other classes over time. What AWMSI is in fact indicating is that the configuration of classes in Anari's landscape is less complex because its design is based on an orthogonal road network. In Machadinho, the design based on topography produces a more complex outcome in landscape shape structure. Other quantitative analyses such as the interior-to-edge ratio relating edge and shape metrics could provide an easier intuitive interpretation. Although these relationships were not computed for this study, it is expected that communal reserves in Machadinho tend to increase the interior-to-edge ratio of forest while the narrow elongated forest remnants in Anari tend to lower the ratio for this patch type.

Mean Core Area Index

Opposing landscape patterns also were found for the mean core area index (MCAI) of forest. It increases in Machadinho and decreases in Anari over time. MCAI of succession and production areas increased in all cases during the period of study and is always higher in Anari (Figure 3e). MCAI is related to the concept of "interior habitat," which is very relevant for a number of species. Our decision to choose MCAI was to avoid redundancy with patch size and patch variability metrics, because core area is generally a function of these latter measurements. MCAI is a relative index that quantifies core area as a percentage of total area. It is based on the selection of an edge width, which should be associated with the phenomenon under investigation. Because this research is related to processes of LULC change, the choice of an edge width of 90 m was based on potential responses of tropical rain forests when subjected to LULC edge effects (Laurance and Bierregaard, 1997). This decision is somewhat arbitrary, and empirical tests could clarify the effects of changing edge width to core-area metrics values. However, for the comparative purpose of this study, the results are already valuable.

MCAI results should be analyzed with caution, as with any metric based on first-order statistics. Interesting results were found for MCAI of forest. In Anari, the average of core areas represent 12.5 percent of the forest class in 1988, but drops to 6.4 percent in 1998. In Machadinho, MCAI of forest represents just 4.1 percent of this class in 1988, but increases more than twofold to 8.8 percent in 1998 (Figure 3e). The meaning of these results can be better interpreted in conjunction with PLAND for forest (Figure 2). Although deforestation is a concurrent process within both landscapes, the architectural design of Machadinho preserves more interior habitat, which relatively increases as the area of forests decrease. This is independent of the large patches of communal reserves and is strictly related to the intricate design of Machadinho. Conversely, the initially lower fragmented patches of forest in Anari have a relatively higher percentage of interior habitats in earlier stages of colonization, which drops abruptly as the occupation process takes place.

Further studies that focus more specifically on edges within these landscapes should explore the role of contrasts and distances between different patch types. Depending on the land-cover class adjacent to forest patches, for example, different effects may be observed in terms of ecological processes. If a forest patch borders open vegetation, such as production areas, this forest fragment may become more susceptible to disturbances in its structure and composition. Conversely, if forest patches are adjacent to succession areas, secondary regrowth may be accelerated. Investigating these relationships would bring a better understanding about the functional significance of each patch type. Such inferences go beyond the purposes of this study, but exploratory results obtained for edge contrast and nearest-neighbor metrics justify the use of these quantitative approaches in further ecological analyses within Amazonian landscapes under processes of LULC change.

Patch-Level Findings

The summary statistics presented above, such as mean patch size (MPS), are useful indicators. However, many class-level summary statistics—MPS in particular—give equal weight to each patch. In the context of forest land-cover dynamics, it is usually the largest forest patches that are most important. Large forest patches are better able to maintain and promote biodiversity and, therefore, should generally receive greater emphasis. The largest patch index (LPI) is useful in this regard, but only focuses on the single largest patch. As a result, we analyzed the size distribution of an arbitrary number (ten, in this case) of the largest forest patches to emphasize large-patch dynamics.

Size Distribution of Largest Forest Patches

Initially, in the 1988 image, both settlements have at least ten forest patches that are 50 km^2 (5,000 ha) or larger in size (Figure 4). By 1998, Anari has no forest patches larger than 50 km², although there still are a number of forest patches that can be considered "large" (i.e., in the 20- to 40-km² range). Machadinho, with its communal forest reserves, is able to maintain the largest forest patches. When the forest reserves are removed from Machadinho, the rate of fragmentation of the largest forest patches is even more severe than in Anari. As discussed above, however, the process of removing the reserves has likely produced an artificial amount of fragmentation.

Fractional Size Distribution of Largest Forest Patches

To provide another (perhaps more fair) comparison of the two settlements, we also analyzed the largest forest patches as a fraction of the total settlement area (Machadinho is 68 percent larger than Anari). When viewed as a fractional size distribution, the largest forest patches show an even higher rate of fragmentation in both Anari and Machadinho without reserves. By 1998, neither settlement pattern had a forest patch that represented as much as 4 percent of the total settlement area (Figure 5). With its large forest reserves, Machadinho is able to maintain five forest patches that are larger than 4 percent of its total area. One forest patch in Machadinho represents over 10 percent of the settlement area, as also indicated by the LPI results.

The impact of these class- and patch-level findings to ecological processes is a promising subject for further studies. Particularly, it is important to follow the trends for forest and succession areas and understand the potential impact of patch location within the landscapes on processes such as vegetation recovery or degradation. For these studies, it will be relevant to consider that forest fragmentation in both settlements may affect the propagation of disturbances across the landscapes. For instance, a highly fragmented forest, taken as a patch type within the landscape, may be less prone to total destruction by fire as a class in its entirety, although the fragments themselves are more susceptible. For other types of disturbances (logging, for example), larger patches of forest may show a higher resilience than several small fragments. These processes should be investigated and monitored for each landscape through time because they may be affected by settlement design.

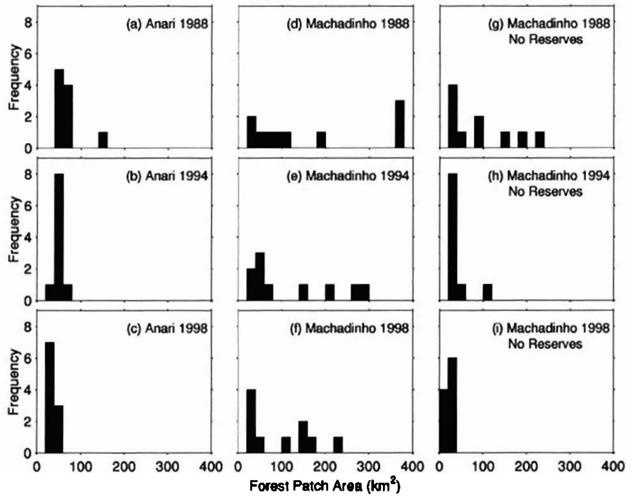

Figure 4. Size distribution of the ten largest forest patches in Machadinho d'Oeste and Vale do Anari in 1988, 1994, and 1998.

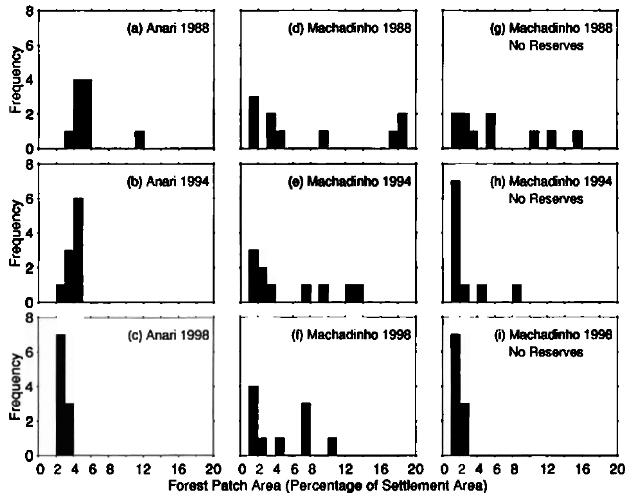

Figure 5. Fractional size distribution of the ten largest forest patches in Machadinho d'Oeste and Vale do Anari in 1988, 1994, and 1998.

Conclusions

The search for quantitative methods to analyze and describe the structure of landscapes has become a high priority in landscape ecology. This article intends to provide elements for discussion regarding landscape change in the Amazon through the use of selected metrics. LULC issues are at the core of this perspective, due to their intricate dynamics and consequences in landscape structure and function. In the Brazilian Amazon, this is particularly relevant because landscape transformation and forest fragmentation are occurring throughout the region. In this sense, this comparative study offers a singular opportunity for the discussion of landscape patterns and processes.

The striking differences in the architectural design of Machadinho and Anari suggested that the LULC spatial patterns are also different. Taking the settlement as a whole (i.e., including the communal reserves in the analysis), Machadinho's forest is less fragmented, has greater shape complexity, and has more interior habitat than does Anari after 15 years of colonization. However, the temporal factor should not be neglected. Results showed that Anari was less fragmented at earlier stages of its implementation. As soon as colonization and deforestation processes took place, the maintenance of forest cover within the communal reserves produced a less fragmented landscape in Machadinho. Selected landscape structure metrics such as LPI and MPS indicated that the design based on topography would lead to more fragmentation if it did not include large patches of preserved forest. In addition, Machadinho's forest patches have on average more core area in relation to the total area of forest within the settlement, including or excluding the communal reserves in the analyses. In this case, the design based on topography plays an important role in maintaining or increasing forest interior habitat relative to the entire landscape area, lowering the impact of forest fragmentation on the occurrence and distribution of organisms.

The use of selected landscape metrics proved to be useful when looking for indicators of landscape structure and change in the region. Comparing different designs of settlements adds to the literature available for areas of fishbone colonization. Other articles in preparation by the authors highlight the human dimensions and socioeconomic factors driving landscape change in Rondônia. These studies emphasize that lower levels of fragmentation in Machadinho are not caused just by the architectural design, including large patches of forest reserves, but by their management by local rubber tappers. The forest communal reserves bring about a key issue in rural development projects in the Amazon, i.e., the compatibility of presence of reserves occupied by native population with private lots occupied by smallholders. Interesting enough, this community heterogeneity in Machadinho fostered less conflictive situations because both groups were granted with distinct land ownership regimes and production systems.

Analyses of the land-use success based on household data have also been carried out. In general, pastureland increased at a higher rate in Anari (Batistella, 2001). Moreover, according to landowners, the condition and productivity of agricultural fields is better in Machadinho. This is confirmed by official productivity indices (IBGE, 2000), suggesting a better management of cropland by landowners in the latter settlement. The trend of the fishbone settlement for pasture extensification is clear, but further studies are necessary to understand how socioeconomic factors (e.g., household characteristics, land tenure, access to infrastructure, agricultural extension, and credit) have affected spatial patterns in Amazônia.

The policy implications of this work in Rondônia are crucial for further initiatives regarding settlement implementation. Development and conservation strategies can be informed by the results achieved, but regional dynamics and local context should be taken into account to avoid political failures. The path for a reasonable conceptual approach explaining the heterogeneous processes of colonization in the Amazon is far from achieved. Hopefully, this article and other initiatives will build frameworks that address the wide array of colonization trajectories within the region and contribute to better social and environmental outcomes.

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