

COMPARATIVE ANALYSIS OF LANDSCAPE FRAGMENTATION IN RONDÔNIA, BRAZILIAN AMAZON

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ABSTRACT

Deforestation processes in the Brazilian Amazon have attracted a great amount of attention. Colonization incentive policies induced the implementation of rural settlements, without considering the constraints of each region and consequent environmental impacts. This paper analyzes the influence of different architectures of colonization upon landscape fragmentation. Two settlements were selected in Rondônia: Vale do Anari, where the orthogonal road network is often referred to as a 'fishbone' pattern, and Machadinho d'Oeste, a settlement designed to conform to local topography. Landscape structure indices were calculated, using a LANDSAT TM image from July 1998. The results show distinct fragmentation patterns in Machadinho and Anari. The method, based on landscape ecology and remote sensing techniques, may be useful to evaluate potential environmental impacts resulted from the establishment of colonization projects in the Amazon.

1. INTRODUCTION

Landscape fragmentation and its potential impact upon problems such as global change, biogeochemical cycles, land-use dynamics, and biodiversity have become central issues in Earth System Science (National Research Council, 1998). As a consequence, new ecological theories (Wilson, 1988), modern methods to study spatial dynamics (Turner *et al.*, 1995) and new applications to natural resources planning and monitoring have taken place (Goodland *et al.*, 1993).

Perhaps the most important ongoing process of natural landscape fragmentation is the deforestation of the Amazon Basin. Different approaches have been used to study land-use/land cover (LULC) change in that region. Research has focused on the amount and rate of deforestation (INPE, 1996; Skole and Tucker, 1993), and related social, economic, and ecological processes involved (Brondizio *et al.*, 1994).

Recent studies have addressed quantitatively the role of deforestation on the fragmentation of Amazonian landscapes (Laurance *et al.*, 1997; Dale and Pearson, 1997; Frohn *et al.*, 1996; Dale *et al.*, 1993, 1994; Skole and Tucker, 1993). Most of this research has been carried out in colonized areas following an orthogonal road network ('fishbone'). This pattern is common in some parts of the Amazon but not all over the region. Rare efforts have been made to compare the effect of the architecture of colonization on landscape fragmentation (Oliveira-Filho and Metzger, 1999; Soares Filho, 1998).

This paper addresses differences between two types of settlement in the State of Rondônia, Brazilian Amazon, suggesting that colonization design affects patterns of landscape fragmentation. The research combines LULC analysis through the processing of georeferenced data, particularly satellite imagery, with landscape ecology theory and methods. Our overall perspective is to contribute to a better understanding of patterns of landscape fragmentation in recent colonized areas.

2. RESEARCH CONTEXT

Understanding landscape fragmentation to achieve a sustainable strategy of colonization is a matter of growing interest to communities in the Amazon, to regional and national policy makers, and to all those concerned with the consequences of deforestation (Laurance *et al.*, 1997). Skole and Tucker (1993) measured deforestation and habitat fragmentation for the entire Amazon Basin using 1:500,000 LANDSAT TM photographic imagery for the period between 1978 and 1988. They quantified deforestation, fragmented forest, defined as areas less than 100 km² surrounded by deforestation, and edge effects of 1 km into forest from adjacent areas of deforestation. Results showed that deforestation increased from 78,000 km² in 1978 to 230,000 km² in 1988, while fragmented habitats, severely affected with respect to biological diversity, increased from 208,000 to 588,000 km².

Rondônia is perhaps the state where processes of colonization in the region have attracted the greatest amount of attention, mainly because of LULC change associated with land appropriation. Development and colonization projects have marked the history of the state in the last 30 years (Fearnside, 1989). Two large projects took place during this time period: Polonoeste, responsible for paving the main road crossing the state and providing access in the southeast-northwest direction; and Planaflo, which financed, among other things, the elaboration of a land zoning program. Negative and positive interpretations concerning the outcome of these projects were made but all agree that the state is facing a period of rapid change (Brown, 1998).

Some studies have used specific metrics to understand landscape structure and fragmentation in the Amazon. There are metrics related to landscape composition, referring to features associated with the presence and amount of each patch type within the landscape but without being spatially explicit. Others are related to landscape configuration, referring to the physical distribution or spatial character of patches within the landscape (Baker and Cai, 1992; McGarigal and Marks, 1995).

Dale *et al.* (1993) used a dynamic model consisting of three linked sub-models that simulate settlement patterns, land-use changes, and carbon release. The model incorporates both household- and regional-level analysis, showing that land-use changes in a fishbone colonization pattern in Central Rondônia are a function of variables such as lot size, land-use history, initial soil and vegetation conditions, land-use choices, and effects of illness on work. Dale *et al.* (1994) used fractal dimension and contagion indices to quantify the effects of different land-management practices. Results indicated the decrease in complexity after 40 years of occupation for the typical- and worst-case scenarios. These scenarios were also used to address the effects of fragmentation in nine groups of animals in terms of gap-crossing ability and land area requirements. Species with large area requirements but with small gap-crossing ability are more affected (Dale *et al.*, 1994). Frohn *et al.* (1996) used satellite remote sensing analysis to evaluate the model proposed by Dale *et al.* (1993, 1994). Percent cleared, contagion, and fractal dimension were also used for comparisons of land cover patterns. The authors showed how changes in resolution affect landscape indices and how simulation of agricultural clearings at the lot level in Central Rondônia captures the majority of variance in the spatial and temporal patterns of deforestation.

Examining further the quantification of habitat fragmentation, Dale and Pearson (1997) suggested a combination of spatial indices to depict the complicated process of LULC change in Rondônia. Indices such as area of habitat, frequency distribution of patch sizes, measures of patch shape, and length of edge between habitat types were of particular interest. They concluded that the percentage of area in a particular land cover type remains appropriate for land use change analysis. Furthermore, the ratio of the largest forest patch to the total forest area may be the most appropriate index for characterizing extreme conditions.

Meanwhile, despite such important findings, few works have addressed the influence of different architectures of colonization on landscape fragmentation. Soares Filho (1998) developed a Markovian model to analyze landscape dynamics in three colonization patterns in Mato Grosso. The analysis was based on regional data simulating LULC change in a multi-temporal basis. Oliveira-Filho and Metzger (1999) looked for thresholds in landscape indices used to describe three different patterns of deforestation in the same state. Other authors have integrated distinct levels of analysis, from the household to the landscape to identify the human dimensions of LULC change (McCracken *et al.*, 1999; Moran and Brondizio, 1998; Moran *et al.*, 1998). This paper is placed in this context, focusing on two distinct settlement designs in the state of Rondônia.

3. ENVIRONMENTAL AND CULTURAL SETTING

Within the Amazon Basin, particular areas offer a great potential to the development and testing of methods of spatial analysis related to forest fragmentation. One of these areas is located in the State of Rondônia (Figure 1), where deforestation rates have been the highest in the Amazon during the last twenty years (Alves, 1999). Following the national strategy of regional occupation and development, colonization projects initiated by the Brazilian government in the 1970's played a major role in this process (Pedlowski, 1999).

In Rondônia, colonization projects were designed based on a fishbone scheme. Often, these projects were implemented with no consideration for environmental constraints and landscape characteristics of each region. Vale do Anari, established in the early 80's, is an example of this process. In 1982, the Brazilian Colonization and Land Reform Agency (INCRA) designed a new model of settlement, in which the road network followed the watershed topography (Figure 2). Within this project, called Machadinho d'Oeste, the lots almost always had access to a water stream. Studies of farming systems and socioeconomic characteristics at Machadinho d'Oeste have suggested this settlement to be a more adequate model of colonization design (Miranda *et al.*, 1997).

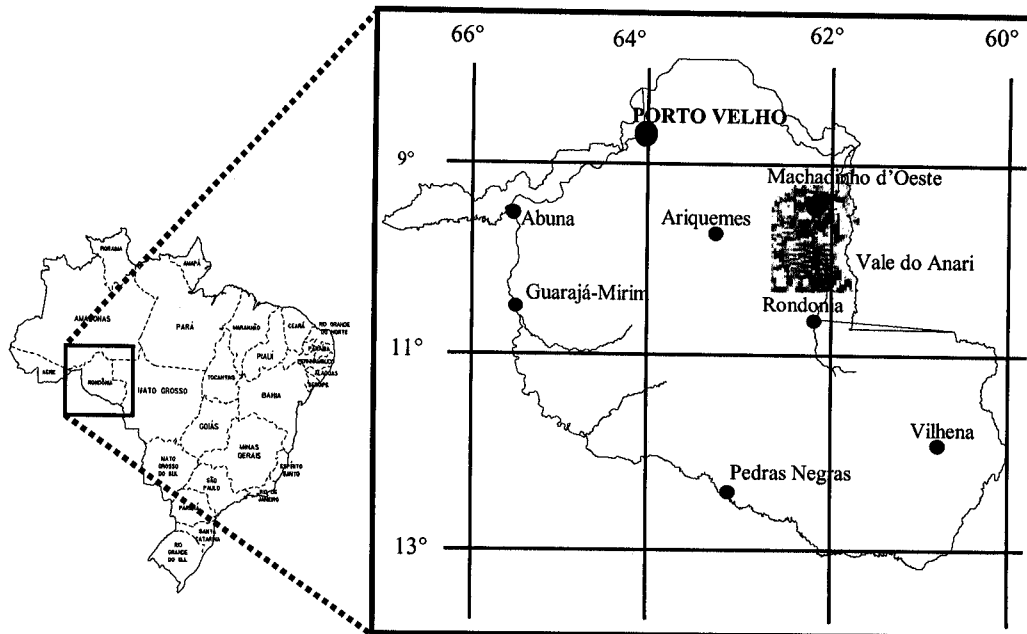


Figure 1. Machadinho d'Oeste and Vale do Anari municipalities on northeastern Rondônia, Brazilian Amazon.

The original Machadinho settlement had an area of 2,090 Km² with 2,934 plots designated for *landless* small farmers from other states. In 1988, Machadinho became a municipality and expanded to incorporate four other settlements and small towns. In 1989, the rural population represented 2/3 of Machadinho's total population. Less than 10 years later, the rural population diminished to 1/3 of the total. The last Brazilian census recorded a total population of 28,949 people, distributed between rural (7,317) and urban (21,632) (IBGE, 1996). This trend follows the recent process of urbanization in other areas of Rondônia, already described in the literature (Batista, 1999; Browder and Godfrey, 1997).

Vale do Anari has a different story. Started by spontaneous colonization, the settlement was established by INCRA also in the early 1980's but with no assistance, urban infrastructure or administrative autonomy. The settlement was part of the municipalities of Machadinho (after 1988) and Jaru. In 1994, Anari became a municipality. This dynamic led to a completely different outcome in terms of the interactions between the colonists and the environment. Also, different institutional arrangements and rules for forest access are observed for the settlements under investigation. As an example, while Vale do Anari follows the 50% rule (50% of the property lot must be kept as forest), Machadinho's design includes 16 forest block reserves.

The two sites are located approximately 400 km from Porto Velho, the capital of the State of Rondônia, between 9°19' and 10°00' S latitude and 61°47' and 63°00' W longitude. Predominant vegetation cover is tropical rain forest. The rainy season lasts from November to April, with an annual mean precipitation of 2,000 mm. The dry season is well defined, lasting from June to September. The annual average temperature is 24°C and the moisture ranges from 80 to 85%. Several soil types were identified, mainly Alfisols, Oxisols, Ultisols, Alluvial soils and other less spatially represented associations (Miranda and Mattos, 1993).

The majority of the colonists came from the south of Brazil, mainly the State of Paraná, bringing with them specific production systems. The result in terms of spatial organization of farming plots is a mosaic of pasturelands, perennial crops, mainly coffee and cocoa, and annual crops (corn, rice, and beans). Land cover characteristics are also defined by different stages of land occupation and secondary succession contrasting with the native rain forest.

4. METHODS

Methodological procedures included image processing and landscape indices calculation. Data was provided by the *Anthropological Center for Training and Research on Global Environmental Change* (ACT), including a 1998 LANDSAT TM scene and topographic maps of 1:100,000 scale.

LULC classifications were derived from manipulation of the geometrically corrected LANDSAT TM image. Visual analysis was conducted to achieve a general concept of the study area, including vegetation, land cover patterns, and possible data limitations, such as cloud cover and noise. Image enhancement techniques were applied to improve the visual interpretability by increasing the varied apparent distinction between features. A portion of the scene including both settlements was selected for LULC classifications. The image was clustered in 50 classes using ISODATA algorithms. An edited signature file derived from statistical separability analysis between these classes was used to classify the entire area.

To carry out the comparative analysis between fishbone and topographically constrained designs of colonization, two subsets of equal form and dimension were selected, each one representing a portion of the studied municipalities with similar age of occupation. As the exact cartographic limits for the settlements were not available we focused on two rectangular areas including the majority of Machadinho d'Oeste and Vale do Anari (Figure 2).



Figure 2. Landsat TM scene showing the orthogonal road network ('fishbone'), including Vale do Anari, and the different settlement design of Machadinho d'Oeste in Rondônia, Brazilian Amazon.

Landscape indices were calculated using Fragstats (McGarigal and Marks, 1995). Index selection was based on their usefulness to address landscape fragmentation (Haines-Young and Chopping, 1996; Dale and Person, 1997). Some indices are particularly useful to test the hypothesis about landscape fragmentation processes in Machadinho d'Oeste and Vale do Anari. Among them, area indices and number of patches are of special interest. Edge, shape, and core area indices were calculated because of their relations with architecture design and landscape configuration. Mean nearest-neighbor index defines the average distance to the nearest patch of same patch type. Interspersion/juxtaposition indices may be useful to compare landscape configurations.

5. RESULTS AND DISCUSSION

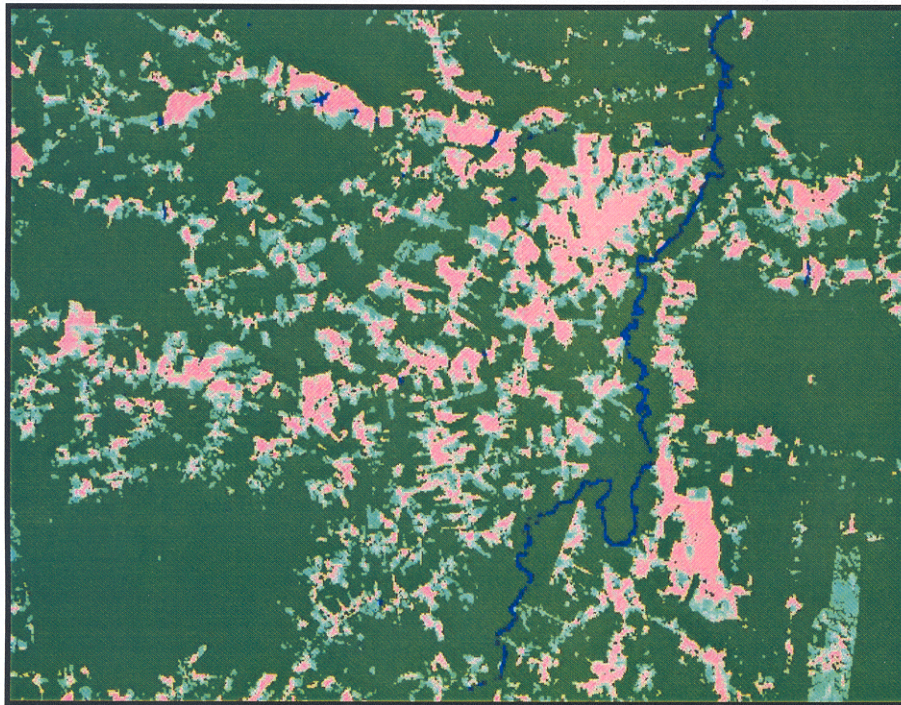
Landscape fragmentation analysis in Machadinho d'Oeste and Vale do Anari was based on four LULC classes: forest, non-forest vegetation, bareland/cropland, and water (Figure 3). Table 1 shows selected landscape indices for the settlements in terms of LULC classes. Results for forest are particularly highlighted. The total area and percentage of landscape of forest is similar in both colonization projects. However, the number of patches and the mean patch size are significantly different. In Machadinho, the mean patch size of forest fragments is 106.59 ha (n=870), while in Anari the mean patch size is 76.94 ha (n=1165). The largest patch index does not depict these differences. Although there are large patches of forest in both settlements, their number and size differ among the landscapes.

| Indices | Machadinho d'Oeste | | | | Vale do Anari | | | |
|-------------------------------------------|--------------------|-----------------------|-------------------|--------|-----------------|-----------------------|-------------------|---------|
| | Forest | Non-forest Vegetation | Bareland/Cropland | Water | Forest | Non-forest Vegetation | Bareland/Cropland | Water |
| Area (ha) | 92729.52 | 13311.54 | 18775.17 | 674.19 | 89638.2 | 15690.06 | 20063.88 | 98.28 |
| Percentage of landscape (%) | 73.89 | 10.61 | 14.96 | 0.54 | 71.43 | 12.5 | 15.99 | 0.08 |
| Largest patch index (%) | 72.56 | 0.24 | 2.32 | 0.04 | 69.5 | 0.16 | 1.42 | 0.02 |
| Number of patches | 870 | 3623 | 2132 | 111 | 1165 | 3943 | 2761 | 48 |
| Patch density (#/100ha) | 0.69 | 2.89 | 1.7 | 0.09 | 0.93 | 3.14 | 2.2 | 0.04 |
| Mean patch size (ha) | 106.59 | 3.67 | 8.81 | 6.07 | 76.94 | 3.98 | 7.27 | 2.05 |
| Total Edge (m) | 3548130 | 3940050 | 3292800 | 175020 | 3905970 | 4472490 | 3692430 | 30030 |
| Edge density (m/ha) | 28.27 | 31.4 | 26.24 | 1.39 | 31.13 | 35.64 | 29.42 | 0.24 |
| Shape index | 26.05 | 28.81 | 24.25 | 2.24 | 28.57 | 32.57 | 27.07 | 1.22 |
| Total core area (ha) | 77808.33 | 1828.53 | 8343.09 | 53.64 | 73264.41 | 2233.17 | 8272.17 | 8.19 |
| Number of core areas | 439 | 1732 | 1109 | 129 | 635 | 1999 | 1236 | 12 |
| Core area density (#/100ha) | 0.35 | 1.38 | 0.88 | 0.1 | 0.51 | 1.59 | 0.98 | 0.01 |
| Mean core area (ha) | 89.43 | 0.5 | 3.91 | 0.48 | 62.89 | 0.57 | 3 | 0.17 |
| Mean nearest neighbor distance (m) | 65.03 | 73.28 | 87.49 | 668.3 | 66.33 | 68.86 | 83.93 | 1940.78 |
| Interspersion and juxtaposition index (%) | 75.85 | 63.59 | 62.57 | 17.93 | 64.25 | 63.41 | 62.59 | 59.31 |

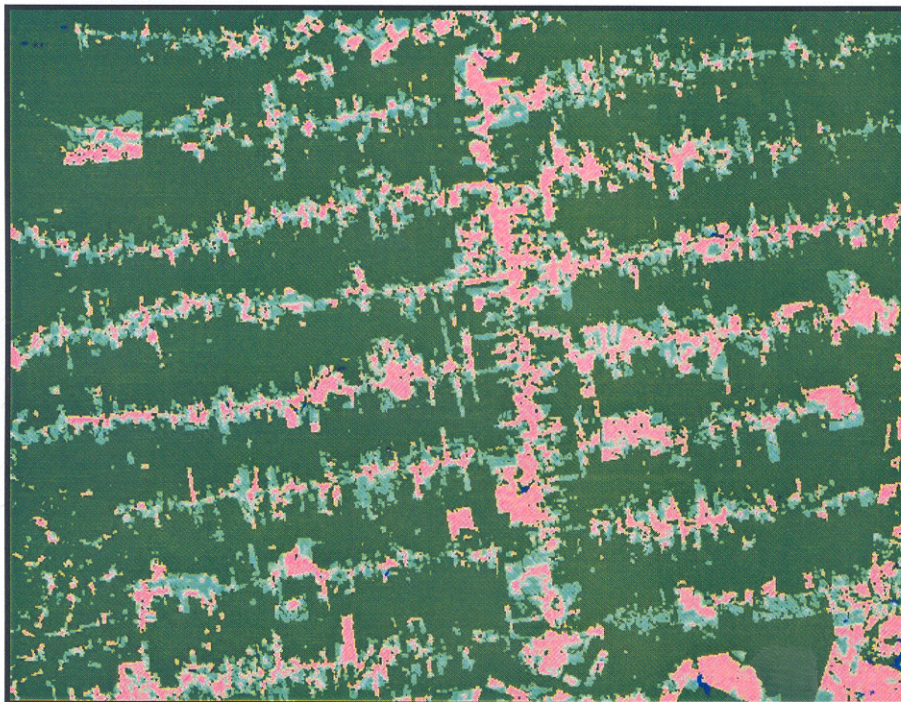
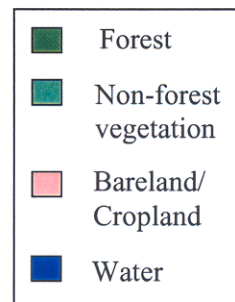
Table 1 - Class indices for Machadinho d'Oeste and Vale do Anari in Rondônia, Brazilian Amazon.

Certainly, settlements' configuration affects these results, based on the protection of many large patches of forest in Machadinho (forest reserves). Core area indices follow the same trend: total core area is similar but mean core area is 89.43 (n=439) for Machadinho and 62.89 (n=635) for Anari. Higher patch density and core area density for forests also suggest a higher fragmentation in Anari and a better conservation of forest remnants in Machadinho. It is important to consider that forest fragmentation in both settlements, as indexed by area and core area metrics, may affect the propagation of disturbances across the landscapes.

This discussion brings up the important role of landscape and patch type edges. The total edge and the edge density have higher values in Anari because edges are longer for all classes, except for water. Depending on the LULC class adjacent to the forest patches, different effects may be observed in terms of ecological processes. For example, if the forest patch borders bareland/cropland, this fragment may become more susceptible to disturbances in its structure and composition. Conversely, if the forest is adjacent to a fallow area (non-forest vegetation), secondary succession may be accelerated. Studies based on field data collection and further analysis are being carried out to address these relationships in both colonization areas.



Machadinho d'Oeste



Vale do Anari

Figure 3 - Land-use/land cover classification for Machadinho d'Oeste and Vale do Anari in Rondônia, Brazilian Amazon.

The relative importance of edge lengths and area of patch types is given by the landscape shape index. Lower values are observed for Machadinho. As the areas of all classes but water are similar in both settlements, the results also highlight the complexity of Anari's landscape, marked by its elongated patches.

Mean nearest neighbor distances do not differ significantly for the forest patch type in both study areas, suggesting important similarities between the settlements in terms of the isolation of forest fragments. In this case, the use of a more detailed classification may also change the neighborhood relationships. The interspersion/juxtaposition index measures adjacencies within a patch type in a landscape. The higher numbers found for forest in Machadinho indicates a higher contiguity of these fragments.

6. CONCLUSION

This comparative study confirms the hypotheses that forest fragmentation in Rondônia is affected by settlement design. Even taking one date into account (1998), differences in terms of landscape structure in Machadinho and Anari are clear. Further multitemporal examination is suggested for a better comprehension of landscape transformation in these areas. Also, the use of more detailed classifications, based on training samples, may maximize the potential of certain indices for the study of ecological processes, such as deforestation and secondary succession. Edge contrast and nearest neighbor indices are potential options.

The interpretation of these findings will contribute to the evaluation of different models of rural settlement in the Brazilian Amazon, assisting in the creation of colonization designs with less environmental impact. In this sense, this paper represents a preliminary initiative based on the use of integrative analytic methods. Studies on vegetation structure and composition, LULC history and institutional arrangements may also bring important elements for an increasingly synthetic approach to building a theoretical model of space in Amazonian colonization areas.

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