CHAPTER 2 - ENVIRONMENTAL AND CULTURAL SETTING: THE OPPORTUNITY FOR A COMPARATIVE STUDY

'Aqui vêm os iludido e vão os arrependido'

2.1 - Amazônia: a land in search of its destiny

The Amazon River and its affluents form the greatest river system on Earth. The Amazon Basin is bordered by the Andes and the massifs of the Guianas and Central Brazil (Orinoco and Paraná Basins), draining 7 million km^2 of land (Sioli 1984). The Brazilian portion of this immense territory is about 5 million km^2 and encompasses several ecological systems (Goulding et al. 1996) (Figure 1).

The early discovery and occupation of the Amazon was facilitated by the existence of numerous waterways and a dense river system, which later scientists and explorers also followed. In the mid-1900s a comprehensive picture of the Amazonian ecosystem began to be formed (Sioli 1984). Up to this period, the heterogeneity of the region was obscured by the notion of a vast and homogeneous 'jungle.'

Early studies on the region tried to explain the apparent lack of social complexity by the existence of 'limiting factors,' which would be responsible for relatively low population densities (Behrens 1992). At the risk of being overly simplistic, the rationales behind these debates are briefly mentioned, as extensive literature has already been published about this subject. The classical paper by Meggers (1954) suggested that levels of social complexity are limited by the agricultural potential of soils in the Amazon. Others have argued that protein sources, not necessarily the production of highly caloric crops, has limited population densities throughout the region (Lathrap 1970, Gross 1975, Ross 1978, among others).

Later studies have challenged these views. Archeological evidence has shown the existence of complex prehistoric cultures in the Amazon (Myers 1973, 1989, Roosevelt 1987, 1989a, 1989b). Agronomic and biophysical surveys have found a diversity of soils and land resources, including areas suitable for large-scale agriculture (Falesi 1974, Cochrane and Sánchez 1982, Nicholaides et al. 1984). Beckerman (1979) and Chagnon and Hames (1979) have shown that, in many Amazonian groups, the amount of protein consumed per capita often equals or exceeds amounts consumed in modern Western societies. And, more recently, the process of colonization itself has made it clear that a much more complex picture has to be drawn if we want to understand the potential of the Amazon for development (Moran 1981, 1983, Becker 1982, Schmink and Wood 1984, Bunker 1985, Hecht and Cockburn 1990, Stewart 1994, Almeida 1996).

In general, the trajectory made possible by limiting factors commented above depends on the ability of human cultures to adapt to heterogeneous environmental conditions and to manage these conditions in order to achieve at least the needs of subsistence (Gross et al. 1979, Moran 1982). But the subsistence assumption has also been challenged by the intensification of production systems, as cultural aspects inter-relate dynamically with population growth and market demands (Boserup 1965, Netting 1977). Together with the theoretical debates about the potentials and limitations of the Amazon, several regional and local processes were taking place due to governmental, private, or spontaneous initiatives of colonization.

The processes of colonization in the Amazon have attracted a great deal of attention in recent years, mainly because of the deforestation associated with land appropriation. Large-scale deforestation began in the early 1960s with the relocation of the national capital to Brasília and the construction of a network of roads connecting the region with the south and the northeast portions of the country: Belém-Brasília Highway, Transamazon Highway, Cuiabá–Porto Velho Highway (BR-364), Cuiabá-Santarém Highway, and the *Perimetral Norte*, among other ancillary roads (Moran, 1993b). *Calha Norte* and *Avança Brasil* represent the more recent versions of road development projects for the region. During and after the Program of National Integration (PIN), road building was generally attached to development and colonization projects, international funding by the Inter-American Development Bank and the World Bank, credit lines provided by the Amazonian Bank (BASA) and the Amazonian Development Agency (SUDAM), and establishment of rural settlements by the Brazilian Agency for Colonization and Agrarian Reform (INCRA) (Kohlhepp 1984, Moran 1984, Schmink and Wood 1992, Comision Amazonica de Desarrolo y Medio Ambiente 1993, Browder and Godfrey 1997). In the words of Sioli (1984), "…former human interventions in the Amazonian ecosystem were small sized while the modern development plans and enterprises are quantitatively and qualitatively of enormous dimensions. They concern the terrestrial as well as aquatic reaches of the region and consist, as a first step, in total or selective deforestation."

The Amazonian debate has then shifted from limiting factors to the determinants of deforestation. Human and environmental dimensions of the process are also under investigation. Methodological techniques to address these dynamics at a broad scale are becoming available. Estimations about the rate and extension of deforestation, once based on personal perspectives or partial approaches of extrapolation, are now being done with higher accuracy. Studies on vegetation regrowth are showing alternative trajectories in land-use/land-cover (LULC) change. Besides possible deforestation causes, consequences and responses of the process are also being addressed, as a way to suggest scenarios for the future after the learning of the past. Currently, the effects of Amazonian deforestation on global change processes such as atmospheric carbon accumulation are on top of the list. Through a critical literature review, it is evident that the scientific community is now facing similar problems in estimating carbon releases as it faced in the past with quantification of deforestation (Fearnside and Guimarães 1996, Houghton et al. 1998, Salomão et al. 1998). It is virtually impossible to touch on all the issues related to the Amazonian deforestation from the global to the local perspective through the pages dedicated to this chapter. Therefore, the following discussion was restricted to the dynamics of frontier occupation in the Amazon, an already very complex and multi-tiered subject.

After overcoming methodological problems to estimate the amount and rate of deforestation in Amazônia, remote sensing–based studies have shown that the region has been cleared at approximately 0.5% per year since the early 1980s (Malingreau and Tucker 1988, Skole and Tucker 1993, INPE 1999). Other studies have discussed the social, economic, and ecological processes involved during deforestation dynamics (Conant et al. 1983, Brondizio et al. 1994, 1996, B. Turner et al. 1993, Moran et al. 1994, Gerber 1997).

Slowly, scientific studies in several fields started to recognize a more complex picture (Moran 1993b, 1995). On the one hand, some basic findings were generalized for the entire region as ‘unifying principles’: a general scarcity of nutrients in the soil (Sombroek 1984); a tightly closed, continuous recycling of nutrients within the biomass of the forest (Herrera et al. 1978, Jordan 1989); extreme diversity of the biota (Prance and Lovejoy 1985); and the regional recycling of a large part of the rainwater, crucial for the maintenance of a climate affected by pluvial processes (Schubart and Salati 1982, Dickinson 1987).

On the other hand, the heterogeneity of such a broad territory was recognized in several fields. Among other regional elements, Amazonian river types were differentiated into whitewater (e.g., Solimões-Amazonas, Madeira), clearwater (e.g., Tapajós, Xingu), and blackwater (e.g., Negro) (Sioli 1984). Sombroek (1984) divided soils into three major categories: well-drained soils of the uplands, imperfectly drained soils in the sedimentary parts of the region, and poorly drained soils in *várzeas* and *igapós*. Cochrane and Sanchez (1982) provided a more detailed classification and distribution of the Amazonian soils: oxisols (45.5%), ultisols (29.4%), entisols (14.9%), alfisols (4.1%), inceptisols (3.3%), spodosols (2.2%), mollisols (0.8%), and vertisols (0.1%). Gash et al. (1996) and Fisch et al. (1998) revised the regional climate and possible effects of deforestation. Braga (1979), Pires (1984), and Pires and Prance (1985) have described several vegetation types. A myriad of papers have addressed the human dimension behind the environmental heterogeneity (Meggers 1974, Moran 1974, Hames and Vickers 1983, Moran and Herrera 1984, Balée 1989, Posey and Balée 1989, Sponsel 1992).

As a consequence of the increasing knowledge about the region, different development schemes and production systems were described and discussed (Anderson 1990). Among others, shifting cultivation (Beckerman 1983, Denevan et al. 1984, Dufour

1990), agroforestry (Hecht 1982, Nepstad and Schwartzman 1992, Smith et al. 1996, Brondizio and Siqueira 1997), cattle ranching (Falesi 1974), and agriculture with fertilization inputs (Cochrane and Sanches 1982, Nicholaides et al. 1984) are included.

Today, a more reasonable way of thinking about the occupation of the Amazon shifted from ‘deforest or not deforest’ to ‘where, how, and how much to deforest’ (Mahar and Ducrot 1998). Embedded in this dynamic process, several modern techniques of environmental assessment were developed. Integration of remote sensing and geographic information systems (GIS) brought the spatial discussion into a broader view of the Amazonian development (Malingreau and Tucker 1990, Conant 1994, Adams et al. 1995, Foody et al. 1996, Hall et al. 1996, Ahern 1998, Moran 1998, Alves 1999). Also, more detailed LULC classifications informed by field data are emphasizing the function of secondary regrowth in Amazonian landscapes (Li et al. 1994, Moran et al. 1994, Lucas et al. 1998). While the deforestation process occurs, secondary vegetation also exists. Thus, issues such as vegetation restoration and succession dynamics should be part of the investigations about land-cover trajectories in the region (Moran et al. 1996).

All these contributions to the knowledge of such a large and diverse region have provided new elements for a better understanding of the colonization process. If we still cannot have a reasonable hope that the rich biodiversity of Amazônia will be saved for future generations, at least we can look at the past and begin to correct the misuse of certain analyses and generalizations. Through this critical approach it may be possible to address complex issues, such as the study of landscape transformation in the State of Rondônia.

2.2 - The fate of Rondônia: rural development vs. landscape transformation

Cycles and interests have affected the history of Rondônia. This western portion of the Amazon was originally populated by Tupi-speaking Amerindian societies (Coimbra 1989). By the 1700s, the Portuguese engaged in several expeditions to the region, when occupation was concentrated along the Madeira, Guaporé, and Mamoré Rivers. During the 18th century, Rondônia received its first migration waves, due to gold mines found along the Guaporé River. By the end of the century, mines were abandoned and the local economy faced a period of stagnation until the rubber boom began in the late 1800s. Stimulated by the high prices in the international market, northeastern populations migrated to Rondônia and penetrated deeper into the forest to establish an extractivist economy based on rubber tapping (Rondônia 1981).

By the beginning of the 20th century, the Madeira-Mamoré railway was inaugurated. It connected the town of Guajará-Mirim, located by the Mamoré River, to Santo Antônio (today Porto Velho, the capital of Rondônia) on the Madeira River. By that time, the Brazilian government had launched initiatives to integrate the area with the rest of the country. Telegraphic lines were built, connecting Cuiabá, the capital of Mato Grosso, to Santo Antônio (Porto Velho) and the trails opened for this purpose allowed the establishment of villages. Rondon, for whom the State was later named, led the operation. In 1943, the area was designated 'Federal Territory,' and the highway Cuiabá-Porto Velho (BR-364) was opened. During that same time, rubber extraction had regained importance due to the mobilization for World War II. After the war, the activity declined and was replaced by to diamond extraction during the 1950s and cassiterite mining during the 1960s. By the end of this period, access to different portions of the territory and the demand for development required massive investments and brought about other important changes.

The recent history of Rondônia is embedded in this complex scenario. Following the national strategy of regional occupation and development, colonization projects initiated by the Brazilian government in the 1970s played a major role in LULC change throughout the State (Moran 1984, Fearnside 1989, Schmink and Wood 1992, Matricardi 1996). These projects were implemented to accommodate landless farmers coming from southern Brazil. Two large development projects are particularly relevant, both funded by the World Bank (Pedlowski 1998). The Northwestern Brazil Integration Development Program (POLONOROESTE, 1981-1985) was responsible for paving the BR-364, the main road crossing the State, which improved access in the southeast-northwest direction (World Bank 1987). The Rondônia Natural Resource Management Project (PLANAFLORO, 1992-1999) funded, among other things, the elaboration of a land zoning for the State (World Bank 1992).

In Rondônia (Figure 2), colonization projects were often designed based on an orthogonal road network, commonly called 'fishbone.' The existence of BR-364 as the backbone of this network drove rural occupation and LULC change into the State. These projects were generally implemented with no consideration for environmental constraints within the landscape or access at the local scale. The combination of a better road infrastructure and huge migration waves from the south with the lack of land-use planning within the settlements was thought to have produced the highest deforestation rates in the Brazilian Amazon during the last twenty years (Alves 1999, Dale and Pearson 1997).

Together with land occupation and landscape transformation, new development trajectories also occurred. Logging has always been associated with road building and land clearing. Cattle ranching still occupies the largest portion of the deforested area (Alves et al. 1999), but, despite earlier predictions, less than 25% of the State has been deforested (Rondônia 1998a). Although most articles written about the State emphasize just the conversion of forest to pasture (60% of the deforested area), Rondônia is the 4th State in terms of national coffee production (Matricardi 1996). Batista (1999) makes an up-to-date socioeconomic analysis based on census data. Rates of population growth have declined drastically during the last decade, due to a decrease in migration and in fertility. Rondônia's gross State product is the 3rd in the north region, after Pará and Amazonas. Agriculture and cattle ranching account for 15%, industry for 15.2%, and services for 69.3%. The largest portion (85%) of all farms are family-managed and have less than 100 ha each. Of the total population, 70% live in urban areas.

Distinct positive forces are present today besides the always-criticized government actions and private initiatives facilitating land speculation. Non-governmental organizations have had a relatively active voice during the land zoning process (Pedlowski 1998). Native communities such as the rubber tappers and indigenous people are having their reserves delimited (Olmos et al. 1999). Conflicts still happen everywhere as reserves are invaded by loggers and road builders, properties are taken over by speculators, county boundaries are still being created, the State government claims for development, and so on (Fearnside and Ferreira 1985). But emergent grassroots organizations are becoming more active in the development process. Also, selected studies about colonization in Rondônia have led to international pressure, national policies, and local initiatives for the preservation of large patches of forest throughout the State (Rondônia 1999a).

Recently, the government of Rondônia decreed the 2nd Approximation of the socioeconomic-ecological zoning (Rondônia 2000). Still obscured by legal obstacles to be effective, the land zoning determines areas with distinct status in Rondônia. The settlements studied in this dissertation — Machadinho and Anari — are assigned to 'areas of agricultural, agroforestry, and forestry' use (Figure 3). The settlements are located at the northeastern portion of the State, adjancent to the borders with Amazonas and Mato Grosso (Figure 4). Studies of farming systems and socioeconomic characteristics at Machadinho have suggested it is a singular model of colonization design (Miranda et al. 1997). Throughout this dissertation, LULC trajectories in each settlement are related to institutional and biophysical aspects underlying landscape transformation.

2.3 - Why Machadinho and Anari?

The settlements of Machadinho and Anari were founded in the shadow of the emancipation of the State of Rondônia in 1981 when a dramatic population growth was taking place due to migratory waves. The colonization of the southern part of the State attracted a huge crowd from other Brazilian States, creating a demand for new settlement projects to accommodate the accelerating population increase.

Machadinho and Anari are adjacent to each other, and share similar features. They are located approximately 400 km from Porto Velho, the capital of the State, and present comparable biophysical characteristics at the scale of study, as described in the following sections of this chapter. In regard to their establishment, Machadinho and Anari were created by INCRA during the same period (early 1980s) and represented pioneer settlement projects in northeastern Rondônia.

Besides biophysical characteristics, an important commonality between the two settlements is related to the characteristics of initial settlers who shared similar personal traits and assets. The majority of colonists in Rondônia came from the southeast and south regions of Brazil, mainly from the States of Minas Gerais and Paraná (Millikan 1992). In the case of Machadinho and Anari, they were selected from the excessive group of applicants to earlier settlement projects, based on two sets of criteria: eliminatory criteria, including personal attributes of the candidate (i.e., age, conduct, and employment condition) and assets (i.e., income, other properties, and former applications); and classificatory criteria, including household age, family labor force, and farming skills.

The parcels handed to the settlers were about 50 ha each, half the size of other projects in the Amazon during that period. The reduction in parcel size was an attempt to accommodate the dramatic population growth in Rondônia (average of 16% per year between 1970 and 1980) (Rondônia 1996d). In sum, both settlements resulted from political pressure to accommodate landless migrants and settled households with similar socioeconomic characteristics who were granted land titles of similar parcel sizes.

Notwithstanding the similarities in some attributes, Machadinho and Anari had major differences in their architectural and institutional design. They were conceived under very distinct processes as far as farmers' incentives toward land-use decisions were concerned. They strongly differed in the implementation phase in regard to the landscape design and how infrastructure was provided and maintained during the consolidation phase. Anyone driving through the villages can easily observe the differences between the paved major streets in Machadinho with several stores and hotels and the gravel roads in the rural area, compared to the chaotic district of Anari, poorly served by services and infrastructure (Photos 1 and 2). The description underlying the characteristics of each settlement is presented below.

2.4 - The landscape in Machadinho and Anari: background data

2.4.1 - Geographic location, boundaries, and settlement architectures

The settlements of Machadinho and Anari are parts of their respective municipalities. Located in northeastern Rondônia (Figures 2, 3, and 4), they are newer colonization initiatives than areas along BR-364 (Cuiabá-Porto Velho Highway). Furthermore, Machadinho and Anari are adjacent to the borders with the states of Amazonas and Mato Grosso, which may offer potentials and constraints for future conservation and development.

Figure 5 shows the areas including both settlements on a subset of a 1998 Landsat TM image. The adjancency of Machadinho and Anari highlights their different architecture, which was appealing for this comparative research. A cartographic representation of these two designs of colonization is presented in Figure 6. It is striking to compare the orthogonal road network and property grid of Anari with the more organic layout of Machadinho. The former had its roads and property lots laid out without regard to topography and the river network. The latter took into account these variables to allocate infrastructure features and communal forest reserves. Causes, consequences, and responses to landscape transformation and land-use preferences within these two localities so close but so distinct are discussed throughout this dissertation.

2.4.2 - Climate

Like the entire Amazon humid region, the State of Rondônia has an equatorial climate, characterized by high precipitation levels, low average annual temperature amplitudes but notable daily temperature amplitudes (Nimer 1989). However, the location of the State in southwestern Amazônia — at approximately 10^{o} south of the Equator — produces some distinct characteristics. Perhaps one of the most important differences is the occurrence of two well-defined seasons, with three dry months during the winter — June, July, and August (Figueroa and Nobre 1990). The climate in the study area follows this pattern, being classified as equatorial hot and humid, with tropical transition. According to Koppen's classification, the climate is *Aw*, with average monthly temperatures higher than 18^{o}C and a well-defined dry season (Rondônia 1998b).

The lack of meteorological stations with a reliable time series of data in Machadinho or in Anari impedes a more detailed and multi-temporal analysis of climatic variability for the settlements. The closest stations are located in Ariquemes and in the Jaru Biological Reserve, both approximately 80 km from the settlements. The following numbers are derived from analyses of the Jaru data for a period of 20 years (1977 to 1996) and publications about related research projects in Rondônia.

According to Fisch et al. (1998), the average daily solar radiation in Rondônia is 18.3 MJ.m^{-2}.day^{-1} for the dry season and 17.1 MJ.m^{-2}.day^{-1} for the wet season (see also Fisch et al. 1997, Gash and Nobre 1997). The annual average precipitation in

Machadinho and Anari is 2,016.6 mm (Table 1). A recent study based on data interpolation for the available network of meteorological stations in the State provides a better gauge of the spatial variability of rainfall (Rondônia 1998b). A map from the study shows an increasing variation in precipitation from the south to the north of Rondônia, including Machadinho and Anari in a range of 2,200 mm to 2,500 mm of rainfall per year.

The annual average temperature is 25.5°C, with the average of maximum temperatures at 32°C and the average of minimum temperatures at 21°C (Table 1). The monthly averages of temperature are very constant throughout the year. Similar regularity occurs for the wind speed (average of 4.5 km/h) (Table 1), predominantly from the south from April to October and from NNE/NE from December to March. Monthly averages for air moisture range from 80 to 85%. These characteristics make the monthly potential evapotranspiration also very constant and, with exception for the dry months, the real and potential evapotranspiration are coincident (Shuttleworth 1998). The climatic diagram shows how each season's definition in the study area is a consequence of monthly precipitation variability rather than of temperature oscillations (Figure 7).

2.4.3 - Geology

From the geologic perspective, the State of Rondônia is located in the west portion of the Amazonian Craton in a single tectonic-metamorphic-magmatic domain, the Rondonian Province of San Ignacio (1.45 to 1.30Gy) (Rondônia 1998d). In this area, the Paleoproterozoic metamorphic basement is of medium to high degree, being recovered by:

- A meta-volcanic-sedimentary Mesoproterozoic group, affected by the Rondonian Orogeny;
- A sedimentary Neoproterozoic group;
- Paleozoic-Mesozoic sedimentary basins;
- Cenozoic deposits related to the drainage network and current morphology.

The Mesoproterozoic, Neoproterozoic, Paleozoic, and Mesozoic groups were deposited in successive extensional tectonic events of rifting, being limited by faults and commonly associated with volcanism (Rondônia 1998e).

The area including Machadinho and Anari is basically formed of Cenozoic deposits over the Pre-Rondonian Basement (Paleoproterozoic), the Pre-Rondonian anorogenic suites (Mesoproterozoic), and the Neoproterozoic groups. There are no Paleozoic-Mesozoic sedimentary basins in the area. A brief description of each group or formation, and lithological materials is given below, after compilation from Leal et al. (1978) and Rondônia (1998d, 1998e).

The Pre-Rondonian Basement is formed of gneisses, granulites, anfibolites, migmatites, and calc-silicate rocks. It is a group with medium to high metamorphic degree, constituted more than 1.6 Gy ago (Amazonian Craton), with low permeability and without hydrogeologic interest, except in zones of intense fractures.

The Pre-Rondonian anorogenic suites, formed 1.25 to 1 Gy ago, are plutonic bodies of varied nature (i.e., granites, rapakivi granites, gabbros, and anorthosites). They commonly have low metamorphic degree, low permeability, and low hydrogeologic interest.

The groups Palmeiral-São Lourenço, Prosperança, and Beneficiente, formed approximately 1Gy ago, represent the Neoproterozoic sectors in the study area. Their lithology includes orthoquartizites, arcosian arenites, conglomerates, tuffs, alkaline rocks, and silt or clay horizons. They present a higher hydrogeologic interest and medium to low permeability.

The Cenozoic superficial formations are of the Neogene-Quaternary periods and evolved with the relief as a consequence of tropical meteoric alteration and fluvial dynamics. Because of their detritic nature and the proximity of the sub-surface waters, they frequently present hydrogeologic interest. In general, the Cenozoic formations are 4 to 40 m deep. Two formations occur in the study area. The fluvial terraces and alluvial or colluvial Pleistocene sediments are materials formed by gravel, sand, silt, and clay with different conglomeratic levels but high permeability. The Quaternary-Neogene covertures form other terraces and alteration surfaces showing medium permeability. Some of these features may present laterization.

The relationship of these data to the study of landscape transformation and LULC dynamics in Machadinho and Anari will become clearer after the discussion about their geomorphology, hydrology, and soils, as the potential use of land is directly related to the characteristics of the geological substratum.

2.4.4 - Geomorphology and hydrology

Two important concepts have been used to characterize geomorphologic situations in the Amazon: morphostructural unities and morphoclimatic domains (Melo et al. 1978). Morphostructural unities are areas where the geologic conditions created erosive environments under clear control, however without corresponding exactly to the specific sense of geologic provinces (Ab'Sáber 1970). Morphoclimatic domains define areas where the geologic influence were practically nullified by erosion systems affected by the soils' evolution and vegetation, under the control of climatic conditions (Ab'Sáber 1971).

The delimitation of morphostructural unities cited below was based on the homogeneity of relief forms and their relative topographic locations (Melo et al. 1978). Machadinho and Anari are located in three main unities (Figure 8):

- Southern Amazon Dissected Highland: formed by dissected relief in crests with pronounced slopes, functioning as the residual relief. It includes mainly the southern portion of Anari;
- Occidental Amazon Lowered Highland: this is the largest morphostructural unity in the Amazon Basin and ends exactly at the western limits of the study area. A flattened area with sectors of mild dissection forming tabular interfluves, where the most important rivers have encased valleys, characterizes it.
- Meridional Amazon Interplateau Depression: this unity includes the largest portions of both settlements. It is characterized by a lowered surface, with an incipient drainage, which induces the relief dissection in hills and tabular interfluves.

In terms of the morphoclimatic unities, the study area is very homogeneous, being totally included in Dissected Plateaus and Depressions and Pediplaned Surfaces (Figure 9). The area shows varied relief, including dissected forms in hills, crests, and tabular interfluves, covered by Dense and Open Forest, which minimizes the erosive processes induced by climatic factors.

Three main basins are defined for the State of Rondônia: Guaporé, Mamoré, and Madeira. The latter includes the Ji-Paraná or Machado River sub-basin, which is the longest river in the State and drains both Machadinho and Anari settlements, flowing from south to north (Rondônia 1998f). The Machadinho and Anari rivers are both tributaries of the Ji-Paraná or Machado River. They drain an undulated terrain, which varies in elevation from 100 to 450 meters. Within the boundaries of the study area, the Machadinho River flows from the southwest to the northeast. Its main tributary, the Belém River, crosses the northern portion of the settlement. The Anari River flows in the west-east direction, crossing the Anari settlement in its southern portion. The boundary between the settlements coincides with Machadinho and Anari watershed boundaries. Both watersheds have a dendritic drainage pattern with incised valleys. Figure 10 shows the waterways and elevation ranges within the study area through a digital elevation model based on contour lines and the river network.

2.4.5 - Soils

Knowledge about soils should be one of the primary assessments before the establishment of a colonization project. However, detailed studies about this important biophysical variable have been rare before the arrival of colonists in the Amazon (Fearnside 1989). In Machadinho and Anari this pattern persisted. Only regional or exploratory descriptions of soils were available in the early 1980s not allowing the distinction of fertile or infertile soils at the scale of a settlement or property lot (Falesi

1974, Amaral Filho et al. 1978, Cochrane and Sánchez 1982, Sombroek 1984). Even the ecological zoning of the State produced results only at a very coarse scale (1:250,000) (Rondônia 1998g). The most detailed studies about soils at the local scale in the study area are Wittern and Conceição (1982) and, more recently, Bognola and Soares (1999). Their descriptions allow a general characterization about edaphic conditions in Machadinho and Anari. During fieldwork in 1999 and 2000, the characteristics for soil texture and color were confirmed. The paragraphs below summarize the characteristics of seven main soil types present in the area.

- YELLOW LATOSOL (Camargo et al. 1987); YELLOW LATOSOL Cohesive (EMBRAPA 1999); OXISOL (USA 1975)

It is a mineral soil, not hydromorphic, with a latosolic B-horizon, dystrophic, very deep (>200 cm), cohesive, permeable, well drained and very homogeneous, of very clayish texture, with low levels of total iron, Al_2O_3/Fe_2O_3 ratio higher than 7.0 and very acidic. The clay levels remain constant along the profile or increase slightly without, however, indicating a textural B-horizon. The transitions between horizons are diffuse, except from horizon A to B, due to the higher level of organic matter found in the former. Its color varies from brown-yellowish to yellow-brownish, yellow, and brown. The soils with latosolic B-horizon occur in places of mild topography, being therefore easily mechanizable. In their natural state, they are resistant to erosion due to the favorable physical conditions and topography. The main agricultural limitation is related to the low natural fertility, strong acidity, and high levels of exchangeable aluminum (saturation higher than 50%).

- RED-YELLOW LATOSOL (Camargo et al. 1987); RED-YELLOW LATOSOL Dystrophic (EMBRAPA 1999); OXISOL (USA 1975)

It is a mineral soil, with sequence of horizons A, Bw, and C, moderate A-horizon and unclear differentiation between horizons, because of the tenuous contrast and ample transitions between them. It is a clayish soil with very low base saturation, saturation for exchangeable aluminum higher than 50%, low cation exchange capacity in the clay fraction, very acidic, well drained, very porous, very permeable, levels of total iron usually between 7 and 15% and molecular relation Al_2O_3/Fe_2O_3 between 3 and 7. The Red-Yellow Latosol Dystrophic is also characterized by its high depth, low clay mobility, which denotes a small textural gradient, low silt/clay ratio, high flocculation degree, low percentage of dispersed clay in water and absence of primary minerals of easy decomposition. The Bw horizon is thick and generally presents colors varying from 4YR to 7,5YR, with values 4 or 5 and chromes 6 or 8. The structure presents porous and firm aspect, breaking in subangular and/or granular blocks. This soil type occurs normally in flat and undulated relief. As with the Yellow Latosol, its main agricultural limitation is related to the low natural fertility, strong acidity, and high levels of exchangeable aluminum in Machadinho and Anari. Both of these soils are used for pasture, annual, and perennial agriculture (coffee).

- DARK RED LATOSOL (Camargo et al. 1987); DARK RED LATOSOL Dystrophic (EMBRAPA 1999); OXISOL (USA 1975)

It is a mineral soil, not hydromorphic, with a latosolic B-horizon, dystrophic, very deep (>200 cm), cohesive, permeable, well drained, very homogeneous, and of very clayish texture. It is very similar to the Red-Yellow Latosol described above, differing mainly in the levels of Fe_2O_3, which produces a lower Al_2O_3/Fe_2O_3 ratio, generally between 1.7 and 2.5. It is a soil with low base saturation and low cation exchange capacity in the clay fraction. The sequence of horizons A, Bw, and C shows poor differentiation. It is also characterized by its low clay mobility, which denotes a small textural gradient, high flocculation degree, and absence of primary minerals of easy decomposition. The morphological characteristics do not vary significantly between horizons, having red-yellow or dark red colors, 5YR and 2.5YR. This Dark Red Latosol occurs normally in flat and undulated relief, associated to the red-yellow latosol and showing similar agricultural limitation and land use.

- RED-YELLOW PODZOLIC (Camargo et al. 1987); YELLOW ARGISOL Dystrophic (EMBRAPA 1999); ULTISOL (USA 1975)

This soil presents profiles with a sequence of horizons A, Bt, and C. It is deep or medium deep, not hydromorphic, clay of low activity, with moderate A-horizon and textural B-horizon, corresponding to the argillic horizon of the American Soil Taxonomy (USA 1975). The yellow shade has a stronger yellow than 5YR in the first 100 cm of the B-horizon (including BA). The A-horizon, with variable thickness of 10 to 30 cm, presents shades that generally vary from 7,5YR to 10YR. The texture varies from sandy to clay-sandy. The transition to the Bt horizon is generally flat and clear and, eventually, flat and gradual. The Bt horizon presents colors with shade varying from 6YR to 10YR, clayish texture, and the structure is weak to moderate. This soil type occurs in relief varying from mild to strongly undulated and is generally used for pasture in Machadinho and Anari. Its main agricultural limitation is related to the undulated topography, low natural fertility, and high acidity.

- DARK-RED PODZOLIC (Camargo et al. 1987); RED NITOSOL Eutrophic (EMBRAPA 1999); ULTISOL (USA 1975)

It is a mineral soil, with shade 2,5YR or redder and with high base saturation (V > 50%) in the first 100 cm of the B-horizon (including BA). It is generally deep, rarely shallow, with moderate A-horizon and brilliant B-horizon, low clay activity and eutrophic. The soil is well drained and occasionally fairly drained and frequently associated with rock outcrops and, sometimes, with rockiness. The moderate A-horizon is between 10 and 30 cm thick, with shade varying from 2,5YR to 5YR, variable clayish texture and transition to B-horizon, normally flat and clear. The brilliant B-horizon, of variable thickness, presents red colors (2,5YR or redder), with predominantly moderate structure, and angular and subangular blocks. This soil type occurs generally in undulated areas. Land use is mainly coffee plantation and pasture in the study area. The most serious limitations of this soil are consequences of topography and the occurrence of rock outcrops and rockiness. Variations to alfisols also occur within these areas.

- *TERRA ROXA ESTRUTURADA* (Camargo et al. 1987); RED NITOSOL Eutroferric (EMBRAPA 1999); ALFISOLS (USA 1975)

It is a mineral soil, not hydromorphic, well drained, deep, with presence of a brilliant B-horizon, clay of low activity immediately below the A-horizon or within the first 50 cm of the B-horizon. Its color is 2,5YR or redder in the first 100 cm of the B-horizon (excluding BA). It originates, in the study area, from the alteration of basic rocks (diabase). Alfisols present clayish texture and are practically free of rockiness. The main variations consist of intermediate profiles looking like the Dark Red Podzolic soil, the difference being detected by higher levels of Fe_2O_3 (from 15% to 36%). Despite its high fertility, the limitation of this soil for agricultural purposes is related to its low levels of Phosphorus. The susceptibility to erosion is moderate. The erosion is facilitated mainly in areas of undulated or steep topography. The thinner the superficial horizon and bigger the difference of clay content between horizons A and B, the greater the susceptibility to erosion will be. The infiltration and water clamping capacity is good. The limitation for mechanization varies, depending on the relief and rockiness.

- PLINTOSOL (Camargo et al. 1987); PLINTOSOL ARGILLIC Dystrophic (EMBRAPA 1999); ALLUVIAL SOIL (USA 1975)

It is a mineral soil, with plintic or litoplintic horizon starting at 40 cm, or at 200 cm when immediately below the A or E horizon. It also may underly horizons with a pale color. The shades of this soil type vary considerably and are described in EMBRAPA (1999). The textural B-horizon is present. The alluvial soil has distinct granulometric composition, having low activity clays, slow or moderate permeability and being imperfectly drained. The morphologic features of the underlying layers to the A-horizon may vary a great deal, mainly in function of the water level height and the clay content. The A-horizon, well differentiated, presents variable thickness between 10 and 30 cm. Normally it is sandy, with low to moderate granular structure and with colors varying from 2,5Y to 5Y. The alluvial soil is located in flat areas, occurring also in small depressions, under undulated topography.

2.4.6 - Vegetation

The use of a classification system to address the biocomplexity of the Amazonian vegetation is not an easy task. Depending on the scale of analysis, one or another system may be satisfactory. Some publications have addressed the subject looking for regional differentiations by focusing on the entire Amazon Basin (Pires 1984, Pires and Prance 1985) or a specific State (Rondônia 1998h). According to these classifications, the State of Rondônia encompasses several vegetation formations, although the Tropical Open Forest type predominates (Table 2).

Forest formations occurring in Rondônia belong to the so-called tropical rain forests (Richards 1996). Tropical rain forests are the latest in a long line of forest biomes to be heavily altered by mankind. Closed forests of the wetter tropical climates are collectively described as tropical moist forests. Tropical rain forests occur where there is only a short dry season or none (Whitmore 1998). Their main characteristics include:

- Distribution: Neotropics (Central America, northwest South America, Amazon Basin, eastern Brazil near the Atlantic coast), Africa (Central-West) and Southeast Asia (Indo-Malayan region);
- Wettest of all vegetation zones; a month with less than 100 mm of rain is considered relatively dry;
- Temperature and light intensities are always high; rainfall is usually greater than 2,000 mm a year;

- Soils are generally infertile, weathered and poor in nutrients;
- The largest amount of nutrients in the ecosystem is contained in the phytomass;
- Litter decays quickly through mineralization and absorption by roots and mycorrhizae;
- Diversity is very high;
- The largest trees emerge above others; middle and lower layers form a dense canopy;
- Canopy leaves adapt to resist transpiration losses through the thick cuticle;
- The roots are shallow; giant trees are stabilized by large buttresses;
- Lianas exploit trees for support; epiphytes use trees for substrate;
- Distinct forest formations differ in structure and physiognomy;
- Forests consist of a mosaic of gap-phase, building-phase, and mature-phase formations;
- Two contrasting ecological species groups: climax species can germinate and establish seedlings below a canopy (below gaps), whereas pioneer species require full light (big gaps).

Machadinho and Anari are areas of relatively high homogeneity in relation to their original vegetation. Their forest formations follow the characteristics above. However, for the purpose of this description, it is more appropriate to focus on the uniqueness of each local vegetation formation. Four main types of tropical rain forests are found in the area, all of them belonging to the severe subtermaxeric bioclimatic sub-region (Barros-Silva et al. 1978, Rondônia 1998h):

- SUB-MONTANE DENSE TROPICAL FOREST, Sub-Region of the Low Mountain Chains of Southern Amazônia, Low Mountain Chains

The dense forest covers the evidences of basements formed by granites, gneisses, migmatites, and quartzites of several geological formations and of the crystalline basement (Rondônia 1998h). In sub-mountainous areas lower than 600 m it presents, according to soil depth, uniform cover or emergent trees. Its canopy is continuous and closed. Trees dominate the canopy, but they can also occur associated with palms in open valleys and lianas in hillsides and closed valleys (Barros-Silva et al. 1978). It has small spatial distribution in the study area, generally associated with more dynamic topography, such as the northeastern and southeastern portions of Machadinho and the north-central portion of Anari.

- ALLUVIAL OPEN TROPICAL FOREST, Alluvial Sub-Region of Amazônia, Terraces

This type of forest grows over shallow and poorly drained hydromorphic soils, in flat terrain up to 100 m high and in floodplains. The alluvial open forest has medium height, up to 30 m, and less than 5% of deciduous species. The canopy may be uniform with occasional emergent species. The understory is usually dense, with dominance of bushes and herbs. The density may be higher than 600 trees per hectare. In dystrophic soils, the density is higher but the average height of the trees decreases (Rondônia 1998h). The dominant physiognomy is the open forest with palms, such as the forest covering terraces of the Machadinho River. In such sites, trees are often covered by herbaceous lianas, giving the false impression of a liana forest (Barros-Silva et al. 1978).

- SUB-MONTANE OPEN TROPICAL FOREST, Sub-Region of Dissected Surfaces of High Xingu/Tapajós/Madeira, Dissected and Undulated Relief

These two forest types differ only in relation to their substratum (dissected or undulated relief). They are the most representative vegetation formation in both Machadinho and Anari, covering more than 80% of the entire study area before the colonization process took place. The dominant landscape is the open tropical forest with palms covering distinct topographic situations over the crystalline basement (Rondônia 1998h). The dominant soil is the red-yellow podzolic (ultisol), where forests of emergent trees, uniform canopy, bamboo, and lianas also occur. The understory in the forests with palms varies from open to medium, and, from medium to dense in the forests with lianas and forest with bamboos (Barros-Silva et al. 1978). In Machadinho, the sub-montane open tropical forest over undulated relief dominates almost the entire settlement, except at the sources of the Ananas River and in areas to the east of the Machadinho River, where the relief is dissected. In Anari, the sub-montane open forest over dissected relief is more spatially representative, dominating the western and southern portions of the settlement.

2.4.7 - Fauna

Landscape fragmentation and its consequences on Amazonian animal habitats have been discussed in several works (Prance and Lovejoy 1985, Dale et al. *Relating* 1994, Laurance et al. 1997). However, there are no data available on fauna resources for the study area. Because of the importance of this biological component on Rondonian landscapes, some comments may be appropriate.

The most recent faunal study covering the entire State is the diagnostic prepared for the second approximation of the socioeconomic-ecological zoning of Rondônia (Rondônia 1998c). Field data was collected for the occurrence of several groups, such as bees, disease vectors, agricultural pests, ictiofauna, herpetofauna, avifauna, and mastofauna. Trying to delimit zoogeographic zones for the State, the authors used the latter three groups as indicators of relatively homogeneous habitats. According to their classification, both Machadinho and Anari belong to a zoogeographic zone of high biodiversity, including endemic, endangered, and threatened species.

The settlements studied differ in terms of conservation management. Machadinho includes sixteen Extractive Reserves in distinct ecological sectors encompassing 33% of its territory. Anari design did not incorporate reserves. In this case, preservation depends solely on a federal rule, stating that 50% of each property lot should be maintained with its forest cover. Ecological consequences of these different strategies are addressed in the next chapters, through the study of LULC dynamics and landscape change.

2.5 - People, time, and labor: the annual cycle of rural production systems in Machadinho and Anari

The major actors transforming landscape in Machadinho and Anari are settlers, loggers, and rubber tappers. A critical discussion of their role in affecting LULC change is discussed in Chapter 6. This section describes how they allocate their time through the year, adjusting their activities to seasonality. Information to build this scenario was obtained from archival work and interviews with landowners, loggers, and rubber tappers during fieldwork. Several organizations related to these activities were also visited in

1999 and 2000: farmers' associations, logging companies, the local rubber tappers' association, extension and agricultural research agencies, the agrarian reform agency, governamental offices (e.g., county agricultural sections and banks), and non-governmental organizations. A general overview of farming and extraction activities is summarized in Table 3. The table shows only the most important products and activities.

- SETTLERS

Previous works have described how farming systems have been differentiated in the study area (Miranda and Mattos 1993, Miranda et al. 1997). The trajectory seems to go from an early stage of colonization with all kinds of initial experiences to a more homogeneous situation after a decrease in the variety of farming systems. The pattern indicates agricultural intensification, which is discussed in following chapters. Farming systems are mainly household-based, and little depends on group efforts. Twenty local associations were created within the settlement but most of them are inactive or have little influence on farming decision-making. The only cooperative is an active smallholder organization and currently has 200 members.

After fifteen years of colonization, five main farming systems can be distinguished (Miranda et al. 1997a):

- Perennial agriculture: most farms have just coffee plantations but other land uses include: guarana, coffee/cacao, coffee/guarana, cacao/*Bixa* (*urucum*), coffee/cacao/guarana;
- Cattle ranching: production system in farms where land clearing often means conversion to pasture;

- Perennial agriculture (mainly coffee) and small cattle ranching: combined system including the two most common activities in the rural area;
- Perennial agriculture, annual agriculture, and cattle ranching: this production system mixes different activities in farming management;
- Agrosylvopastoralism: very diversified system including all activities mentioned above plus agroforestry.

The existence of these farming systems was confirmed during fieldwork through interviews with landowners and visits to their properties. The occurrence of cultivation systems within the farming systems is summarized in Table 4.

- RUBBER TAPPERS

Communal forest reserves in Machadinho are State Reserves decreed by the government in 1994 and 1995, legalizing the situation of many families of rubber tappers (Olmos et al. 1999). In 1996 and 1997, governmental and non-governmental organizations established management plans for the reserves (Rondônia 1997). The plans were approved by the local rubber tappers association. Institutional arrangements concerning the reserves and their role in land cover are discussed in Chapter 6. This section mentions just the main activities of families living in those areas.

Rubber extraction from native trees is the main source of income of rubber tappers in the study area. In general, each household explores three to six trails containing 100 to 300 trees each. The production of rubber varies from 150 to 300 kg per month per family (Rondônia 1996c). The extraction is made in the early morning and sometimes in the afternoon throughout the year, with exception to the driest months (mainly August) (see Table 3). Other extractive activities, such as copaíba (*Copaifera sp*) oil harvesting and seed collection, are less important in the communities. The communities also plant manioc (their main staple food), subsistence annual crops (corn, rice, and beans), and small coffee plantations.

- LOGGERS

Logging activities were always associated with the opening of new colonization frontiers in the Amazon (Schminck and Wood 1992). Loggers play a major role in providing access to remote areas within the settlement as they open trails through the forest to reach valuable species. Doing so, they also disturb extensive forest patches and increase their flammability (Nepstad et al. *Flames* 1999).

Unfortunately, logging activities in Machadinho and Anari still follow the predatory scheme. Stimulated by market demands, loggers take the larger and most valuable trees without worrying about maintaining the vegetation structure. In general, the leftover vegetation is a forest remnant degraded in structure and species composition (Rondônia 1996a). Only recently, management plans began to be implemented, both in private properties and in communal lands. In all cases, logging is also dependent on access and seasonality because trafficable roads are necessary for taking the wood to sawmills. In the study area, this is usually possible only from May to September, but also in April and October in dryer years (Table 3).

The next chapters discuss in detail how the landscape has been transformed through the introduction of rural production systems in Machadinho and Anari following settlements' implementation. The actions and interactions of settlers, rubber tappers, and loggers are particularly important in generating such outcomes.