PROTECTING AN URBAN FOREST RESERVE IN THE AMAZON: A MULTI-SCALE ANALYSIS OF EDGE EFFECTS, POPULATION PRESSURE AND INSTITUTIONS

Maria Clara Silva-Forsberg

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Accepted by the Graduate Faculty, Indiana University, in partial fulfilment of the requirements for the degree of the Doctor in Philosophy.

Emilio Moran, Ph.D.(Chair)

Elinor Ostrom, Ph.D. (Co-chair)

Doctoral
Committee

J. C. Randolph, Ph.D.

Eduardo Brondizio, Ph.D.

June 16, 1999

To Elisa S. Perfeito

More than a daughter, Elisa has been my best companion, my "twin lake." Since she was 5 years old, Elisa has followed me and accomplished with me "the Amazon endeavor " with the same excitement and good sense of humor of her father, doing what he dreamed but could not do. Nowadays we have a very similar heart with three sharp directions: one touching Florianopolis (South of Brazil), another Manaus (Amazon) and the other one touching Bloomington where we had our house since 1994.

***In Memoriam* of Gustavo Perfeito Neto**

Gustavo and I had a plan to implement after finishing our college degrees. We planned to move to the Amazon where as a biologist, I would study and help to "save" the rainforest, and he, as a physician, would help to eliminate the tropical diseases which were killing hundreds of people in the beginning of the 1980s. Unfortunately, he left us during the fall of 1983, before he could even graduate. However, he gave me Elisa, who has been my "guiding star," the best gift I ever had.

***In memoriam* of Basilêo José Da Silva**

He taught me the importance of being respectful and maintaining certain traditions without being conservative. I learned many, many lessons with my Dad, but one in particular helped me to accomplish my doctoral degree. He advised me to never give up my dreams or betray my intuition and soul, no matter how difficult the situation might be. My thoughts were with him many times during the last two years when even my chairs encouraged me to undertake a less ambitious project. I am really happy and satisfied to have followed his advice.

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Abstract

This dissertation addresses human and environmental problems that arise in restricted-use forest reserves. It aims to explain degradation and restoration in these forest reserves, and examines the role of edge effects, population pressure and institutions in an urban forest reserve in Manaus, state of Amazonas, Brazil. Given the multi-level complexity of problems associated with conserving forest reserves, a multi-scale analysis was undertaken. This study employed an interdisciplinary approach to examine the preservation of the Campus Forest over a 30 years period. This research integrates social, biophysical and institutional data to examine the causes of forest structural changes. The data collected includes: a) forest mensuration data, b) remotely sensed land cover data, c) household surveys, and d) in-depth qualitative interviews concerning institutional variables. Using the framework employed in this dissertation, I examine the direct and indirect causes of degradation in the Campus Forest reserve. This study shows that the current ecological characteristics of the Campus Forest are shaped by both local and regional level processes. Biophysical and institutional edge effects may affect the conservation performance of a forest reserve, but these factors do not explain ecological decline by themselves. Other key variables such as history of land use inside and outside of the reserve, government incentives motivating migration, conflicts between squatters and reserve managers, and the creation and evolution of the reserve's institutional arrangements are also needed to explain the Campus Forest's degree of preservation.

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Chapter 1

INTRODUCTION

Debate over the causes of environmental degradation has been on the policy agenda of many countries, particularly during the past fifty years. The debate started at the local level and became an international issue after the 1960s, during the so-called "Road to Stockholm."[1] General explanations of environmental degradation have traditionally been based on the assumption that the contemporary way of life is incompatible with nature conservation and the maintenance of the ecological support system. This incompatibility between human activities and nature conservation[2] has historically been assumed by natural scientists such as biologists and foresters, professionals who worldwide have created, managed and controlled conservation agencies and have played a crucial role in the definition and implementation of conservation policies. This vision has led to a conservation approach based on a dichotomy between humans and nature.

In the last two decades, this growing awareness of global environmental problems such as tropical deforestation, global warming and loss of biodiversity has motived the creation of national parks and other protected conservation units all over the world. While

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[1]Caldwell, 1990 "International Environmental Policy" provides a detailed description of this period.

[2]In a general sense, conservation means a careful preservation and protection of something. Related to environmental policies, conservation means the planned management of a natural resource to prevent exploitation and destruction (Agee & Johnson, 1988).

1263 protected areas[3] existed globally in 1969, 1315 new units were created in 1970 alone (Guimire, 1991). Today, most old growth forests are found in small patches around densely populated landscapes, or in national parks and biosphere reserves governed by national and international agencies. These reserves are designed to conserve the most representative and relatively intact ecosystems of the earth in order to protect endangered species, biodiversity and natural ecosystems. Most of the protected areas created during the 1970s and 1980s were reserves with various restricted human uses. National parks, natural monuments, nature conservation reserves and protected landscapes have the followings goals: (1) to maintain sample ecosystems in their natural state, (2) to maintain ecological diversity and environmental regulation, (3) to conserve genetic resources, and (4) to provide education, research and environmental monitoring. Thus, it is expected that forest ecosystems managed for these goals would be preserved as intact entities except for some changes caused by natural factors such as wind, lightning, storms or fires.

According to the conservation literature, protected areas have, however, experienced severe negative impacts on their natural attributes. Most of the deterioration has been attributed to human disturbances. Scholars dealing with conservation issues have used different approaches to understanding degradation in protected areas. Ecologists have focused on biophysical aspects of the reserves such as habitat fragmentation and edge effects (e.g., Laurance, 1991, 1997) to explain the reserves' ecosystem impoverishment. Others, drawing on neo-Malthusian approaches, explain degradation through population

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[3]Brechin, West, Harmon and Kutay (1991) define a protected area as "any finite area of land or water that comes under a systematic managerial regime which itself includes some set of basic objectives to be accomplished."

pressure and inequality (Green & Sussman, 1990; Vandermeen & Perfecto, 1995; Shaffer, 1995; Godway, 1997). Institutional failure and conflicts between indigenous people and conservation agencies (Raval, 1991, Guimire, 1991, Colchester, 1994; Silva-Forsberg, 1996) have also been cited by many social scientists. However, these three approaches explain just part of the problem.

Because most of the restricted-use reserves are found around agricultural and semi-urban landscapes where human populations play an increasing role, it is necessary to look not only at the direct biophysical and social context that could affect a reserve preservation, but also at its underlying causes. Thus, to really understand the problem of reserve conservation we should analyze and integrate local and regional causes of forest degradation with reliable ecological indicators of forest reserve attributes such as species richness and biomass.

In this dissertation, I examine the process of the installation, establishment and management of a forest reserve and the impact of this process on the preservation of the forest. Historical, social, economic and biophysical contexts are evaluated. A longitudinal framework is used to analyze causes of degradation in this reserve and how those factors influence the current conditions of the forest.

Campus Forest, at Manaus in the state of Amazonas, Brazil, was selected to be studied because it is a critical case that represents a conservation area as part of the rapid urbanization process that dominates many Latin America areas. Campus Forest also represents a dynamic case where the existing population, new settlers, research and educational goals are active within a well-defined ecological and institutional landscape.

This study helps to understand the dynamics of forest use in urban settings and also contributes to environmental education. In addition, it requires both the integration of methods across scales (remote sensing, archives, interviews, site inventories) and integration of theoretical approaches from several disciplines, including ecology, anthropology and demography and political science. Finally, it allows the testing and comparison of different conservation paradigms such as biophysical and institutional edge effects, land use and land cover changes, and restoration.

1.1. Conservation policy and the National Conservation Unit System (SNUC) in Brazil

After a long process of discussion and negotiation among the different interested parties, a law to create and regularize a National Conservation Unit System (SNUC) for Brazil was approved by the Brazilian Congress on June 10, 1999, and it is currently under review in the Senate. The approval of this law is an important step toward creating a clearer conservation policy and protecting Brazilian biodiversity and parts of the most important ecosystems distributed in Brazilian land. The main goal of SNUC is "to establish criteria and norms to create, implement and manage the Brazilian conservation units" at the national, state and municipal levels.

The National System of Conservation Units is currently composed of 298 restricted-use reserves -- 22 ecological stations (EEs), 24 biological reserves (REBIOs), 5 ecological reserves (ECOREs), 39 national parks (PARNAs), 208 private reserves of national patrimony (RPPNs); and 77 multi-use reserves-- 46 national forests (FLONAs), 22 area of environmental protection (APAs) and 9 extractivist reserves, under the national government (IBAMA, 1999). Each state and county should have its own conservation system, but with some exceptions such as São Paulo, Minas Gerais, Paraná, Rio Grande do Sul and Espírito Santo, the Brazilian states do not have representative areas under protection (Jorge Padua, 1993).

Campus Forest, the area selected for this study, was never formally part of the national conservation units program, or any state or municipal program, and it is still not part of SNUC. Campus Forest is managed as an informal conservation unit in order to maintain its governance under the University of Amazonas. Its autonomy and independence from national conservation control and bureaucracy makes it different from the majority of Brazil's protected areas. Unlike most parks and biological reserve in the Amazon, Campus Forest is not an officially constituted reserve. But, it gives an example how local initiative can contribute to the conservation of important samples of the Amazon ecosystem without official state control. However, as discussed in the following sections, it has faced many of the same problems common to the majority of the Brazilian conservation units, except for the RPPNs[4] created legally since 1996.

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[4] Reservas Particulares do Patrimônio Natural is a new modality of restricted-use reserve created by Decree # 1.922 on June 5, 1996. This modality is a novelty in Brazilian conservation philosophy and policy because for the first time a restricted-use reserve can be created, managed and governed by private or civil initiative.

1.1.1. Restricted-use reserves in Brazil: national parks and biological reserves

Brazil's national conservation program officially began in 1937 with the creation of Itatiaia National Park (Brazil, IBDF, 1980). Inspired by the creation of Yellowstone Park in the US in 1876, the first national park in the world (Jorge Padua, 1985), Andre Rebolsas suggested that Brazil adopt a similar model and specified the Bananal Island and the Sete Quedas areas as potential park sites (Jorge Padua, 1985). However, 80 years were to pass before Rebolsas' suggestions were fully implemented with the creation of the Araguaia National Park (including Bananal Island) in 1959, and the Sete Quedas National Park in 1961 (Brazil, IBDF, 1980).

During the 60s, the creation of national parks and other biological and ecological reserves in Brazil were justified primarily by scenic beauty. By 1974, 17 of these "scenic" national parks had been created. In the early 70s the former Brazilian Forest Development Institute (IBDF) began to criticize the scenic beauty criterion for being "too vague and weak to guarantee the preservation of Brazil's critical ecosystems" (Jorge Padua, 1985). After this, IBDF began to elaborate a plan for the creation and management of conservation units based on technical and scientific criteria. The Brazilian Plan for Conservation Units was based largely on the paper "An Analysis of Nature Conservation Priorities in the Amazon" by Wetterberg et al.(1976). Following the plan's recommendations, the Brazilian Government established as a goal to preserve a minimum of 18.5 million hectares in the Amazon region for national parks and biological reserves, and another 5 million hectares in the rest of the country (Jorge Padua, 1982).

During the period from 1979-1982, 9 new national parks and biological[5] reserves were created by law, preserving a total area of 8 millions ha. By 1985, the Amazon possessed 9 million ha of federally protected area (Jorge Padua, 1985), including both the newly preserved areas and the 1 million ha Amazon National Park created in 1974 (Brazil, IBDF, 1980).

One of the key criteria used to define the locations of protected areas in the Amazon, based on recommendations of the RADAM BRASIL Project for Conservation Units, was the existence of Pleistocene Refuges within park limits. Pleistocene Refuges are areas where plants and animals are believed to have been isolated for considerable periods of time during cold, dry eras when the Amazon was not completely forested. Later these refuges are believed to have been centers of dispersion critical for the repopulation of other parts of the region. It was believed that large numbers of endemic species would be found where these presumed refuges overlapped or joined, a prediction that was supported by data on the geographic distributions of birds (Halfer, 1969, 1974), lizards (Vanzolini, 1970, Vanzolini & Williams (1970), plants (Prance, 1973), and butterflies (Brown, 1975, Wing, 1973) and by other types of data evaluated in the POLAMAZONIA Project and the RADAM BRASIL Project for Conservation Units (Jorge Padua, 1982, 1985). The inclusion of these highly endemic areas within conservation units was viewed as a safeguard for protecting much of the existing

[5]Biological reserves are the most restricted-use conservation units in Brazil (Law 6902/81). They are defined as "representative areas of the Brazilian ecosystems where only activities related to ecological research, environmental protection and conservation education are permitted." Ecological stations share with biological reserves the restricted-use status, but ecological stations are mostly created to protect animal populations.

biodiversity in the region as well as the mechanisms which maintain it. Based on this criterion, 34 potential conservation units were evaluated and 13 were considered priorities for inclusion in the park and reserve program.

The Brazilian government considered its conservation policy to be a great success, based on the many national parks and biological reserves created in the 1970s and 1980s. However, as in most South American countries, these protected areas existed only on paper. The funds needed to manage and monitor these newly formed conservation units areas were generally woefully inadequate (Jorge Padua, 1993). Additionally, in around 40% of these areas, mostly national parks, traditional human populations have lived for generations (Copabianco, 1994), but these people were disregarded by the state conservation agencies.

Thus, the creation of many restricted-use reserves, mostly national parks, negatively impacted traditional populations. These social impacts stimulated a strong debate inside the Brazilian conservation community, which became divided into two groups: on one side, those who argue for the maintenance of resident populations in national parks (the socio-environmentalists), and on the other side, those who argued for the maintenance of the current model of national parks, which restricts the residence of human populations (the preservationists). This debate, which lasted for a decade, helped to create a more sound conservation policy for Brazil, as we can see in the SNUC law, concerning the participation of local communities and civil organizations in the creation and management of conservation units, even though the traditional national park model was maintained. However, this debate also delayed the law approval process for more than a decade. Lack of empirical information about the conservation performance of restricted-use reserves and measurement of the direct and indirect cause of their degradation complicates decisions regarding whether or not traditional populations should be maintained in restricted-used areas. Campus Forest experienced this process in the beginning of its installation. Thus, the lessons acquired in this case can contribute to this discussion.

1.2. Forest degradation in protected areas: three main approaches

Many types of researchers are interested in forest degradation in protected areas. A great number of them are involved with three main approaches: fragmentation and edge effects, population pressure and inequality, and institutional failure and conflicts between villagers and reserve managers. In this section, a short literature review is presented for each approach.

1.2.1. Fragmentation and edge effects

Biologists concerned with forest ecosystems have been debating whether it is possible to preserve the world's biodiversity in forest patches surrounded by tree plantation or by agricultural, industrial, and urban development. Based on this discussion, the notion of an ideal restricted reserve size to protect biodiversity has been growing throughout this century. Conservation biologists point to the need for large[6]

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[6]In attempting to determine the minimum area required for preserving viable populations, several authors have shown that animal species' richness increases with the size of areas (see Harris, 1984:177; MacArhur & Wilson 1967s: chapter 2). Studying 14 national parks in the Western United States, Bekele (1980) found a significant positive correlation between the number of resident large mammal species and

reserves to preserve all native species characteristic of an area (Shafer, 1995). The debate about the minimal size of reserves has been one of the "hottest" in the conservation realm, focusing on discussion about "Single Large or Several Small" (SLOSS) reserves debate (Lovejoy, 1997). However, most discussion has focused on the requirements of single species[7], especially large vertebrates. As several studies have shown (Shafer, 1995; Brown & Hutching, 1997) a better answer for this question is SLASS -- Several Large and also Several Small reserves, where it is still possible.

Restricted-use reserves vary from several hundreds to millions of hectares in area[8]. As the landscape grows ever more fragmented, most of these reserves have become isolated forest units, or "islands" in the middle of an "ocean" of agriculture and urban areas. Habitat fragmentation has been taken for granted as a process responsible for ecosystem decay (Bierrgaard & Lovejoy, 1989). It is generally accepted that isolated

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the size of the area. Large carnivores and insectivores require a large home-range (Harris, 1984). Vertebrates --mammals and birds--are often treated as indicator species or "umbrella species" in strategies to design and manage minimal size reserves. This is based on the assumption that the preservation of indicator species will also provide protection for smaller or less dependent species (Salwasser, 1988).

[7]Harris and Gallagher (1989) concluded that a 100- or 500-ha reserve would not be large enough to preserve "a minimum viable population" of the Florida panther (*Felix concolor*), which is estimated to require an area more than twice the size of the state of Florida. Similarly, the lemuroid ringtail possum (*Hemibelideus lemuroides*), an arboreal marsupial of the rain forest of northern Queensland, Australia, avoids secondary forests entirely and is predicted to disappear from forest fragments of less than 600 ha in only a few decades (Laurance, 1991, 1997). However, it is likely that these areas would be adequate to help in preserving various types of vegetation (see also Shafer, 1995) such as the endemic vegetation on white-sand *campinarana* which are distributed in the Central Amazon and the upper Rio Negro in the form of "islands" dispersed throughout the rain forest.

[8]Around the study area we can find a great variation in the size of restricted-use reserves. The Campus Forest is around 600 ha while the Reserva Ducke is around 10,000 ha and Jau National Park covers 2,272,000 hectares.

fragments become poorer[9] in their ecological attributes than the original forest. However, faster degradation rates are expected in smaller fragments that have proportionally more area covered by edge habitats.

The edge effect model has thus been offered to explain ecosystem degradation in forest fragments, by affecting the species' richness and other structural attributes of the ecosystem. Changes in species richness are associated with the tolerance of species to habitat and micro-climatic changes occurring within fragments or along the ecosystem's margins. It is predicted that small fragments should lose many species because they have the highest perimeter-area ratios and the most habitat edges, while large fragments should gain many species because their main areas are large enough to support original species plus the tolerant species which would colonize the perimeter edge habitats (Wilcove, McClennan, & Dobson, 1986; Margules, 1992; Saunders, Hobbs, & Margules, 1991; Laurance, 1991, Malcon, 1994).

Even though strong changes in the physical and biotic factors at the forest edge have been reported for several areas (Kapos, 1989, Kapos et al., 1997; Willians-Limeira, 1990; Laurance, 1991,1997; Malcon, 1994), species and groups respond differently to edge effects. For example, while understory insectivorous birds decline sharply in forest fragments (Bierrgaard & Lovejoy, 1989, Bierrgaard & Stouffer, 1997), terrestrial small

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[9]Part of this assumption comes from the equilibrium and nonequilibrium models of island biogeography (MacArthur & Wilson, 1967; Crowel, 1986), which have been used as predictors in fragmentation studies. These models predict that overall species richness will decrease in habitats of reduced area, due to an increase in extinction rate, and that species numbers should stabilize after fragmentation when the rate of extinction and colonization reaches a point of equilibrium. At the equilibrium point, these models predict that species composition should change over time, or exhibit turnover.

mammals (Malcon, 1997), butterflies (Brown & Hutching, 1997), frogs (Tocher, Gascon, & Zimmerman, 1997), and terrestrial invertebrates (Didham, 1997) tend to increase in abundance.

In the case of vascular plants, it has been difficult to show the influence of edge effects on plant species richness (see Harrington, Irvine, Crone & Moore, 1997). Corlett and Turner (1997) estimated the extinction rates for vascular plants in Singapore and Hong Kong fragments -- areas with more than 150 and 350 years of isolation respectively. They concluded that vascular flora declines much more slowly than vertebrate fauna, and a substantial fraction of original plants' matrixes can survive even after several centuries in unprotected forest and highly disturbed fragments (1997:345). However, other structural attributes of vascular flora communities, such as biomass, might be affected sooner by edge effects than species richness.

Studies have shown that forest fragment edges are more exposed to differences in solar radiation, water, wind, and nutrient regime than continuous forest, thus tree falls and canopy openness increase close to the edges (Laurance, 1991, 1997; Kapos et al., 1997). In the Central Amazon, Laurance et al., (1997) showed that permanent study plots within 100 meters of newly fragmented edges lost more than 30% of their biomass in the first 10 to 17 years after isolation. They predict it is unlikely that forest edges will return to their original condition, because fragmented forest is prone to wind disturbance, which can often kill and damage many trees. Thus, in the presence of fragmentation processes, old-growth rain forests tend to be replaced by shorter, scrubby forests with smaller volume and biomass (1997:1118). Laurance (1997) also reports strong edge effects on forest structure[10] for two "hyper-disturbed parks" in Australia.

Thus, ecologists approach forest reserve degradation issues primarily by looking at the physical and biological aspects of the reserves. Forest fragment size, shape, degree of isolation, location, context, and habitat heterogeneity are the principal factors being analyzed and used to explain degradation and ecological decline in protected areas. Those factors are often used to evaluate animal and plant persistence, community composition and ecosystem processes in forest fragments. A considerable number of these scholars have agreed that species richness declines as fragment area decreases. The size of a habitat fragment influences the processes occurring therein due to the changes caused by habitat edges that experienced shifts in micro-climatic attributes. Adjacent habitat types, land management regimes, and intensity of human activities are also known and cited by ecologists to have an influence on fragments (Laurance & Gascon, 1997), but ecologists do not go further than the analysis of the permeability of forest fragments' boundaries. Hence, ecologists' work concerning forest reserve degradation in general does not consider the effect of anthropogenic factors in and around those areas.

1.2.2. Population pressure, inequality and human impact

In developing countries, population pressure, poverty, and inequality are the most cited causes of deforestation and forest degradation, even inside protected areas. Sussman

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10 An opposite trend was reported for other fragments in Guatemala and Australia (Williams Limeira, 1990; Turton & Freiburger, 1997) where canopy openness decreased near forest edges and increased even when forest edges became older.

and Green (1990), using Landsat images, showed active deforestation fronts cutting into several Madagascar natural reserves. They linked the level of forest degradation to population pressure and concluded that in regions with high population density, progressive deforestation occurred. Forest and wildlife reserves in Costa Rica have also been damaged by severe squatter pressure in several areas (Hartshorn et al., 1982; Kauck & Tosi, 1989). Land ownership concentration has pushed people to marginal areas. Combined with rising wood scarcity, this fact is expected to increase the pressure for access to Costa Rican protected forests (Butterfield, 1994).

The discussion of whether population growth causes environmental degradation has been discussed by the followers of the historical theoretical tradition associated with Malthus[11] (Ehrlich, 1968; Hardin, 1968, 1971; Ehrlich & Holdren, 1971, 1974; Eckholm, 1976; Meadows et al., 1972, 1992; see also reviews of Sherbinin, 1993; and Marquette, 1994) and Boserup[12] (Simon, 1981, 1990; Harrison, 1990), even though neither Malthus nor Boserup were concerned with environmental degradation *per se*.

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[11]Malthus was concerned with the relationship between population and food supply under conditions where technology and land resources remained constant. He stated that while population tends to grow geometrically, food production only grows arithmetically (Malthus, 1960, updated version). Thus, human numbers would surpass the capacity to produce food and "positive checks" such as famine, poverty, disease and war would impose downward pressure on the rate of population growth in the absence of fertility control (Sage, 1994).

[12]One hundred and fifty years after Malthus' original statements and the agricultural revolution which Malthus could not observe, Boserup (1965, 1976 and 1981) stated that population growth and the resulting increased population density might induce technological changes that would allow food production to keep pace with population growth. Thus, high population density induces technological innovation in which agricultural systems evolve into increasingly land-intensified systems. Like Malthus, Boserup was not primarily concerned with the environment but with food supply. The application of their models to the relationship between population and environment was done *a posteriori* by their followers, who still debate in favor or against population control to solve the world's environmental calamities.

The so-called neo-Malthusians cite population pressure and inequality as the "enemies" of forest conservation. Many scholars using neo-Malthusian theories have approached the degradation in reserves by considering population growth and socio-economic status to be the principal driving forces. The observed linkages between human activities and forest degradation, however, vary according to context and level of analysis. Several statistical analyses at the national level showed a significant relationship[13] between population growth and deforestation (Allan & Barbes, 1985; Rudel, 1989, Turner, 1998). At the regional level, however, factors such as type and size of forest, policies and government incentives[14] seem to be stronger determinants

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[13]However, in many cases this trend does not work. Studies exploring the processes which link population and deforestation found that the relationships between them are more complex and varied according to context. Ostrom et al. (1996) and Asher (1995) point out the importance of intervening institutional variables that mediate the relationship between population and forest degradation. In several Amazonian countries (e.g., Brazil and Ecuador), colonization has been promoted by national governments aimed at stimulating migration to rain forest areas, a fact which has shaped a different pattern of forest degradation than that of other Latin American countries. In non-Amazonian forest areas such as Costa Rica, Honduras and Mexico, the expansion of commercial agriculture and increasing land concentration in recent decades seem to be the primary factors responsible for deforestation, forest degradation and other forms of ecological destruction (Stonich, 1989; Hamilton, 1990; Dewalt & Stonich, 1992; Cruz et. al, 1992; Dewalt, 1993; Provencio & Carabias, 1993).

[14]An analysis of the institutional factors that affected patterns of deforestation in the South Ecuadorian Amazonwas undertaken by Rudel (1993). Based on a historical review, he proposed that the causes of deforestation could vary according to forest type and size, and settlement pattern. He identified three institutional patterns driving deforestation-- two associated with large continuous forest and one with small forest patches. In a large forest where commercial logging or ranching interests predominated, those activities were the most important determinants of deforestation, both directly and indirectly through peasant settlers who often take advantage of penetration roads. But where a coalition of actors (e.g., urban investors and small farmers) predominated and competed for credit and access, infrastructure opportunity and investments were the most important factors driving deforestation. However, when a forest is small and where settlements by small farmers predominate, immigration has been the most important determinant of deforestation, and inequality and population growth can best explain forest degradation. Rudel suggested that those patterns can represent different stages in forest development following a deforestation succession over time, from large continuous to smaller separated forests in which settler immigration becomes the main determinant of deforestation. This distinction is important since most forested areas in the tropics today are found in forest remnants and protected areas. Thus, understanding the process which drives forest degradation in smaller forests is particularly essential for conservation.

(Schmink, 1988; Wood & Shmink, 1993; Rudel, 1993; Wood & Skole, 1998; Turner, 1998). At the local level, household composition, ethnicity, age of settlements, quality of soils, residents' affluence and institutional arrangements are important factors in either driving forest degradation or in preventing it (Pichon et al. 1993; Rudel, 1993, Agrawal & Yadama, 1997; Varughese, 1998). Given that the size of national parks and other restricted use reserves varies from several hundred to millions of hectares, the local and regional levels of analysis should be considered when evaluating the status of preservation. The relationship between the demographic, economic and political factors and the ecological attributes of the reserves at the local and regional level need to be evaluated to understand the forest preservation dilemma.

1.2.3. Institutional failure and conflict between local people and conservation officers

Two factors related to the creation, establishment and management of restricted-use reserves have also been studied to understand the underlying causes of degradation in forested reserves: institutional failure and conflict between people and park managers. Failure of institutions in implementing environmental protection programs in terms of technical, administrative, and financial constraints is the most widely cited problem. This is related to the size of the budget and to the limitations on the quality and quantity of human resources to police and administer protected areas (Peres & Terborgh, 1994; Alcorn, 1993; West & Brechin, 1991; Fearnside & Ferreira, 1985).

Conflicts between people and park managers have also been used to explain reserve resource degradation. These conflicts are primarily due to the lack of compensation to local people who have lost their homes or means of livelihood through the process of creating protected areas (Ghimire, 1994; West & Brechin, 1991). The expansion of protected areas has concentrated land control in government hands. In general, areas designed to become restricted reserves are or were inhabited by local residents who often have their own kind of resource management and institutional arrangement[15]. In several sites, local communities depend on a few resources to make a living (Balakrishnan, 1992; Sharma & Shaw, 1993). Restrictions on the parks' resources have resulted in negative attitudes towards conservation and pushed local residents to continue using their former land to harvest or grow products in order to maintain their families. Thus, the implementation of conservation units, limiting human activities and making a political choice to secure the power of the state over local resources at the expense of the local population, can generate conflicts between local residents and state officers, and can lead to degradation instead conservation.

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[15]In Africa and Asia, Arnold (1998) reported that during the 1960s many countries nationalized for conservation purposes all lands which had not been recorded as private property. The institutional arrangements developed by local users to limit entry and use lost their legal status, but the national governments were not able to monitor the use of the natural resources effectively due to the lack of funds and personnel. In Brazil, the same situation occurred in several parts of the Amazon where the low human density was misconceived. Lands that became reserves were described as untouched and uninhabited by man, or "terras devolutas", meaning land with no tenure claims, belonging to the government, and the authorities did not recognize the existence or the legal rights of traditional populations. Peres and Terborgh (1994), analyzing the protected reserves of the Amazon, concluded that from 40 to 100 % of those areas are open to illegal users because of the lack of institutional support to enforce conservation legislation. Comparing the available infrastructure in the US to that in Brazil, they showed that while the US allocated 4002 park guards deployed in situ, Brazil had only 23 to cover all Amazon reserve areas, which corresponds to a 1:6053 park guard-to-area ratio (1994:39).

Conflicts between local populations and conservation officers have been well-documented (e.g., West & Brechin, 1991; Ghimire, 1994; Colchester, 1994; Capobianco, 1995; Silva-Forsberg, 1996). Most of these studies conclude that conflicts between conservation agencies and indigenous people have made protected areas unmanageable. As a consequence, environmental degradation persists, particularly increased rates of deforestation (Ghimire, 1994; Alcorn, 1993). The state chronically lacks both the capacity and the political interest to control and manage protected areas effectively (Colchester, 1994; Utting, 1994). However, the majority of studies looking at both the effects of institutional failure and the conflicts between people and park managers do not show the direct linkages between those two variables and degradation in forest reserves. Almost no studies use reliable forest indicators to explain the assumed linkages between those variables and changes in the forest.

Protected areas such as national parks and natural reserves, in general forest ecosystems, are defined by institutional analysts as common-pool resources (CPR), where excluding users is difficult (but not impossible) and the yield of the resource system is subtractable (Ostrom & Ostrom 1977; Ostrom et al., 1994). Conceptualizing restricted-use reserve ecosystems as CPRs helps in understanding the dilemma of protecting reserves and its possible solutions.

The term CPR refers to the physical qualities of the natural resource systems in spite of the social institutions that human beings have attached to them. Two traits define CPRs: (1) exclusion problems-- it is costly to develop physical or institutional means to exclude potential beneficiaries from them. Without institutional mechanisms to exclude non-contributing beneficiaries from CPRs, they are essentially open-access resources; (2) subtractability-- the units harvested by one individual are not available to others [16]. They are subtractable or rivalrous in consumption, and can be degraded (Ostrom et al., 1994; McKean,1996; Ostrom et al., 1999). The difficulty of excluding beneficiaries and the extractability of resource units may create CPR dilemmas. When CPR users interact without establishing a set of rules to limit access and define rights and duties, two forms of free-riding are expected: (1) overexploitation, and (2) lack of provision or supply for maintaining and improving the CPR itself (Ostrom, 1998).

The effective capability to monitor, sanction and arbitrate property rights rules in regard to the use of CPRs has been considered essential to accomplish long-term CPR sustainability. Ostrom (1990) summarized a set of design principles[17] that characterize robust institutions with which individuals using CPRs have overcome "the tragedy of the

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[16]Besides exclusion and extractability, other physical characteristics of CPRs affect the problems of formulating governance regimes to manage resource systems. Attributes such as size and carrying capacity of resource systems, measurability of the resources, temporal and spatial availability of resource flows, and amount of storage in the system are some of these characteristics.

[17] E. Ostrom identified eight design principles that were used by robust CPR institutions: (1) **clearly defined boundaries**-- individuals or households have rights to withdraw resource units from the CPR and the boundaries of the CPR itself are clearly defined; (2) **congruence**-- (a) the distribution of benefits form appropriator's rules is roughly proportionate to the costs imposed by provision rules, (b)appropriation rules restricting time, place, technology, and/or quantity of resource units are related to local conditions; (3)**collective-choice arrangements**-- most individuals affected by operational rules can participate in modifying operational rules; (4) **monitoring**-- monitors, who actively audit CPR conditions and appropriators' behavior, are accountable to the appropriators and/or are the appropriators themselves; (5) **graduate sanctions**-- appropriators who violate operational rules are likely to receive graduated sanctions (depending on the seriousness and context of the offense) from other appropriators, from officials accountable to these appropriators, or from both; (6) **conflict-resolution mechanisms**-- appropriators and their officials have rapid access to low cost, local arenas to resolve conflict among appropriators or between appropriators and officials; (7) **minimal recognition of rights to organize**-- the rights of appropriators to devise their own institutions are not challenged by external government authorities; and (8) **nested enterprises**-- for CPRs that are part of larger systems, appropriation, provision, monitoring, enforcement, conflict resolution, and governance activities are organized in multiple layers of nested enterprises (Ostrom, 1990).

commons" and achieved rational resource management. These principles assume that where individuals create rules that can solve appropriation and provision problems related to the use of CPR's, successful governance of forest resources will be reached[18]. These rules include: (1) boundary rules that limit who can use, for example, a forest; (2) authority and scope rules that specify how much of what type of forest product can be extracted; (3) authority rules that empower monitoring, sanctioning, and arbitration. Thus, protected areas where agencies do not have ways to monitor boundaries or to solve conflict-resolution problems with villagers in regard to resource uses are unlikely to reach sustainable resource management.

Effective monitoring and partnership with local residents are important variables in considering conservation goals in restricted-use reserves. In some cases, even when a government agency cannot monitor the reserve by itself, it can develop a good partnership with villagers who have learned to have similar interests in conserving the resources. When this occurs, conservation can be achieved. For example, in their "solution to the tragedy of the commons", Smith and Berkes (1991) compared the sea-urchin (*Tripneustes ventricosus*) management in three different sites in St. Lucia, West Indies, and concluded that the successful conservation outcome from two sites (Laborie Bay and Maria Island Reserves) was associated with the set of informal rules developed by villagers designing resources property rights. Residents living in Laborie Bay controlled the area and the resources and they were able to enforce on all users their own informal rules. Maria

[18]Agrawal (1994), evaluating six *panchayat* forest communities in India, concluded that a significant relationship exists between enforcement and resource conditions using the proportion of *panchayat* expenditures on monitoring, sanctioning and arbitration as independent variables.

Island, a marine reserve which did not have any government officers controlling its boundaries, was also informally protected by fishermen and other resource-users. According to the authors, the planning for Maria Island to become a park had involved a great deal of local participation in decision-making in such a way that park boundaries are backed up by local social approval and are informally protected.

Nevertheless, when agencies invest a great amount of resources in reserve monitoring through policing and punishment, they can restrict non-allowed users from the core area of the reserves, but, in general, intense patrolling causes edge effects. Albers and Grinspoon (1997) analyzed the effect of enforcement of access restriction in the Khao Yai National Park-KYNP (Thailand), where managers use policing and punishment mechanisms to deter resource use. They concluded that the KYNP's policing and punishment policy has successfully deterred extraction from the central core of the park, but the policy has not prevented extraction in the outer regions of the park, and has also induced villagers to undertake socially-costly avoidance activities to reduce the chance of being caught.

Institutional failure and conflict between park managers and local villages can indeed be good indicators of unsuccessful management strategies and, consequently degradation of forest cover in reserves. However, the majority of studies do not show the direct linkages between these two variables and degradation on the forest reserves. Given the complexity involving restricted-use reserves, the linkages between forest degradation and institutional failure, and conflicts between local populations and park managers need to be analyzed based on historical, geographical, economic, political, cultural and social contexts. Studying the attitudes of rural residents in Machalilla National Park, Ecuador, Fiallo and Jacobson (1995) found that the principal sources of the negative attitudes of villagers included: lack of public participation in the park's creation and misunderstanding of the national parks concept, perceived restriction on resource-use outweighing perceived benefits from the park, and conflicts between local inhabitants and the park staff. Positive attitudes tended to increase with respondents' level of education and knowledge about conservation issues, age (younger residents), perceived benefits from the park, and good relations with park personnel. In summary, the potential and intensity of conflicts will depend on the attitudes of the residents related to reserves which can vary among communities and also within a community, depending on residents' attributes such as age, affluence, knowledge about parks, level of education and relation with reserve staff.

1.3. Theoretical approach

The majority of studies evaluating forest reserve preservation have focused basically on physical and biological characteristics of reserves, on social and economic contexts in and around reserves, or on the institutional profile and capability of agencies in charge of reserve management. However, they rarely connect those factors and processes with measurements of the forest attributes.

This dissertation combines and examines three different approaches and assesses their usefulness in explaining causes of degradation in restricted-use reserves: edge effects, population pressure, and institutional failure. Given the multilevel complexity of restricted-use reserves, each approach is assessed spatially and temporarily. First, edge effects, population pressure and institutional arrangement are analyzed spatially, taking into consideration local and regional scales. Second, their historical development is followed over time. Thus this study adopts both an interdisciplinary framework and integrates a set of methodological tools to examine the current and long term degree of preservation of a forest reserve. It evaluates the relationships between physical, biological, historical, social, economic and institutional factors and the structural attributes of the forest using indicators such as species richness, biomass and land cover changes, over time.

This dissertation draws on the Institutional Analysis and Development (IAD) framework. The IAD framework is a useful general analytical tool for helping to understand the queries undertaken in this study because it integrates three basic elements: attributes of the physical world, attributes of community, and rules-in-use. By identifying and analyzing how attributes of the physical world interact with those of the general cultural setting and with specific rules which govern a specific situation (Ostrom, 1993), the IAD framework is an essential tool when examining the theoretical approaches used in this study. It has been used by social scientists to analyze a variety of questions. One among them is how rules affect the behavior and outcomes achieved by individuals using CPRs (Ostrom, Gardner & Walker, 1994). In this dissertation, the effects of enforcement of rules on villagers' behavior and their use of forest reserve products are also analyzed. The analytical examination then goes beyond that by including spatial and temporal levels of analysis. However, the outcomes are primarily analyzed in regard to the physical setting-- the forest's structural attributes.

The main goal in creating and maintaining restricted-use forest reserves is to preserve a significant sample of forest ecosystems in their mature status. A mature forest ecosystem is not a static entity. Non-anthropogenic factors such as wind, storms, high rainfall, and seasons induce changes of differing intensity. Thus, a natural forest ecosystem is a mosaic formed by vegetation exhibiting various ages of regrowth. Most natural disturbances of forests have been well-studied by ecologists and taken into consideration in the measurement when evaluating forest ecological conditions. Hence a well-preserved forest reserve is one which exhibits no significant impact on its ecological attributes over time.

To evaluate the degree of preservation and forest degradation, the ecological attributes of the forest must be measured and evaluated, as well as compared over time. For this reason, a traditional forest ecology approach is used to measure and evaluate the horizontal and vertical attributes of the forest. One time point analysis of the forest, however, gives us a static picture of the forest condition. To follow forest conditions over time, a combination of tools must be utilized and combined. Thus, vegetation, history of land use, and remote sensing data, which provides multi-spectral and multi-temporal information, are used. With such tools, one is able to not only follow the performance of the forest located in the reserve, but to also understand the history of land use, and the land-use regime that surrounds the reserve's environment.

As Jansen (1983) has said, "no park is an island." The surrounding habitat types and human activities influence the ecological process of areas reserved for conservation. Humans may affect forest reserves directly in two principal ways: first, by clearing areas for agriculture or for other anthropogenic activities that cut part of the forest down inside or at the forest boundaries; and second, by having access to forest products and services such as timber, firewood, game, and recreation. Humans may further alter forest reserve edges in rural and urban areas by gathering firewood, pruning limbs, dumping grass clippings or cropping in these habitats.

In this study, the land-use dynamics around the reserve are analyzed over time (1977-1995), taking into consideration the demographic transition and urbanization and their indirect effect on the reserve. Since such attributes of the communities as population size and density, affluence, origin, cultural background, and household structure are important variables in how people use forest products, they are examined here to evaluate the outcomes in the forest's structural attributes. As cited earlier, enforcement of rules that govern a forest also directly affects its preservation. The creation and evolution of the rules in managing the forest reserve are thoroughly analyzed and integrated to evaluate the preservation of the reserve, as well as the performance of the agency in charge of its governance.

1.4. Research design and data collection

The Campus Forest of the University of Amazonas was selected as "the case study" to test three hypotheses derived from the theoretical approaches used in this dissertation. Because it has experienced many of the problems faced by other tropical restricted-use reserves during its creation, establishment, and management over time, the Campus Forest serves as an empirical case to be studied. Studying the historical development of this reserve can contribute to a better understanding of the dilemma of protecting national parks and other restricted-use reserves in tropical countries.

With the creation of Campus Forest as a forest reserve in the beginning of the 70s, the University faced problems with former landowners upon acquiring land tenure control of the area. During the same decade, the Manaus area where the forest reserve is located experienced fast demographic changes due to industrialization and urbanization that resulted in invasions of Manaus' rural and semi-urban forested lands, including the Campus Forest area. The land invasion process continued to cause conflicts between settlers and reserve officers for at least 5 years. In addition to the forested land lost due to invasions, the areas surrounding the reserve were deforested during the last two decades, transforming it into a forest fragment. Neighborhoods of different socio-economic status were established, thus increasing the number of potential users of the forest. A management plan was designed and partially implemented by the University of Amazonas to conserve the area, but it always faced budget problems, which influenced its ability to control the entrance of outsiders into the forest. As is common in most tropical forest reserves, the Campus Forest officers also claimed that the forest was degrading because of the unallowed use of the forest products by neighboring residents.

1.4.1. Hypotheses to be examined in this study

Three hypotheses derived from the three main approaches used to explain forest degradation (biophysical edge effects; population pressure and inequality; and institutional failure and conflicts between reserves managers and villagers) are tested separately using

Campus Forest data. The three hypotheses are presented next with a short description of each one, followed by a detailed discussion of the predictors and indicators used to test these hypotheses.

H1: Forest degradation is caused by edge effects resulting from fragmentation.

A substantial number of ecologists argue that when forests are cut the remaining fragments are affected by wind and other edge effects. Thus, forest structure attributes such as stand height and basal area will be poorer closer to the edges.

H2: Forest degradation is a result of population pressure and inequality.

Forests located near or around densely populated areas and areas experiencing high population growth will be cleared or overused by people living near them, especially when the humans are poor and rely on forest products to make their living.

H3: Forest degradation is a result of institutional failure.

This hypothesis argues that if institutions do not develop a set of rules and measures to manage, control and sanction inappropriate forest use, a protected area will be transformed into an open access one and the "tragedy of the commons" will take place. Thus, forest degradation will be a function of both internal and external variables such as uncoordinated land use decisions by the different agencies' members and the attributes of the human communities that live surrounding the protected area.

1.4.2. Predictors and indicators used to test the hypotheses

Biomass decay on the edges-- The traditional edge effect model predicts ecological decay on the edges of recently fragmented forests due to biophysical factors. Because forest fragment edges are more exposed to different solar radiation, water, wind and nutrient regimes than a large continuous forest, one should expect more tree falls and a more open forest closer to the edges. In the Central Amazon, it is expected that forest fragments within 100 meters of newly fragmented edges will lose at least 30% of their biomass in the first 10 to 17 years after isolation (Laurance et al., 1997). Mature forests around Manaus present an average basal area (BA) of around 35 m^2/ha. Basal area is a reliable indicator of biomass. Thus, according to the biophysical edge effect model, the earlier the isolation period, the lower should be the basal area found in forest plots close to the forest edges.

Social and institutional factors also have edge effects on forest attributes (institutional edge effects). Forest reserves surrounded by populated areas are more prone to the use of outsiders. When agencies invest in policing and punishment policies to protect reserves, outside users will undertake socially-costly avoidance activities to reduce the chance of being caught by extracting products mostly from the outer regions of the forest (Albers & Grinspoon, 1997). In spite of that, one should expect to find more forest degradation around the borders of the reserves that are located close to those communities that depend on some forest products. Hence, if people use the forest for consumptive purposes and reserve patrolling is effective, the biomass will be less in the borders of the forest.

The attributes of the household and the communities also influence people's behavior in regard to the use of the forest. Depending on their needs and preferences, residents can use the forest for consumptive and non-consumptive uses. Consumptive uses are expected to contribute to forest degradation much more than non-consumptive uses. Thus, if the residents use the forest for consumptive uses and the forest agency does not control outsiders' access, residents will not only use the borders but also all areas of easy access, for example, along trails, and other non-forested areas where it is easy to extract forest products. As in most of the forests around the world, there are several trails of 1-4 meters wide around the campus which would probably be minimally affected by biophysical effects but which allow access for forest users. Thus, one should expect to find poorer biomass closer to the non-forested areas located near the neighborhoods.

Land cover change over time-- Ground-based data from forest surveys such as basal area, height and species richness are reliable indicators to evaluate the ecological conditions of a forest. But they can show only what is happening in ecosystems at one point in time. To evaluate the temporal dynamic of a forest, it is necessary to take measurements over time (Laurance et al., 1997), and/or use a combination of ground indicators with remote sensing, and other socio-economic data. Remote sensing images of both MSS and TM sensors provide multi-spectral data to analyze land cover change over time. Even with the limitations of MSS imagery (e.g., Moran, 1993; Moran et al., 1994; Mausel et. al., 1994), this lower resolution satellite instrument can provide useful data to evaluate changes on the forest biomass, showing when a patch of forest changes to a clear area or to secondary succession and vice-versa. Thus, it has been possible to evaluate land cover change over time even when higher resolution remote sensing instruments were not available, as in the 1970s.

As variation in forest biomass can be captured by remote sensing images showing different spectral signatures, forest, secondary succession and cleared areas are identified and clustered in classes to analyze the spatial distribution of forest change in Campus Forest (see details in Chapter 2).

1.5. Data collection strategy

Given the interdisciplinary nature of the theoretical and methodological approaches used in this dissertation, the collection of data and information for this study followed a combination of strategies. First, the methodology of the International Forestry Resources and Institution (IFRI) research program coordinated by the Center for the Study of Institutions, Populations, and Environmental Change (CIPEC) was used. IFRI methodology collects information about different types of biological and sociological entities, cataloging data about trees, saplings, ground cover, and soils, as well as forest user groups and products, and rules that are used by these groups. The information required by IFRI methodology was mostly collected in the summer of 1996 when 61 forest plots were measured. In that season, the social organization and history of each of the surrounding settlements was also completed by interviewing elder residents, leaders of local associations and other residents. A copy of the 1991 census data was obtained from the state communication company (TELAMAZON) through the University of Amazonas. A map covering the entire study site was obtained from the Brazilian Census Bureau (IBGE) (1:5000), and several thematic maps of the campus area were obtained at the University of Amazonas (e.g., topographic map, vegetation classification map, construction planning map, and a land-use map). Three satellite images (Landsat TM from 1988, and 1995 and MSS from 1977) were also obtained. A 1-hour flight was made covering the study site on June 21, 1996. The study area was videotaped and aerial photographs were taken.

During the summer of 1997, 10 more IFRI forest plots were measured and the University of Amazonas archives were explored to obtain historical information about the creation, development and current status of the governance of the Campus Forest. During this visit, over 30 interviews were conducted with Campus Forest officials including officers, professors and forest guards. The forest guards' patrolling routine was followed twice to observe their behavior and attitudes during their activities. A household survey was also undertaken in two neighborhoods to evaluate residents' behavior in regard to the forest reserve. A thorough description of the study area and methodology used in this study is provided primarily in Chapter 2.

1.6. An overview of the dissertation

Given the framework I have presented in this chapter, I will now provide a brief overview of the rest of the study.

In Chapter 2, the study area and methodologies are discussed. Presenting the location, size and altitude of the Campus Forest, this chapter provides a brief description of the physical attributes of the study area region. The climate, hydrology, geology, geomorphology and pedology of Manaus and the Central Amazon region follow. A general and brief presentation of the vegetation of the study area is also presented by way of introduction, since a more detailed literature review of that material is provided in Chapter 3, as well as the history human occupation of the Campus Forest. A set of methodological tools used for measuring the forest attributes, interviewing households, analyzing land cover change, and the development of the institutional analysis is described.

Chapter 3 summarizes the historical occupation of Manaus and its influence on forest changes of the Manaus urban area. It is composed of three sections: Section 3.1 starts by showing some traces of pre-historical populations which lived around the Manaus area, and then moves to a more complete analysis of five centuries of European occupation (1500-1960). Section 3.2 discusses the contemporary occupation of Manaus. It is based on both a literature review and information derived from three remote sensing images. Land cover change analysis focuses on three time points: 1977, 1988, and 1995 showing the fast urbanization process of Manaus and its influence on deforestation and forest fragmentation around the city's urban and semi-urban areas. In Section 3.3 the ecological attributes of the Central Amazon forests are discussed and analyzed based on several surveys undertaken around that region. The ecological characteristics of secondary succession vegetation and some measures to differentiate them from mature forests are also defined as a baseline to be used in the following chapters.

In Chapter 4, Campus Forest vegetation is analyzed. Using biomass and species composition as main indicators, it integrates the land-use history of both the inside and the outside of the Campus Forest with ecological attributes of the vegetation. It concludes that two main types of vegetation cover Campus Forest, but that parts of both were in different stages of secondary succession.

Chapter 5 deals with the biophysical and institutional edge effects of forest fragmentation on the Campus Forest structural attributes. It uses basal area as a biomass indicator derived from the forest survey data collected in 1996, and land cover change analysis derived from a set of three Landsat images. An institutional analysis of the creation and evolution of the institutional arrangements of the Campus Forest is also undertaken and compared with land cover analysis over time to determine the institutional edge effect on the forest attributes.

Chapter 6 deals with the surrounding communities' effects on the structural attributes of the Campus Forest. In addition to analyzing the relationship between biomass and distance from non-forest areas in the four-forest sectors related with the neighborhoods, the use of the Campus Forest products and services by the residents is also analyzed. How they perceive and value the forest, and the sources that could explain the resident's attitudes in regard to the Campus Forest conservation, are evaluated as well.

In the final chapter, the theoretical framework is reviewed. The findings of the case study are summarized in light of the proposed framework. The implications of this study for the understanding of the dilemma of preserving national parks and other restricted-use reserves are analyzed, and, finally, an agenda for future studies is presented.

Chapter 2

STUDY AREA AND METHODOLOGY

This chapter presents the characteristics of the study area and the methodologies used in this dissertation. It describes the physical attributes of the study area region, followed by a general description of the climate, hydrology, geology, geomorphology and pedology of Manaus and the Central Amazon region. A short description of the vegetation is also presented to introduce it, as well as the human occupation of the Campus Forest. This is followed by a description of the methodological tools used for measuring the forest attributes, population characteristics, institutional arrangements and land cover changes.

2.1. Study area

2.1.1. Location, size and elevation

The Campus Forest of the University of Amazonas (UA) is located between Estrada do Contorno and Estrada do Aleixo, 8 km from downtown Manaus, capital of the state of Amazonas, Brazil, at between 03°04' 34"S - 59° 57' 50"W and 03° 06' 44"S - 59° 58' 23" W (Figure 2.1). It has been a state property administered by the University of Amazonas since 1968. Created in 1965 as a Foundation, UA acquired most of the campus land from the former landowners through a process of expropriation. An area of 800 hectares was purchased, which includes the current area where there is a residential neighborhood today (i.e., Coroado settlement). The total forested area of the campus is around 600 ha.

The Amazon as a whole is predominantly lowland, but to the north and south there are several mountains whose presence leads to a diversity of climatic conditions such as seasonality (Bigarella & Ferreira, 1985). However, the Central Amazon plateau has a mean slope of only 2.5 cm/km (Salati 1985). The topography of the Campus Forest is uneven, varying from 40 to 90 meters, and it is covered by several slopes and two main plateaus where the University buildings are located (Figure 2.2).

2.1.2. Climate and hydrology

The climate of Manaus is type Am[1], warm and moist all year long (Köppen classification). The mean annual temperature is around 26 C°, fluctuating 2 C° monthly on average. During the rainy season (December to May) the mean monthly temperatures vary mostly between 25.8 and 26.8 C°, and during the dry season (June to October), especially in September, October and November, vary between 26.8 and 28 C° (see Figure 2.3). The mean annual values of the maximum and minimum temperatures are around 31C° and 23C° (Brasil, Projeto RADAMBRASIL, 1978). The extreme absolute temperatures recorded over 70 years (1911-1980) were 18.5 C° on July 31, 1955, and 37.8 C° on October 3, 1935 (Salati & Marques, 1984). However, the extreme absolute values recorded from 1974 to 1995 (data collected for INEMET which were used to run Figure 2.3) were 17.1 C° on July 9, 1989, and 40.1 C° on November 13, 1991. According to

[1] A: a tropical rainy climate, where mean monthly temperatures are never below 18 °C ; and **m:** a climate where there is a relatively long dry season, but the total annual rainfall is enough to prevent plants from wilting. Nevertheless, around Manaus, where there is a fairly well defined dry season from June to October, trees on Oxisols begin to lose their leaves after a dry period of 10-15 days, indicating, probably, some deficit of water in the soil (Salati, 1985).

Leopold et al. (1987), the isothermic condition (very low temperature variation) of the Central Amazon plateau is a direct consequence of the water vapor, which is always high in the region. The mean annual relative humidity is around 82% with a range of 79-84%, but with a higher variation during the dry and rainy seasons (see Figure 2.4).

The mean annual rainfall is approximately 2,100 mm (Ribeiro, 1976; Ribeiro & Adis 1984; Salati, 1985). The rainiest months tend to be March and April, with about 300 mm each, while July, August, and September normally receive less than 100 mm each (Figure 2.5). The mean rainfall for the period between 1911 and 1980 was 551 mm in the dry season (June to November) and 1554 mm in the rainy season (December to May) (Ribeiro & Adis 1984; Salati 1985).

The Amazon basin presents a huge diversity of water bodies, varying from large rivers and lakes to millions of small streams which join to form or contribute to the large rivers. The Amazon streams' network is one of the most dense in the world (Junk, 1983). The Central Amazon plateau is exceptionally flat with a maximum slope of 100 meters over almost 4,000 km (Salati, 1984). From the western frontier town of Tabatinga to its mouth at Belem (almost 3,000 km), the Amazon riverbed falls only 60 m, an average of 2 cm/km. According to Leopoldo et al. (1987), with this little slope, the heavy rains from December to May flood the eastern forests to a depth of 7-9 m.

In the Manaus area, the hydrographic system is formed by two black water basins. In the western area, the basin is constituted by a stream network which joins to form the Riacho Grande (big stream). The Riacho Grande drops its water into the Tarumazinho, which drops its waters into Taruma Grande, which joins the Rio Negro in the Upper

Manaus area (see Figure 2.1). The eastern basin is also formed by many streams, which end in the Puraquequara River, which drops its water into the Amazon River in the lower area of Manaus where the two large rivers meet (Negro and Amazon Rivers). Thus, Manaus City, and specifically the study area, is located in a water divisor between the two basins. Similar to other parts of the Amazon, the several small streams found in the study area flood their banks and create swamps in the rainy season.

2.1.3. Geology, geomorphology and pedology

The geologic basement of the Amazon basin is made up entirely of crystalline rocks of the Precambrian Age (Putzer, 1984). In the basin between the Precambrian Brazilian and Guyana shields, sediments weathered from the crystalline rocks of those shields have accumulated since the Paleozoic Age. The surface is formed by Cretaceous sediments, and outcrops of Paleozoic sediments occur only at the edges of the shields (Irion, 1989). Mountains which reach 800 meters in the south and around 3,000 meters in the north are distributed around the latitudinal limits of the lowland areas (Bigarella & Ferreira, 1985). From Manaus to the mouth of the Xingu River, in the middle Amazon basin, soft Tertiary sediments that belong to Formation Alter do Chão (Putzer, 1984) predominate, while most of the western parts of the Amazonia lowland are covered by more recent sediments from the Quaternary, which eroded from the Andes. These sediments are richer than those from the Tertiary, composed mostly of quartzic or kaolinitic sediments on alluvium. Three lithostratigraphic units have been identified in the Manaus area: (1) the Trombeta Formation; (2) the Tertiary Formation Alter do Chão on top of the Trombetas', and (3) Quaternary sediments which cover locally the Alter do Chao Formation (Dias et al., 1980).

The soils of the region are acidic, deep, yellowish brown and well-drained (Sombroek, 1966, 1984). The Tertiary sediments of the formation that accompany the major rivers through the central basin known as Alter do Chão (Santos, 1984) are sand or clay. Their main constituents include resistant minerals such as kaolinite, quartz, and small amounts of oxides of iron and aluminum (Dias et al., 1980; Ranzani, 1980; Chauvel et al., 1982). The Tertiary sedimentary plain is well dissected by its drainage system, resulting in plateaux, valleys and slopes (Dias et al 1980). Most of the cations have been leached from these geologically old soils. They are generally low in phosphorus and high in aluminum (Brasil, Projeto RADAMBRASIL, 1978).

The most common soils in the Amazon are Oxisols (latossolo amarelo, or yellow latosol) and Ultisols (terra roxa distrófica, or purple earth) (Camargo & Falesi, 1975; Sanchez, 1976). It was formerly estimated that the Oxisols covered 67% and Ultisols only 15% of the Brazilian Amazon area (FAO/UNESCO 1974). However, the current EMBRAPA map shows that Oxisols cover around 39% of the Brazilian Amazon, while Ultisols cover around 30% (Richter & Babbar, 1991).

In the Central Amazon, Oxisols are common. Oxisols with a clayed texture account for about 60% of the soils in the area between km-30 and km-105 of the BR-174, the federal road which links Manaus to Boa Vista (capital of the state of Roraima) (Dias et al., 1980). In the Central Amazon, the soils in the uplands have been classified on the EMBRAPA map (1981) as "Podzois hidromorficos" (Klinge, 1965) or "Areias quartzosas" (quartzitic sands), both of them among the poorest soils in the Amazon.

2.1.4. Vegetation[2]

The Campus Forest is a fragment of the Central Amazonian tropical rainforest. It is covered mostly by upland forest (terra firme) on Oxisols and Ultisols. Terra firme or dense forest in the Central Amazon is high forest with a large biomass of around 730.7 metric tons/ha (Fittkau & Klinge, 1973), with a basal area of 30.55 m^2/ha, tall trees with heights of 30 to 50 meters, with an average height for the first branch of 11.6 m, and averaging between 3 and 32m (Higuchi, 1987, Rankin-de-Merona et al.,1992), closed canopy, large lianas of limited frequency, and relatively sparse ground cover. Trees per hectare vary from 167 (Rodrigues, 1967) to 637, and number of tree species per hectare from 125 to 171 (Rankin-de Merona, 1992). Prance (1990) compared data on woody plant families at several sites in the Central Amazon and concluded that the most important woody plant families in that region are Sapotaceae, Lecythidaceae, Moraceae, Caesalpiniaceae, Burseraceae, Chrysobalanaceae, Lauraceae, Melastomataceae, Mimosaceae, Fabaceae, and Annonaceae. The same author highlights that *Eschweleira odora* is the most abundant species in the forest on the 1-ha inventory near the Ducke Ecological Reserve (Reserva Ducke).

The Reserva Ducke is the best well-known mature forest reserve close to Campus Forest (see Section 3.2.3, especially note 13), and also one of the most researched patches

[2] More information about central Amazon forest types is provided in Chapter 3, section 3.3.

of the Amazonian forest by many disciplines (Prance, 1990). In the Reserva Ducke, four types of vegetation have been described (S. Ribeiro et al., 1994), all relating to both topography and pedology: dense forest (floresta de plato), slope forest (floresta de declive or vertente), savanna forest (campinarana), and wet forest (mata de baixio).

Dense forests are distributed on the upland areas with well-drained soils. With a canopy ranging from 25-35 meters where the emergent trees can reach 50 m, dense forest presents a large basal area of around 39 m^2/ha (Tello, 1995). In this forest, the most dominant families are Mimosaceae, Lecythidaceae, Sapotaceae, Annonaceae, and Moraceae. *Dinizia excelsa, Eschweilera coriacea, Oenocarpus bacaba, Bocageopsis multiflora,* and *Euterpe precatoria* are the most dominant species (Tello, 1995).

Slope forests are distributed on areas sloping down from dense forest. In this forest, well-drained clay and sandy-clay soils predominate. Its canopy ranges from 25-35 meters, but with just a few emergent trees. Slope forest basal area is around 31 m^2/ha. The most dominant families found in this forest are Lauraceae, Chrysobalanaceae, Moraceae, Mimosaceae, and Caesalpiniaceae. The most dominant species are *Eschweilera coriacea, Corythophora alta, Protium apiculatum, Osteophloeum platyspermum* and *Eschweilera atropetiolata* (Tello, 1995).

Campinarana forests are distributed around the lowlands on sand soils (areia quartzosa). Considered to be paleo-lake beaches that have modified over time, campinarana is a low biomass forest, with basal area averaging around 26 m^2/ha (Tello, 1995). Canopy trees ranges between 15-25 m with high light penetration (S. Ribeiro et al., 1994). Caesalpiniaceae, Mimosaceae, Bombacaceae, Sapotaceae and Lauraceae are the most dominant families, while *Bocoa alterna, Parkia sp., Scleronema micranthum, Ocotea cymbarum and Manilkara cavalcantei* are the most dominant species in this type of forest (Tello, 1995).

Wet forests are distributed on the lowland along the streams and in the bottom of paleo-lakes covered by sandy soils. Forest canopy ranges from 20 to 35 m with few emergent trees, but with a very dense under store. Presenting fewer emergent trees than dense forest, the biomass measured in this forest is higher than in dense forest, showing a basal area of around 48 m^2/ha (Tello, 1995). The most dominant families in this forest are Verbenaceae, Sapotaceae, Moraceae, Caesalpiniaceae, and Chrysobalanaceae, while *Vitex calothyrsa, Chrysophyllum sanguinolentum, Dicorynia paraensis, Nauclepsis sp, and Jessenia bataua* are the most dominant species.

2.1.5. Human Occupation of the Study Area[3]

Development projects promoted by the Brazilian government in the Amazon have generated high deforestation rates and migration. In recent decades, the Amazon region has experienced high immigration rates from other Brazilian regions to rural areas as well as high rural emigration of local populations to large cities. Manaus is one of the cities which has suffered the greatest impact from such projects. In 1967, the Free Trade Zone (SUFRAMA) was established along with the Industrial Zone in the city (Souza, 1994) and the Agricultural Zone located 80 Km north of Manaus where activities such as farming,

[3] Historical and contemporary occupation of the Study Area are analyzed in Chapter 3, Section 3.1 and 3.2.

logging, and cattle ranching were subsidized by the government (Lovejoy & Bierregaard, 1990). The population of Manaus increased from 173,703 inhabitants in 1960 to more than 1,200,000 in 1995 (IBGE, 1960, 1991). The fast urbanization process occurring in Manaus led to a rapid destruction of forests in that area. Currently, the largest piece of forest that remains in the Manaus urban area is located on the Campus of the University of Amazonas (UA), which covers an area of 600 hectares of the forest.

The Campus Forest underwent three main stages, closely linked in time. The first was the construction of the University of Amazonas in 1969, when the area was scarcely occupied. The second was the human occupation around the campus that occurred mainly through land invasions and residential parks. That process can also be divided into two periods: the beginning of a rural exodus to cities was caused by frequent flooding and lack of economic alternatives in the countryside, and, in the last 10 years when it was stimulated by electoral interests. The third stage was the construction of an industrial zone (SUFRAMA) close to the campus, in the beginning of the 1970s as part of the development plan for the Amazon (see also Chapter 3).

The occupation on the Campus Forest border and its progressive isolation as an urban forest fragment began in 1971. Since then, political, economic and ecological factors have contributed to transforming Manaus into a frontier area. Rural exodus caused by the frequent flooding and lack of economic alternatives in the countryside, plus the government propaganda about the economic benefits that would be created by the development programs to be installed in the Central Amazon, attracted thousands of people to Manaus. Invasions by squatters occurred on several forested lands located in peri-urban and rural Manaus areas, accelerating its urbanization process. One of the areas invaded was the northwestern part of the Campus Forest where the Coroado neighborhood is currently located. The University of Amazonas lost 119 hectares of forest at that time. In the early 1970s, the University did not have total control over the area nor the infrastructure to manage it. Conflicts between Coroado residents and University officials were in part resolved in the early 1980s when the area was formally given to the population.

The Campus Forest is currently surrounded by six neighborhoods (Figure 2.1) with different histories and socioeconomic features. Coroado is the oldest neighborhood resulting from the invasion process and is densely populated. By 1990, more than 30,000 residents lived there, distributed in more than 3,000 households (IBGE, 1991). Most of the residents are low-income workers, and more than 60% never finished elementary school (Lima, 1997).

Acariquara is also located on the opposite northern border of the campus. Acariquara was created in 1980 by a private initiative designed for University employees (professors and staff). It is a middle class neighborhood where most of the inhabitants have at least a high school level of education (Lima, 1997).

In the middle 1980s, another residential park (Dom Bosco) was built 200m from the campus, further north, at the border between Coroado and Acariquara. However, in 1992 that part was isolated with the invasion of the current Ouro Verde neighborhood. The Ouro Verde residents did not invade campus land.

The construction of Nova Republica began in the middle 1980s on the southern border, but the residents only moved there in 1991. Thus, Nova Republica is one of the youngest neighborhoods and has not created conflicts with Campus Forest officers. This settlement has around 3,000 inhabitants distributed in 621 households. It is a middle class neighborhood and almost 70% of its residents have a high school education.

On the southern border is also located the Atilio Andreazza neighborhood. This neighborhood is not located directly on the border of the Campus Forest. It is separated by a road and a forest buffer (see Figure 2.1) and is a high middle class neighborhood, established in 1992.

2.2. Methodology

In this section, the procedures used to measure and analyze the vegetation and land cover changes in Campus Forest and Manaus area are presented, as well as the tools used to survey the households located around the Campus Forest and to undertake the institutional analysis.

2.2.1. Types of vegetation in the Campus Forest

Campus Forest is mostly covered by Amazon upland forest. However, Amazon upland forests are not homogeneous. There are many subdivisions of the basic vegetation types, and an immense variation and niche diversity within the forest ecosystems (see Chapter 3 Section 3.3.).

The Campus Forest has been classified by Coutinho (1994) into three main types of vegetation, using the INPE-SGI (Geographical Information System) and a Landsat TM image from 1989: (1) Floresta Ombrofila Densa -OD (dense tropical forest) with 236,3 ha; (2) Floresta Ombrofila Aberta-OA (open tropical forest) with 227,6 ha;, (3) Vegetacao de Campina-CC (savanna forest) with 35,4 ha, and (4)Area Antropica with 93,8 ha (manmade area) (Figure 2.6). Izel and Custodio, (1996) using aerial photography from 1990, extended that classification to six classes: dense forest, open forest, savanna (Campinarana), sandy area, crop area, and area of anthropogenic action (Figure 2.7).

To capture the forest mosaic within both the Campus Forest as a whole and the different types of vegetation, the entire forest area was surveyed with randomly selected plots, and two levels of analysis were developed: first, by considering the Campus Forest as an ecological unit; and second, by disaggregating each type of vegetation. A preliminary vegetation cover map was developed to use in sampling (Figure 2.8). I combined information provided by Coutinho (Figure 2.6) in regard to spatial distribution of CC, and Izel and Custodio (Figure 2.7) in regard to OD and OA. These were selected because they were closer to our preliminary field observations of the CF vegetation zones. For the purpose of this work, all forest types were combined into one class during image classification.

2.2.2. Vegetation survey

As described above, a preliminary vegetation map was developed for sampling. Thus, seventy-one plots were randomly selected in the Campus Forest area following the

CIPEC (Center for the Study of Institutions, Population and Environmental Change (CIPEC) methodology[4] (Ostrom, 1996). Using the IFRI forest plot form, data from each plot were coded. An IFRI forest plot[5] is composed of three concentric circles of 1, 3, and 10-meters radii, centered on a randomly selected point in the forest. Ground cover and seedlings are sampled in the smallest circle, shrubs and tree saplings in the middle-sized circle, and trees in the largest circle. Thus, in the large plot (10 meters), trees with a diameter at breast height (dbh.) equal to or greater than 10cm were examined to establish species, diameter, stem, and total height. In the medium plot (3-meter), tree saplings (diameters between 2.5 and 10 cm) and shrubs were examined to establish species, diameter, and total height. In the smallest plot (1-meter), tree seedlings and other ground cover were measured to establish species and their percent of ground cover. These measurements were taken to calculate frequency, density, dominance, and importance value, and also the vertical attributes of the forest such as basal area, distribution of diameter classes and height.

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[4]The International Forest Resource Institution (IFRI) Research Program is an integrated methodology for sustained observation and systematic analysis of forest resources. It addresses the complexities of forest ecosystems, including the diversity of forest products and users, consumptive and non-consumptive uses of forest products and the complexity of mechanisms governing product use (Ostrom, 1996).

[5]The IFRI forest plot is not only designed to obtain information about the condition or state of the forest on observing tree growth, forest composition and species diversity, but also presence of livestock, soil quality, and pest damage in the randomly selected plots (Ostrom, 1996).

2.2.3. Institutional analysis

The CIPEC methodology was originally developed as part of the IFRI-Research program. It was used to analyze the institutional arrangements which govern the Campus Forest. This program is based on the Institutional Analysis and Development (IAD) framework, which has been developed over several decades at the Workshop in Political Theory and Policy Analysis at Indiana University. The IAD framework is a method for identifying and analyzing how attributes of the physical world interact with those of the general cultural setting and with the specific rules that govern a specific situation. Institutional analysis allows the scholars to look either at the formal rules that are created by institutions or at the informal rules, often called rules-in-use or working rules that govern a particular environment and affect the incentives facing individuals in particular situations and the likely outcome (Ostrom et al., 1994).

The IFRI research instruments are composed of a relational database and a set of 10 coding forms: (1) Site overview form, (2) forest form, (3) forest plot form, (4) settlement form, (5) user group form, (6) forest association form, (7) forest-user group relationship form, (8) forest products form, (9) nonharvesting organization form, and (10) organizational inventory and interorganizational arrangements form (see a summary of the information collected in each IFRI form in Table 2.1).

To fill out each IFRI form, in addition to the vegetation inventory explained in Section 2.2.2., interviews, group discussion and meetings were carried out with key informants in order to obtain information about the history of land use inside and around the campus; socio-demographic and geographic information of settlements; size, socioeconomic status, and specific forest user groups; institutional information about forest associations, including association's activities, rules structure, membership, and record keeping; forest products' temporal harvesting patterns, alternative sources and substitutes, harvesting tools and techniques, and harvesting rules; and information about all organizations that relate to a forest. Semi-structured interviews (Bernard, 1994) were undertaken with University officers, and University of Amazonas archives were searched. An historical analysis of surrounding neighborhoods was completed by interviewing elder residents, leaders of local associations, and other residents. Group discussion with residents of two of these associations, Nova Republica and Acariquara, were conducted twice, and a meeting with a third neighborhood association (Coroado) was also set up. These collective discussions helped to obtain a wider picture of the study area context. Some specific information was also captured by the household survey (see next section).

2.2.4. Household survey

In addition to the regular IFRI protocols, a household survey was designed in order to evaluate the patterns of individual household use of the Campus Forest. Structured household interviews were administered in 120 households by a random sampling procedure in each of two neighborhoods (Coroado and Nova Republica) immediately surrounding the urban forest. This was done in order to evaluate whether there was a relationship between household attributes and degradation or conservation of the Campus Forest. Household questionnaires were structured with questions related to demography, socioeconomic activities, land use, origin of the household heads, mobility, access to urban facilities, historical relationship between residents and Campus Forest managers, and patterns of CF product uses (see a copy of the household survey in Appendix 2.1).

Households in each neighborhood were selected randomly by placing a grid over a map of each neighborhood. Using a random number table, coordinates of random points in the neighborhood map were selected. As the neighborhood maps only provided the size and distribution of streets, the location of the random houses selected for interviews was made by driving slowly through 10% of the streets in each neighborhood and counting the number of houses on each side of the street. Doing that, it was possible to estimate the average number of houses found in the streets: 7.1 houses for each cm of street on the Coroado map and 3 houses on the Nova Republica map. Thus, it was possible to know what house should be located to undertake the survey. When the household heads were not at home or refused to participate in the interviews, the house immediately to the left was selected.

2.2.5 Remote sensing

In addition to the IFRI research instrument and forest and household surveys, three Landsat scenes were analyzed: two Thematic Mapper (TM) scenes (path 231, row 062) from August 16, 1988 and September 20, 1995, and one MultiSpectral Scanner (MSS) from July 31, 1977. Each image was processed through radiometric calibration and atmospheric correction[6], and geometric correction[7]. Radiometric calibration and atmospheric correction for Landsat 5 TM scenes were processed using the Excel spreadsheets developed by CIPEC. The steps followed are described in the CIPEC Remote Sensing of Global Change lab manual V3.1 (lab #3), modified with procedures from Teilet and Fedosejevs (1995) (see Green, Schweik, & Hanson (1998). The radiometric calibration and atmospheric correction for Landsat MSS scenes procedures also used the CIPEC methodology developed by C. Schweik (1998). The steps to calibrate Landsat MSS are also described in the CIPEC Remote Sensing of Global Change lab manual V3.1 (Lab#3) (see also Green, Schweik, & Hanson, 1998). After calculating the Rspace at the satellite reflectance equations and the range factors in Excel, the images were calibrated in MultiSpec 1.0 (Landgrebe & Biehl, 1997).

The images were geometrically corrected to UTM map projection using ERDAS Imagine 8.3. Ground Control Points (GCP) were taken from available 1: 50,000 topographic maps (DSG, 1984). Images were registered to each other and registration accuracy was carried out in points selected in different places, especially along roads and rivers. A subset of the three images was used to undertake the analysis of the land cover change in the city of Manaus (2° 90' S - 60°.12' W, and 3° 15' S - 59° 79'). The area selected to evaluate the urban change in Manaus followed two criteria: 1) the current

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[6]Radiometric calibration deals with variations in the pixel intensities (digital numbers or DNs) that are not caused by the object or scene being scanned, including atmospheric and topographic effects, and malfunctioning of the detectors. It is a process that converts satellite derived digital numbers to at-satellite reflectance values (Markham & Barker, 1986)

[7]Geometric correction deals with errors related to the position of the pixels. It is a process of projecting the data onto a plane and making it conform to a map projection system.

urban and semi-urban area of the city, taking the area of Reserva Ducke as a baseline, and 2) the total urban area covered in 1977.

To evaluate the area deforested over time due to urbanization, five land-cover classes were used: 1) forest, 2) secondary succession, 3) urban[8], 4) rio Solimoes, and 5) rio Negro. These classifications were based on a hybrid approach: unsupervised[9] and supervised classification (these procedures were developed mostly by E. Brondizio and are available in the CIPEC Remote Sensing of Global Change lab manual V3.1, lab#5b [see also Mausel et al., 1993; Moran at al., 1994; Brondizio, 1996], run in ERDAS/Imagine 8.3, using the three compatible bands 1, 2, and 3 of MSS 1977, and 2, 3, and 4 of TM 1988 and 1995. First, an unsupervised classification was run, using the ISODATA algorithm to obtain 20 clusters. A conceptual analysis of each cluster (unsupervised class based on the spatial and spectral pattern of each class) was done to give a preliminary name for each one. A visual analysis of the spatial distribution of each class was undertaken by combining a color composite image with field data. To aggregate the 20 general classes into the 5 final land cover classes, an analysis of each cluster's statistical separability was also developed. After the statistical processes and verification with some training samples[10] collected in 1996 and 1997, the 5 classes were used to run a supervised classification of each of the three images.

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[8] Urban here means any new or formerly cleared area, including areas of bare soil but not under urban use.

[9] Unsupervised classification is "a process whereby numerical operations are performed searching for natural grouping of the spectral property of pixels" (Jensen, 1996).

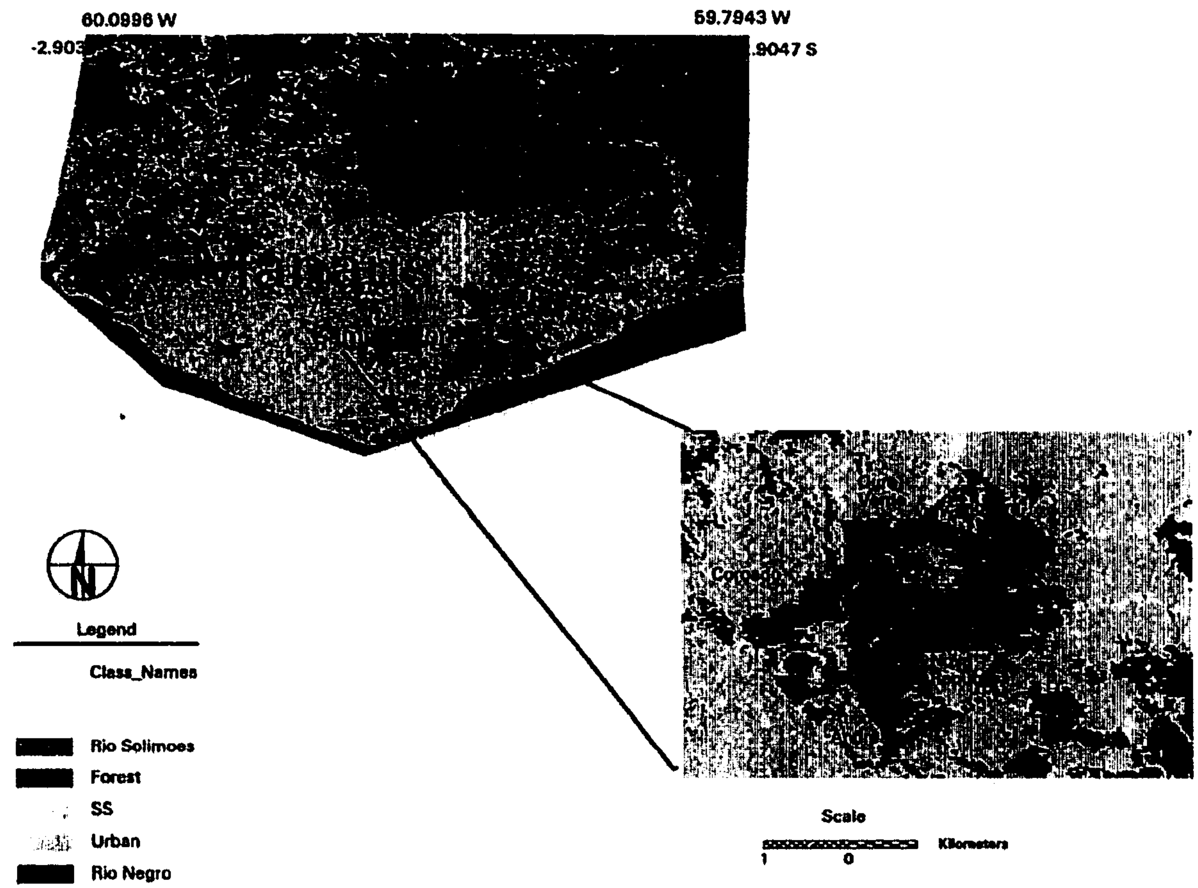
[10] Training samples (TS) are generally referred to as areas of known identity that are used during remotely-sensed image classification processes.

Having the three images classified with the 5 selected classes (forest, secondary succession, urban, Rio Solimoes and Rio Negro), a land cover transition matrix[11], using the supervised classification from MSS 1977 and TM 1988, and also TM 1988 and 1995, was developed to calculate the land cover changes over the three dates. The results of this analysis are presented in Chapter 3, Section 3.3. A subset of the Campus Forest area was taken from each of the classified images. Then, a transition matrix was developed to show the land cover change inside of the Campus Forest using 1977 and 1988 images, and also 1988 and 1995 images. The results of this analysis are presented in Chapter 5.

In addition to study area characteristics and the methodological procedures presented in this chapter, the next chapter presents and discusses the historical human occupation of Manaus and how humans have influenced forest changes over time in the Manaus area. The current ecological characteristics of the Central Amazon forest types are then discussed in detail, including an examination of the horizontal and vertical structure of the dense forest, and also the characteristics of the secondary succession vegetation, to define a baseline to be used in Chapters 4, 5, and 6, which deal with hypothesis testing.

[11] Matrix analysis "produces a thematic layer that contains a separate class for every coincidence of classes in two layers" (ERDAS, 1997). Thus, for both land cover change analyses I undertook two transition matrix analyses to cover the three images dates.

Figure 2.1. Location of the study area showing the Campus Forest and the surrounding neighborhoods in the city of Manaus, state of Amazonas, Brazil. (from supervised classification of a landsat TM 1995)



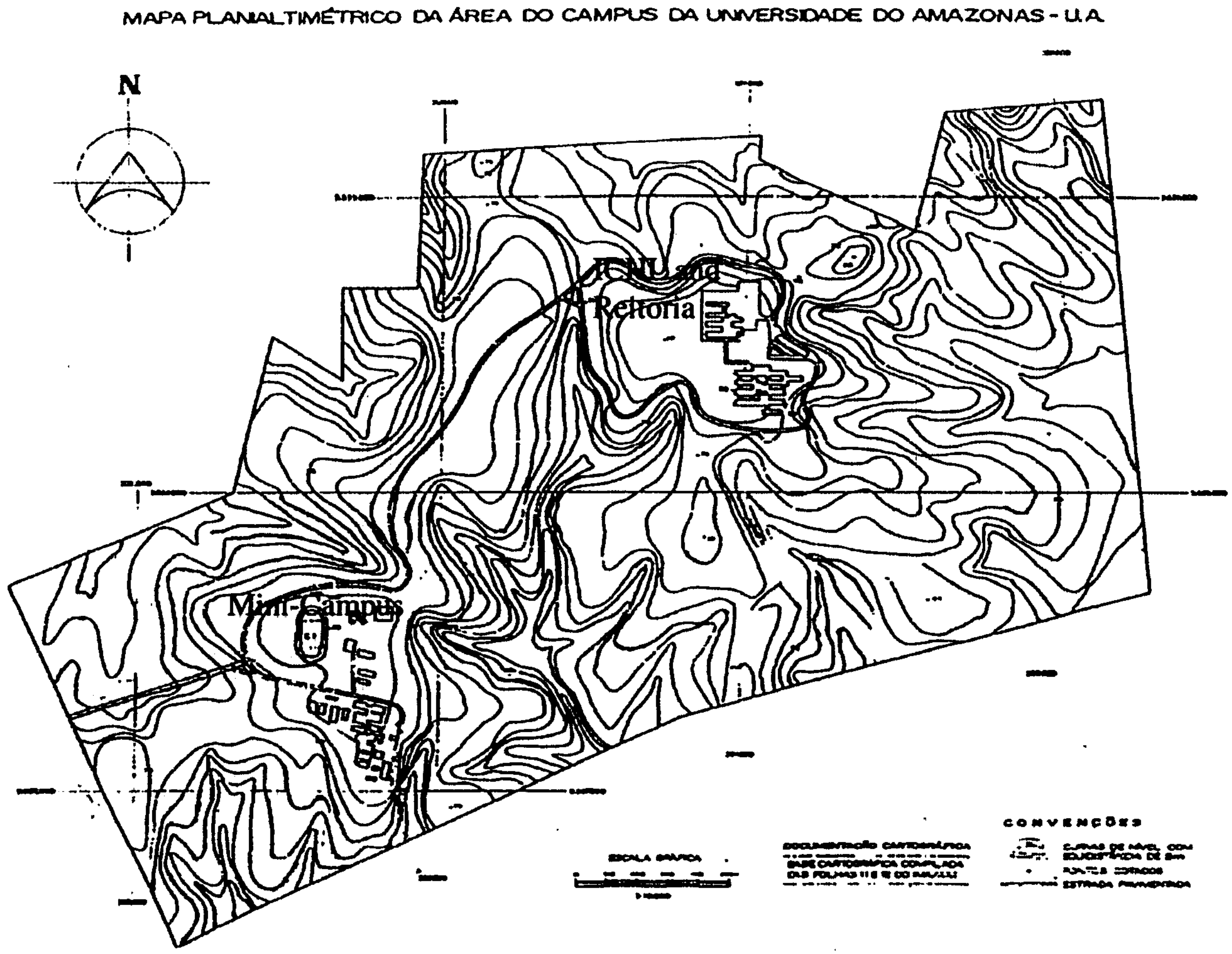


Figure 2.2. Topographic map of the Campus of the university of Amazonas, showing the location of the buildings on the two main plateaux

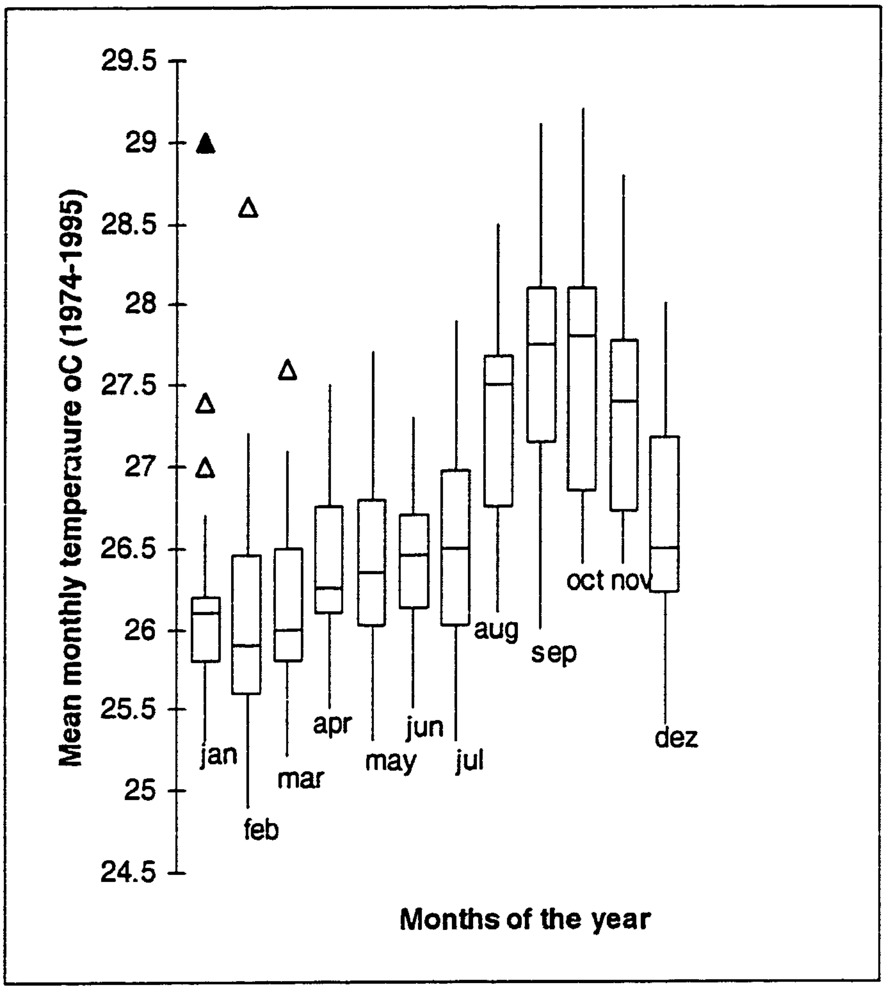


Figure 2.3. Distribution of mean monthly temperature (°C), in Manaus, AM, between 1974-1995 (data from INEMET- Agricultural Ministry District)

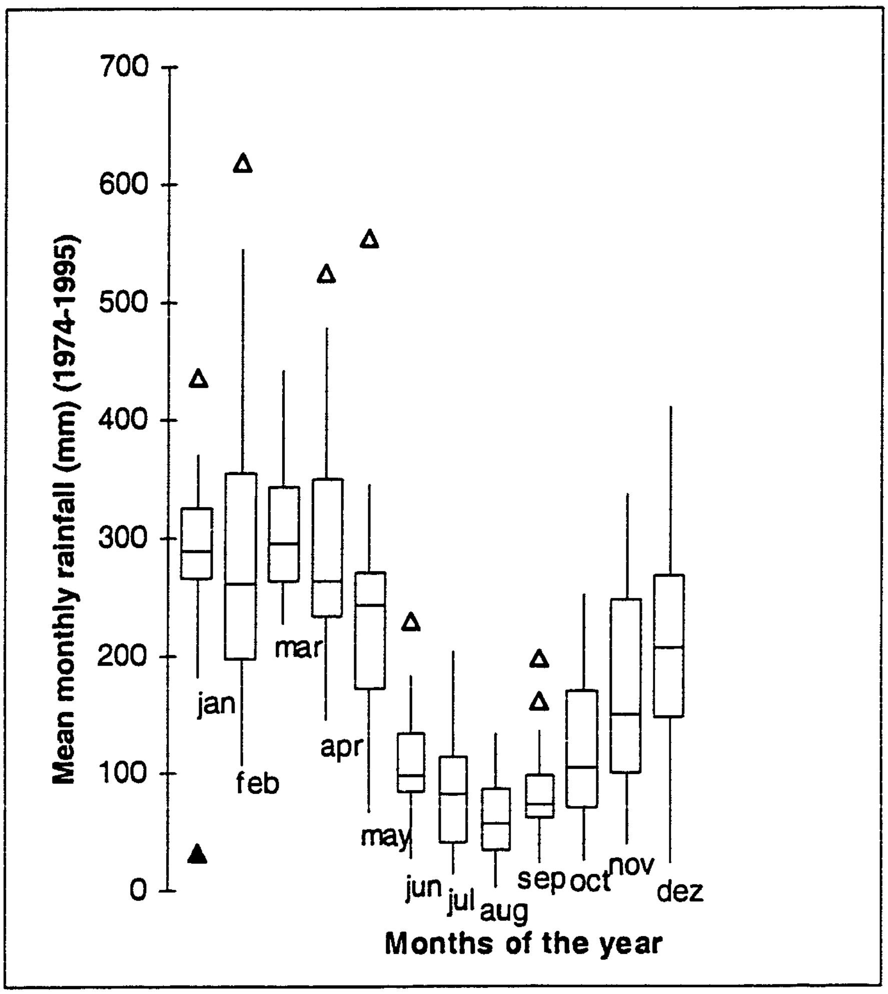


Figure 2.4. Distribution of mean monthly rainfall (mm) in Manaus, AM, between 1974-1995 (data from INEMET- Agricultural Ministry District)

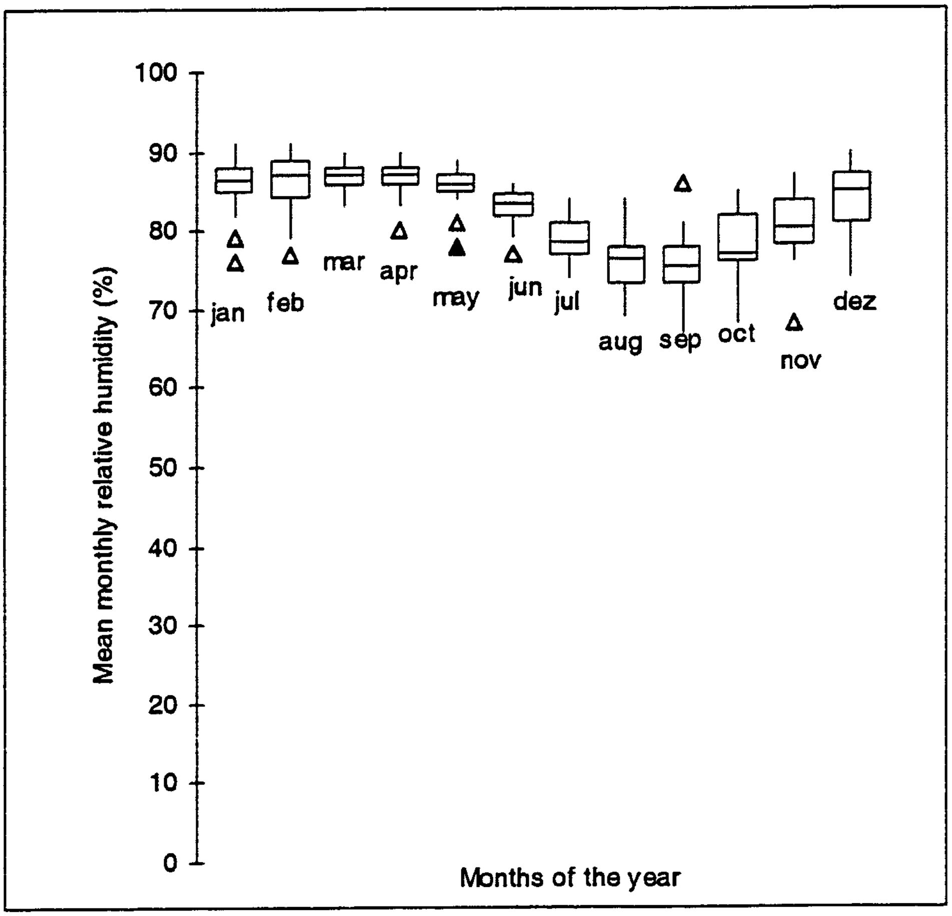
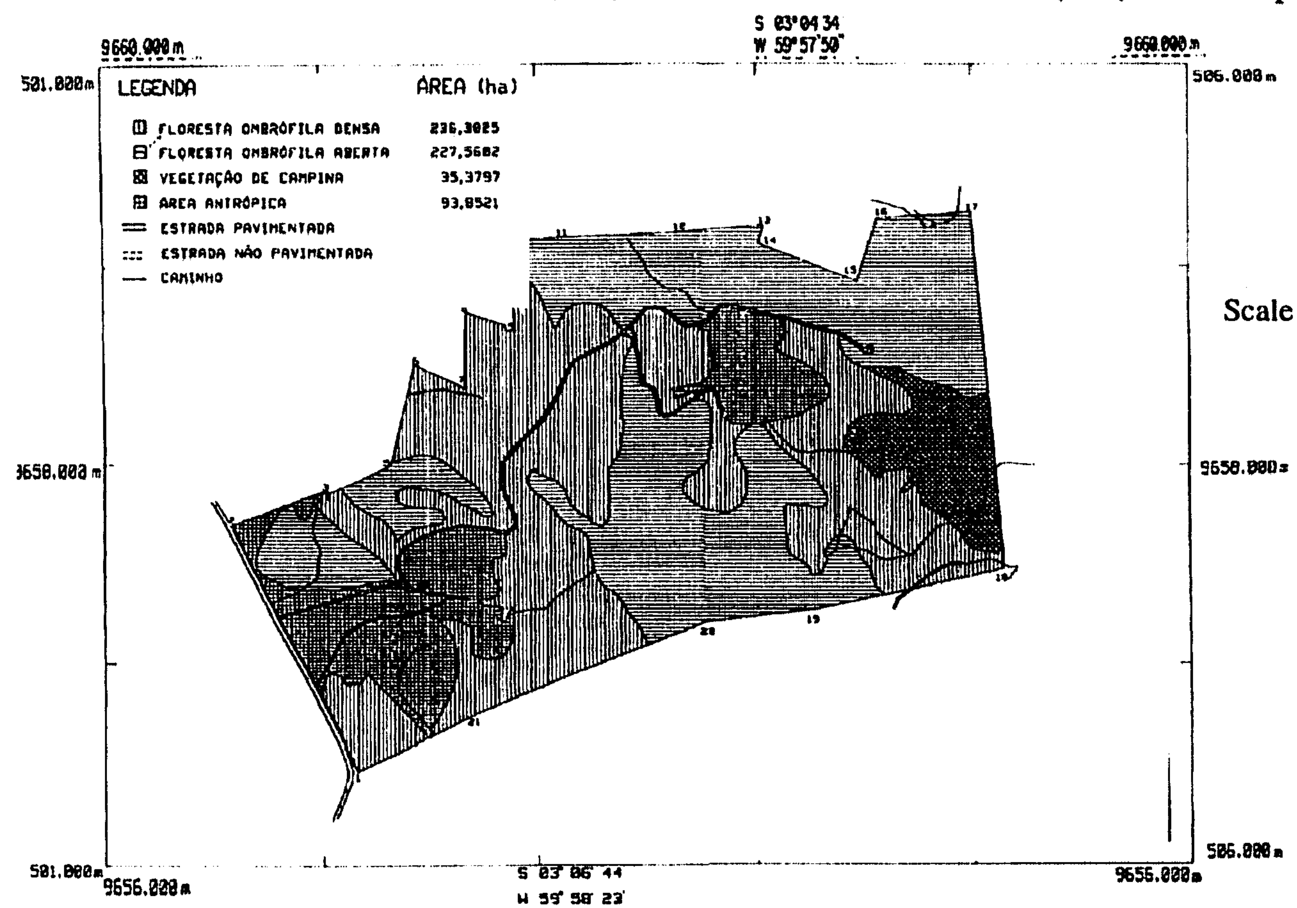


Figure 2.5. Distribution of the mean monthly relative humidity (%) in Manaus, AM between 1974-1995 (data from INEMET- Agricultural Ministry District)

Figure 2.6. Vegetation map of the Campus Forest developed by Coutinho (1994), showing the spatial distribution of Floresta Ombrofila Densa (OD), Floresta Ombrofila Aberta (OA) and Campinarna (CC)



Scale 1: 7,500

Figure 2.7. Vegetation map of the Campus Forest developed by Izel and Custodio (1996), showing the spatial distribution of Floresta Ombrofila Densa (OD), Floresta Ombrofila Aberta (OA), and Campinarana (CC)

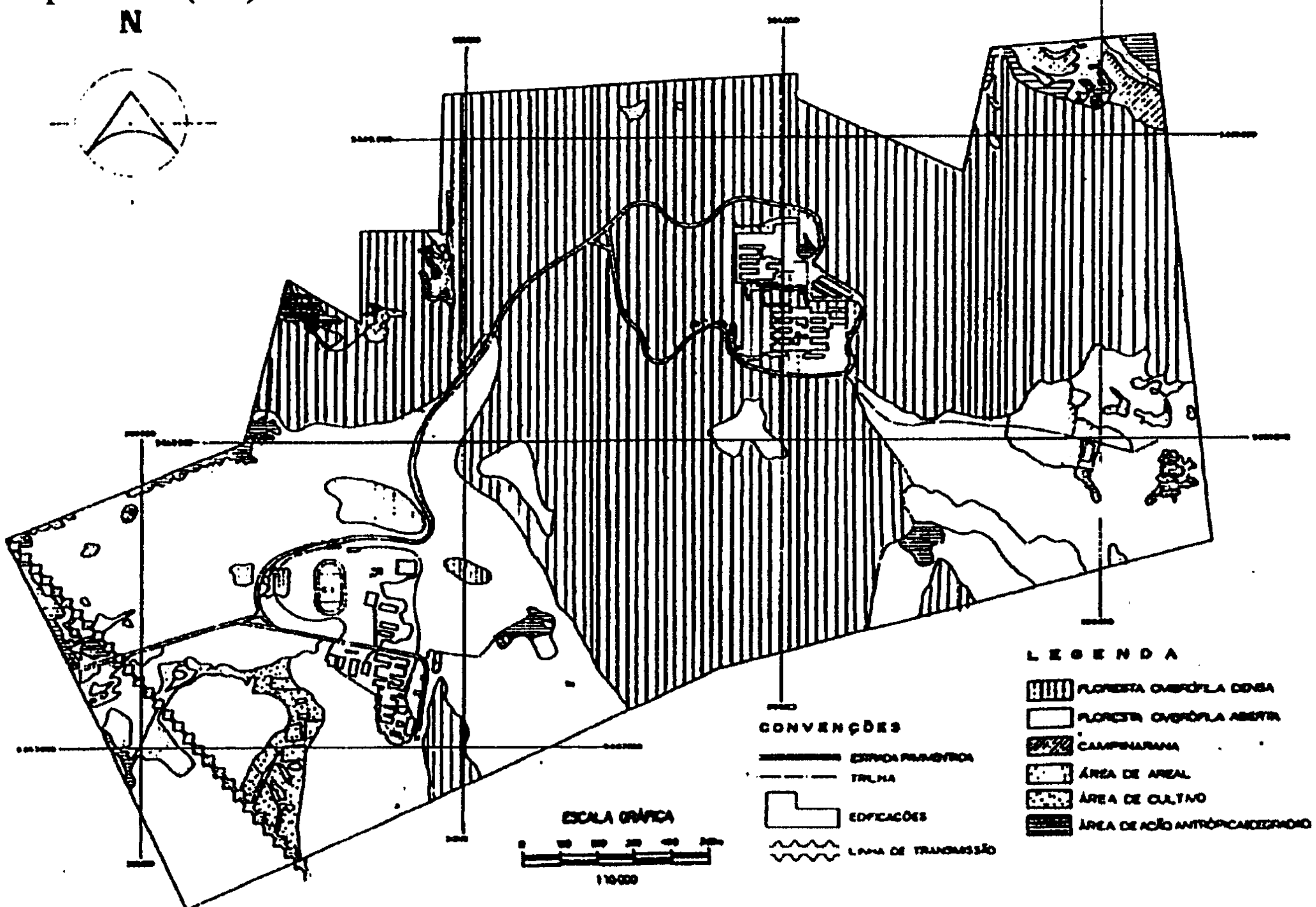


Figure 2.8. Spatial distribution of the proposed types of vegetation zones (1. dense forest, 2.open forest, 3. Campinarana) showing also the limits of the Campus forest and the neighborhoods around the forest. Landsat TM 1995 RGB, 543.

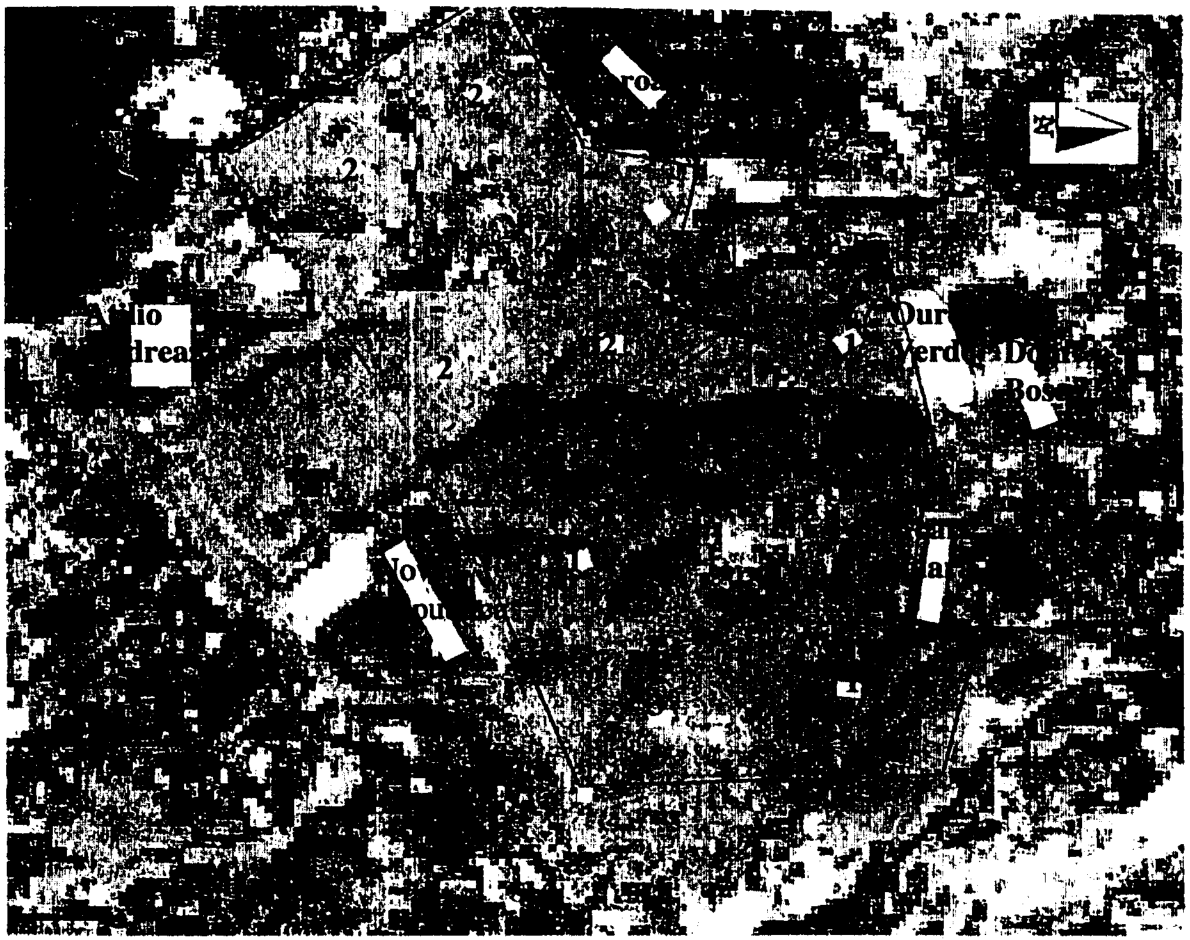


Table 2.1. Summary of IFRI research instruments

IFRI Form	Information Collected
Site Overview	site overview map, local wage rates, local units of measurement, exchange rates, recent policy changes, interview information
Forest Form	size, ownership, internal differentiation, product harvested, uses of products, master species list, changes in forest area, appraisal of forest condition
Forest Plot Form	tree, shrub, and sampling size, density, and species type within 1, 3, and 10-meter circles for a random sample of plots in each forest, and general indications regarding forest condition
Settlement	sociodemographic informatiom, relation to markets and administrative centers. geographic information about the settlement
User Group Form	size, socioeconomic status, attributes of specific forest user groups
Forest Association Form	institutional information about forest association (if one exists at the site), including association's activities, rules structure, membership, record keeping
Forest-User Group Relationship Form	products harvested by user groups from specific forests and their uses
Forest Products Form	details on three most important forest products (as defined by user group), temporal harvesting patterns, alternative sources and substitutes, harvesting tools and techniques, and harvesting rules
NonHarvesting Organization Form	information about organizations that make rules regarding a forest(s) but do not use the forest itself, including structure, personnel, resource mobilization, and record keeping
Organizational Inventory and interorganizational Arrangements form	information about all organization (harvesting or not) that relate to a forest, including harvesting and governance activities

From IFRI Manual (Ostrom, 1996: II-4)

Chapter 3

THE HUMAN OCCUPATION OF MANAUS AND ITS INFLUENCE ON THE FOREST CHANGES IN MANAUS' URBAN AREAS

Information on the study area and the methodologies used in this dissertation was presented in Chapter 2. The current chapter deals with the human occupation of Manaus from pre-historical times until 1995 and its influence on changes in the forest. It is divided into three sections. Section 3.1 examines evidence related to the pre-historical populations that lived around Manaus. Next, it traces European occupation of the Manaus region, which lasted nearly five centuries from 1500 to 1960. Included are the embryonic stages of settlement, passing through "the Paris of the Tropics," until the advent of the rubber crisis that left the city of Manaus in stagnation for a half century.

The contemporary occupation of Manaus is discussed in Section 3.2. This section is based on data from the literature and information derived from three remotely sensed Landsat images. Land cover change analysis spans the dates 1977, 1988 and 1995 and reveals the rapid urbanization process that took place in Manaus and its influence on deforestation and forest fragmentation in and around Manaus' urban and semi-urban areas.

In Section 3.3, the ecological characteristics of the Central Amazon forest fragments are presented. First, the different classifications used for Amazon vegetation are discussed. General characteristics of the three main Central Amazon types of vegetation are presented. Then, the horizontal and vertical structure of dense forest is examined based on several forest surveys undertaken within that region. Finally, the ecological characteristics of secondary succession vegetation and some measures used to differentiate them from old growth forests are outlined. A baseline is defined and used in the following chapters, which deal with hypothesis testing.

3.1. Pre-history and five centuries of human occupation of Manaus

The Amazon rain forest has long been considered a pristine ecosystem following Clements' ecological community succession theory which stressed the unidirectional, exclusively progressive course of succession in the absence of disturbance to an inevitable and fixed climax. However, several recent studies have challenged the "natural stable climax" approach to the Amazon rainforest by showing evidence of dry season fires[1] associated with human actions. Balee (1989) has argued that cultural factors [2] (e.g., human factors) were significant in the formation of the several upland Amazonian forest types. Using several plant species[3] and other indicators such as the presence of ceramics and charcoal as evidence of past human occupation, he classified several cultural forest

[1]Currently the recognition of the effect of Pleistocene climate changes on the vegetation of the Amazon (Damuth y Fairbridge, 1970; Van der Hammen, 1972, 1974; Van der Hammen & Absy, 1990) has been accepted by most scientists working in this area (see Haffer, 1969; Brown, 1972, 1976; Prance, 1973, 1978). The wide-spread occurrence of vegetal charcoal in this large area has corroborated the idea that the Amazon forest has been disturbed and shaped by natural and human induced fires (see Saldarriaga, 1994).

[2]In several other parts of the Amazon (lowlands of Bolivia, Colombia, Venezuela, Peru and Guiana), evidence proves the strong role of pre-historical Amerindians in manipulating their environment (Denevan, 1966; Denevan and Zucchi, 1978; Lathrap, 1970).

[3]Several Amazonian cultivated plant species, especially palms, are cited as indicators of past human occupation when found in "primary forest" (see Ferreira, 1983; Andrade, 1983; Balick, 1984; Balee, 1989, 1994).

types: (1) Mata de cocais (*Orbignya phalerata* forest); (2) Palm Forests; (3) White sand Campina; (4) Mata de bambu *(Gradua spp.* Forest); (5) Apetê Forest (forest island in the central Cerrado); (6) Castanhais (*Bertholletia excelsa* Forest); and (7) Mata de Cipó (vine forest).

Although the archeological evidence found in lowland South America falls short of making one confident about the size and spatial mobility of pre-Colombian populations, several estimates have been made to calculate[4] population numbers and understand how the Amazon forest peoples lived and used their environment. According to several studies, the lowland tropical forest culture was based on hunting and gathering from 12000 to 1000 (B.C.), and the development of slash and burn agriculture began between 5000 and 3000 (B.P) (Lathrap, 1970; Meggers, 1971, 1982; Roosevelt, 1980). According to Correia et al. (1994), in the beginning of the Christian Era, the Amazon was totally occupied by groups of different cultural patterns. Most of them based their subsistence on slash and burn agriculture[5].

The pre-history of the Central Amazon, specifically of Manaus, is not well known. Studies developed in the last two years by a group of archeologists, however, have shown some evidence of the continued human occupation of Manaus during the last three

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[4] Using historical information collected after the 1500's for voyagers, several authors have calculated the pre-Colombian indigenous population of the Amazon. The numbers are very controversial and can vary from 500,000 (Moran, 1974) to 6,000,000 (Denevan, 1976).

[5] Slash and burn or shifting cultivation is still the most common form of agriculture in the Amazon. Clearings are opened in the original forest during the dry season, the cut vegetation is allowed to dry and is then burned. Crops are planted at the beginning of the rainy season. The cultivation period lasts from one to two years. Afterwards, the areas are abandoned during a long fallow period, sufficient for the regeneration of the site quality prior to cutting the secondary succession in preparation for the next cropping period (Silva-Forsberg & Fearnside, 1997).

thousand years (E. Neves, personal communication). According to Neves, the urban area of Manaus had many archeological sites which were recently destroyed. Eduardo Neves' team also found 19 archeological sites around Manaus (close to the Amazon and the Negro River) and information about several others which they have yet to investigate. Three of those sites were very large-- the largest covering about 400 hectares. All of them have *terra preta de indio* (Amerindian black earth) of a depth of more than 1 meter. This information demonstrates that the Manaus area was highly populated before the European arrival and the Amerindians were intensely modifying the environment. Manaus was also described as a highly populated area by the first Europeans to arrive in the area-- lead by Francisco de Orellana in 1542 (Carvajal, 1941)

3.1.1. European Occupation of Manaus: 1500-1960.

Several European explorers traveled through the Amazonian lands at the beginning of the 16th century, even before Pedro Alvares Cabral, the official discoverer of Brazil in 1500. However, it was Francisco de Orellana who was the first to sail the Amazon river from Peru to its mouth at Belem, Brazil, passing through Manaus where the Amazon River meets the Rio Negro, Orellana reached the land which today is the city of Manaus on June 3, 1542 and gave the Rio Negro its name. According to Gaspar de Carvajal, Orellana's chronicler, it had water "black as ink." In that time, the Amazon River was described as a highly populated area. The Rio Negro where Manaus was later established, was inhabited by several Amerindian groups. According to Bessa Freire (1994), the majority of these groups spoke the Arawak language. Among those groups, three are known to have faced conquerors: the Manaos, the Bares, and the Taruma. The occupation of Manaus reflected the Portuguese colonial economic policies.

The first phase of Portuguese colonization of the Amazon was characterized by the establishment of Catholic missions and Amerindian slavery. The initial goal of the Portuguese Crown in the Amazon was to secure its domain against the threat of foreign occupation. In order to establish and defend territorial sovereignty, the expansionist policy of the Portuguese Monarchs resorted to missionary activities (Dussel, 1982). During that time, the missions controlled the majority of Aldeias, villages where Amerindians were "domesticated," "Christianized" and forced to work for missionaries, the colonial government and white settlers (Fragoso, 1982).

The first occupation of the current Manaus county was made by slaving expeditions, known as *"tropas de resgate."*[6] The first *tropa* arrived and settled an *arraial*[7] in 1657 at the mouth of the Taruma River. That *tropa* left Sao Luiz do Maranhao on June 22 (Acuna, 1891), captured Amerindians and came back to Belem. Each year, until 1661, the missionaries lead *tropas de resgate* to the Rio Negro and captured more than 5,000 Amerindians to be enslaved in Belem (Bessa Freire, 1994). Besides slaves, the Tropas were also looking for spices or *drogas do sertao*[8]

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[6] *Tropas de resgate* was a group of Portuguese, in general, headed by army officials to hunt Amerindians to supply slave labor force to the Brazilian civilian colony.

[7] Small village.

[8] Rain forest products collected by Amerindians with high demand in the European markets.

Fortaleza de São José da Barra: the Embryonic stage of a settlement (1665-1840)

Until 1665, the current Manaus area was only temporarily inhabited by Europeans. Each year, the "tropas" came into the area, stayed long enough to capture slaves and drogas do sertao, and returned to Belem. However, after that time, the Portuguese concerned with the threat of foreign occupation, started to build a military fort on the left bank of the Rio Negro. In 1669, lead by Captain Francisco de Mota Falcao, the construction of the fort was started (Ypiranga Monteiro, 1994). The fort maintained its function of avoiding foreign invasion, mainly Spanish, for more than a century. Alexandre Rodrigues Ferreira, in his "Viajem Filosofica ao Rio Negro," reported that the fort had approximately 200 hundred soldiers in 1774 (Ferreira, 1983). Around the fort, a small settlement was created and developed with the help of the Carmelite missionaries. In 1695, a church covered by palm leaves was built. Sampaio (1825) reported that several Amerindian families went to Lugar da Barra, attracted there by the Carmelites; among them Pace, Bare, Baribas and Juris. However, Bessa Freire (1994) argued that Barra struggled with problems to grow as a village because most of the individuals there were itinerant. Barra was an "Amerindian storage" where they were left until they were sent to Belem as slaves or rented to Whites for collecting drogas do sertão.

For more than a century, the Lugar da Barra experienced political, demographic and economic stagnation. By 1786, Alexandre Rodrigues Ferreira estimated Barra's population to be around 301 inhabitants (47 Whites, 243 Amerindians, and 11 African slaves). The village had a church, a ceramic shop and 45 households (Ferreira, 1983). At the turn of the 19th century, the Lugar da Barra continued to be an insignificant village of the Capitania de Sao Jose do Rio Negro, whose capital was located at Barcelos. Barra only started to experience some development when the governor, Lobo d'Almada, transferred the capital of the Capitania of São José do Rio Negro from Barcelos to Barra. During that short period, d'Almada built several buildings for public service as well as shops to manufacture cotton and indigo. However, afraid to lose power to Dom Francisco Couto, governor of Para, made appellation and the capital returned to Barcelos in 1798, determined by a Carta Regia (Royal Letter) (Reis, 1989).

Only in 1808 did Barra receive its permanent status as capital of the Capitania of the Rio Negro. In 1809, according to the naturalist H. W. Bates, Barra was the principal town of the Rio Negro, attracting Portuguese and Brazilian migrants from other provinces (Bates, 1979). Germans Karl Martius and Joan Von Spix reached Barra in 1819. According to them, its population was around 3,000 inhabitants, but only a portion lived in the "urban" part of the village. They described Barra as a settlement established in an "uneven land carved by several streams," stating that its houses were mostly built wattle-and-dumb and covered by palm leaves.

Barra improved somewhat by the end of the colonial period when the state of Para was divided into three comarcas (districts): Grão-Pará, Baixo Amazonas (Lower Amazon), and Alto Amazonas (Upper Amazon). The Capitania of Rio Negro was replaced by the Comarca of Rio Negro, and Lugar da Barra received the Status of Vila (village), named Vila de Manaos, the Capital of the Comarca (Reis, 1989). At that time, the improvement of Manaos was evident in descriptions of Alcides D'essalines d'Orbigny in his "Viajem Pitoresca Através do Brasil" where he explained that the Vila had European style houses, a beautiful church in the square, wooden bridges on two streams, and a hospital being constructed. He also noted that Manaos had several shops where women manufactured cotton fabric and cord (D'orbigny, 1976).

"Cidade da Barra do Rio Negro": Building a City (1840-1870)

Historically, the area covered by the Capitania de São José do Rio Negro (now the state of Amazonas) was forgotten by the Colonial authorities located in Rio de Janeiro. The remote Amazon region, mainly the Rio Negro basin, was only a concern for the Crown when foreign nations tried to occupy the area. Portugal began to pay attention to the Amazon when it lost the Indian trade and needed to stabilize its economy. According to Gondim (1996) the voyage made down the Amazon by Alexandre Rodrigues Ferreira in 1786 illustrates the intent of the Portuguese Crown to know more about the economic possibilities of the region.

International pressure to open the Amazon to other nations increased after 1840. In 1845, for instance, the state secretary from the US government appealed to Brazilian officials for permission to explore the Amazon River's natural resources (Medeiros, 1938). Those pressures forced the Brazilian Crown to make new decisions. In 1848, the Vila of Manaos was promoted to the status of city (Cidade da Barra do Rio Negro) and was finally named Manaus in 1856. Also, in 1850, Amazonas was promoted to a province, no longer dependent on Belem, and Manaus was named its capital.

International concerns related to the Amazon also stimulated many researchers, explorers and artists to travel through the region, leaving their impressions about the area. In 1849, Alfred Wallace arrived in the Cidade da Barra. As Martius and Spix had described, "the village was settled on a uneven terrain carved by two streams with bridges." Wallace added that the streets were irregular, full of holes, which were very unpleasant to walk on at night (Wallace, 1979). In that time, Cidade da Barra had 16 streets, 2 churches, 1 square and about 4,000 inhabitants distributed in 243 houses (Bessa Freire, 1994).

During its first decade, Cidade da Barra faced many problems. Historically, as Capitania and Comarca of Para, Amazonas and Barra never had their own budget. The taxes collected there were sent to central officials in Belen who decided how much should be returned to the region. At that time, the lack of money, materials and qualified labor was a constant problem faced by the new officials in charge of building the new city. Otoni Moreira de Mesquita, in his "Manaus: Historia e Arquitetura (1852-1910)," provided the details of the embryonic phase of Manaus by describing the complaints left in the officials' reports (see Mesquita, 1997). In addition budget problems, early Manaus was also affected by the decrease of the traditional labor force provided by Amerindians. That fact is stressed by Bates when he returned to Manaus in 1859. Nine years after his first arrival, Bates described Manaus as a city in decadence. According to him, the Amerindians started to flee from the settlement as soon as they knew about the law that protected them against forced labor. The new Amerindian conditions also affected agricultural production. Bates noted the scarceness of basic products. For instance, not enough manioc flour was produced to supply the local demand. All products were imported from elsewhere. According to Bates, the White families who settled in Manaus were not interested in cultivating the land. Their only interest was with market and government affairs (Bates, 1979).

From 1840-1870, several other foreigners recorded their European impressions of Manaus. Agassis (1865) described the city as an "arrangement of houses where part of them were in a state of decomposition" and made ironic comments about the local "public buildings". Keller-Leuzinger (1874) stated that "besides its status to be the capital of the Provincia of Amazonas, Manaus is an insignificant city... streets without any pavement and standard, and with primitive houses without any care for architectural fashion". In that time, Manaus was "an exotic urban agglomerate", mixing native and western traits that were different from the European standards (Mesquita, 1997). The urban aspects of Manaus followed much more the ecological aspect of the region and used local materials such as clay, wood and palm leaves.

The Rubber Boom and Manaus' emergence as "the Paris of the Tropics" (1870-1920)

A new economic era, however, was about to start in the Amazon which would dramatically change the city of Manaus. In 1827, the Amazon began to export rubber[9]. New technological tests using rubber began in Europe at the end of the 18th century and

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[9] Rubber is a vegetal gum produced by ***seringueira***, a native tree from the Amazon rain forest named ***Hevea brasiliensis***. To obtain the rubber product, the seringueira milk, or latex, was tapped, coagulated, smoked, and stored in a big ball to be exported.

early 19th century. Thomas Handcock and Charles Macintosh in Europe and Goodyear in the US were responsible for the new uses of rubber and its commercialization, which grew at an enormous rate with the advent of the automobile industry (Santos, 1980; Prado, 1945)

The Amazon rubber extraction was located around Belem during 1820-1840, but it spread to the hinterlands and by 1850, the Amazon had achieved a significant volume of production due to the international demand (Santos, 1980). After 1850, rubber extraction attracted millions of migrants, mainly from the northeast of Brazil, to the Amazon, which had historically had a scarce labor force. In 1877, the region experienced an intense migration process driven by a severe drought in the northeast that forced families to look for other alternatives outside of that region, and the attractive promises of good jobs and a better life offered by rubber barons and Amazon government officials. By 1872, the population of the Amazon was around 58,000 inhabitants, not including Indigenous peoples, began to be counted only in the 1990 census. Most of the migrants went to remote areas of the forest (e.g., to the Purus and Madeira basin), places naturally rich in *Hevea brasiliensis.* They only used Manaus as a bridge between their home and the forest. However, many of them stayed in Manaus, forming the labor force used to build the urban public infrastructure. In that period, Manaus also attracted foreigners and Brazilians from other regions who together significantly impacted the demography of the city, increasing its population from 5,000 inhabitants in 1870, to 9,000 in 1885, 20,600 in 1890, 30,000 in 1900, and around 70,000 in 1915 (Souza, 1873 cited by Mesquita, 1997; Ypiranga Monteiro, 1994; Bessa Freire, 1994).

The increasing European and American demand for rubber transformed the Amazonian economy. The Amazon region supplied most of the world's demand for rubber until the first decade of the 20th century (Santos, 1980). Rubber's economic power promoted the consolidation of a system of hierarchical trading relationships based on credit and indebtedness, called *aviamento*[10].

That system created a pyramid where the Barons and the businessmen who were the rubber store landlords controlled the import-export trade and controlled the terms of exchange, which provided them with huge profits. At the bottom, were the *seringueiros* extracting the product from the forest and living in conditions of semi-slavery. While the *seringueiros* were living in the forest collecting the "green gold", the Rubber Barons lived in the cities, and Manaus grew and was transformed to support their demands.

The city built modern urban infrastructure based on European styles. With increasing money flow from rubber exportation, new technologies and the support of European enterprises, several public services were installed in Manaus such as a residential water, electricity, disposal services, telephone, telegraph and a floating harbor. The construction of public buildings such as *Teatro Amazonas, Instituto Benjamin Constant, Palacio da Justica, Palacio do Governo, Palacete da Imprensa Oficial. Palacio Rio Negro, Casa de Detencao de Manaus, Biblioteca Publica and Igreja dos Remedios* (Mesquita, 1997) happened quickly, as well as a system of banks, stores, hotels, restaurants and cabarets, all following European styles, particularly French which was the

[10] *Aviamento* is a word from the Portuguese verb "*aviar*," which refers to the advance of capital or goods on credit, to be repaid with products of extraction. The term *aviamento* is equivalent to the English colloquial term "grubstake" (Whitesell, 1988).

culture and language preferred at the time. Thus, Manaus became a modern city with European characteristics, entering into the delirium of the *belle-époque* (Mesquita, 1997). However, the cornucopia of the "Paris of the Tropics" was only available for the rubber elite. The majority of Manaus' population continued to live in houses with miserable sanitary conditions. In that time, Manaus contained around 10,400 households. More than 50% were very poor and did not have basic urban facilities such as electricity and sewage (Bessa Freire, 1996).

Manaus' environment also changed completely in that period. New streets, boulevards, squares and yards were projected. The sloped terrains were flattened and streams filled, opening space to build the two principal avenues of the city. As a consequence, the city lost its Amerindian appearance. Manaus not only lost its Amerindian characteristics by replacing its traditional houses, streets and squares with European ones, but also by replacing part of its forest areas with urban construction, leaving few trees in the urban areas. By 1888, the president of the City Counsel was already asking for an urgent urban reforestation program to control the "hot weather" of Manaus (Mesquita, 1997).

The rubber crisis and the subsequent half century of stagnation

Manaus would experience the glamour of being Paris of the Tropics for only a short period of time. At the end of 19th century, Henry Wickham stole 60,000 *seringueira* seeds and sent them to the Royal Botanical Gardens at Kew, London. The seeds were planted at Kew Gardens, and later replanted as seedlings in Southeast Asia in a managed plantation system which ultimately dismantled the monopoly of the Amazon rubber elites (Santos, 1980; Souza, 1994; Gondim, 1996). With rubber production dominated by Asians' who could supply international demand with a better quality final product at a lower price, the Amazon rubber exporters lost control of the market. By the first decade of the 20th century, Amazon rubber exportation steadily decreased year by year, and Manaus entered into decay, losing its status as a commercial port. The city was abandoned by thousands of people, among them many northeasterners who received governmental incentives to return to their former towns (Souza, 1994). Based on the regional economy, the city could not maintain the urban infrastructure that had been gained during the rubber boom and thus entered a period of decline.

The post-rubber economic crisis transformed the Amazon, especially Manaus, into a desolate place. That situation was also reflected in the political arena. In 1924, the military began to take control over the regional political space. In that year, Lieutenant Ribeiro Jumior took over as the governor of Amazonas. With his military followers, public officers and other poor workers, he controlled the political power in Manaus. Generalized corruption, expropriation decrees and invasion of rich houses were common. The situation was controlled only when military troops coming from the state of Para threw them out (Souza, 1994). During this time, the state population decreased and the rural people returned to their traditional subsistence activities such as gardening, fishing and hunting. Despite its decline, Manaus continued to slowly grow demographically during the first half of the century due to regional rural to urban migration.

During the Second World War, however, Amazon rubber was again needed to supply the Allied countries' wartime demand. The Brazilian government made an agreement with the US to supply the Allied international demand and the Amazon reactivated its *seringais*. During this time, the services of the *Servico Especial de Saúde Pública* (SESP) were established in the region, and since then, these health services have plied the waters, providing medical service and education in towns throughout the region, with central offices in Manaus and Belem. Yellow fever and malária, for instance, were brought under control by the use of DDT, antimalarial medications and health education (Wagley, 1974).

Manaus entered into a euphoric economic period again where new jobs and good salaries were offered by the offices associated with rubber production. Nevertheless, this was a short period and ended with the war. The improvements made in the medical field and urban facilities were maintained. Nevertheless, many human lives were lost in the *seringais* to support the rubber war demands. The Constitutional Congress Commission concluded that more than 20,000 workers died in the *seringais* during that period. Many more people died in the *seringais* than in the *Força Expedicionária Brasileira* sent to Italy to help the Allied forces (Souza, 1994).

During the 1950s and 1960s, the urban area of Manaus increased again. In 1951, the spatial urban area of Manaus was around 3,000 hectares (Municipal Law # 367 of July 28,1951), and in 1966 by had grown to 12,000 hectares (Law #964 of May 2, 1966). In 1953, the Brazilian government created the *Superintendência do Plano de Valorização da Amazônia* (SPVEA) with the purpose of developing the Amazon by investing 3% of the total federal tax funds in the region. However, this SPVEA project failed basically because it invested in subsidizing projects related to extractivism, such as, offering bank credit for rubber production, which were not economically profitable, and excluded incentives for crops such as black pepper and *jute*[11]. In the early 50s jute and black pepper were introduced in the Amazon by Japanese immigrants. Black pepper was spread to the Bragantina Zone, transforming the Amazon into the top world producer until 1970.

Jute was introduced in the Amazon lowland (varzea) in the Lower Amazon, mostly in Santarém (Pará) and Parintins (Amazonas), but also in Manacapurú, a small city located close to Manaus. Jute production grew in the beginning of the 1940s reaching 1,100 tons, increasing to 39,000 in 1960, and 54,000 in 1964. Thus, once again, Manaus served as a peripheral mercantile entrepot for trade in extractive commodities, expanding and contracting with the boom-and-bust cycles of resources extracted from the vast forests and rivers of the Upper Amazon Basin. After the 1960s, however, Manaus changed its economic and urban profile.

Since the construction of Brasília in the 1950s, the Amazon frontier became again a focus of attention in the political integration and national economic growth strategies. Occupation of the region needs to be understood through the philosophy and strategy for regional development formulated by the Brazilian military. The 1964 military takeover in Brazil led to a number of changes in the Amazon. After 1964, they replaced SPVEA with SUDAM (Superintendencia do Desenvolvimento da Amazonia). The Program of National

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[11] Jute or Indian hemp (*Corchorus capsularis*) is a species of the Tiliaceae family used for fiber production (Gentil, 1988).

Integration (PIN) was established within which a second Plan for Amazon Development was spelled out in detail, including a creation of a duty-free port or Zona Franca (SUFRAMA) in Manaus to stimulate industrial development by reducing the high import tariffs in effect elsewhere in Brazil. The free port was associated with fiscal incentives for private investment in the Amazon, such as the possibility of allocating up to 50% of annual federal taxes into SUDAM/BASA-approved industries and agropastoral concerns (Moran, 1981). With the advent of the Zona Franca, Manaus changed drastically, as is demonstrated in the following section.

3.2. Contemporary Occupation of Manaus from the 1970s -1995

3.2.1. Manaus under the Era of the Zona Franca

The Zona Franca de Manaus (ZFM) was conceptualized as "an area of import-export free trade and special fiscal incentives in order to create an industrial, commercial and agropastoral center in the interior of the Amazon with economic conditions to develop the region" (Decree law 228 on February 18, 1967). The Zona Franca was installed in the Central Amazon region which had been a peripheral extractive economy, stunted by long-term regional isolation and economic dependence on resource extraction.

With the Zona Franca, the Amazonas public sector was able to attract national and foreign capital to the remote Upper Amazon by improving the physical infrastructure and providing generous fiscal incentives to investors. New roads were constructed in the state of Amazonas and an international airport was built to receive hundreds of people. These conditions helped the ZFM provide an export enclave for industrial growth, based mainly on the development of assembly plants manufacturing imported component parts (Browder & Godfrey, 1997). An industrial district was constructed not far away from the new international airport, about five kilometers from downtown Manaus. Development projects were exempted from import and export duties and from the manufacturers' sales tax (Depres, 1991). The incentives stimulated many national and foreign firms to settle in Manaus. SUFRAMA approved 140 development projects by 1975 and 811 were approved in 1991 alone, most of them in the electronic industry (Salazar, 1992).

With ZFM, Manaus expanded in all directions, invading the upland forest areas by following a model of mixed occupation, combining fast spontaneous occupation and efforts by city planners to organize the city's expansion. Its population grew from 173,000 in 1960 to 312,000 inhabitants in 1970, 634,000 in 1980, and by 1996 was 1,157,357 (Brasil, IBGE, 1960, 1970, 1980, 1996). The new industries, which planned to create more than 40,000 jobs in 20 years, were not able to integrate the huge number of native Amazonians who migrated from the interior to the capital, joining the mass of unemployed and under-employed workers (Bessa Freire, 1994).

Urban invaders created neighborhoods without any kind of urban facilities. The urban infrastructure of Manaus remained almost the same as in 1910, limited to the commercial and residential center. The *caboclos* who came from the interior, most of them landless, started to systematically invade the "unoccupied" space around the city. In 1969, the invaded area of Compensa received the name of "City of Palm" (Cidade de Palha), referring to the kind of material used to build the houses -- the same style used by the

Manao Indians who had resided in that area a long time before (Bessa Freire, 1994). By 1970, the north part of the Campus Forest (the study area of this dissertation) was invaded and the University of Amazonas lost 119 hectares of its forest land. The invasions created slums, without electric power, water, sewage, mired in the dust and mud, and connected to the city by precarious public transportation which had difficulty coping with the fast spontaneous occupation.

However, several neighborhoods were planned to attend to the demand of the middle class from the industrial and public sector. In the beginning of 1974, the COHAB-AM (Habitational Company of the Amazonas) built habitation parks sponsored by the National Habitation Bank (BNH) where around 7,600 houses were constructed. But to construct these parks, all the trees were cut down, leaving the landscape totally bare, and ignoring the regional ecological landscape, as can be seen in the next section.

3.2.2. Land cover change in Manaus from 1977 - 1995: a remote sensing analysis

As discussed earlier, the rapid demographic changes in Manaus under the Zona Franca Era, related to both the industrial installation plants and urban services, drastically modified the city landscape. The dramatic change can be seen clearly in remote sensing analysis using three image dates (Landsat MSS 1977, TM 1988 and 1995). The distribution of the five land cover classes derived from a supervised classification of Landsat MSS 1977 is provided in Figure 3.2.1. Even with the rapid changes that started in the late 1960s, by 1977 the Manaus urban area[12] was concentrated in a rectangle about 5 by 20 km in size along the east side of the Rio Negro. At that time, the urban area covered 6,434 hectares, representing 7.9% (Table 3.2.3) of the Manaus uplands selected for this analysis (see Chapter 2). In 1977, the Campus Forest and the Reserva Ducke[13] were still part of the same continuous forest patch.

In the short span of a decade (1977-1988), however, deforestation reached 10.7% of the Manaus area (Table 3.2.2). This dramatically increased the size of the city. The core urban area of Manaus increased more than 100% from 6,434 to 15,525 hectares (Table 3.2.3). Forest degradation, which describes the changes from forest to early secondary succession, also represented land cover change processes during that decade. An amount of 7,047 hectares of forest was cut down and began to regrow during 1977-88 (Table 3.2.2). By considering the two land cover change processes together, it is possible to determine that around 19% of the Manaus forest area was cut down to be used as urban commodities. But it is also important to note that afforestation and regrowth occurred

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[12] It is important to remember that "urban area" here means the area which is or was cleared or is in bare soil, not the municipal legal urban area. Thus, to avoid confusion I am using "core urban area" instead.

[13] Reserva Ducke is a 100-km² forest reserve created officially in February 1963 when the government of the state of Amazonas donated to INPA (the National Amazon Research Institute) that patch of Central Amazon Forest to be preserved. Its creation was proposed by the Brazilian botanist Adolph Ducke in 1954 (Barros et al, 1969). However, only in 1972 was Reserve Ducke transformed into a Biological Reserve. During the first 12 years, 1960-1972, INPA developed several silvicultural projects using the reserve as an experimental station for forest enrichment, forest nurseries and the establishment of plantations of useful native tree species. Besides the areas used for silvicultural experiments, 1,479 ha were partially cut by a Manaus industrialist who invaded the reserve area, and a small part of its south side was invaded by inhabitants of Cidade Nova, a result of the urban expansion of Manaus. Nevertheless, over 90% of the reserve remains untouched by both silvicultural experiments and invasions. According to Prance (1990) "it's one of the most intensively researched patches of the Amazonian forest by many disciplines" due to its localization near Manaus and the scientists of INPA.

during that period as well. Nevertheless, these processes only account for 5% of the land cover change in the area (Table 3.2.2).

Land cover change in Manaus between 1977-1988 occurred almost totally on the west side of the city where Cidade Nova, São José I, II, and III were established, just to cite a few of the neighborhoods created in that period (see Figure 3.2.2). Besides deforestation and forest degradation, another process evident on the west part of the city was forest fragmentation, which almost isolated the Campus Forest. The Campus Forest and Reserva Ducke, which were part of just one forest corridor, became totally separated (compare Figure 3.2.1 and 3.2.2). The Campus Forest was transformed into an urban forest fragment but for 2 or 3 small forest buffer areas (see Figure 2.8). By 1988, the borders of the Reserva Ducke also came to be more easily visualized through remote sensing images (Figure 3.2.2). A large part of the forest located on its southern limits was cleared along with other small patches around the reserves borders. Thus, during the decade of 1977-88, the urbanization process in Manaus not only almost transformed the Campus Forest into an urban forest fragment, but also started to transform the Reserva Ducke into a peri-urban forest reserve.

In the next seven years, 1988-1995, total deforestation in Manaus followed the same trend as in the early decade, reaching 8.4% (Table 3.2.2). More than seven thousand hectares of forest were cleared. Still, the area experiencing forest degradation was much smaller than that of the earlier decade. While during 1977-1988 deforestation and forest degradation affected 19% of the Manaus forest area, from 1988 to 1995 these two processes together explained only 11 % of its land cover change. However, afforestation was as high as deforestation in Manaus during that same period. Around 6,898 (8.2%) hectares of land returned to forest, and 2,407 (2.9%) hectares turned into early secondary succession. Afforestation and forest regrowth also explain 11.06% of the land cover change in Manaus during 1988-1995 period. On the whole, it can be said that afforestation and forest regrowth compensated for forest lost due to deforestation and forest degradation. However, it is important to analyze the spatial distribution of these processes and the consolidation of the urban core area of Manaus.

Most of the area deforested from 1988-95 was located in the central part of Manaus and also on its west side between the Campus Forest and Reserva Ducke area (Figure 3.2.3), expanding the urban core area that was 15,526 hectares in 1988 to 23,704 ha in 1995 (see Table 3.2.3; also Figure 3.2.4). Most of the afforestation and forest regrowth happened in the peri-urban area of Manaus located mostly on the east side of Reserva Ducke. Forest clearing during this period also affected a large forest patch located below Reserva Ducke between Campus Forest and Rio Puraquequara, increasing the fragmentation of that forest. Several forest patches around Campus Forest and Reserva Ducke were also cut down. Campus Forest became definitively an urban forest fragment and Reserva Ducke, a peri-urban reserve.

By 1995 the Manaus core urban area was delimited from the banks of the Rio Negro to the Eduardo Gomes airport and to the south side of Reserva Ducke except for the forest fragments close to the Rio Puruquequara (Figure 3.2.4 presents the distribution of the 5 land cover classes derived from a supervised classification of the Landsat TM 1995). During that 17-year period (1977-1995), a significant amount of primary forest was cut down to open space for urban facilities in Manaus. The fast urbanization process not only cleared a large amount of forest around the Manaus peri-urban area, as could be seen through the remote sensing images, but it was responsible for clearing the small forest patches and many trees that had been distributed around downtown Manaus (compare Figure 3.2.1 with Figure 3.2.4), mostly in the area located between Igarapé (stream) do São Raimundo and Igarapé dos Educandos, which have been almost totally canalized or filled in. Several new avenues were constructed to accommodate the thousands of new cars that had invaded the city. Several rivers and stream branches (around 37 Km) (Bessa Freire, 1994) located around the city, which had survived the rubber boom, were considered a problem to traffic flow by the city planners and as a result, several have been filled in.

As Bessa Freire (1994) highlights "the concept of urban space and collective life has not been considered in the Manaus urban expansion." The square spaces remaining from the rubber era have been reduced and their trees cut to give space to parking garages or to public buildings. Most of the new residential parks have no green spaces or leisure areas. Given the lack of leisure areas, the children play on the street, competing with the cars for right of way. Furthermore, a city created without respect for the ecological characteristics of the rainforest has transformed the local climate. Instead of the "nice and cool climate" described by voyagers who visited Manaus until the beginning of this century, the city is currently nothing short of a sauna.

According to Souza in his *A Expressão Amazonense,* the current architecture of Manaus is the converse of the experiences of the ecological architecture of Severiano

Mario Porto[14], an Amazonian architect who developed projects which use Amazonian materials and elements of the Amerindian culture in the search for solutions to the habitation and occupation of the Amazonian landscape.

Thus, the current core urban area of Manaus is sparsely covered by trees and green spaces. Just a few forest fragments have survived the rapid urban expansion characterizing the last three decades. The Campus Forest exemplifies this process. In a single decade, the Campus Forest changed from a peri-urban reserve to an urban forest fragment facing the many problems associated with these changes. Similar trends can be observed around Reserva Ducke. Since the city cannot expand much more to the south where the Negro river are located, the natural trend is to grow towards the north in both east and west directions. It is expected that what has happened with the Campus Forest will be repeated at the Reserva Ducke. In the future it will be transformed into an urban reserve, probably facing problems similar to those experienced by the Campus Forest in the last 25 years. Hence, lessons to be learned from the Campus Forest case will be very useful in dealing with the efforts to conserve Reserva Ducke and other reserves experiencing fast population growth and urbanization processes around their borders.

3.3. Characteristics of Manaus' forest fragments: defining a baseline

As described above, the occupation of Manaus left few forest fragments in its urban area. Looking at the remote sensing images, most of these fragments seem to be

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[14] S.M. Porto was a professor of the University of Amazonas until recently. He was in charge of the Campus Forest building projects and was engaged in all environmental commissions organized by that University.

primary forests. However, what comprises a primary forest in a tropical rainforest is a controversial issue. Primary forest, generally, in the ecological literature, has meant "virgin forest," a forest type that evolved through a primary ecological succession[15] during a long period of time and reached a climax stage. As mentioned before, tropical rain forests-- the oldest forests on the planet, which evolved in a period of 60 to 100 million years, have experienced climate changes during the Pleistocene era with the advance and retreat of continental glaciers from polar regions and mountains. Although controversial, it is believed that the forests contracted and fragmented into refugia while savanna communities expanded. As rainfall increased, forests expanded again and merged (Haffer, 1969; Brown, 1972, 1976; Prance, 1973, 1982). Hence, most of the forests currently called primary forest are mature secondary forests that have evolved over a long period of time, and may be reaching a condition similar to the original primary forests.

Besides the climate change that occurred during the Pleistocene, much evidence has pushed scientists to realize that most rain forests are anthropogenic[16] (Balee, 1989, 1992, 1993, 1994; Denevan, 1992; Gomes-Pompa & Klaus, 1992). For a long time,

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[15] Ecological succession (ES) is a central concept to understanding the dynamic of ecosystems. Developed within the plant ecology field, it is an attempt to develop a theory to explain the distribution and abundance of plants across the landscape (Clement, 1916, 1928, 1936). In a broad sense, ecological succession is a term used to imply a sequence in time. It is a step-wise, directional process driven by the effects of dominant plants on their environment. In Clement's view, plant communities are highly co-evolved and integrated systems that are structured largely by competition from dominant plants. ES change occurs as a consequence of alteration of the environment by one community of plants in a way that allows other communities to compete at that site more efficiently. The ultimate endpoint of this process is the plant community that alters its environment in such a manner as to perpetuate itself (climax). On the longest time-scale, primary successions are credited to sites not previously occupied by vegetation, and secondary succession to sites which have been previously occupied (Drury and Nisbet, 1973)

[16] Anthropogenic forests are those that have a bio-cultural origin that would not have existed without past human interference (Balee, 1989).

humans have been changing the tropical forest environment by selecting prey, domesticating plants, nurturing roots through shifting cultivation and modifying soil composition (Hecht & Posey, 1989; Sponsel, 1992; Balee, 1994). According to Balee (1989), at least five of the classified primary forests in the Amazon and 12% of the all "primary forests" are anthropogenic. Thus, it is difficult to know exactly which parts of the rain forest evolved through human selection. Sponsel et al (1996) define the tropical rainforest today as a "patchwork of various stages of succession growth interspersed with mature forest."

However, it is through secondary succession a forest also reaches a mature stage, which most scientists often call primary or pristine forest. Before a plant community reaches a mature stage it is mostly a matter of time and level of disturbance (natural or human- induced). Knowing the secondary succession dynamics of the different rainforest types is imperative to human dimension[17] studies of deforestation and forest change, especially information about the ecological characteristics of the mature forest stage. The current global change and the human dimensions agenda have raised several questions related to the effect of human behavior on forest ecosystems, such as how has human behavior at household and community levels influenced forest ecosystems?, or how do institutional arrangements influence the degree of the impact of human driving forces on forest ecosystems and global change? (Moran, Ostrom, & Randolph, 1998). However, not much has been written about how one can really measure the impact of those factors

[17] Human dimension is a term used by most social scientists to describe "the more immediate human contexts and aspects of the phenomena and processes of deforestation and forest change at the local community level" (Sponsel et al., 1996).

on forest structure. For this dissertation, which aims to study the causes of degradation on protected areas, the structural characteristics of mature upland forest and its secondary succession phase will be summarized to serve as a baseline to be compared with Campus Forest data.

3.3.1. Classifying Amazon vegetation[18]

Amazonian vegetation has been classified in several ways. The most commonly used classifications are those developed by Prance (1978), Braga (1979), Pires and Prance (1985), and Whitmore (1990). These classifications divide, broadly, the principal vegetation types of Amazonia into six general categories: (1) **forest on terra firme** (non-flooded); (2) **open Forest and its sub-classifications** [2.1. w/ vines and palms; 2.2. w/palms; 2.3. w/ vines (lianas forests); 2.4. dry forest; and 2.5. montane forest]; (3) **varzeas and igapos** (seasonal and permanent swamp) and its sub-classifications [3.1. forest on clay soil; 3.2. varzea forest of Upper Amazonia; 3.3. varzea forest of Lower Amazonia; 3.4. estuarine varzea forest; 3.5. Lower Rio Branco swamps (chavascal or pantanal de Rio Branco); and 3.6. seasonal igapo forest on white sand); (4) **savanna and other low biomass non-forest vegetation** [4.1. terra firme savanna; 4.2. open savanna; 4.3. orchard savanna (campo aberto); 4.4. Roraima savanna; 4.5. rock outcrop formations (campo rupestre); 4.6. coastal savanna; 4.7. varzea savanna]; (5) **caatinga and campina** - oligotrophic formations on white sand ; and (6) **vegetation covering restricted areas**

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[18] The term vegetation, here, is used to refer to "the life-forms which are associated, in various ways, in each area, or are the result of the adaptation which better adjust it to environmental variation" (Pires and Prance, 1985)

[6.1. mangrove swamp; 6.2. restinga; 6.3. buritizal (*Mauritia* formations) 6.4. pirizal and cariazal].

These classifications have often been used by Amazonian scholars. As with many phytogeographic classifications, however, they utilize regional terms to describe certain types of vegetation that have already been used to designate totally different kinds of vegetation in other parts of Brazil. For example, campina, a term that has been used to name natural grassland from southern Brazil for at least a century (e.g., Schimper, 1903; Burtt-Davy, 1938; Dansereau, 1949; Trochain, 1955), is used in these classifications to describe an Amazonian endemic type of vegetation that is well defined and characterized because it grows over pure leached white sand (an Amazonian endemic type of vegetation).

Thus, in order to find a more universal scientific language about Amazonian vegetation, I will use the Brazilian Institute for Geography and Statistics (IBGE) system of classification for Brazilian vegetation (Brasil, IBGE, 1992), which integrates a universal nomenclature by approaching forest formation in a hierarchical, physionomic-ecological way. In this classification, the principal vegetation types are designated by a universal nomenclature followed by regional terminology when applicable.

3.3.2. Types of Vegetation in the Central Amazon Uplands (Terra Firme)

The Central Amazon uplands are covered by three principal types of vegetation: (1) dense forest (Floresta Ombrofila[19] Densa), (2) open forest (Floresta Ombrofila Aberta) and (3) campinarana.

Dense forest is distributed in high, non-flooded ground and covers approximately 85% of the Amazon basin. It is high a forest with high total biomass, emergents, a closed canopy, abundance of large lianas and relatively sparse ground cover. There is great species diversity in Amazon tropical forests, which indicates the large number of ways in which the plants can make use of the environment. The density of many species' populations with DBH (diameter at breast height) equal or higher than 10 cm is less than one individual per hectare (Black et al. 1950, Rankin-de -Merona et al., 1992).

Based on species density, most dense forest tree species are considered rare, and true dominance of one species does not occur. However, according to Pires and Prance (1985), there are generally a number of species, five or ten or even sometimes up to 30, whose total number of individuals is more than 50% of the total number of trees. The more abundant species surveyed in the Central Amazon range up to a mean of 12 trees per ha, which, according to Rankin-de-Merona et al. (1992), means that several species have clumped distribution, leading to great variation in the local species abundance. Alencar

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[19] Floresta Ombrofila or Floresta Pluvial Tropical, is a term coined by Ellemberg and Mueller-Dombois (1965) to designated 'friend of the rains". This type of vegetation which is characterized by the distribution of large trees, lianas and abundance of epiphytes, has its principal ecological characteristics based of distribution of the rainfall. Thus, the Amazon dense and open forests are strictly associated with tropical climatic factors such as high temperatures (around 25oC) and high rainfall well distributed throughout the year (0-60 dry days) which determine a bio-ecological condition without dry biological periods (Brasil, IBGE, 1992)

(1986), however, found that in the Reserva Ducke, 25 km from the Campus Forest, the floristic diversity was associated with characteristics of soils. Tree species diversity tends to increase with the quality of the soil. The number of species was higher in clay than in sandy soils (Alencar, 1986:178).

Plant species richness in the Central Amazon is relatively high, showing a great diversity of species, especially for trees (Gentry, 1990). In a survey of 70 hectares within the reserves of the Biological Dynamics of Forest Fragments Project, Rakin-de Merona et al. (1992) found 698 species, while at the Reserva Ducke, a 10,000 ha reserve, different studies have registered 825 species (Prance, 1990), 1.199 (S.Ribeiro et al., 1994), and 2,175 species (INPA, 1998). The species richness per hectare cited for this area, however, presents high variation, ranging from 122 (Rakin-de-Merona et al. 1992) to 191[20] (Prance et al., 1976) (Table 3.3.1).

Dense forest all over the Amazon has been described as large forest with high biomass which can exceed 40 m^2 of basal area, but normally ranging from 25-40 (Pires & Prance, 1985; Balee & Campbell, 1990; Saldarriaga 1994; Moran et al, 1997). In the Central Amazon the average is around 35 m^2 (Table 3.3.1).

Open Forest (Floresta Ombrofila Aberta)-- For a long time, the type of forest which presents shorter trees and considerably lower basal area-- in general, around 20 m^2 per ha (Pires & Prance, 1985)-- was considered a transitional forest between the Amazon and extra-Amazon areas (Brazil, IBGE, 1992), and received its name of Open

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[20] This number is a low estimate, and accounts only for the trees higher than or equal to 15 cm of DBH. They found 56 more species in the DBH class from 5 to 15 cm.

Forest from the RADAMBRASIL project. It is considered a facie[21] of the Dense forest and is classified into three broad types of formation according to IBGE[22] (1992): Low land, Sub-montane, and Montane. Each one of these are subdivided into four specific types depending on the dominance of specific species: w/ palm, w/ vine, w/ bamboo, and w/ sororoca.

The lower biomass of the open forest and its facies is considered to be the result of several environmental factors such as lower water table, the impermeability of the soil, poor drainage and other conditions which do not permit tree root penetration, as well as the occurrence of relatively long dry seasons and lower relative humidity (Pires & Prance, 1985). However, these characteristics have also been associated with its anthropogenic origin due to the intense forest management developed by ancestral Amazon populations (Balee, 1989).

According to Pires and Prance (1985), the various types of Open Forests are very similar in regard to floristic composition. The major differences among them are the presence or absence of palms or lianas. In these types of forest, gigantic trees such as *Bertholletia excelsa, Hymenaea parvifolia, Bagassa guianensis , Tetragastris altissima,*

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[21] Facie describes particular parameters in the forest landscape which highlight phisionomic characteristics such as types of canopy, specific life form (species), and presence or absence of gallery forest, for example.

[22] The IBGE classification is based in the geographical distribution of vegetation with regard to latitude and altitude, and also the dominance of specific species or groups of species such as palms, bamboo, vines, and others. All open forest are distributed between 4° N and 16° S, varying according to different levels of altitude. Low land forests are located from 5 to 100 m of altitude, and are predominantly palm forests. Sub-montane forests are distributed up to 100 m of altitude, sometimes reaching 600 m, and present all four facies (palm, vine, bamboo, and sororoca). Montane forests are distributed between 600 and 2,000 m (Brasil, IBGE, 1992).

Astronium gracile and *Ampuleia malaris* also occur sporadically throughout the forest. The geographic distribution of open forests has been associated with geomorphological characteristics of the Amazon basin. In the whole basin, the Cenozoic and Tertiary terrains are covered by open forest dominated by palms, while vine forest and open forest with sororoca are mostly found in depressions of Pre-Cambrian ancient terrain with rich mineral deposits such as iron, aluminum, manganese, nickel, gold and others (Pires & Prance, 1985), and in the bottom of several Amazon mountains (Brasil, IBGE, 1992). For the Central Amazon, the distribution of most of the open forests (palm, bamboo and sororoca) has mostly been explained except for liana forest[23].

Palm forest-- open forests dominated by palms are distributed in the states of Amazonas, Para, and Roraima. This formation is similar to other open forests with trees of about the same height and density and of a similar floristic composition. The most frequent palms found in these forests are *Attalea racemosa* (babassu) *Oenocarpus distichus, Jessenia bataua* (patauá), *Euterpe precatoria* (acai da mata), *Maximiliana maripa* (inajá), *Oenocarpus distichus, Elaeis oleifera* (caiaue) and other species of the genus Oenocarpus (Pires & Prance, 1985). One of these species may dominate, or may

[23] Liana forest is open forest with an abundance of lianas. Liana forest is rarely found around the Central Amazon. Its major distribution is associated with the state of Para, occurring in abundance along the Transamazon highway from Maraba up to the Xingu River with less frequency as far as the Tapajos River. To the south it extends to the southern limit of Amazonia to the boundary of the Cerrado of Central Brazil (Pires & Prance, 1985). In many places it also contains babacu palm and Brazil nut, either together or separately. In certain areas the dominance of lianas is so high that they transform the few gigantic trees into "climber towers." Liana forest is a variation of Amazon vegetation of special importance because it covers an area around 100.000 square km (Pires, 1973). The most common liana families found in this forest are Leguminosae, Bignoneaceae, Malpighiaceae and Menispermaceae (Pires & Prance, 1985).

dominate along with other palm species. For instance, forests of cocais or babassual dominated by *Attalea racemosa* are distributed throughout the state of Pará, Amazonas, Roraima, and Acre, covering around 196,370 square km, approximately 6% of the Amazon upland forest (Pires, 1973). But, in Maranhão and Pará this vegetation is expanding as secondary forest because this species has a very successful adaptative strategy to survive fires in areas of growing human occupation (Balee, 1989). Another species that dominates some palm forests is the caiaué (*Elaeis oleifera*), which according to Balee (1989), is associated with Terra Preta do Indio (type of soil resulting from past human occupation) in several parts of the Central Amazon.

Forest of Bamboo-- forest dominated by *Gradua superba*[24]. The dominance of this species is so high in certain areas of open forest that it is known in Brazil as floresta-de-bambu (bamboo forest). It is distributed along the borders of the states of Acre and Amazonas, covering an area of approximately 85,000 square km (Braga, 1979). The first record of this species in the Brazilian Amazon was made by Huber in 1909 in reference to the state of Acre (Huber, 1909). The origin of bamboo forests has also been associated with fire and land management of past Amazon human occupation (Sombroek, 1966). During the 1970s, the RADAMBRASIL project surveyed the large areas of bamboo forest using Radar images and included it as a facie of the open forests. According to Brazil, IBGE (1992) these areas are in expansion in the Amazon, probably caused by human interference.

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[24] The genus Gradua probably originated from the current Andean area of Peru and Bolivia. However, it has been invading the Amazon open forest area (Brasil, IBGE, 1992).

Forest with Sororoca-- Forest with dominance of *Phenakosperma guyanensis* (Estrelitziaceae). P. guyanensis is a species that looks banana-like. It is distributed around the south area of the Amazon basin, mostly along the Xingú River in temporarily inundated areas. However, it can be found in small patches within the states of Amazonas, Rondonia, and Roraima (Brasil, IBGE, 1992).

Campinarana[25] (Campina[26]) is a term used to describe types of Amazon vegetation which grow over leached white sands. It was first used by Ducke (1938) and Sampaio (1944) to designate the vegetation which has its core distribution in the Upper Rio Negro, but is also found along other black water rivers of the Lower Rio Negro (area of Central Amazon). Ducke and Sampaio, like Spruce in 1908, also called this type of vegetation campina and caatinga. However, Egler (1960) started to use the term campinarana for this type of Amazon vegetation.

Different from dense forests, campinarana is distinct in structure, physiognomy, and floristics. It is dominated by one or a few species distributed in small patches of lower diversity vegetation associated with Spodosols (white sand soils) (Ducke, 1938; Sampaio, 1944; Ducke & Black, 1953; Egler, 1960; Takeuchi, 1960; Lisboa, 1975; Anderson et al., 1975; Brasil, RADAMBRASIL, 1976; IBGE, 1992). It is found on soils derived from

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[25] In tupi language, rana=pseudo, thus pseudo campina, also referred to as campina alta (high campina) (Guillaumet, 1987). As campina, the term campinarana has also been associated with "falso campo" (false field).

[26] Lisboa (1975) used the term campina to describe the "vegetation islands" on white sand common in the Rio Negro basin and in other areas located north of the Amazon River. Spruce (1908) had used the term caatinga-gapo to describe it, which became "caatinga of Rio Negro" in the Brazilian phytogeography. Here, campinarana instead of campina or caatinga, following the Brazil, Projeto RADAMBRASIL (1976) and IBGE (1992) classification, is used, because campina and caatinga have been used to describe totally different types of vegetation in other Brazilian regions for ages.

siliceous parent materials which became podsolized soils with coarse texture, highly acidic, poor in base, lacking any buffering capacity due to a shortage of sesquioxides (Whitmore, 1984).

RADAMBRASIL (1976) classified this vegetation under three types: forested campinarana, arboreal campinarana, and grass-wood campinarana. IBGE[27] (1992) follows a similar classification. Lisboa (1975) argued that campinarana should be used only to specify the more developed portion of the gradient campina-campinarana, meaning that the three types of vegetation represented different sere of the forest succession process. He also differentiated the campinarana (campinas) of Upper Rio Negro from those of the Central Amazon based on level of rainfall, altitude and occurrence of several grass families.

Grass-wood campinarana of Central Amazon (Campina Amazônica da Amazônia Central) are any of those campinarana that receive less rainfall than the Upper Rio Negro (around 3,400 mm) and are located at an altitude below 100m. Their vegetation is low and scleromorphic, sometimes so sparse that patches of bare soil show around the area. They are characterized by vegetation islands, some very small,[28] where canopy cover only approaches 50% (named campina aberta by Anderson et al., (1975). This small island structure is relatively homogeneous and is divided into two strata: a lower one formed by shrubs reaching 2m, and an upper one formed by shrubs and small

[27] As mentioned early, here I am following the IBGE classification.

[28] See Braga and Braga (1975) for a detailed description of the floristic composition of these islands.

trees from 2-5 meters high (Anderson et al., 1975). In the Central Amazon, the occurrence of grass families such as Rapateaceae, Eriocaulaceae and palms is very restricted or absent in this type of vegetation (Lisboa, 1975).

Larger and denser islands where canopy cover exceeds 50% are also part of this type of campinarana (Anderson et al., 1975 called them campina sombreada), and Brazil, IBGE (1992) arboreal campinarana. They are dominated by *Glycoxylon inophyllum* (casca doce), and eventually trees of *Aldina heterophylla* (macucu) can be found, reaching 7 meters high. These islands are more floristically diverse than the small ones. Anderson et al. (1975) found 29 plant species in the larger islands. Besides *G. inophyllum and A. heterophylla,* other wood species such as *Ouratea spruceana, Swartzia dolicopoda*, *Clusia aff. columnaris, Maytaba opaca, Talisia cesarina, Protium heptaphyllum* and *Humiria balsamifera* were found.

Forested campinarana of Central Amazon (Campinarana Amazônica da Amazônia Central) is the most developed vegetation of the campinarana succession[29] gradient. It is a relatively low forest with thin-stemmed trees reaching 20 meters high, with exceptionally large broad-trunked individuals, with or without buttresses, and a massive presence of epiphytes (Guillaumet, 1987, Brazil, IBGE, 1992)). It is, in general, distributed along grass-wood campinarana (Lisboa, 1975). However, in the Central Amazon, forested campinarana is more frequent than grass-wood campinarana (Guillaumet, 1987). For example, at Reserva Ducke, a 10,000-ha forest reserve where I

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[29] Anderson et al. (1975) in describing the complex campinarana of Reserva Biologica de Campina located 60 km from Manaus, argued that there is a vegetation succession from grass-wood campinarana (campina aberta) to arboreal campinarana (campina sombreada), and from arboreal campinarana to forested campinarana.

collected training samples to register the remote sensing images, I observed at least three areas covered by forest campinarana but none with grass -wood campinarana.

The floristic composition and species diversity of campinarana are very similar to the larger islands[30] (campina sombreada). At Reserva Biolόgica da Campina, *Psychotria barbiflora* is the only dominant species[31] found in forested campinarana but absent in arboreal campinarana (Anderson et al. 1975). In campinara areas, species of Araceae, Bromeliaceae, Orchidaceae and Cyclanthaceae families are very common not only around the ground, but also on the trees. Anderson et al. (1975) listed a total of 36 species for the Reserva da Campina forested campinarana. Dominant species were *Glycoxylon pedicellatum, Aldina heterophylla, Clusia aff. columnaris, and Psychotria sp.* However, at Reserva Ducke, in a forested campinarana bordered by dense forest instead of wood-grass campinarana, 113 species distributed among 83 genus and 37 families were surveyed by Tello (1992). *Bocoa alterna, Ocotea cymbarum, Qualea paraensis, Catostemma sclerophyllum, Scleronema micranthum and Alchorniopsis floribunda* were the most abundant species. The basal area for this forest was estimated at around 26 square meters, similar to the average basal area in open forests. Thus, it seems that the floristic diversity and structure of campinarana may currently depend on its location.

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[30] According to Anderson et al. (1975), there is no clear limit between forested and arboreal campinarana, because the two are mixed in a continuous gradient where the floristic composition and structure change gradually.

[31] Several scholars do not differentiate forested from arboreal campinarana (e.g., Guillaumet, 1987, Luizão, 1995).

3.3.3. Secondary Succession Vegetation[32]

Areas covered by secondary vegetation in the Amazon, mostly derived from dense forest, have dramatically increased in the last three decades due to intense human occupation. However, studies of secondary succession in the Central Amazon have been few and far between compared with other Amazon regions because of the lower colonization intensity in this area. As open forests are not found around the Manaus area, and Campinarana has not been used for agricultural and other human purposes, the characteristics of secondary succession discussed here will refer to those derived from dense forest.

Dense forest in the Amazon is often cleared for agriculture. When the fields are abandoned, secondary vegetation starts to regrow and/or be established through sprouting from cut roots and stems, regeneration of remnant individuals, germination from the soil seed bank, and seed dispersal and migration from other areas. A young secondary forest (1-10 years) is dominated by pioneers species, which display a short life cycle, high growth rate and reproductive resource allocation (Gomes-Pompa & Vasques-Yanes, 1981). Early young secondary forest is basically dominated by light-demanding herbaceous species, seedlings, and saplings. For example, in the Eastern Amazon, species of the Poaceae, Asteraceae, Fabaceae, and Verbenaceae families are the most common in this stage, with an average of 117,000 individuals per hectare (Moran et al., 1997). However, later on, a large number of young trees of the Cecropiaceae, Mimosaceae, Caesalpineaceae and

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[32] Secondary forests, here, are not considered a specific type of vegetation, but the anthropogenic stages of a particular type of primary vegetation.

Arecaceae families are common. The number of individuals per hectare range from 553 to 1080 (Moran et al., 1996), and the regional mean average ranges from 3 meters in a 1-year fallow to 10 meters in a 10 year-fallow (Moran et al., 1997).

In an intermediary or early mature secondary forest (11- 25 years), the changes in the vegetation structure are visible. Shade-tolerant mature species trees start to dominate and replace pioneer species. The average stand height in this stage varies from 10 to 22 meters, and total basal area ranges from 10 to 25 m^2/ha, reaching over 30 m^2/ha in nutrient-rich soil such as those in the alfisols in Altamira and Rondonia (Moran et al., 1997).

As Moran et. al (1997) have shown, the quality of soil and land use are key factors influencing vegetation structure of secondary forests in several parts of the Amazon. There is little variation in height of secondary forests from 25 to 50 years old. This is quite similar to the range also found in mature forest in poor soils. Stand height in secondary forests over 25 years old varies between 12 and 15 meters, while in mature forest in rich soils, height varies between 15 and 23 meters. Basal area in those mature secondary forests varies from 18 m^2/ha in poor soils to 38 m^2/ha in rich soils, while, in the mature forests it is rare to find basal area below 25 m^2/ha. Most of the mature forests measured in the Amazon range from 30 to 58 m^2/ha (Moran et al., 1997). Thus, given that the vertical structure of many secondary forests over 25 years old is similar to mature forests, the horizontal structure (indicators related to floristic composition such as species density, frequence and dominance) helps discriminate them from mature forests.

To differentiate old secondary forest from tropical mature forest is not a trivial task. Besides the memory of local people who have managed them, the ecological life history of most tropical trees in unknown and ages of the largest trees remain to be determined (Chambers et al., 1998). Different from temperate, trees which leave annual rings, these marks can be non-existent or irregular on tropical forests trees (Fahn et al., 1981). Thus, the only way to determine the age of tropical trees directly is through $_{14}C$ dating. Dating twenty large emergent trees from the Central Amazon with $_{14}C$, Chambers et al. (1998) found that emergent trees from these forests can be older than 1,400 years. However, to figure out the distribution of tree ages in a rain forest is a difficult task. Besides using $_{14}C$ dating which is an expensive method, there is no direct measurement. In general, tropical tree ages are based on extrapolation from growth or mortality rates compiled from permanent plots where observations intervals are short, compared with the longevity of most trees. Criticism has been made of the use of indirect methods, because growth rates vary within species and over time, leaving age estimates highly subject to error (see Chambers et al. 1998).

Nevertheless, at least in the Central Amazon area, just a few trees reach diameters higher than 60 cm. Most mature trees are distributed in diameter classes not higher than 20 cm (Rankin-de-Merona et al., 1992), and data collected in several secondary forests of known age have shown that 50-80 yr-old fallows, are often indistinguishable from mature forest (Richards, 1955; Budowski, 1961; Moran et al., 1996). Thus, in the tropics, secondary forest older than 50 years old is, in general, classified as mature forest not only because its ecological attributes are very similar to mature forest, but also because it is difficult to find local people who can give precise information about land use history. However, in the Amazon as a whole and in the Central Amazon in particular, rapid secondary succession processes have occurred in the last 30 years. Still, the ecological attributes of the forests associated with land use history can give us a good estimation to classify and differentiate the forest stages. Thus, in the next chapter, a vegetation analysis integrating land use history and the horizontal and vertical structural attributes of the Campus Forest will be integrated to assess the current ecological characteristics of that forest and define an ecological framework to test the hypothesis described in Chapter 1.

Figure 3.2.1. Spatial distribution of five land cover classes derived from supervised classification of Landsat MSS 1977 for Manaus, AM, Brazil.

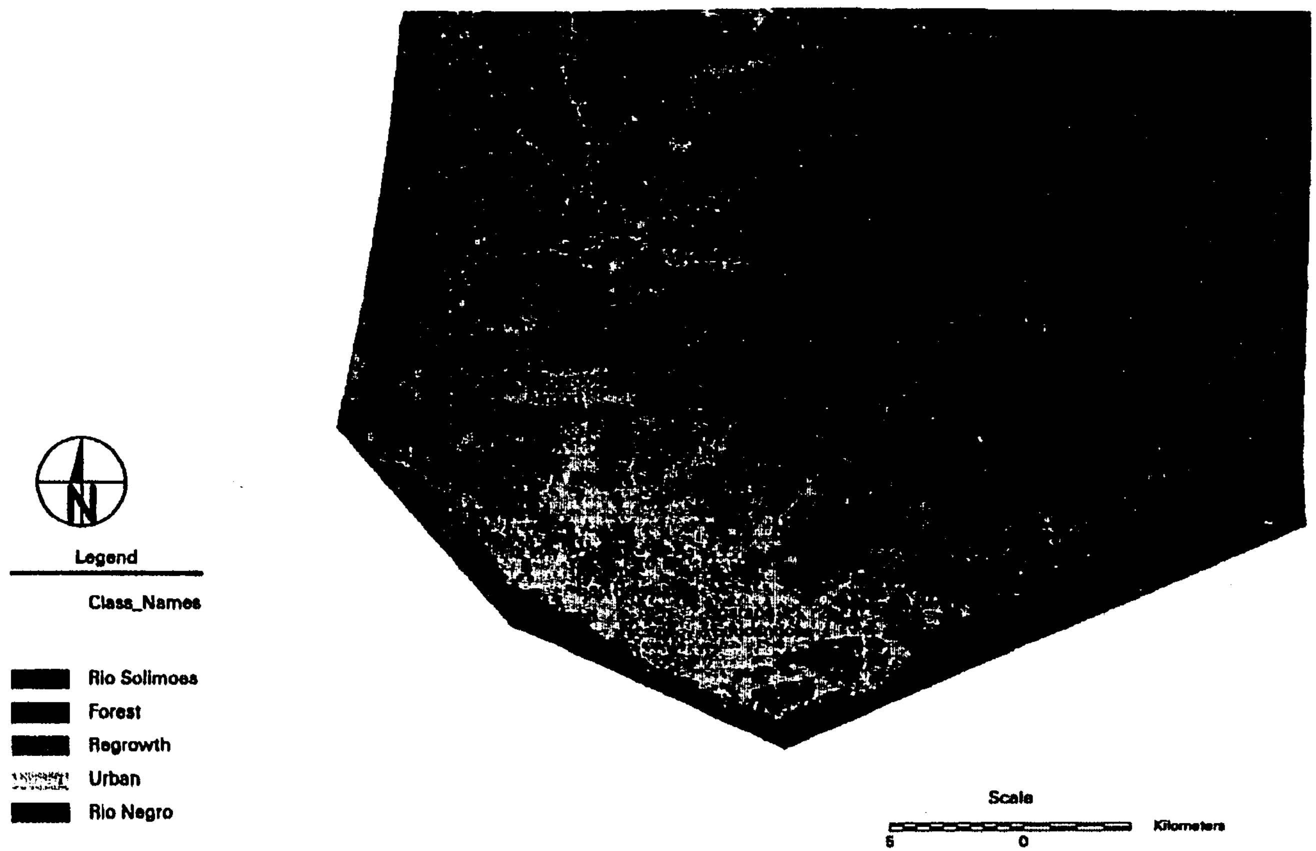

Figure 3.2.2. Spatial distribution of land cover and land cover change classes derived from Landsat MSS 1977 and TM 1988 for Manaus, AM, Brazil.

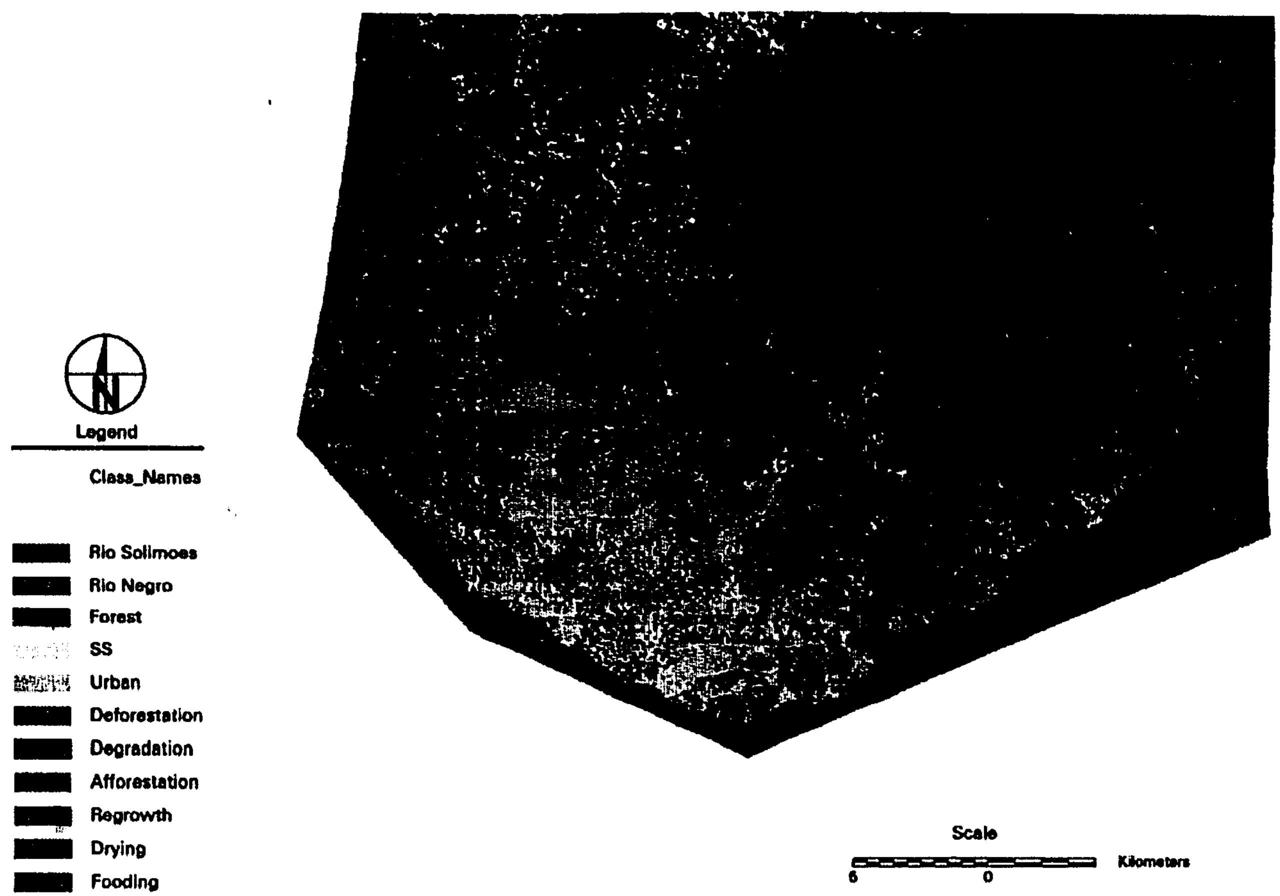

Figure 3.2.3. Spatial distribution of land cover and land cover change classes derived from Landsat TM 1988 and 1995 for Manaus, AM, Brazil.

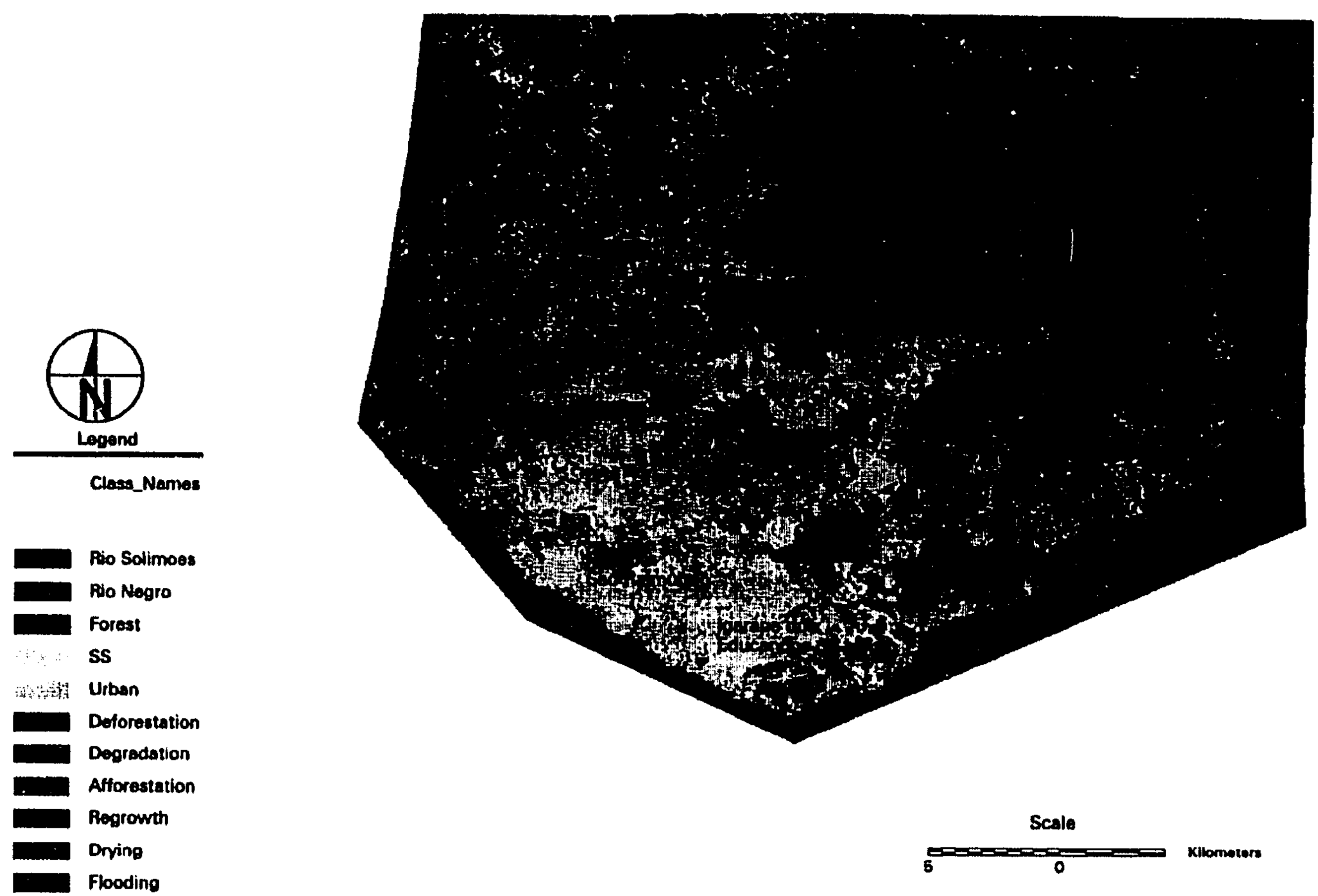

Figure 3.2.4. Spatial distribution of five land cover classes derived from supervised classification of Landsat TM 1995 for Manaus, AM, Brazil.

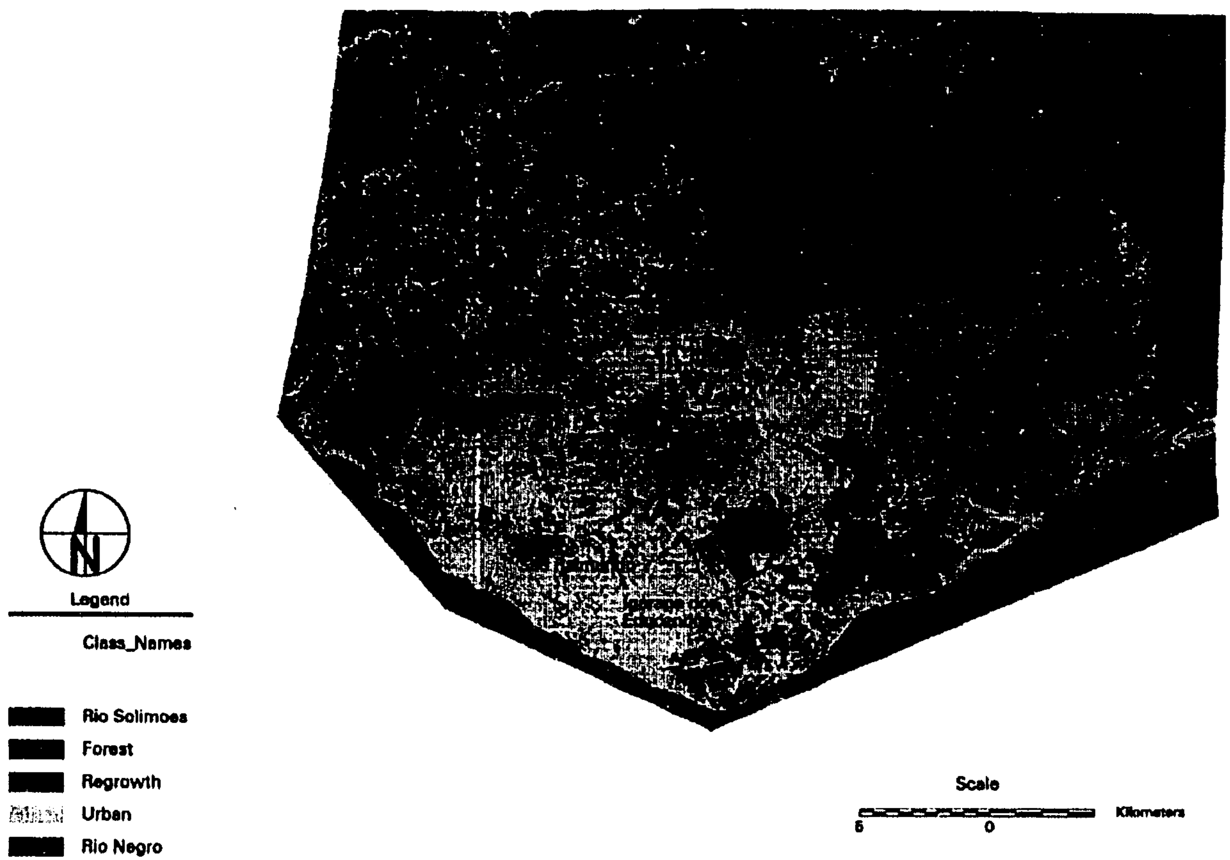

Table 3.2.1- Summary of Land cover changes in Manaus, AM, 1977-1988-1995

classes	1977-88			1988-95		
	# pixels	HA	%	# pixels	HA	%
solimoes-solimoes	13006	1170.54	1.39	12347	1111.23	1.32
solimoes-forest (drying)	0	0	0	5	0.45	0.00
solimoes-ss (drying)	10	0.9	0.00	41	3.69	0.00
solimoes-soil (drying)	243	21.87	0.02	799	71.91	0.08
solimoes-negro	2604	234.36	0.27	1537	138.33	0.16
forest-solimoes (flooding)	75	6.75	0.00	193	17.37	0.02
forest-forest	494491	44504.19	52.93	468482	42163.38	50.15
forest-ss (degradation)	78305	7047.45	8.38	24181	2176.29	2.58
forest-urban (deforestation)	59468	5352.12	6.36	38272	3444.48	4.09
forest-negro (flooding)	1772	159.48	0.18	32	2.88	0.00
ss-solimoes (floooding)	79	7.11	0.00	68	6.12	0.00
ss-forest (aforestation)	25885	2329.65	2.77	60603	5454.27	6.48
ss-ss	42264	3803.76	4.52	36961	3326.49	3.95
ss-urban (degradation)	39906	3591.54	4.27	40954	3685.86	4.38
ss-negro (flooding)	185	16.65	0.01	43	3.87	0.00
urban-solimoes (flooding)	192	17.28	0.02	953	85.77	0.10
urban-forest (afforestation)	5785	520.65	0.61	16052	1444.68	1.71
urban-ss (regrowth)	15449	1390.41	1.65	26753	2407.77	2.86
urban-urban	62970	5667.3	6.74	126616	11395.44	13.55
urban-negro (flooding)	341	30.69	0.03	797	71.73	0.08
negro-solimoes	1377	123.93	0.14	10307	927.63	1.10
negro-forest (drying)	4999	449.91	0.53	352	31.68	0.03
negro-ss (drying)	2601	234.09	0.27	632	56.88	0.06
negro-urban (drying)	8584	772.56	0.91	11743	1056.87	1.25
negro-negro	73548	6619.32	7.87	55416	4987.44	5.93
TOTAL	934139	84072.51	100	934139	84072.51	100

Table 3.2.2- Distribution of land cover change processes in Manaus, 1977-1988-1995.				
	1977-1988			1988-1995
Process of Change	ha	%	ha	%
Deforestation	9043.54	10.74	7130.34	8.48
Degradation	7047.45	8.37	2176.29	2.58
Afforestation	2850.3	3.38	6898.95	8.20
Regrowth	1390.41	1.65	2407.77	2.86
Drying	1479.22	1.75	1221.48	1.45
Flooding	237.98	0.28	187.74	0.22
In forest	44504.19	52.87	42163.38	50.15
In water	8148.15	9.68	7164.63	8.52
In ss	3803.76	4.51	3326.49	3.95
In urbam	5667.3	6.73	11395.55	13.55
Total	84172.3	100	84072.62	100

Table 3.2.3- Distribution of the three upland cover classes in Manaus in 1977, 1988 and 1995					
land cover feature	1977		1988		1995
	ha	%	ha	%	ha
forest	65971.35	81.94	56888.01	68.69	59429.07
ss	8097.21	10.05	10394.1	12.55	4847.94
urban	6434.01	7.99	15525.63	18.74	23703.84
Total	80502.57	100	82807.74	100	87980.85

Table 3.3.1. Results of Dense Forest Surveys in the Central Amazon, Brazil.

Author	Local	Total area sampled (ha)	Sampling strategy	trees/ha	# spp	# spp/ha	Botanical classification	Basal Area (m^2/ha)
Prance et al., 1972	EMBRAPA, 30km NE of Manaus	1	continuous plot	350	191	191	common name with botanical voucher	---
Jardim, 1985	INPA-S.E.S[1], 55 km N of Manaus	8	non-continuous plots	247	326	41	common name with same botanical voucher	---
Rankin-de Merona et al., 1992	BDFFP[2], 75 km N of Manaus	70	mostly non-continuous plots	637	698	122	common name with botanical voucher	35
Tello, 1995	Reserva Ducke, 20 km NE of Manaus	1	non-continuous plots	745	192	192	common name with botanical voucher	38.9
Silva-Forsberg (this study)	Campus Forest, Manaus urban area	1.1	non-continuous plots	458	169	153	common name with botanical voucher	21.5

[1] Tropical Forestry Experimental Station of INPA (National Institute for Amazonian Research)

[2] Biological Dynamics of Forest Fragments Project

Chapter 4

VEGETATION ANALYSIS: FLORISTIC COMPOSITION AND OTHER STRUCTURAL ATTRIBUTES OF THE CAMPUS FOREST

This chapter examines the vegetation types of the Campus Forest and describes their floristic composition. In chapter 3, it was shown that Central Amazon vegetation types are relatively well-known compared to other Amazon areas. However, the Campus Forest had never been the subject of a systematic forest survey prior to this study. Thus, important information such as species composition was still missing for the area as well as the ecological characterization of the three types of vegetation present in the area. The lack of information is not only a constrains to manage the area but also hindered my ability to test the hypotheses underlying this study. Before testing the hypotheses it is necessary to underline the ecological and historical characteristics of this forest in order to be sure that correct baselines have been used.

According to Coutinho (1994)[1] (Figure 2.6) and Izel and Custodio (1996)[2] (Figure 2.7), the Campus Forest is covered by three types of vegetation: (1) dense forest (OD), (2) open forest (OA) and (3) campinarana (CC). These types of vegetation are identical to the main types found in the Central Amazon area as described in Chapter 3 (Section 3.2.).

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[1]Using the INPE-GIS package and a Landsat TM image of 1995, he classified the Campus Forest into three types of vegetation: 1) Floresta Ombrofila Densa - OD (dense forest), 2) Floresta Ombrofila Aberta - OA(open forest), and 3) Veegatação de Campina - CC (savanna forest)

[2] Using aerial photography from 1990, they extended the Coutinho's classification by including crops and areas of anthropogenic action.

Nevertheless, a survey of the entire Campus Forest area in 1996 carried out by a team including three experienced botanists, revelead that the Campus Forest is more patchy than described by the two maps. The areas described as open forest and campinarana by Coutinho (1994) and Izel and Custodio (1996) seemed to be largely fallows (secondary succession of dense forest and campinarana) interspersed with small patches of dense forest and campinarana. In those same areas, according to the Universidade do Amazonas' patrimonial map (Figure 4.1), small-scale farmers used to cultivate crops. Thus, different parts of the Campus Forest were used for different purposes before the University acquired the area.

To capture the forest mosaic within both the Campus Forest as a whole and the different types of vegetation, the entire forest area was surveyed with randomly selected plots (see Chapter 2 for more details). For this, two levels of analysis were developed: first, considering the Campus Forest as a whole; and second, disaggregating by vegetation type. A preliminary vegetation cover map was developed for this analysis (Figure 2.8). Information provided by Coutinho (Figure 2.6) in regard to spatial distribution of campinarana, and Izel and Custodio (Figure 2.7) with regard to dense forest and open forest was combined. I selected this information since they were more similar to my preliminary field observations of the Campus Forest vegetation zones.

In addition to vegetation inventory traditionally used to describe floristic composition, to undertake the Campus Forest vegetation analysis, interviews, group discussion and meetings were conducted with key informants to gather data about the history of land use inside and around the forest (see also Chapter 2 for further methodological details). This data facilitated the analysis of vegetation types found in the Campus as well as provided information to test the hypothesis that the two types of vegetation described as mature open forest and campinarana are, for the most part, old fallows.

Before starting the results section, it is important to note that two criteria have been used to classify Amazon vegetation: biomass and species composition (see Pires & Prance, 1985). Biomass is used to give a general characterization of the current structure of the different vegetation types. However, different types of vegetation can have similar biomass. For example, the range of biomass cited for open forest is similar to old fallows (Chapter 3, Section 3.3). Thus, in this analysis, species composition is combined with biomass information to present a more detailed vegetation classification for this area. Finally, let me provide a brief overview of the rest of this chapter. The next section presents the history of land use inside and outside of the Campus. Later, vegetation analysis is presented for the Campus Forest as a whole, followed by the analysis of vegetation types. Finally, a new classification for the Campus Forest vegetation is suggested, as well as a framework to analyze the effect of fragmentation on the forest.

4.1. History of land use in the Campus Forest

4.1.1 Land use inside of Campus Forest

In 1968, The University of Amazonas bought the Campus Forest land through a process of expropriation from 36 different owners. The location of each piece of the land is provided in Figure 4.1. The size of the land parcels varied from 0.5 to 375 hectares, distributed as follows: 26 (0.5-10 hectares) were located on the northwestern border of the area near the Coroado neighborhood, most of them located in open forest -- vegetation zone 2 (Figure 2.8); 4 (10-40 hectares)-- were also located in open forest on the southwestern border. It is near the current Atilio Andreazza neighborhood separated in part by a buffer forest zone, also inside of forest zone 2. Four other pieces of land (2-10 hectares) were located on the eastern border, in campinarana forest-- zone 3, which has also not yet been totally isolated. A forest owned by several SUFRAMA enterprises still serves as a buffer zone along that border. Two others (100 and 375 hectares) were located in the dense forest area -- vegetation zone 1.

According to University of Amazonas officials, most of the small landowners lived in and used the area for various purposes, mainly shifting cultivation. Though the forest has been cut in several parts of those properties, it has regrown, turning into secondary succession. Many of the former owners accepted the University of Amazonas' payment offers and left the area promptly at the end of the 1960s and beginning of the 1970s. However, several did not. The University did not gain total control of the area until 1975 when the two most persistent former residents left. Seven legal cases against the University are still being litigated within the state-level justice system (see Chapter 5).

The University of Amazonas also built several infra-structural facilities (i.e., buildings, roads and an experimental field for the agronomy school) around the area (see Figure 2.7). Most of these facilities are located in the northwestern side -- vegetation zone 2. On the east and southeastern area, where the white sand campinarana vegetation is located -- zone 3, the University extracted sand for construction and employees have used the streams and other parts for recreational purposes for the past 15 years. Thus, on the west, at both northwestern and southwestern -- vegetation zone 2 -- and at the southeastern sides also -- vegetation zone 3-- several patches of the forest have been used by the former owners for such activities as shifting cultivation, as well as by the University. These areas, which have been classified as open forest by Izel and Custodio (1996) and campinarana by Coutinho (1994), are not predominantly mature forest anymore but rather a mosaic of old fallow interspersed with a few small patches of mature forest. These patches can be seen in Figure 4.5, which shows the distribution of basal area among vegetation types. For the open forest and campinarana, the outliers are the plots which presents mature forest attributes.

4.1.2. Land use outside of the Campus Forest and its fragmentation history

Occupation along the Campus Forest border and its progressive isolation as an urban forest fragment (see Table 4.8) began in 1971 with the invasion of the northwestern area where the Coroado neighborhood is currently located (Figure 2.8). At that time the University of Amazonas lost 119 hectares of the forest. As mentioned before, in the early 1970s the University did not have total control over its total area (around 800 ha) nor the infrastructure required to manage it. During the invasion process, invaders not only cut the forest and settled in the area which currently belongs to the Coroado neighborhood, but they also cut some patches at that border (vegetation zone 2) which still continues to belong to the University. The constant conflicts between Coroado residents and University officials were in part resolved in the early 1980s when COHAB/AM (Habitation

Company of the Amazon) paid back the University for the invaded area (Director Counsel, resolution # 017/79). However, according to University officials, conflicts were also generated due to residents' frequent incursions into the forest to hunt and collect forest products. By 1990, more than 30,000 residents were living there, distributed in more than 3,000 households (Brasil, IBGE, 1991). Most of the residents are low income workers, and more than 60% never finished elementary school (Lima, 1997). Thus, the forest border close to Coroado has been cut since 1971 (Table 4.8) and the University officials still blame the Coroado residents for trespassing onto forest borders to collect products.

Acariquara is also located on the opposite northern border of the campus (Figure 2.8). Acariquara was founded in 1980 by a private initiative designed for University employees (professors and staff), when the forest area between Acariquara and the Campus was cleared. It is a middle class neighborhood where most of the inhabitants have at least a high school level of education (Lima, 1997). According to some Acariquara residents, they rarely trespass onto campus land.

In the middle 1980s, another residential park (Dom Bosco) was built 200m from Campus, further north at the border between Coroado and Acariquara. However, in 1992 that part was cleared with the invasion of the current Ouro Verde neighborhood (Figure 2.8). Former Ouro Verde residents did not invade Campus land, but used forest resources such as poles, trunks and game in the occupation phase (at vegetation zone 1). As with Coroado, it is a low income neighborhood where more than 20% of its residents are illiterate and almost 50% never finished elementary school (Lima, 1997).

Also in the middle 1980s, part of the southern border was cut when construction of the Nova Republica residential park began. (Table 4.8). However, the residents only moved there in 1991. This settlement has around 3,000 inhabitants distributed in 621 households. It is a lower middle class neighborhood and almost 70% of its residents have a high school degree. According to some N. Republica residents, they do not often use Campus Forest resources, however, their workers and housemaids who live in other neighborhood, frequently use the forest as a shortcut to avoid the expense of taking a bus.

Therefore, the historical forest disturbances were caused by both the former campus small landowners and the University at vegetation zones 2 and 3. Other forest disturbances were caused by settlement. These disturbances are associated with the two land invasion processes that led to Coroado and Ouro Verde. However, the Coroado invasion seems to have affected the Campus Forest much more than Ouro Verde's.

4.2. Floristic Composition of Campus Forest as a whole

The species composition analysis shows that Campus Forest has at least 449 species distributed among 217 genera and 77 families (Table 4.1), including tree, shrub, herb, vine, liana and epiphytes. Of the total, 151 species were identified at the genus level. Forty-five samples were only identified at the family level.

4.2.1. Vascular plants from Campus Forest

At the family level, Leguminosae *sensu latu*, and all three legume segregate families (Fabaceae , Mimosaceae and Caesalpiniaceae) were among the 15 most diverse families. The dominance of Leguminosae as the most diverse family in Central Amazonia was also confirmed in other studies in the Reserva Ducke (Prance, 1999; S. Ribeiro et al,. 1992) and in the BDFFP (Biological Dynamics of Forest Fragments Project) (Rakin-de-Merona, 1992) as in other locations (Rodrigues, 1967; Alencar et al., 1972; Prance et al., 1976; Jardin, 1985; Higuchi, 1987). Among the legume segregate families, Fabaceae emerges as the most species-rich family, with 28 species.

Even though the species of the fifteen most common families are dominated by trees following the general trends of the Central Amazon (Prance, 1990; Gentry, 1990; S. Ribeiro et al., 1994), a considerable number of shrub, herb and vine species were identified within the Fabaceae, Moraceae, Rubiaceae, Melastomataceae, Euphorbiaceae and Myrtaceae families.

4.2.2. Species-rich Genera from Campus Forest

Of the 18 most species-rich genera (5 species per genus is used as the arbitrary minimum cut off for species-rich in order to compare Campus data with those from Reserva Ducke [Prance, 1990] and BDFFP [Rankin-de-Merona et al., 1992] Miconia (Melastomataceae), Protium (Burseraceae), Virola (Myristicaceae), Swartzia (Fabaceae), Ocotea (Lauraceae), Inga (Mimosaceae), Eugenia (Myrtaceae), Eschweilera (Lecythidaceae), Pouteria (Sapotaceae), Licania (Chrysobalanaceae), Duroia (Rubiaceae) are the top eleven genera encountered in the Campus Forest (Table 4.2). All 18 of the species-rich genera belonged to the 20 most diverse families, but they did not follow the same descending rank. Thirteen other genera such as Rollinia, Trattinickia, Diospyros, Dipterys, Casearia, Licaria, Byrsonima, Myrcia, Neea, Palicourea, Psychotria, Matayba and Talisia appear with 4 species each. Fifteen of them are also listed as the 21 most species-rich genera at Reserva Ducke (S. Ribeiro et al., 1994). However, the other six most diverse genera in Reserva Ducke-- Sloanea, Aniba, Micropholis, Mouriri, Bactris and Strichnos -- were not among the 31 genera that had at least 4 species in Campus Forest. Of the 18 species-rich genera of Campus Forest, 6 are not found in Reserva Ducke's 21 most diverse genera. They are Eugenia (8), Duroia (6), Guatteria (5), Brosimum (5), Cecropia (5), and Leonia (5). Most of them are well distributed in disturbed and secondary forests. The wide distribution of these genera in Campus Forest is an indication of the historical disturbance affecting this forest (see land use inside and outside of the Campus)

4.2.3. Most Abundant Species

The five most abundant and frequent species in the Campus Forest as a whole (Table 4.3) do not come from the 10 most species-rich families. *Attalea maripa* and *Oenocarpus bacaba* (Palmae), *Tapirira guianesis* (Anacardiaceae), *Myrcia fallax* (Myrtaceae), and *Eschweilera odora* (Lecythidaceae) were the species with the highest IVI (Importance Value Index). Except for *Eschweilera odora*, the sixth in density and frequency, but with significant dominance (based on basal area), the importance of the other four species were determined mainly by density and frequency.

The dominant presence of palms in the Central Amazon forests is not unusual. Rankin-de- Merona et al. (1992) noted that *Oenocarpus bacaba* was the 3rd most abundant species within 70 noncontiguous inventory hectares at BDFFP (the Biological

Dynamics of Forest Fragments projects), approximately 70 km away from the Campus Forest. Closed canopy undisturbed forests in the Central Amazon with a high density of small diameter trees are characterized by both juvenile pinnate leaf palms on the ground and a high abundance of arborescent palms in the canopy and mid-story (Rankin-de-Merona, 1992). However, "inajá" (*Attalea maripa*) is not one of those. The natural habitat of *A. maripa,* as with other species of the Attlalea group (Henderson et al., 1995), is in open areas such as clearings, light gaps and river margins (Hogan, 1988). They have enhanced ability to grow and thrive in disturbed areas such as cleared pasture. Another well known example of palms' ability to colonize disturbed area is "babassu" (formerly *Orbignya phalerata,* now *Attalea racemosa*), which form dense stands in areas where forest has been cleared, especially for pasture, in several parts of the Amazon, mainly on the southern border (Anderson et al., 1991). Thus, the massive presence of *A. maripa* in the Campus Forest is a strong indicator of human disturbance on that forest. This trend is clear once one notes its presence is much more intense in the north side, where human pressure due to the Coraodo invasion has occurred since the 1970s.

4.3. Types of vegetation: Comparing Dense Forest, Open Forest and Campinarana

Of the 71 inventory forest plots (total area of 2.2 ha), 37 were sampled in the dense forest, 15 in the open forest, and 19 in the campinarana. Species composition analysis of trees greater or equal to 10cm diameter at breast height (DBH) (Table 4.4) showed the number and distribution of species in each of the three types of vegetation. Of the 240 tree species, 169 occurred in dense forest, 81 in open forest and 70 in campinarana. The species richness in the dense forest is 50% greater than in open forest and campinarana. Eighteen species were shared by the three vegetation types, 32 species were shared between dense and open forest, 12 between dense forest and campinarana, while only five were shared between open forest and campinarana. Of the total species, 102 were found only in the dense forest, 25 in the open forest, and 32 in the campinarana. Of the 18 species shared by the three forest types, eight are within the most dominant species (highest IVI) in all three forests (Tables 4.5, 4.6 and 4.7). Most of these species are widespread in different types of soil and vegetation. The difference between the dense forest (OD) and the other two types of vegetation is remarkable in the number and composition of species and in other forest structural attributes.

The five most abundant species in the dense forest (Table 4.5) are *Oenocarpus bacaba* (bacaba), *A. maripa (*inaja), *Eschweilera odora* (mata-mata preto), *Tapirira guianensis (*maria preta) and *Buchenavia macrophylla (*tanimbuca). Besides *M. maripa,* the other four are species prevalent in mature or very old fallows (Silva et al., 1977). As noted above, *O. bacaba* and *E. odora* are commonly found in undisturbed Central Amazon forests. *B. macrophylla* grows in both mature forest and old moist fallows (Silva et al., 1977), and *T. guianensis* is extremely widespread and prevalent in most types of lowland forests, besides being notoriously poisonous (Gentry, 1993).

In the open forest, *A. maripa (*inaja), *Myrcia fallax (*murta), *Croton lonjouwensis (*dima*), Casearia grandiflora (piabinha*), and *O. bacaba* are the most abundant species (Table 4.6). Different from the dense forest, the top dominant species in the open forest are small and medium-sized trees prevalent in fallows and disturbed and/or open areas. *O. bacaba* can be also found in both fallows and mature forest. The dominance of these species clearly shows that the area which has been considered open forest does not consist of mature vegetation. Rather, given the dominant species composition found here, it is an area affected by anthropogenic disturbance.

In the campinarana, *T. guianensis* (Table 4.7), which is common in both undisturbed and disturbed forests, is among the top five dominant species. *A. maripa* and *Myrcia fallax* are prevalent in disturbed and fallow areas, while *Simarouba amara* (marupa) and *Aldina heterophylla (macucu)* are large tree species with a straight cylindrical trunk, and diameter of up to 80 cm (Brasil, INPA, 1991). *S. amara* and *A. heterophylla* are also found in fallow, but *A. heterophylla* is frequent in forested campinarana, vegetation on white sand soil with a canopy between 15-25 meter (Anderson et al., 1975). Thus, as in open forest, campinarana area also presents dominance of species common in fallows and disturbed areas. This shows that these areas had been used in the past as was described in the land use history section. However, dominance of *A. heterophylla* indicates that mature characteristics of the campinarana area are still maintained in some patches.

Based on diameter and height of trees greater or equal to 10cm DBH (Figure 4.2), the structure of Campus Forest is formed mostly by trees with DBH between 10-25 cm and height around of 20 m. Large numbers of small diameter trees is a pronounced characteristic of upland undisturbed Central Amazon forests, however their canopy height is between 30-40 m, much taller than found in CF. These CF structural characteristics vary among the three types of vegetation (Figure 4.3). In the dense forest, the number of trees within the DBH classes greater than 20cm is 8% and 5% more frequent than in open forest and campinarana, respectively. These numbers can be seen as small differences, however few emergent trees with large trunk diameters strongly influences the structure of a forest.

Most emergent trees in the CF are found in the dense forest area (Figure 4.4). This reflects significantly on the distribution of basal area among the different types of vegetation. The total basal area in the CF is 18.8 m^2 per ha (Figure 4.5), however in dense forest it is 21.5 m^2 per ha, whereas it is only 13.1 in the open forest, and 17.4 in the campinarana. Basal area of the Brazilian Amazon dense mature forest is on average around 35 m^2 per hectare (Pires, 1978), most ranging between 30- 40 (Saldarriaga et al., 1988; Ulh et al., 1988; Rakin-de Merona, 1992; Moran et al., 1996). However, depending on the quality of the soil, basal area can vary between the extreme values of 20 to 50 (Moran et al., 1996). Thus, based on basal area, the Campus Forest as a whole forest unit would be classified as a patchy mature forest on poor soils, presenting a mosaic of heterogeneous patches of both mature forest (dense forest with basal area greater than 20 m^2/ha) and intermediate or advanced secondary succession where basal area varies mostly between 10- 20 m^2/ha (see Moran et al., 1996).

Thus, in summary, the Campus Forest as a whole can be characterized as a mature forest if the number and composition of species are also considered. However, by examining the three vegetation zones, dense forest exhibits some patches with mature forest features as in species composition as in terms of other structural attributes. Open forest reflects the average basal area of an intermediate fallow and a species composition dominated by fallow species. The same trend was found for the campinarana vegetation. The most dominant species in the campinarana area were not from the dominant species usually found in this type of forest, but from fallow and disturbed areas, except for *Aldina heterophylla*.

4.4. Reclassifying the Campus Forest Vegetation types

Different from what was described by Coutinho (1994) and Izel and Custodio (1996), the Campus Forest is not covered only by mature forests. The influence of historical human use is very clear on the forest attributes. On the Campus Forest west side -- vegetation zone 2 (Figure 2.8) where the vegetation had been classified as open forest, in reality, that area is mostly covered by secondary forest enriched by a few small mature forest patches. However, while both north and southwestern borders had been used by former owners and the University, only the north was cut for more than 25 years due to the Coroado invasion. Thus, because of the different intensity of land use, the secondary succession at Coroado is younger than that on the south side, which is closer to the Atilio Andreazza border.

The same kind of evidence could be seen on the east side -- vegetation zone 3, where Savanna vegetation is located. That border is still buffered by a forest zone, but, except for at most 3 hectares of a less disturbed campinarana forest patch, secondary vegetation covers the area. In addition to the fact that farmers and the University used that area until two decades ago, the white sand soils are the poorest nutrient environment in the Amazon (Klinge & Herrera, 1977), a fact which increases both the vulnerability of these areas to human impact and the time required for campinarana vegetation to recover from disturbance.

The forest in the dense forest area -- vegetation zone 1, demonstrates species composition and biomass of mature forest. However, the average basal area for this dense forest is very close to the lower limit of this type of vegetation, ranging between 20 and 50 m^2/ha (Moran et al., 1996). High plant biodiversity is still found in the dense forest area and in the Campus Forest as a whole. Vascular plants have been described as having high resilience and low response to fragmentation (Collet and Turner, 1997; Bierregaard et al., 1997), but types, quantity and frequency of the forest resource uses by human communities have to be assessed to understand what is happing plant biodiversity to that forest fragment.

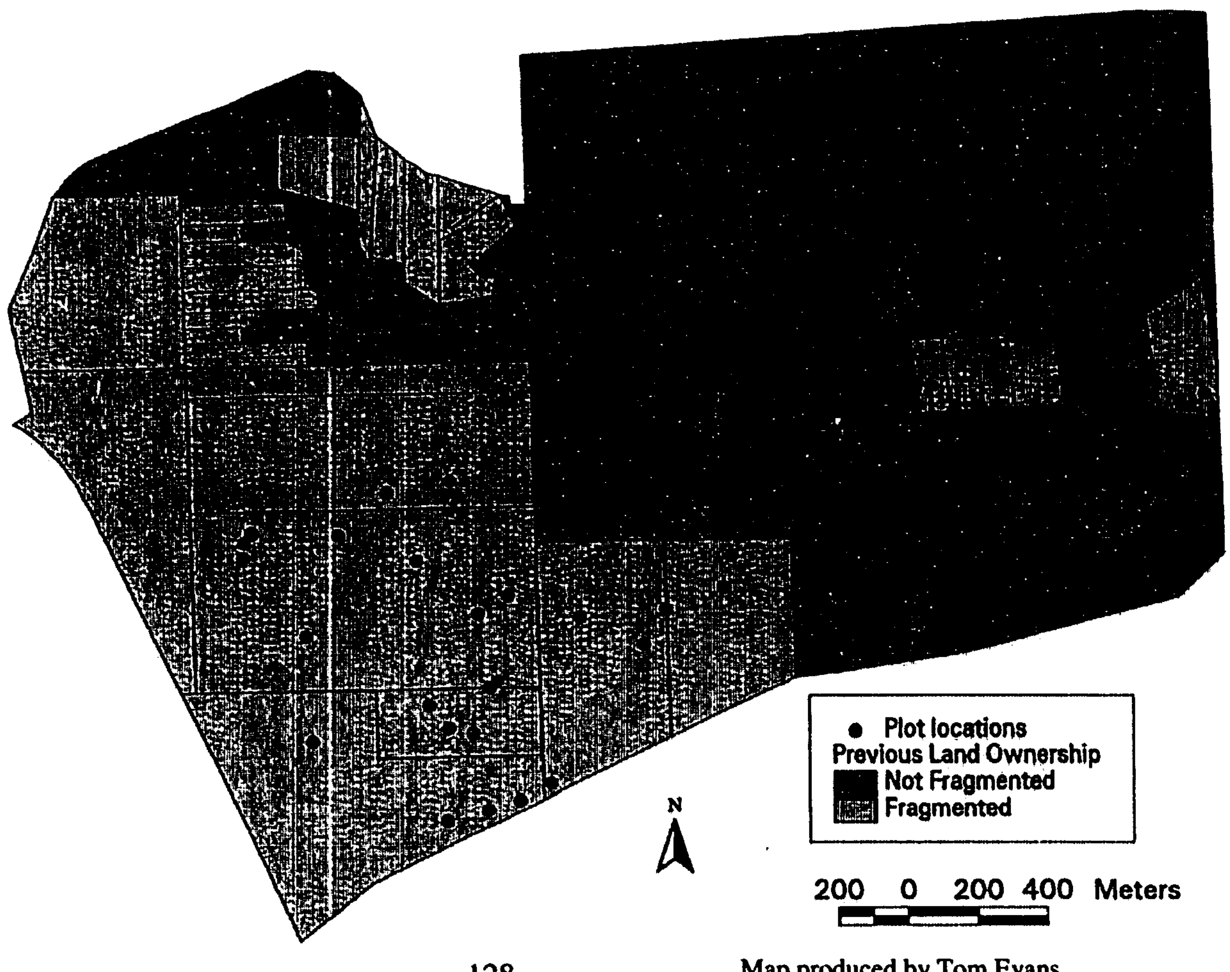
Thus, the Campus Forest is covered by two main types of vegetation: dense forest and campinarana, and their specific secondary successional stages. It is important to remember that here campinarana is used as just one type of vegetation, following the IBGE's (1992) classification system, and secondary succession as the regenerative stages resulting from cutting and regeneration of a forest (see Chapter 3, Section 3.3). For the Campus Forest vegetation map zone (Figure 2.8), vegetation zone 1should be maintained as dense forest, but zone 2 and 3 should be renamed. For zone 2, I suggest naming it secondary succession of dense forest (SS-OD), and the Amazon secondary succession average attributes will be used as a baseline in the next chapter's analysis. However, zone 3 should be named disturbed campinarana (DIST-CC) because even though the secondary succession species have dominated the area, the forested campinarana area seems to maintain its ecological integrity related to species composition and biomass. Nevertheless, the total campinarana area will be excluded off from the next chapter's analysis (effect of fragmentation) for two reasons. First, this vegetation comprises a very complex context because it is formed by three vegetation sub-categories where basal area range from almost zero m^2/ha in the grass-wood campinarana to 26 m^2/ha in the forested campinarana (Chapter 3, Section 3.3) And, second, because it will be very difficult to discriminate the effect of past land use on its biomass from its high natural variation of sub-types. Futhermore, this becomes more complex when edge and fragmentation effect are taken into account.

How to analyze the effect of fragmentation on the Campus Forest

Given the high variation in the internal and external factors which isolated the Campus Forest as an urban forest fragment, analysis of the direct and indirect effects of fragmentation cannot consider it as just one fragment. It must be considered to be at least four different forest fragments when the internal road and buildings are taken into account (Figure 2.8). On the north side from Coroado to Acariaquara, for example, one finds a fragmented piece of forest that varies from 300 to 500 meters wide. However, that fragment cannot be analyzed as just one unit either, because depending on the location, parts of that fragment have been exposed to different isolation times, and internal and external land-use practices.

Thus, two criteria are taken into consideration for the next chapter's analysis. (1) type of vegetation zone related to history of land use inside the Campus, and (2) time of fragmentation (the age of the forest isolation on the outside border). Using these two criteria, and treating the vegetation zones as three different units, four sector fragments are selected to test the three hypotheses described in Chapter 1 (Table 4.9): sectors I - Acariquara, II- Nova Republica, and III- Ouro Verde all, located within dense forest but with different histories of forest isolation along the outside border; and IV-Coroado, covered by SS-OD (secondary succession with 25 years of isolation) (see Table 4.9, and also Figure 4.6 which describes the spatial distribution of the forest sectors). Thus, finally, in the next chapter, which analyzes the biophysical and institutional edge effects on the Campus Forest, attributes are tested, using, first the three vegetation zones, and second, the four fragment sectors.

Figure 4.1. Patrimonial map of the Campus Forest, showing the spatial distribution of the former land owner lots and of the forest plots surveyed on 1996.



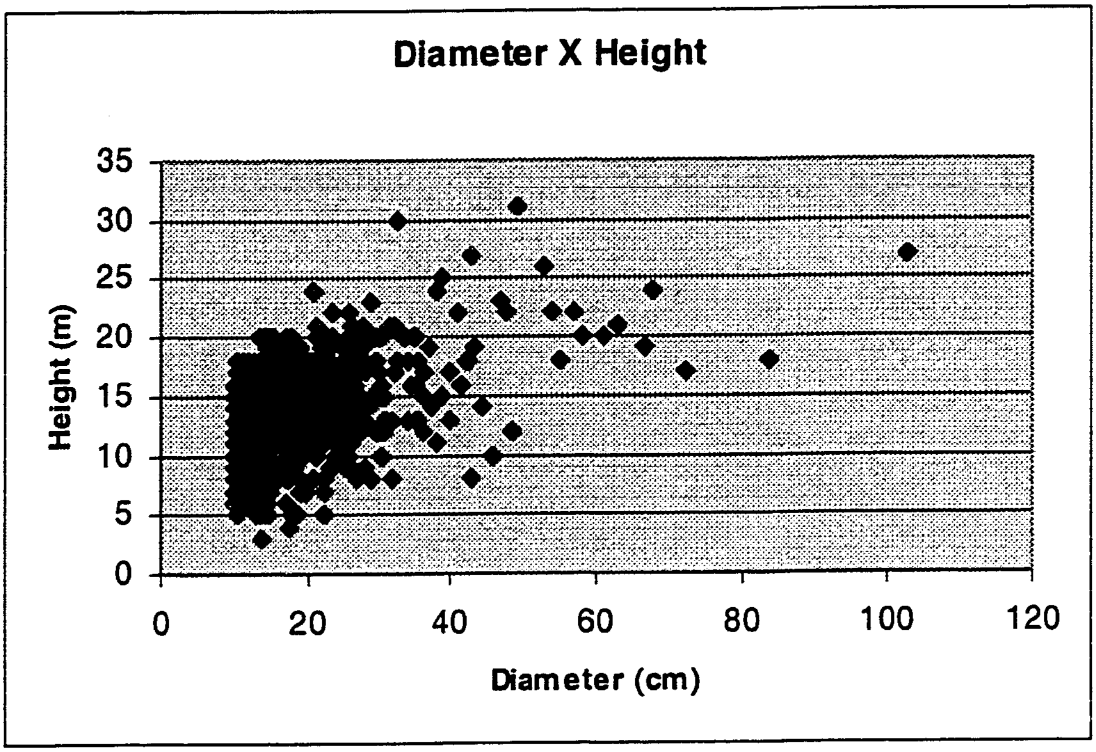


Figure 4.2- Distribution of diameter (cm) and height (m) within the Campus Forest

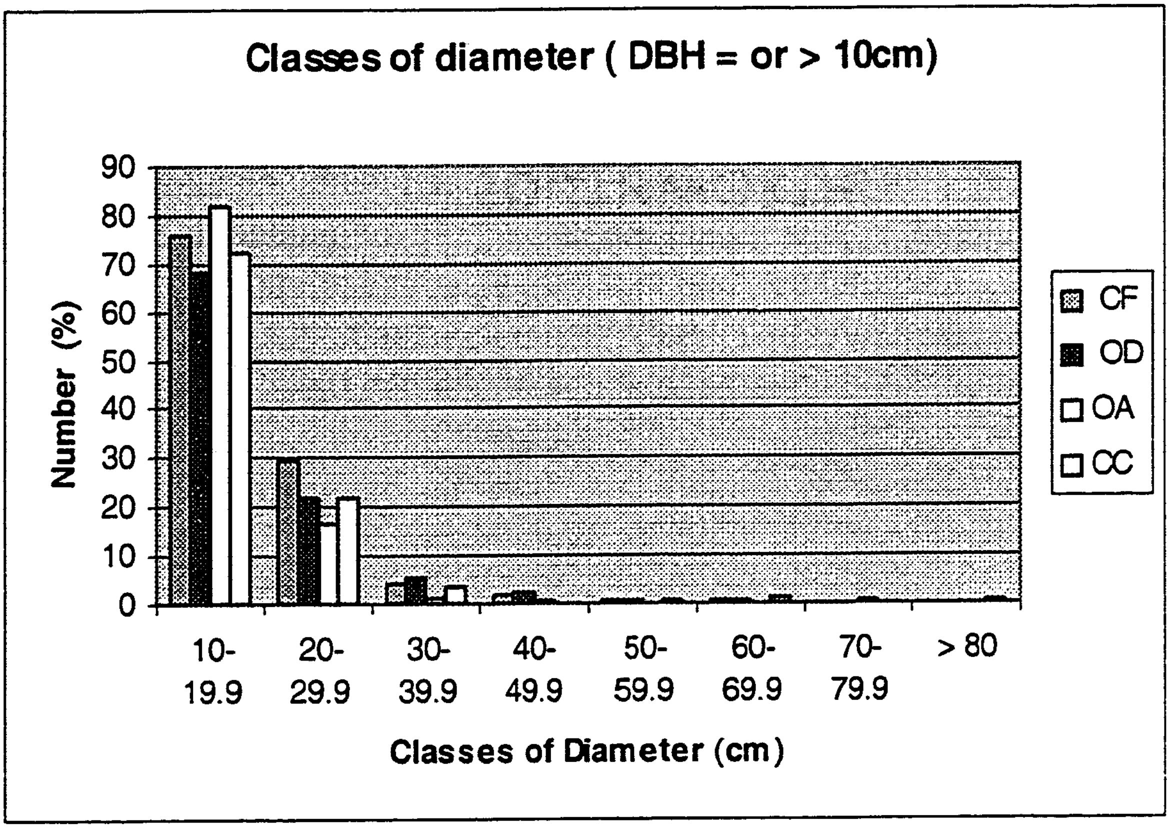


Figure 4.3- Distribution of trees (%) by classes of diameter (cm), (CF- Campus Forest, OD- dense forest, OA- open forest, and CC- campinarana)

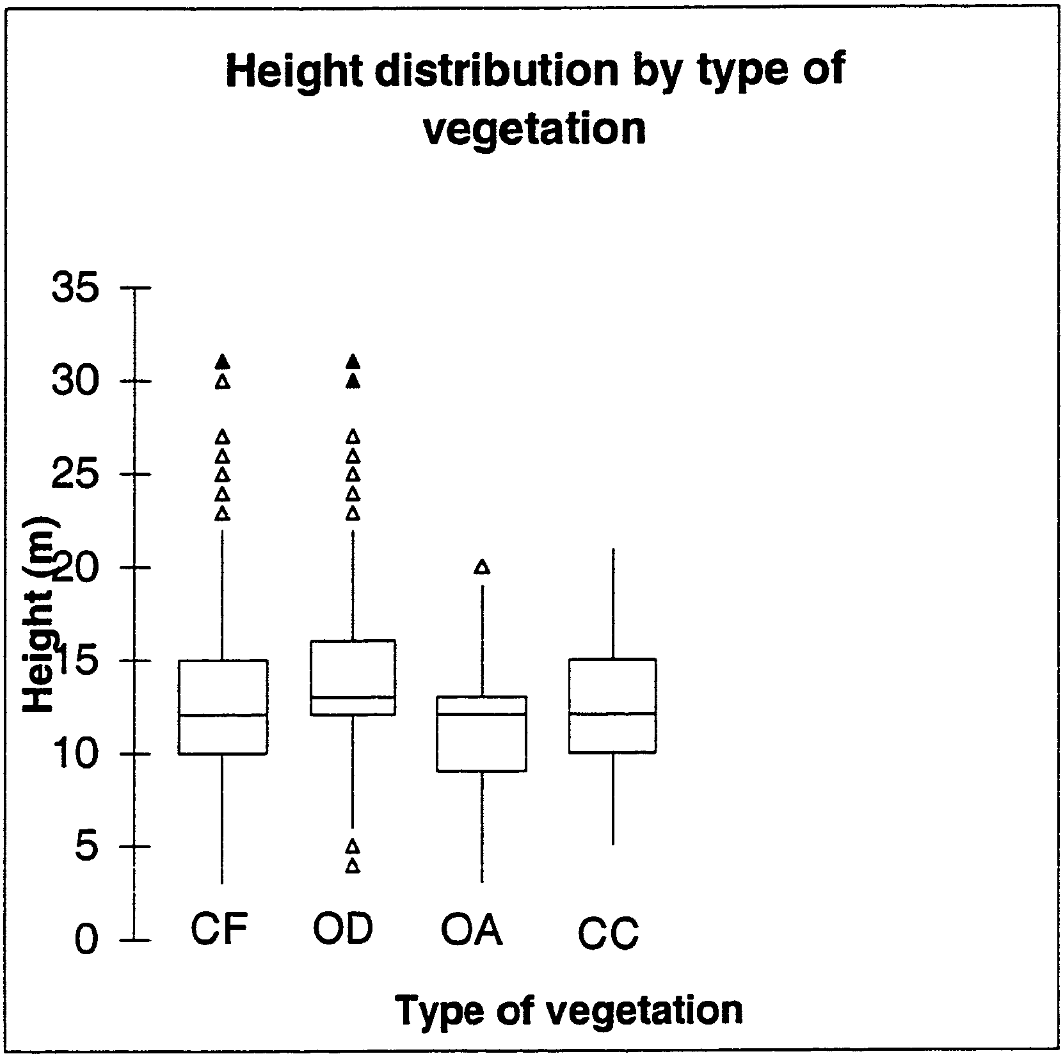


Figure 4.4- Distribution of height (m) by the types of vegetation (OD- dense forest; OA- open forest; CC- campinarana) in the CF- Campus Forest

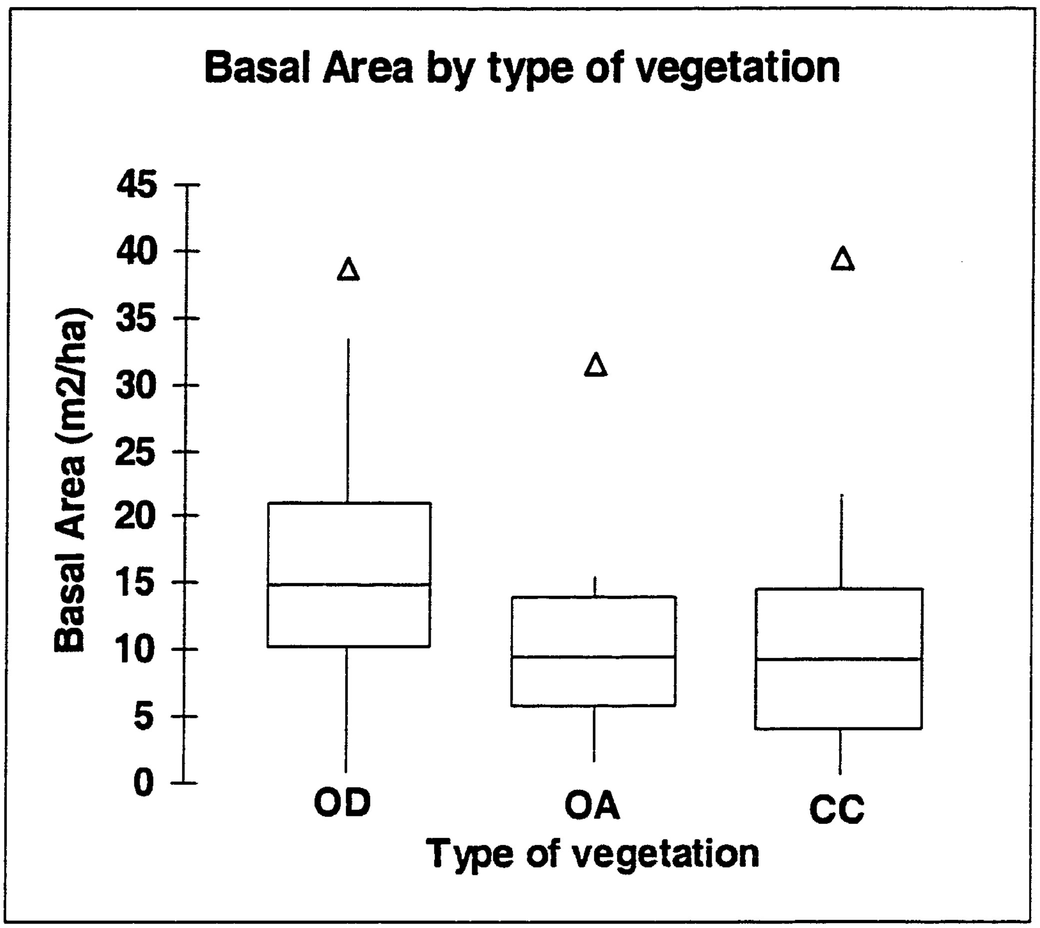


Figure 4.5- Distribution of basal area (m^2/ha) by type of vegetation (OD- dense forest, OA- open forest, and CC- campinarana) in the Campus Forest

Figure 4.6. Spatial distribution of the Campus Forest fragment Sectors located between the campus mainroad and the neighborhoods: I. Acariquara (15years), II. Nova Republica (10 years), III. Ouro Verde (4 years), and IV. Coroado (25 years). Vz (vegetation zone) 1. dense forest, 2. secondary succession, and 3. campinarana. Lansat TM RGB, 345 composite.

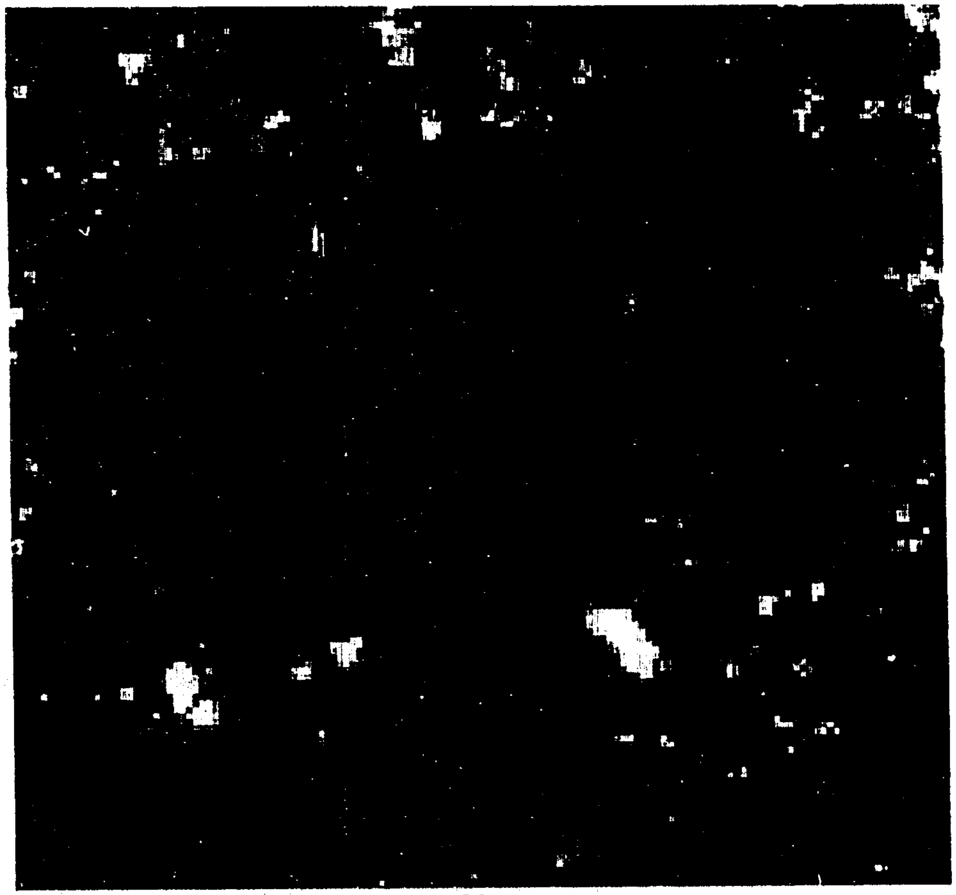


Table 4.1. Vascular Plants from of the Campus Forest, Manaus, AM, Brazil

Family	Species (N)	Genera (N)	Habits
Leguminosae	58	31	tree/vine
(Fabaceae)	28	13	tree
(Mimosaceae)	17	8	tree
(Caesalpiniaceae)	13	10	tree/strangler
Moraceae	23	12	shrub/tree
Rubiaceae	23	9	shrub/tree
Melastomataceae	21	5	shrub/tree
Annonaceae	19	9	tree
Lauraceae	17	6	tree
Myristicacea	17	4	tree
Euphorbiaceae	16	11	tree/shrub
Burseraceae	15	2	tree
Sapotaceae	15	5	tree
Sapindaceae	13	6	tree
Chrysobalanaceae	13	4	tree/vine
Lecythidaceae	12	5	tree
Myrtaceae	12	2	tree/shrub
Apocynaceae	11	6	tree/vine
Arecaceae	11	10	palm
Cecropiaceae	10	2	tree
Violaceae	8	3	tree
Clusiaceae	7	4	tree/shrub
Flacourtiaceae	7	3	shrub/tree
Humiriaceae	6	4	tree
Meliaceae	6	2	tree
Simaroubaceae	6	3	tree
Anacardiaceae	5	4	tree
Malpighiaceae	5	2	tree/vine
Dilleniaceae	4	2	liana
Ebenaceae	4	1	tree
Nyctaginaceae	4	1	tree/herb
Rutaceae	4	2	tree
Vochysiaceae	4	3	tree
Boraginaceae	3	1	tree/shrub
Cyperaceae	3	3	herb
Elaeocarpaceae	3	1	shrub/tree
Loganiaceae	3	2	liana/shrub

Menispermaceae	3	2	liana/shrub
Amaranthaceae	2	2	herb
Bignoniaceae	2	2	liana/shrub
Bombacaceae	2	2	tree
Combretaceae	2	1	tree
Erythroxylaceae	2	1	shrub
Heliconiaceae	2	1	herb
Hippocrateaceae	2	1	liana
Linaceae	2	1	herb/tree
Maranthaceae	2	2	herb
Olacaceae	2	2	tree
Piperaceae	2	1	shrub
Quiinaceae	2	1	tree
Rhizophoraceae	2	1	tree
Schizaeaceae	2	1	herb
Sterculiaceae	2	1	tree/shrub
Verbenaceae	2	1	liana/shrub/tree/herb
Caricaceae	1	1	shrub/tree
Celastraceae	1	1	tree
Commelinaceae	1	1	herb
Connaraceae	1	1	vine
Convolvulaceae	1	1	liana
Cyatheaceae	1	1	tree/herb
Dichapetalaceae	1	1	tree
Dioscoreaceae	1	1	vine
Gnetaceae	1	1	liana
Hymenophyllaceae	1	1	herb
Icacinaceae	1	1	shrub/tree
Liliaceae	1	1	herb
Monimiaceae	1	1	liana/shrub
Ochnaceae	1	1	shrub/herb
Poaceae	1	1	herb
Polygalaceae	1	1	tree/shrub/vine
Polygonaceae	1	1	herb
Polypodeaceae	1	1	herb/epiphyte
Sellaginellaceae	1	1	herb
Strelitziaceae	1	1	shrub
Theaceae	1	1	shrub
Tiliaceae	1	1	tree
Ulmaceae	1	1	tree
TOTAL = 77	447	217	

Table 4.2. Species-rich Genera of the Campus Forest, Manaus, AM, Brazil.

Genera	Species (n)	Habit	Family
Miconia	13	tree	Melastomataceae
Protium	11	tree	Burseraceae
Virola	10	tree	Myristicaceae
Swartzia	8	tree	Fabaceae
Ocotea	8	tree	Lauraceae
Inga	8	tree	Mimosaceae
Eugenia	8	tree	Myrtaceae
Eschweilera	7	tree	Lecythidaceae
Pouteria	7	tree	Sapotaceae
Licania	6	tree	Chrysobalanaceae
Duroia	6	tree	Rubiaceae
Guatteria	5	tree	Annonaceae
Cecropia	5	tree	Cecropeaceae
Couepia	5	tree	Chrysobalanaceae
Brosimum	5	tree	Moraceae
Pouroma	5	tree	Moraceae
Iryanthera	5	tree	Myristicaceae
Leonia	5	tree	Violaceae

Table 4.3. Species with Highest Importance Values (IVI) in Campus Forest (DBH>10cm), Manaus, AM, Brazil.

#	Species	# inds.	# plots	BA/sp	Rel. dens.	Rel. freq	Rel dom	IVI
1	Attalea maripa	87	37	30994	0.08	0.05	0.10	0.24
2	Oenocarpus bacaba	109	36	17675	0.10	0.05	0.05	0.21
3	Tapirira guianensis	48	23	9966.3	0.04	0.03	0.03	0.11
4	Myrcia fallax	50	23	7872.3	0.04	0.03	0.02	0.10
5	Eschweilera odora	28	12	8847.7	0.02	0.01	0.02	0.07
6	Miconia myriantha	26	13	7112.3	0.02	0.01	0.02	0.06
7	Croton lonjouwensis	29	9	7394.8	0.02	0.01	0.02	0.06
8	Simarouba amara	19	8	5589.5	0.01	0.01	0.01	0.04
9	Miconia regelii	15	10	4747.1	0.01	0.01	0.01	0.04
10	Casearia grandiflora	20	10	2983.9	0.01	0.01	0.00	0.04
11	Astrocaryum aculeatum	13	10	4615	0.01	0.01	0.01	0.04
12	Guatteria discolor	16	11	3017.7	0.01	0.01	0.00	0.04
13	Guatteria olivacea	16	7	4551.3	0.01	0.01	0.01	0.04
14	Protium sp.	12	10	4055.1	0.01	0.01	0.01	0.03
15	Inga alba	11	9	4188.6	0.01	0.01	0.01	0.03
16	Byrsonima spicata	15	8	2715.1	0.01	0.01	0.00	0.03
17	Couepia longipendula	7	6	5605.3	0.00	0.00	0.01	0.03
18	Goupia glabra	9	8	3970.3	0.00	0.01	0.01	0.03
19	Buchenavia macrophylla	2	2	8452.8	0.00	0.00	0.02	0.03
20	Aldina heterophylla	2	1	7917.4	0.00	0.00	0.02	0.02
21	Pouroma guianensis	12	5	2784.1	0.01	0.00	0.00	0.02
22	Rollinia insignis	8	7	3010.1	0.00	0.01	0.00	0.02
23	Corythophora rimosa	5	5	4764.4	0.00	0.00	0.01	0.02

Table 4.4. Species Distribution by Types of Vegetation (DBH > 10cm) in the Campus Forest (OD- Dense forest; OA- Open forest; CC- Savanna forest).

#	Family	Species	OD	OA	CC	od - oa	od - cc	oa - cc
1	Menispermaceae	Abuta sp.	1					
2	Euphorbiaceae	Alchornea schomburgkii	1		1		1	
3	Fabaceae	Aldina heterophylla Spruce ex. Benth.			1			
4	Ulmaceae	Ampelocera sp.	1	1		1		
5	Anacardiaceae	Anacardium spruceanum Engl.	1					
6	Fabaceae	Andira parviflora Ducke	1					
7	Lauraceae	Aniba sp.	1					
8	Lauraceae	Aniba williansii O.C. Smidt.	1		1		1	
9	Fabaceae	Abarema sp.			1			
10	Euphorbiaceae	Aparisthmium cordatum Baill.			1			
11	Apocynaceae	Aspidosperma album (Vahl) R. Ben.	1					
12	Apocynaceae	Aspidosperma obscurinervium Azambuja	1					
13	Arecaceae	Astrocaryum aculeatum G. Mey.	1	1	1			
14	Arecaceae	Astrocaryum gynacantum Mart.	1		1		1	
15	Melastomataceae	Bellucia glossularioides (L.) triana	1					
16	Melastomataceae	Bellucia imperialis Sald. & Cogn	1	1	1			
17	Annonaceae	Bocageopsis multiflora (Mart.) R. E. Fr.	1		1		1	
18	Bombacaceae	Bombacopsis sp.			1			
19	Moraceae	Brosimum parinarioides Ducke	1	1		1		
20	Moraceae	Brosimum rubescens Taub.	1					
21	Combretaceae	Buchenavia macrophylla Eichl.	1		1		1	
22	Combretaceae	Buchenavia sp.			1			
23	Malpighiaceae	Byrsonima crassifolia (L.) Kunth		1				
24	Malpighiaceae	Byrsonima crispa A. Juss.		1	1			1
25	Malpighiaceae	Byrsonima spicata (Cav.) DC.		1	1			1
26	Caricaceae	Carica papaya		1				
27	Lecythidaceae	Cariniana decandra Ducke	1					
28	Flacourteaceae	Casearia grandiflora Cambess.	1	1		1		
29	Flacourteaceae	Casearia sp.	1					
30	Flacourteaceae	Casearia sylvestris Sw.	1	1		1		
31	Cecropiaceae	Cecropia pachystachya			1			
32	Cecropiaceae	Cecropia purpurascens C. C. Berg			1			
33	Cecropiaceae	Cecropia sciadophylla Mart.			1			
34	Sapotaceae	Chrysophyllum sp.	1					
35	Moraceae	Clarisia sp.	1					
36	Clusiaceae	Clusia grandiflora Splitg			1			
37	Clusiaceae	Clusia sp.			1			
38	Polygonaceae	Coccoloba sp	1					
39	Boraginaceae	Cordia silvestris	1	1		1		
40	Lecythidaceae	Corythophora rimosa W. Rodr.	1					
41	Chrysobalanaceae	Couepia canomensis (Mart.) Benth. ex Hook		1				

42	Chrysobalanaceae	Couepia guianensis Aubl.	1					
43	Chrysobalanaceae	Couepia longipendula Pilg.	1					
44	Chrysobalanaceae	Couepia sp.	1					
45	Apocynaceae	Couma macrocarpa Barb. Rodr.		1				
46	Moraceae	Coussapoa cf. latifolia			1			
47	Euphorbiaceae	Croton lonjouwensis Jablonski	1	1		1		
48	Sapindaceae	Cupania sp.	1					
49	Dilleniaceae	Davilla sp.	1					
50	Caesalpineaceae	Dialium guianensis (Aubl.) Sandw.		1				
51	Caesalpineaceae	Dimorphandra parviflora Spruce ex. Benth.	1					
52	Ebenaceae	Diospyrus praetermissa	1		1		1	
53	Fabaceae	Diplotropis purpurea (Rich.)		1	1			1
54	Fabaceae	Dipteryx cf. polyphylla Huber			1			
55	Fabaceae	Dipteryx sp.	1	1		1		
56	Rubiaceae	Duroia hirsuta (Poepp. & Engl.) Schum.			1			
57	Rubiaceae	Duroia saccifera (Mart.) Hook. f. ex K. Schum	1					
58	Rubiaceae	Duroia sp.	1		1		1	
59	Humiriaceae	Endopleura uchi (Huber) Cuatr.	1	1		1		
60	Mimosaceae	Enterolobium schomburgkii Benth.		1				
61	Caesalpineaceae	Eperua bijuga	1		1			1
62	Annonaceae	Ephedranthus amazonicus R. E. Fr.	1					
63	Vochysiaceae	Erisma sp.			1			
64	Lecythidaceae	Eschweilera cf. amazonica R. Knuth	1					
65	Lecythidaceae	Eschweilera coriaceae (D.C.) Mart. ex Berg.	1					
66	Lecythidaceae	Eschweilera fracta R Knuth	1					
67	Lecythidaceae	Eschweleira micrantha (Berg.) Miers	1					
68	Lecythidaceae	Eschweilera odora (Poepp.) Miers	1	1		1		
69	Lecythidaceae	Eschweilera sp.	1					
70	Myrtaceae	Eugenia sp	1					
71	Myrtaceae	Eugenia uniflora L.	1					
72	Rubiaceae	Faramea multiflora	1	1		1		
73	Moraceae	Ficus cf. obtusifolia (Miq.) Miq.			1			
74	Celastraceae	Goupia glabra Aubl.	1	1		1		
75	Meliaceae	Guarea cf. pohlii	1					
76	Meliaceae	Guarea duckei C. DC.	1					
77	Meliaceae	Guarea sp.	1					
78	Annonaceae	Guatteria discolor R. E. Fr.	1	1	1			
79	Annonaceae	Guatteria olivacea R.E. Fr.	1	1				
80	Annonaceae	Guatteria procera R.E. Fr.						
81	Moraceae	Helicostylis podogyne Ducke	1	1		1		
82	Moraceae	Helicostylis tomentosa (P. & E.) Rusby	1	1		1		
83	Moraceae	Helianthostylis cf. sprucei Baill.	1					
84	Caesalpineaceae	Heterostemon sp.			1			
85	Euphorbiaceae	Hevea guianensis Aubl.	1					
86	Apocynaceae	Himatanthus sp.						
87	Apocynaceae	Himatanthus sucuuba (spruce)	1	1	1			

		Woodson						
88	Humiriaceae	Humiria balsamifera (Aubl.) St. Hil.			1			
89	Fabaceae	Hymenolobium cf. pulcherrimum Ducke		1				
90	Fabaceae	Hymenolobium excelsum Ducke						
91	Fabaceae	Hymenolobium sp.	1					
92	Mimosaceae	Inga panurensis Spruce ex. Benth.	1	1	1			
93	Mimosaceae	Inga alba (SW.) Willd.	1	1	1			
94	Mimosaceae	Inga paraensis Ducke	1					
95	Mimosaceae	Inga sp.	1	1		1		
96	Mimosaceae	Inga umbratica poepp. & Endl.	1					
97	Myristicaceae	Iryanthera sp.1			1			
98	Myristicaceae	Iryanthera sp.2			1			
99	Myristicaceae	Iryanthera sp.3	1	1		1		
100	Myristicaceae	Iryanthera tricornis Ducke	1					
101	Bignoneaceae	Jacaranda copaia (Aulb.) D. Don	1	1	1			
102	Arecaceae	Jessenia bataua (Mart.) Burret			1			
103	Apocynaceae	Lacmellea arborescens (Muell. Arg.) Marxgr.			1			
104	Apocynaceae	Lacmellea gracilis (Muell. Arg.) Marxgr.	1	1		1		
105	Quiinaceae	Lacunaria jemmani Ducke		1				
106	Lecythidaceae	Lecythis jarana	1	1		1		
107	Violaceae	Leonia cf. glyxicarpa Ruiz & Pav.		1				
108	Violaceae	Leonia cymosa Mart.			1			
109	Mimosaceae	Leucaena latisiliqua		1				
110	Chrysobalanaceae	Licania egleri Prance			1			
111	Chrysobalanaceae	Licania latifolia Benth. ex Hook		1				
112	Chrysobalanaceae	Licania micanthra Miq.			1			
113	Chrysobalanaceae	Licania sp.	1	1	1			
114	Lauraceae	Licaria canella (Meissn.) Kosterm. augustata Kurz			1			
115	Lauraceae	Licaria guianensis Aulb.	1					
116	Lauraceae	Licaria sp.	1	1		1		
117	Euphorbiaceae	Maprounea sp.		1				
118	Moraceae	Maquira cf. calophylla (P. & E.) Berg	1					
119	Sapindaceae	Matayba cf. inelegans Raldk.			1			
120	Arecaceae	Attalea maripa	1	1	1			
121	Melastomataceae	Miconia cf. eriodonta			1			
122	Melastomataceae	Miconia cf. tetrasperma Gleason	1	1		1		
123	Melastomataceae	Miconia dispar Benth.	1					
124	Melastomataceae	Miconia egensis Cogn.		1				
125	Melastomataceae	Miconia elaeagnoides Cogn.	1	1	1			
126	Melastomataceae	Miconia gratissima Benth. ex Triana	1					
127	Melastomataceae	Miconia holosericea (L.) DC.			1			
128	Melastomataceae	Miconia myriantha Benth.	1	1	1			
129	Melastomataceae	Miconia poeppigii Triana			1			
130	Melastomataceae	Miconia phanerostila Pilg.	1	1		1		
131	Melastomataceae	Miconia regelii Cogn.	1	1	1			
132	Melastomataceae	Miconia sp.	1					
133	Sapotaceae	Micropholis guyanensis (A. DC.) Pierre		1				
134	Melastomataceae	Mouriri trunciflora Ducke	1		1		1	

135	Melastomataceae	Mouriri vernicosa Naudin	1					
136	Myrtaceae	Myrcia fallax (Rich.) DC.	1	1	1			
137	Nyctagenaceae	Neea altissima (Rich) DC.	1	1		1		
138	Nyctagenaceae	Neea sp.	1					
139	Lauraceae	Ocotea guianensis Aubl.	1	1		1		
140	Lauraceae	Ocotea rodriguesii Kurz	1					
141	Lauraceae	Ocotea schomburgkiana	1					
142	Lauraceae	Ocotea sp.	1					
143	Lauraceae	Ocotea sp.6	1					
144	Lauraceae	Ocotea sp.A	1					
145	Arecaceae	Oenocarpus bacaba Mart.	1	1	1			
146	Fabaceae	Ormosia coarctata	1	1				
147	Fabaceae	Ormosia sp.						
148	Ochinaceae	Ouratea discophora Ducke	1					
149	Mimosaceae	Parkia oppositifolia	1	1		1		
150	Mimosaceae	Parkia sp.	1					
151	Mimosaceae	Parkia sp.1		1				
152	Euphorbiaceae	Pera schomburgkiana Muell. Arg.		1				
153	Moraceae	Perebea sp.	1					
154	Strelitziaceae	Phenakospermum sp.		1				
155	Mimosaceae	Pithecollobium racemosun Ducke	1					
156	Cecropiaceae	Pouroma guianensis Aubl.	1		1		1	
157	Cecropiaceae	Pouroma minor Benoist.						
158	Cecropiaceae	Pouroma sp.						
159	Sapotaceae	Pouteria cf. campanulata Baehni	1					
160	Sapotaceae	Pouteria cf. parviflora			1			
161	Sapotaceae	Pouteria guianensis Aubl.	1					
162	Sapotaceae	Pouteria jariensis	1					
163	Sapotaceae	Pouteria lasiocarpa	1					
164	Sapotaceae	Pouteria sp.1	1					
165	Sapotaceae	Pouteria sp.2	1					
166	Burseraceae	Protium cf. altsoni Sandw.	1					
167	Burseraceae	Protium cf. apiculatum Swart	1	1				
168	Burseraceae	Protium cf. aracouchini (Aubl.) March.	1					
169	Burseraceae	Protium decandrum (Aubl.) March.	1					
170	Burseraceae	Protium giganteum Engl.	1					
171	Burseraceae	Protium heptaphyllum (Aubl.) March.			1			
172	Burseraceae	Protium paniculatum Eng. & Swart						
173	Burseraceae	Protium sp.	1	1	1			
174	Burseraceae	Protium sp2	1					
175	Moraceae	Pseudolmedia cf. laevigata Trecul.	1					
176	Moraceae	Pseudolmedia sp.	1					
177	Rubiaceae	Psychotria calitata	1					
178	Vochysiaceae	Qualea paraensis Ducke	1					
179	Vochysiaceae	Qualea sp.	1					
180	Sapotaceae	Richardella cf. rivicoa		1				
181	Sapotaceae	Richardella sp.		1				
182	Violaceae	Rinorea racemosa (Mart. ex Zucc)	1	1		1		

		Kuntze						
183	Annonaceae	Rollinia cuspidata Mart.	1					
184	Annonaceae	Rollinia exsucca	1	1		1		
185	Annonaceae	Rollinia insignis R. E. Fr.	1	1		1		
186	Humiriaceae	Sacoglottis cf. guianensis Benth.	1		1		1	
187	Caesalpineaceae	Sclerolobium melanocarpum Ducke	1					
188	Bombacaceae	Scleronema micranthum Ducke	1		1		1	
189	Simaroubaceae	Simaba sp.		1				
190	Simaroubaceae	Simarouba amara Aubl.	1		1		1	
191	Simaroubaceae	Simarouba sp.	1					
192	Monimiaceae	Siparuna guianensis Aubl.	1					
193	Elaeocarpaceae	Sloanea guianensis (Aubl.) Benth						
194	Elaeocarpaceae	Sloanea sinemariensis			1			
195	Arecaceae	Socratea exorrhiza (Mart.) H. Wendl.	1					
196	Moraceae	Sorocea hirtella	1					
197	Moraceae	Sorocea sp.	1					
198	Anacardiaceae	Spondias lutea L.		1				
199	Rhizophoraceae	Sterigmapetalum obovatum Kuhlm.	1	1	1			
200	Mimosaceae	Stryphnodendron guianensis (Aulb.) Benth.	1					
201	Fabaceae	Swartzia brachyrhachis	1					
202	Fabaceae	Swartzia polyphylla DC.	1					
203	Fabaceae	Swartzia recurva Poepp. in P. & E.	1					
204	Fabaceae	Swartzia sp.	1					
205	Sapindaceae	Talisia sp.	1					
206	Anacardiaceae	Tapirira guianensis Aubl.	1	1	1			
207	Dichapetalaceae	Tapura sp.	1					
208	Theaceae	Ternstroemia dentata (Aulb.) Sw.		1				
209	Sterculiaceae	Theobroma silvestris Aubl. ex Mart.	1	1		1		
210	Sterculiaceae	Theobroma sp.	1					
211	Anacardiaceae	Thyrsodium paraense Huber			1			
212	Anacardiaceae	Thyrsodium schomburgkianum Benth.	1					
213	Sapindaceae	Toulicia guianensis Aulb.	1	1		1		
214	Sapindaceae	Toulicia sp.	1	1		1		
215	Burseraceae	Trattinnickia glaziovii Swart			1			
216	Burseraceae	Trattinnickia lursirifolia	1	1		1		
217	Burseraceae	Trattinnickia sp.	1					
218	Burseraceae	Trattinnickia suarilosum						
219	Meliaceae	Trichilia cf. septentrionalis C. DC.	1					
220	Meliaceae	Trichilia micrantha Benth.		1				
221	Unknown	Unknown ao	1					
222	Burseraceae	Unknown at	1					
223	Euphorbiaceae	Unknown aw	1					
224	Lauraceae	Unknown b	1					
225	Unknown	Unknown bj	1					
226	Moraceae	Unknown c	1					
227	Unknown	Unknown z		1				
228	Humiriaceae	Vantanea sp.	1					

229	Fabaceae	Vatairea sericea Ducke	1					
230	Myristicaceae	Virola calophylla Warb.	1	1		1		
231	Myristicaceae	Virola multinervia Ducke	1					
232	Myristicaceae	Virola pavonis (A. DC.) A. C. Smith	1					
233	Myristicaceae	Virola sp.1	1					
234	Myristicaceae	Virola sp.3	1	1		1		
235	Myristicaceae	Virola sp.4	1					
236	Myristicaceae	Virola venosa (Benth.) Warb.	1		1			
237	Clusiaceae	Vismia guianensis (Aulb.) Choisy	1	1	1			
238	Verbenaceae	Vitex triflora Vahl	1					
239	Vochysiaceae	Vochysia vismiifolia	1					
240	Annonaceae	Xylopia amazonica R. E. Fr.		1	1			1
	TOTAL	240	169	81	70	32	12	5

Table 4.5. Species with the Highest Inportance Values (IVI) in OD- Dense Forest of the Campus Forest,Manaus, AM, Brazil.

	Species	# inds.	# plots	BA/sp	Rel dens	Rel freq	Rel dom	IVI
1	Oenocarpus bacaba	82	28	12193.69	0.01	0.06	0.06	0.14
2	Attalea maripa	52	18	16887.17	0.00	0.04	0.08	0.14
3	Eschweilera odora	27	11	8749.16	0.00	0.02	0.04	0.07
4	Tapirira guianensis	14	8	5331.65	0.00	0.01	0.02	0.04
5	Buchenavia macrophylla	1	1	8332.04	0.00	0.00	0.04	0.04
6	Couepia longipendula	7	6	5605.26	0.00	0.01	0.02	0.04
7	Miconia myriantha	12	6	4694.70	0.00	0.01	0.02	0.04
8	Protium sp.	10	8	3789.73	0.00	0.01	0.01	0.04
9	Myrcia fallax	12	9	3077.46	0.00	0.02	0.01	0.04
10	Goupia glabra	8	7	3880.41	0.00	0.01	0.02	0.03
11	Corythophora rimosa	5	5	4764.40	0.00	0.01	0.02	0.03
12	Croton lonjouwensis	17	6	3805.23	0.00	0.01	0.01	0.03
13	Brosimum rubescens	2	2	5211.93	0.00	0.00	0.02	0.03
14	Guatteria olivacea	12	5	3114.38	0.00	0.01	0.01	0.03
15	Inga alba	6	5	2855.07	0.00	0.01	0.01	0.02
16	Rollinia insignis	5	5	2306.70	0.00	0.01	0.01	0.02
17	Pithecolobium racemosum	5	5	2235.47	0.00	0.01	0.01	0.02
18	Hevea guianensis	3	3	3123.91	0.00	0.00	0.01	0.02
19	Virola venosa	7	7	944.07	0.00	0.01	0.00	0.02
20	Miconia regelii	6	3	2673.18	0.00	0.00	0.01	0.02
21	Qualea paraense	1	1	3599.60	0.00	0.00	0.01	0.02
22	Miconia elaeagnoides	6	6	980.05	0.00	0.01	0.00	0.02
23	Vochysia vismiifolia	1	1	3494.04	0.00	0.00	0.01	0.02

Table 4.6. Species with the Highest Important Values (IVI) in OA- Open Forest of the Campus Forest, Manaus, AM, Brazil.

	Species	# inds.	# plots	BA/sp.	Rel. dens	Rel. freq	Rel dom.	IVI
1	Attalea maripa	18	9	5567.42	0.08	0.06	0.11	0.26
2	Myrcia fallax	17	7	2527.80	0.07	0.05	0.05	0.18
3	Croton lonjouwensis	12	3	3589.54	0.05	0.02	0.07	0.15
4	Casearia grandiflora	13	6	1651.47	0.05	0.04	0.03	0.13
5	Oenocarpus bacaba	11	5	2362.58	0.05	0.03	0.04	0.13
6	Enterolobium schomburgkii	2	2	4342.87	0.00	0.01	0.08	0.11
7	Astrocaryum aculeatum	7	4	2487.44	0.03	0.02	0.05	0.11
8	Miconia myriantha	8	5	1015.40	0.03	0.03	0.02	0.09
9	Guatteria olivacea	4	2	2120.43	0.01	0.01	0.04	0.07
10	Byrsonima spicata	7	3	931.37	0.03	0.02	0.01	0.07
11	Tapirira guianensis	5	3	968.76	0.02	0.02	0.01	0.06
12	Miconia regelii	4	3	1030.21	0.01	0.02	0.02	0.06
13	Leucaena latisiliqua	6	1	1047.54	0.02	0.00	0.02	0.05
14	Trattinnickia lursirifolia	6	3	267.82	0.02	0.02	0.00	0.05
15	Guatteria discolor	4	3	673.34	0.01	0.02	0.01	0.05
16	Miconia phanerostila	4	1	1166.54	0.01	0.00	0.02	0.04
17	Bellucia imperialis	3	3	603.49	0.01	0.02	0.01	0.04
18	Inga alba	3	2	786.67	0.01	0.01	0.01	0.04
19	Rollinia insignis	3	2	703.42	0.01	0.01	0.01	0.04
20	Bocageopsis multiflora	2	2	885.15	0.00	0.01	0.01	0.04
21	Pourouma sp.	2	2	875.85	0.00	0.01	0.01	0.04
22	Vismia guianensis	3	2	566.10	0.01	0.01	0.01	0.04
23	Xylopia amazonica	3	2	416.20	0.01	0.01	0.000	0.03

Table 4.7. Species with the Highest Importance Values (IVI) in CC- Savanna Forest of the Campus Forest, Manaus, AM, Brazil.

	Species	# inds.	# plots	BA/sp.	Rel. dens	Rel. freq	Rel dom	IVI
1	Tapirira guianensis	27	13	3665.86	0.12	0.10	0.05	0.28
2	Attalea maripa	15	9	8539.13	0.06	0.06	0.13	0.27
3	Simarouba amara	17	6	4543.21	0.07	0.04	0.07	0.19
4	Myrcia fallax	22	7	2267.03	0.09	0.05	0.03	0.18
5	Aldina heterophylla	2	1	7917.36	0.00	0.00	0.12	0.14
6	Oenocarpus bacaba	15	3	3119.10	0.06	0.02	0.04	0.13
7	Heterostemon sp.	6	2	5797.00	0.02	0.01	0.09	0.13
8	Byrsonima spicata	8	5	1783.74	0.03	0.03	0.02	0.10
9	Humiria balsamifera	6	3	1591.24	0.02	0.02	0.02	0.07
10	Miconia regelii	5	4	1043.67	0.02	0.02	0.01	0.06
11	Miconia myriantha	6	2	1402.19	0.02	0.01	0.02	0.06
12	Guatteria discolor	5	4	564.06	0.02	0.03	0.00	0.06
13	Buchenavia sp.	1	1	3117.15	0.00	0.00	0.04	0.06
14	Eperua bijuga	4	3	815.58	0.01	0.02	0.01	0.05
15	Pouroma guianensis	5	2	873.86	0.02	0.01	0.01	0.05
16	Vismia guianensis	5	2	677.78	0.02	0.01	0.01	0.04
17	Astrocaryum aculeatum	3	3	722.74	0.01	0.02	0.01	0.04
18	Licania sp.	4	1	1287.18	0.01	0.00	0.02	0.04
19	Diplotropis purpurea	3	2	657.98	0.01	0.01	0.01	0.03
20	Inga alba	2	2	546.81	0.00	0.01	0.00	0.03
21	Clusia grandiflora	2	1	974.44	0.00	0.00	0.01	0.03
22	Miconia elaeagnoides	2	2	389.60	0.00	0.01	0.00	0.03
23	Himatanthus sucuuba	2	2	316.23	0.00	0.01	0.00	0.02

Table 4.8. Summary of the Attributes of the Campus Forest Fragmentation Process on the Outside border

Border	Type of Vegetation	Age of Isolation
Coroado	Open forest	25
Atilio Andreazza	Open forest	10
Acariquara	Dense forest	15
Nova Republica	Dense forest	10
Ouro Verde	Dense forest	4
Campina/campinarana	Savanna forest	0

Table 4.9. Summary of the Attributes of the Forest Fragment Sectors in the Campus Forest

Sector	Type of vegetation	Age of Isolation (years)	Expected basal area (m2/ha
I-Acariquara	Dense forest	15	20-50
II- Nova Republica	Dense forest	10	20-50
III- Ouro Verde	Dense forest	4	20-50
IV- Coroado	SS-OD	25	10-25

CHAPTER 5

BIOPHYSICAL AND INSTITUTIONAL EDGE EFFECTS OF FOREST FRAGMENTATION ON THE STRUCTURAL ATTRIBUTES OF THE CAMPUS FOREST

In Chapter 4, I analyzed the Campus Forest vegetation zones using basal area, three height and species composition as indicators of forest attributes. By integrating the land-use history data both inside and outside of the campus, I concluded that Campus Forest is covered by two main types of vegetation: dense forest and campinarana, but parts of these vegetation were in different stages of secondary succession. Land-use history also showed that different parts of the Campus Forest were isolated in different time periods. Thus, the analysis of the effect of fragmentation on that forest considers both vegetation types and different ages of fragmentation (see Table 4.9).

In this chapter, I examine both the biophysical[1] and institutional edge effects of fragmentation on the Campus Forest structure using two types of indicators: (1) basal area as biomass indicator estimated from the forest inventory undertaken in 1996, and (2) land cover change analysis over time as an indicator of forest change using a set of three remotely sensed images (Landsat MSS from July 31, 1977, and two Landsat TM image from August 15, 1988 and September 21, 1995). The biophysical and institutional edge

[1] Here I am considering the edge effect model developed by biologists to be biophysical because it doe not consider the role of human beings.

effects are tested by considering the three vegetation zones and the four forest fragment sectors.

For each vegetation zone and fragment sector (see Table 4.9, and also Figure 4.5. which describes the spatial distribution of both), basal area is the dependent variable and the distance from both the main road and the outside border edges are the independent variables. As discussed in Chapter 1, habitat fragmentation has been assumed as a process responsible for ecosystem degradation in both species richness and biomass. Although it has been difficult to show the influence of edge effects on plant species richness, the structure of vascular flora communities is expected to be affected earlier by edge effects. Tree fall and canopy openness are expected to increase close to the edges. It is predicted that the forest biomass will decrease on the edges, mostly within the first 100 m (Laurance et al., 1997).

Variation in forest biomass can also be captured by remote sensing images showing different spectral signatures. Forest, secondary succession and open areas are identified and clustered in classes to analyze the spatial distribution of changes in the Campus Forest. As described in Section 3.3, forests in the Central Amazon are associated with high biomass, secondary succession with low to moderate biomass, and open areas (urban) with little or no biomass. Land use and land cover change analysis are used here to show the changes in biomass over time around the Campus Forest.

Changes in forest biomass can be the result of several processes such as deforestation, forest degradation, afforestation and regrowth. Deforestation shows changes from forest to cleared area and represents a total loss of forest biomass. What I define as degradation shows changes from forest to secondary succession. Loss of forest biomass through forest degradation is interpreted in the remote sensing analysis as areas where deforestation occurred but forest recovery has already taken place, and also areas where forest has been disturbed by physical and human effects, resulting in lower biomass. Afforestation is here defined as the process of change from both cleared area and secondary succession into forest, that is, a high increase in forest biomass between two dates. Finally, regrowth is defined as the process of change from cleared areas to secondary succession, that is, areas that show moderate increases in total biomass.

Biophysical and institutional edge effects can then be traced through time. If forest biomass decreases close to the edges, it is expected that secondary succession is replacing mature forest on the edges. This process has been predicted by Laurance et al. (1997) as biophysical impact. Forest biomass can still be much poorer on the outside border edges where the communities are located as predicted by institutional edge effects (Albers & Grinspoon, 1997).

Monitoring and enforcement have been described to have edge effects on the forest attributes. Forest reserves surrounded by populated areas are more likely to be impacted by outside users. When agencies invest in policing and punitive enforcement policies to protect the reserves, outside users undertake socially-costly avoidance activities to reduce the chance of being caught by extracting products only on the forest's edges, that is, institutional edge effects. Thus, to evaluate the role of monitoring and enforcement on the Campus Forest structural attributes, both a multi-temporal remote sensing analysis and an institutional analysis are undertaken to compare the creation and evolution of Campus Forest institutional arrangements with the land cover analysis over time.

5.1. Biophysical Edge Effects

5.1.1. Effects of fragmentation on the three types of vegetation: Dense forest, Secondary succession of dense forest (SS-OD), and Campinarana

The relationship between basal area and distance from both the mainroad and from outside borders in the three vegetation zones is shown in Figures 5.1 and 5.2, and the statistical results are given in Table 5.1. These indicate that the basal area in these three types of vegetation does not depend on distance from both the main road and the outside border, even within the first 100 meters. Since the outside borders experienced different timing of isolation, or non–isolation such as at the campinarana limits, the results are not surprising. Even though both dense forest and campinarana were isolated by the Campus mainroad at the same time, the forest plots measured close to these two types of forest also do not show any influence of distance from the road edge on the basal area. Besides a few outlying points (Figure 5.1), the basal areas in the three vegetation zones are similar from zero to at least 500 meters inside of the forest, and do not show any edge effect on the Campus Forest attributes.

5.1.2. Effect of fragmentation on the forest fragment sectors

The relationship between basal area and distance from both the mainroad and from outside borders in the four forest fragment sectors is shown in Figures 5.3 and 5.4, and the statistical results are also given in Table 5.1. These results indicate that only in sector I-Acariquara, where the outside border was isolated 15 years ago, is basal area influenced by distance from both forest edges. The relationship is statistically significant, with distance from the mainroad explaining 70%, and distance from the outside border 62 %, of the basal area variance. However, basal area is higher close to the road edge than inside of the forest, showing a trend opposite (Figure 5.3) to what is predicted by the edge effect model. In this sector, edge effects seem to have a positive influence on the forest biomass in the way that basal area decreases progressively toward the forest core area. Nevertheless, it is difficult to justify this trend due to biophysical edge factors. However, soil is probably one of the physical factors that could influence the biomass distribution related to distance in this sector. The Acariquara sector shares borders with campinarana forest on white sand soils. White sand (Spodosols) is the poorest soil type in the Amazon, and forests on this type of soil present, in general, lower biomass than dense forests.

Acariquara's proximity to Ouro Verde is another factor that may affect basal area distribution in the Acariquara sector. Residents from these two neighborhoods have behaved differently in regard to the Campus Forest. Acariquara is a middle class neighborhood where residents are very concerned with forest conservation, particularly within the campus. In the last 7 years, not only have Acariquara residents organized environmental education programs involving their children, but also their security guards have watched the forest borders that they share with the campus. One of their concerns is the presence of Ouro Verde residents collecting products in the forest.

As described earlier, Ouro Verde is a neighborhood created through land invasion in 1992. Ouro Verde residents formerly gathered forest products from the campus, mostly during the neighborhood establishment period. However, Ouro Verde residents may also gather forest products around the Acariquara sector. However, given the presence of Acariquara residents and security guards, they do not use the forest close to the Acariquara border, or close to the campus main road, where students, staff, professors and guards often circulate. However, they would probably use trail network to gather forest products in the forest sector core areas. This strategy reduces the probability of being observed by a guard.

The relationship between basal area and distance from the outside border is also statistically significant. The results, however, have been influenced by two points located between 200 and 300 m from the edges. The distribution of the basal area within the first 100 m does not shows biomass decline as a function of distance from edges. Indeed, basal area distribution varies mostly from 5 to 20 m^2/ha independent of the 100 m distance from the Acariquara edges. However, it increases around 300 m from the edge. This trend could be a slight indication of biophysical edge effect from the Acariquara border since residents have not been using Campus Forest products.

5.2. Institutional Edge Effects

No relationship between biomass and distance from the edges was detected in the remote sensing analysis during the period of 1977-1988-1995. Figure 5.5 shows the spatial distribution of the three main land cover classes in the Campus Forest in 1977. Secondary succession is distributed in patches around the Mini-campus and some in the campinarana area instead of being located along the edges. From 1977-1988, the spatial distribution of the land cover changes (Figure 5.6) shows forest changes inside the campus areas and several pixels with land cover changes on the borders mostly on the north side. However, changes on the borders are not consistently associated with degradation (i.e., changes from forest to secondary succession). Instead of degradation, land cover change analysis shows a progressive afforestation around the whole Campus Forest area (see Figure 5.6 and 5.7). Deforestation occurred when campus buildings and other services were installed.

5.3. Land use and land cover change in the Campus Forest

As described in Chapter 4, in the beginning of the 1970s, the Campus lost 119 hectares of forest caused by the Coroado invasion. According to Campus Forest officers, since that invasion, the Campus Forest has been in a progressively degrading process. Instead, analysis of land cover over time shows a different trend. In 1977, 81.5 % of the Campus Forest was covered by forest, 13.8 % by secondary succession, and 4.6 % by cleared areas (urban) (Table 5.3). Even though 65 hectares of the forest were cleared by the University of Amazonas to build its main road, the main campus buildings where the Reitoria and ICHL are located, and also the Agronomy School training area, the level of afforestation and regrowth increased substantially in the same period, reaching more than 50 hectares (Table 5.2). In the last period, 1988-1995, the afforestation area was three times larger than the deforested area (Table 5.2), showing a high level of forest recovery instead of progressive forest degradation. In 1995, instead of having less area covered by forest due to campus infrastructure expansion, which covered 3% the Campus Forest, more area was covered by forest than in 1977, increasing the area covered by forest by around 6%.

In contrast to both biophysical and institutional edge effect models and the reports of Campus Forest officers, instead of being degraded around the edges, since 1977, the Campus Forest has been progressively gaining biomass. It was not possible to show any influence of biophysical and institutional edge effects on its attributes by using indicators such as basal area and land cover changes over time. Therefore, do these results mean that the University is successfully managing and monitoring the Campus Forest? Are the communities around the campus not using the consumptive forest products? How can we explain the ecological recovery in the Campus Forest?

5.4. Governance and Institutional Arrangements in the Campus Forest

Looking at the current level of monitoring and enforcement of rules that govern the Campus Forest, one may think that it is almost an "open access area". The University of Amazonas does have formal rules to regulate the use of forest products. Trees, herbs, and animals can be collected only for scientific or educational purposes, although there is no systematic monitoring of those forms of use. A research project planning to collect forest products or having direct or indirect impact on the forest system is expected to follow the suggestions developed by the land use zoning commission in 1989. When the implementation of a project generates conflicts, it should be submitted to the University

Superior Counsel (CONSUNE) for resolution. In one such case, a Professor from the Engineering Department proposed to build mini-dams using several of the campus streams. The project received so much criticism that the dams were never developed.

Even though the Campus Forest must be accessible only to University users, people from outside have also used the forest in several ways such as getting water, opening and using soccer fields, and for recreation and appreciation of nature. These uses are informally allowed, whereas collecting vegetation products and hunting are not. However, no sanctions exist for people who do not follow these rules. The Campus Forest is sporadically patrolled by the Security Department (Departamento de Vigilância) of the University.

Since 1996, the area has been patrolled twice a week, only during daylight hours, by six guards. The guards are divided into two teams of three men. Each team leaves the main entrance at around 8:00 a.m. and walks in different directions, always following a large trail on the external limits of the campus. They arrive back at the principal entrance between 4-5 pm If a guard meets a person cutting a tree or hunting, he must act as an educator, trying to convince that person to preserve the forest by not collecting products. The maximum penalty allowed to the guards is to confiscate the product and expel the poacher. In the past, there were cases where guards took guns, but this is always a dangerous situation. Guards do not receive guns from the University because their role is considered to be educational. However, all guards use their own guns for personal security because of the presence of ruffians and gangs in the area. These are the rules and behavior that University officers and guards say work there.

Given these circumstances, why is the campus as a whole not only maintaining its ecological attributes but also recovering its biomass through afforestation? It is counter intuitive since the forest is located in a very populated region and does not have a strong enforcement system to prevent the forest from being used by outsiders. It is important, however, to know the history of the creation and establishment of that reserve as well as its relationship with those who live around it in order to explain this trend.

5.5. Creation and evolution of Institutional Arrangements Governing the Campus Forest

5.5.1. Settlement of the Campus Forest: Invasion and the Institutional Establishment, 1968-1975.

The Fundação Universidade of Amazonas bought the campus land in 1968 when Manaus was starting to become a frontier area (see Chapter 3, Section 3.2). The main goal of the University was to have a campus where all academic units could be close to their respective training sites around an Amazon native forest that could also be used for scientific and educational purposes. At that time, the Campus Forest was located in a peri-urban region and the university could have the legal right to the whole area only after a legal process of seven years. Before any of its infrastructure could be built or its borders delimited, part of th land was invaded by squatters on its north side (Sector IV- Coroado). The demographic changes in Manaus and the process of invasion were so rapid in the beginning of the 1970s that the University did not have the structure and coordination to expel people from the area. Thus, the Campus Forest institutional arrangement was created and established within two different processes: 1) conflict with squatters to control the land invasion, and 2) hard negotiation with some of the small landowners who were resistant to the idea of selling and leaving their land.

The land invasion started in the northeast corner of the campus and spread to other areas in three waves, creating the current Coroado I, II and III. From the original 800 hectares bought by the University, 119 were invaded. Until 1973, the University had just four guards to control the land invasion (see Table 5.5 that summarizes the effective monitoring on Campus Forest borders over time). By 1974, the security department was created and the number of guards increased to 25 and others were progressively hired. The security department was organized by an army lieutenant. In that time the country was ruled by the military. Those guards tried to control the invasion with the help of the State Police and the Army on several occasions. During 1974 and 1975, the campus area closer to the invaded area was intensively patrolled and fences were repaired almost daily.

By 1975, a street was opened around the Campus Forest to help the patrolling effort. At that time around 80 guards (Table 5.5) composed the security unit. Each guard was trained in four basic points: how to use a gun, how to approach and identify a person in the campus area, how to take care of the forest patrimony, and how to make an arrest. The guards had orders to arrest any non-allowed person found around the area. The security department spelled out a set of rules about the use of the forest to guide the guards and other University employees. No forest product could be taken from the campus, including sand and water. In the case of a stranger being caught inside the area, the product and the gun had to be taken out and the person sent to the state police to be treated as a thief. In addition to these measures taken by the security department, the University Superior Secretary created an informal rule that any person residing or involved with the Coroado invasion could not be hired as an employee, enforcing thus a long term sanction on the people involved direct or indirectly with the land invasion. This rule worked until the middle of the 1980s. According to several guards who had always lived in the invaded area, many Coroado residents used wrong addresses in order to be hired by the University. According to same guards, that rule worked well since the University was a large potential employer for the people living in the area. Construction had begun on most of the physical infrastructure of the campus by 1975, thus Coroado residents who needed a job did not want to be associated with land invasion or Campus Forest poaching activities.

An important factor which helped to solve the land invasion conflicts was the initiative of Habitation Company of the Amazon (COHAB/AM) to buy the invaded University area, which they named "Favela do Coroado" (of. #00248/75). A report made by a technical commission to evaluate the cost of the invasion concluded that the invaded area of the University was around 1,110,924,62 m² (111 ha) priced at approximately Cr$ 11,109,246,00. COHAB/AM proposed to pay 2 million in currency and the remaining in infra-structure services for the campus. The negotiation between the University and COHAB/AM finished in 1979 when the University finally accepted the COHAB/AM proposal after the size of the invaded area was corrected from 111 to 119 hectares and the price to Cr$ 11,191,784,50. During the four years of negotiation, COHAB/AM improved the Coroado area with several urban services, thus decreasing some of the pressure placed by residents on the Campus Forest products.

Besides dealing with the invasion, the University of Amazonas was also consolidating the process of patrimonial property. Sixteen small land owners were not pleased to sell their land to the University. Most of their complaints were associated with the low price defined by the Fundação Universidade do Amazonas to buy their land. It was not a free market deal. After seven years of litigation, the most resistant land owner left the area, but without receiving his payment. The payment transaction process was very low and most of the sellers only received payment long after leaving their land. The state justice department gave all its support to the University, and when a resistant "seller" was not following the "agreement," the police were called in to help with conflict resolution. According to the security department chief (1974-1977), the last two remaining owners were very "problematic." One of them was arrested twice and left only after spending time in prison. According to her, this resistant owner came back from the prison more calm and left the area, but without money or a place to live.

Thus, during this era, the relationship between the University officers and the remaining landowners was one of "violence," since most of them were forced to sell their land. According to guards, they were always armed and did not even agree to talk with University employees. They continued using their land, cutting the forest, burning it, hunting and in a couple of cases, facilitating access of invaders. However, after 1975 when the last landowner left, the University had total control of the area.

5.5.2. Institutional Consolidation of the Campus, 1975-1977

After controlling most of the land invasion and having control over the whole campus area, the University eventually gained the legal status of the campus area ownership and was respected for that. For example, COHAB/AM paid for the invaded area that was lost to Coroado. The state power company (ELETRONORTE) asked to open an easement (*servidão*) to pass a power line. An area 1400 m long by 20 m wide was opened, but only after a serious negotiation process in which UA concerns in regard to the location of its building and to the mature forest area were taken into account.

The guards also started to mobilize themselves in order to transform the security service into a full-fledged department. As part of the prefecture of the campus through the Division of General Affairs, they did not have much autonomy. Since the conflicts between them and both invaders and former owners were solved or minimized, they experienced institutional crises. They wrote a document entitled "the need to institutionalize the campus security service." In the document, they give a historical description of their activities. Because the security service was created within a context of invasion, their principal activities were to watch the Coroado border and remake that border fence almost every day. However, in order to avoid becoming a group of "jagunços" (gunman), the security group was trying to institutionalize its activities by: a) acquiring legal and constitutive status; b) concentrating all people related to security activities into just one unit; and c) organizing and instrumenting their work structure in order to carry out their task of preserving and taking care of the ecological and physical patrimony of the campus. They received almost no support from the University except for new clothes and shoes to patrol the area. However, the guards began to gain allies from people in charge of planning and preserving the Campus Forest.

5.5.3. GT Biota and Conservationist Concerns: Designing a preliminary management plan for the Campus Forest, 1977-1985

Following the institutional consolidation, two professors (Frederico Arruda and Severiano Mario Porto) sent a letter to the University president explaining the need to study the campus biota in order to preserve it. A working group named GT Biota (Biota working group) was created on September 22, 1977 (GR # 886/77) to design a preliminary management plan for the Campus Forest. Basically, the GT Biota was formed to: (1) create rules and procedures for the selection of areas on which to construct physical infra-structure (buildings and other services); (2) establish rules on planning, executing and conserving the campus road network; (3) elaborate rules and proceedings for maintaining the security and physical integrity of the campus; (4) identify and catalogue plant and animal species, as well as streams and other environmental features in order to elaborate a program to conserve them.

During the GT Biota period (1977-1985), the rules governing the use of the forest continued to be the same as those used in the invasion period. These rules were similar to those used in reserves of restricted-use (i.e., national parks, natural monuments, nature conservation reserves and protected landscapes). The goals of these rules are to: (1) maintain sample ecosystems in their natural state, (2) maintain ecological diversity and environmental regulation, (3) conserve genetic resources, and (4) provide education, research and environmental monitoring.

The main goal of the GT Biota was to restrict any use of the forest besides that which is necessary for research or educational purposes. Through its regulations and monitoring, a master plan for the Campus Forest was designed and executed as part of the physical expansion of the campus infra-structure, including construction of roads, buildings and parking lots. The work of GT Biota was divided into several commissions, dealing with internal and external environmental problems concerning the Campus Forest.

A special working group was designed to structure an environmentally-integrated project aiming to study the relationship between the local environment (forest ecosystems) and the construction of buildings. Three main goal pursued by the group were to: (1) undertake studies about the interactions between the forest environment and the physical construction of the campus; (2) plan urban expansion; and (3) develop methodological tools to plan and manage ecological systems capable of providing a more adequate framework to economic development planning in the Amazon. After intense work, the environmental integration was developed with the "Plano Diretor I da Universidade do Amazonas" (the Universidade do Amazonas's master plan), which established the distribution and architectural profile of the physical infrastructure of the campus.

An environmental commission was created to study the campus's biota. This team made a preliminary list of the botanical species of the campus, a diagnosis of the ecological conditions of the forest ecosystems, and identified and listed more than 800 trees planted in the area which were deforested by squatters and former owners. Besides biological research, this team also helped in monitoring forest conditions and evaluating damage made by unplanned use of the area. For example, the team monitored the activity of ELETRONORTE when the company cleared a forest area to pass a power line through campus. The Power company was charged for each mature tree cut out of the planned area. Thus, every space and activity to be developed inside of the Campus Forest was evaluated by the GT Biota, and they had relatively good control of activities. However, they did not have much control over the borders and the communities surrounding the area.

To monitor and control the entrance of outsiders, the GT biota worked on an assessment to identify the areas more prone to invasion and the activities which could damage the forest and its products. They concluded that from the total perimeter of 11,806 m, the only area relatively well-monitored was the 1,400 m that covered the principal entrance. The remaining 10,400 m was susceptible to squatters and poacher's invasions since the monitoring system capability had decreased over time in number of guards. With the construction of new buildings, part of the guards were allocated to patrol the new installations, and the number of guards in charge of the forest decrease progressively from 80 to 20.

Some specific Campus Forest points were even dangerous, putting at risk the life of guards. Alarmed by the poor monitoring, GT biota members started also to watch the most vulnerable areas. In their final report, entitled "Segurança e defesa dos recursos naturais da area global do campus da Universidade do Amazonas" (security and defense of the natural resources of the University of Amazonas Campus), they identified the most vulnerable points around the campus, and proposed types of instruments and numbers of people to be allocated during days and nights, as well as weekends in order to be able to protect the area.

Besides the 14 most vulnerable points where the 20 available guards were located during nights and weekends, it was recommended that more guards be hired to undertake permanent and continuous patrol around the borders, preferably on horseback. All points to become security stations were drawn on a map and sent to the Campus prefecture. Several other measures were recommended by the GT biota to complement the monitoring activities: (1) to increase the number of guards, (2) to provide guards with clothes and shoes compatible with their activities and roles, (3) to adopt a permanent communication service among several security stations and the central post, (4) to build shelters at all station points, including necessary facilities for effective performance independent of the time of day and weather.

Finally, they highlighted the importance of implementing the measures recommended to monitor the Campus Forest, indicating that for guards to perform their job properly they needed to have the means to be noticed and respected by anyone without the need of armed conflict or violence. And they also needed to remain at their posts, inform the central post of occurrences or ask for help from the state police as soon as possible. Another point highlighted by them was the role of the station houses to become scientific field laboratories where plants and animals could be measured and scientific instruments could be stored, since good information about the campus biota was still lacking. However, most of the biota project's recommendations to complement the

Campus Forest monitoring on its outside borders were not implemented; the number of guards was not increased, a permanent communication was not adopted, and no shelters were built at any station points, except for four stations that were constructed, but later abandoned.

Another important role of the GT biota in preserving the Campus Forest was related to environmental education. The group made a big effort to translate the information they had collected into simple language for the University community and for outside agencies and city neighborhoods. Several newsletters were published, talks and workshops prepared, and also training of University staff and guards was undertaken. The activities of the GT biota ended when a zoning commission was created in 1985.

5.5.4. Zoning Commission-- Designing and Implementing a Management Plan for the Campus Forest, 1985-1992

By 1985, most of the Plano Director I (the Campus master plan) had already been implemented. New buildings needed to be planned in order to allow for the expansion of the University of Amazonas. A zoning commission (Comissão de Zoneamento) was created on July 5, 1985 (GR# 812/85), in order to define locations on which to install new buildings and facilities by following the ecological criteria already established for the campus. The zoning commission was also asked to define the Campus Forest vegetation zones and regulate their use and conservation now that the University had expanded and the forestry and agronomy schools were applying for training sites around the forest area.

During the zoning commission period, some of the Campus Master Plan 1 definitions were modified to attend to the University community's needs. In that time, the buildings were located on the two major plateaux, Mini-campus (68m) and Reitoria-ICHL (94 m) (see Figures 2.1 and 2.2), but those areas were fully occupied. Thus, part of the green area located around the Mini-campus which had been planned to became an Amazonian Green Museum was used to expand the agrarian sector project, the Social Activities Center, the Center of Environmental Science and other buildings related to the Biological Science Institute. Another master plan was developed, however.

By November 1989, the commission released the first version of "Planejamento Estratégico da Universidade do Amazonas" (Strategic Plan of the University of Amazonas), including the "Projeto de Manutenção da Integridade Física do Campus Universitário" (project of maintenance of the physical integrity of the campus) as its main subject. In order to develop its strategic plan, the zoning commission worked through two steps. The first step was to evaluate future academic and administration expansion and project the first approximation of a potential final physical plan. As a second step, they divided into two groups. The commission members worked on three measures to maintain the physical integrity of the Campus, its forest lands and the ecological attributes of the forest. Three projects resulted from their work: (A) construction of an outer boundary wall, (B) Campus Forest zoning, and (C) improvement of the vigilance system.

Those projects were designed to solve two types of threat that could damage the campus: (1) outsiders' threats that could violate the property limits and disturb the forest by cutting trees, and hunting; and (2) inside threats by the University community itself, which could use the area without coordination, causing as many problems as outsiders. Thus, project A, a wall 11.8 km long and 3 m high covering the whole perimeter, and project C, which dealt with the security system and patrolling of the campus, were developed to solve the first problem. Project B, which deals with the Campus zoning and space use regulations, was developed to solve the second problem.

The commission made several site visits to the campus area to elaborate a final zoning for its management plan: the campus management zoning map was divided into 8 zones (Figure 5.9):

(1) Forest park (covering the whole north side from Coroado to the limits of Campina, below Acariquara). This zone has the objective of conserving and restoring forest areas located around the park. It is designed to be used for educational, recreational and scientific activities. Human occupation is not allowed, nor any kind of forest harvesting, or any kind of activity that can disturb or pollute the area.

(2) Biological station (the whole area of sector II- Nova Republica): The biological station has the objective of preserving and reconciling the area with its scientific uses. Areas of limited use are not permitted for the harvesting of vegetal and animal products of any kind, the introduction any type of wild or domestic species, nor the disturbance or pollution of the environment. Only researchers with formal authorization can use the area.

(3) Ecological station of the Campina (Area located at vegetation zone 3): It is an area of the campina ecosystem to be preserved and used for pure ecological and biological research. Area of restricted use where harvesting vegetal and animal product of any kind is not permitted, nor is the introduction of any kind of wild or domestic species, or

disturbing or polluting the environment permitted. Only researchers with formal authorization can use the area.

(4) Agrarian Science Area (the whole area of Atilio Andreazza sector): An area to instal the agrarian sciences facilities and the food production project. This is an area of restricted-use destined to raise animals. It does not allow any kind of activity which can cause erosion and destruction of soil, stream or any water bodies. Also, it does not permit the indiscriminate use of those agrochemicals and fertilizers that can put at risk the health of animals and human beings.

(5) Native fruit species project (Small area located on the south part of Mini-campus facilities): It is a project of environmental education to promote and disseminate the use and plantation of native fruit species in urban areas. Area of restricted use where use or occupation not associated with the goals of the project is not permitted.

(6) Agroforestry experimental station (a small area located on the west part of the mini-campus): Area designed to execute research projects in agro-silviculture, restoration of degraded land and models of ecologically adapted agro-ecosystems. Area of restricted use where human occupation not related with the station goals, or any activity which can degrade the soil, the hydrological network and nutrient cycle is not permitted.

(7) Construction areas and lines of access: Areas already constructed as buildings and roads, and some areas projected for future installations. Any future street or building to be constructed must be approved by the zoning commission.

(8) Protection zone: Buffer line 50 m wide along the streets and around the buildings which serves as a transition area between the urban and protected areas of the

campus. These areas will be maintained free of any kind of occupation except for installation of a bus shelter, vigilance station, or power network.

By the time the commission finished the strategic plan for the campus, they already had the final design to build the wall (Project A), as well as a complete inspection around the whole campus perimeter to be constructed. A budget to start the construction was the one thing lacking in that endeavor, but they were in advanced negotiations with SUFRAMA to obtain enough support. However, that project was never implemented. Since the Coroado invasion, the campus borders have been delimited by fences made with wood and barbed wire.

Once the area had been zoned and the use for each zone defined (Project B), the next step was: (a) to send copies of the projects to all academic and administrative units to disseminate information related to the use of the campus land; (b) to include in the University constitution a chapter describing the zoning plan and all rules associated with it, as well as institutionalize the zoning commission; (c) elaborate projects to establish zones defined by the commission, and search for financing to execute the plans.

The improvement of the surveillance system (project C), an updated version of the GT biota project that was never fully implemented, continued to be only a project on paper for monitoring the campus borders and restricting outsiders' access to the forest areas. During the GT biota time, as mentioned earlier, four security stations were built, but later abandoned. The number of guards allocated to monitor the forest decreased over time. In the late 1980s, around six men patrolled the forest daily, and four to six men twice per week during the 1990s (Table 5.5). Small improvements in the communication system to connect the central station and the guards located in the different buildings and sites were installed in 1995/96 after recommendations made by the "Workshop Sobre a Area do Campus Universitario"[2] (workshop about the Campus green area).

5.6. Conclusion

If on the one side, the creation of a management plan with specific regulations was evolving inside of the campus, on the other side, monitoring and enforcement of those rules on the borders to avoid outside users were decreasing over time. In the last ten years, patrolling has been light. Residents can, in general, notice the presence of the guards and predict exactly the day and time when they will be around the Campus Forest. In this case, monitoring institutions do not seem to have strong impact on the edges of the forest. Absence of monitoring by leaving it technically as an open access area should stimulate people to overuse forest products as predicted by the tragedy of the commons. However, the results of land cover change analysis have shown that the forest has gained biomass over time. Thus, the Campus Forest neighborhood residents must be using

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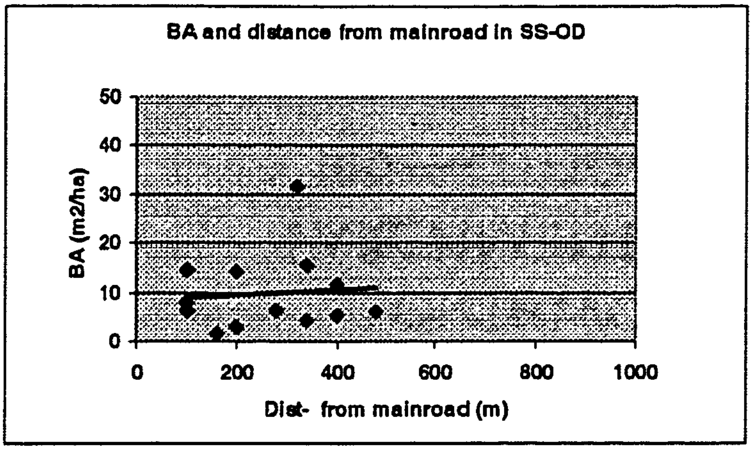
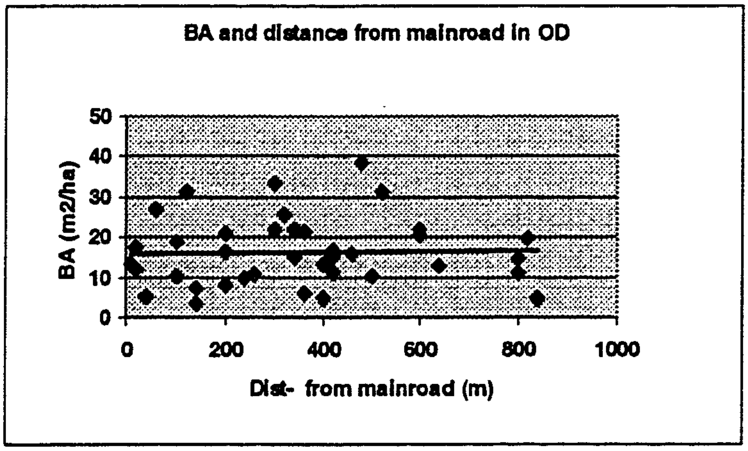
[2] As budget constraints were an obstacle to creating an adequate surveillance system of the Campus Forest, the president of the University of Amazonas called a meeting on May 24, 1994 to form a working group to study the possibility of formalizing the Campus Forest as a conservation unit and including it in the national conservation unit network funded by the state and other agencies. A workshop (workshop sobre a area do Campus Universitario) formed by professors, university staff and a few local residents discussed all conservation problems and some solutions for the area during June 13-17, 1994. After the workshop, a project to improve the campus surveillance system was sent to the minister of the environment. This project could improve the border fences, clean some trails and acquire a communication system to the bases. However, no guards could be hired to increase patrol activities. Also, the Campus Forest was never included in the national conservation units system because the University does not want to lose its autonomy in regard to managing the forest. The workshop results were published as Universidade do Amazonas, 1994. *Workshop sobre a Area do Campus Universitario.* A universidade Debate 2. CCA, Universidade do Amazonas, Manaus.

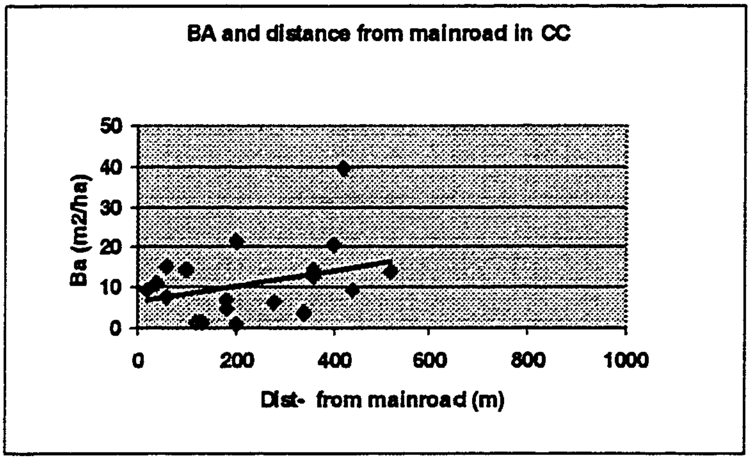
primarily non-consumptive forest products, or other factors are impeding them from using the forest. In order to investigate these questions, in the next chapter, the results of the household survey in regard to the use of the Campus Forest will be presented.



A. SS-OD

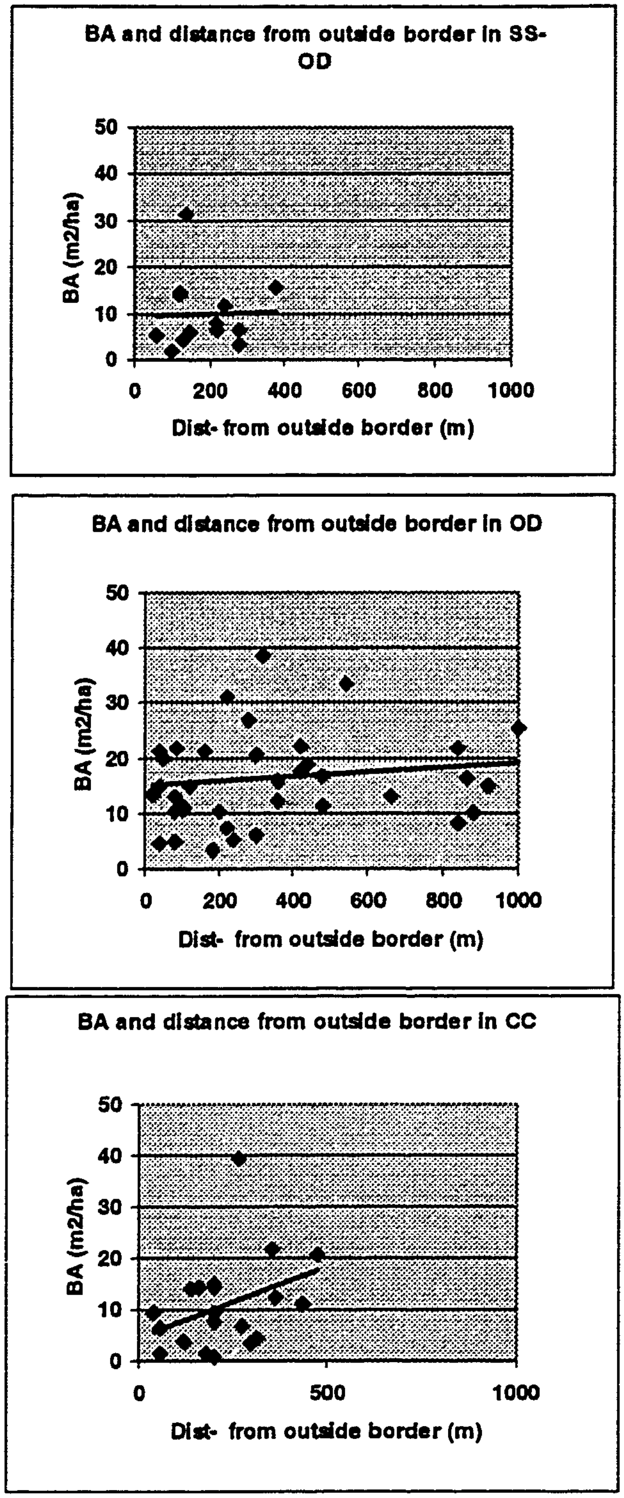


B. dense forest



C. campinarana

Figure 5.1- Relationship between basal area (m^2/ha) and distance from Campus mainroad (m) by type of vegetation: A: SS-OD (secondary succession of dense forest), B: dense forest, and C: campinarana

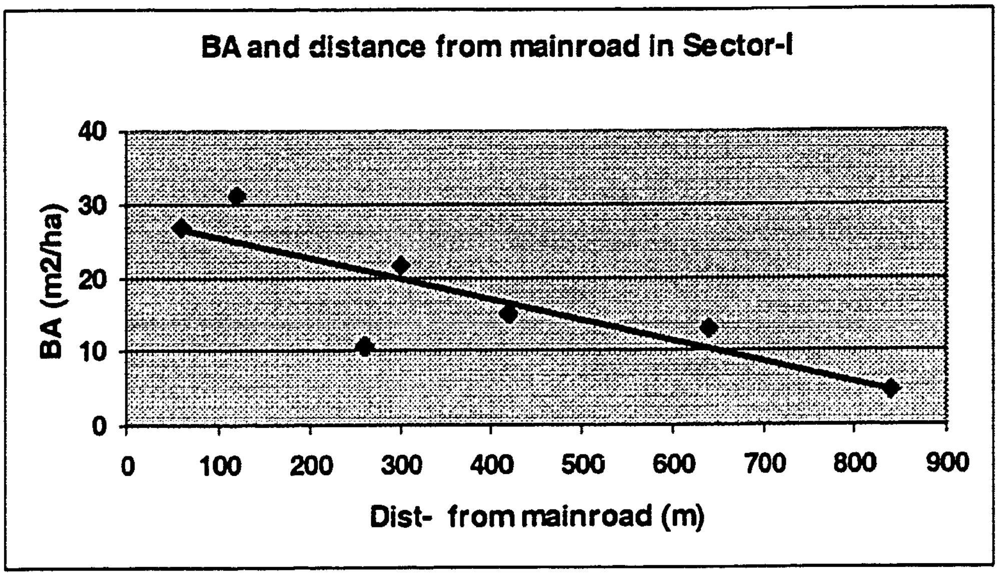


A. SS-OD

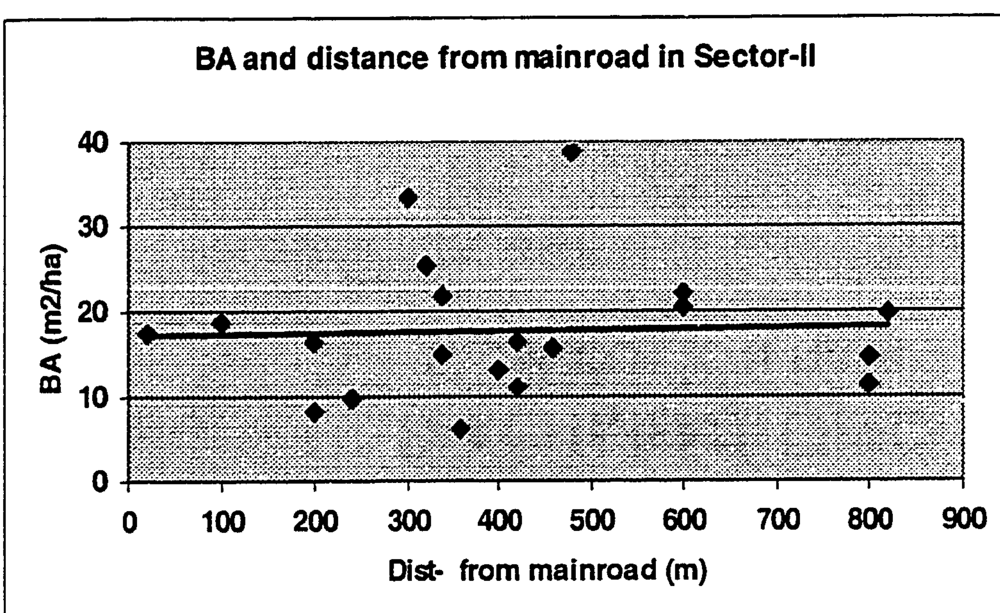
B. dense forest

C. campinarana

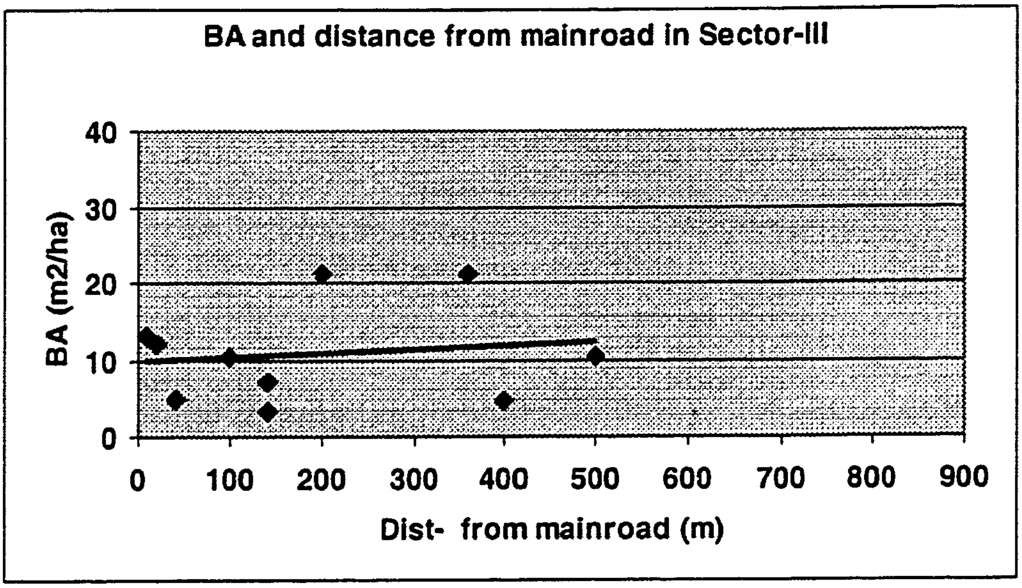
Figure 5.2- Relationship between basal area (m²/ha) and distance (m) from outside border by type of vegetation: A: SS-OD (secondary succession of dense forest), B: dense forest, and C: campinarana.



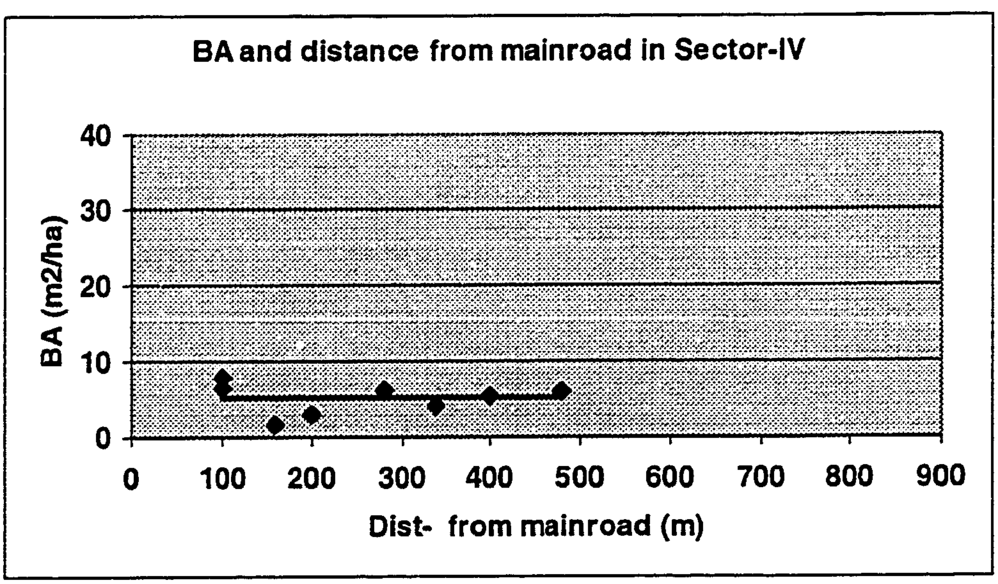
I. Acariquara



II. Nova Republica

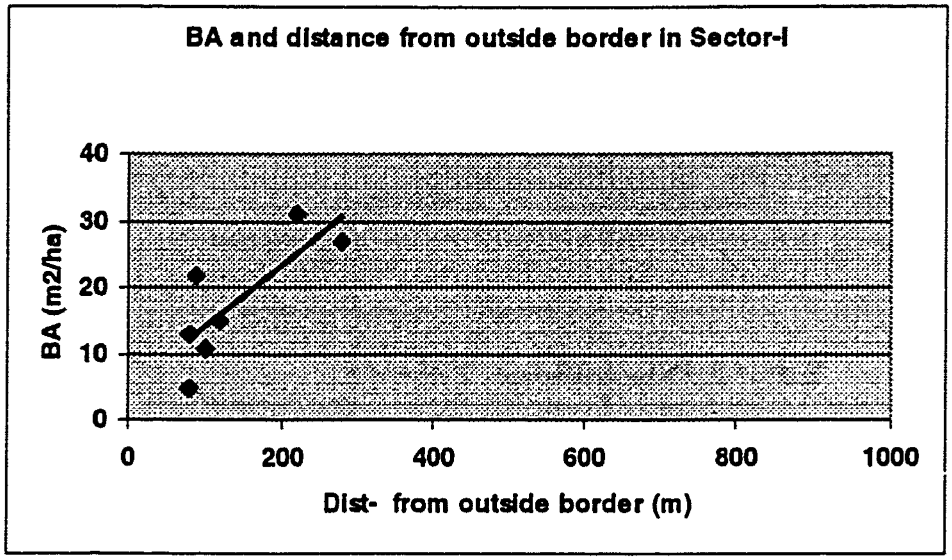


III. Ouro Verde

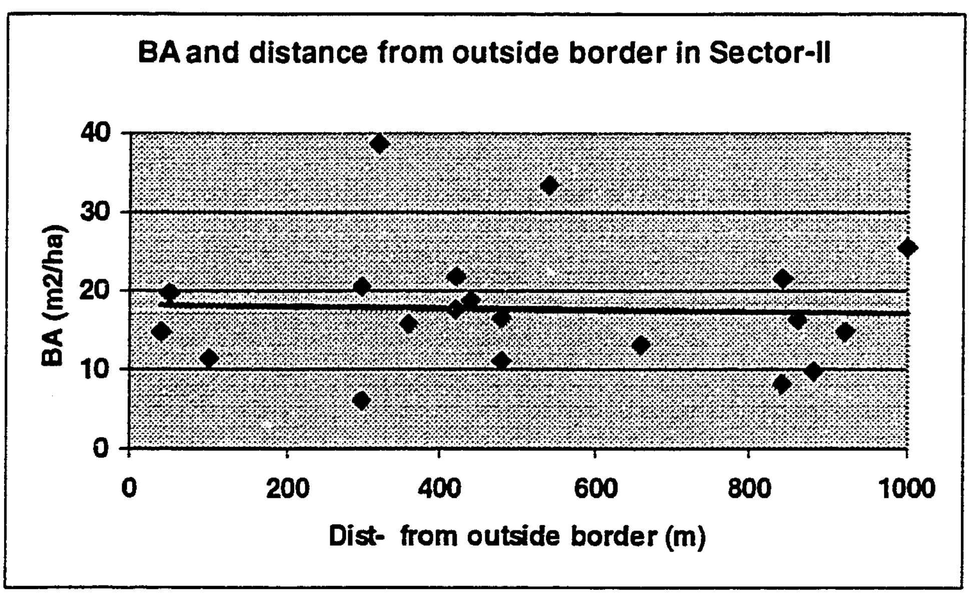


IV. Coroado

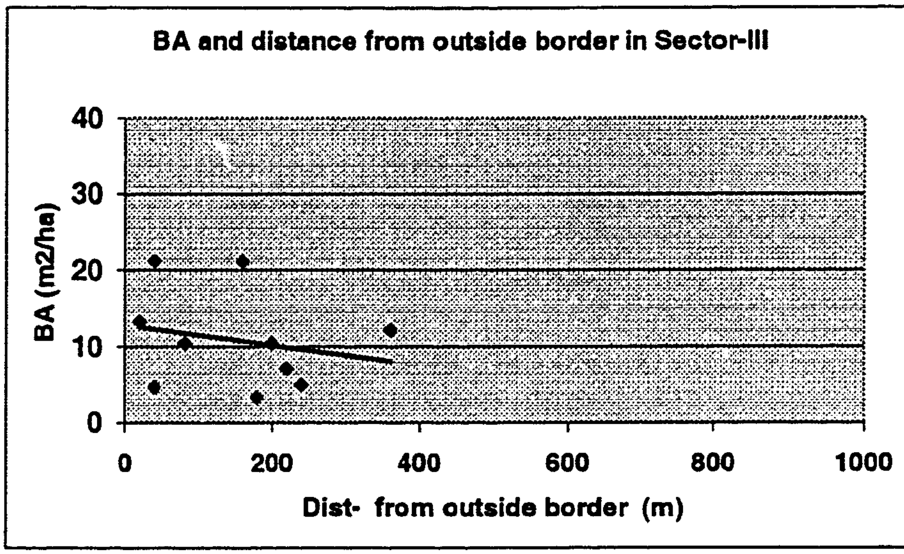
Figure 5.3 - Relationship between basal area (m^2/ha) and distance from Campus mainroad (m) by Sectors: I: Acariquara (15 years of isolation), II. Nova Republica (10 years of isolation), III: Ouro Verde (4 years f isolation) and IV. Coroado (25 years of isolation).



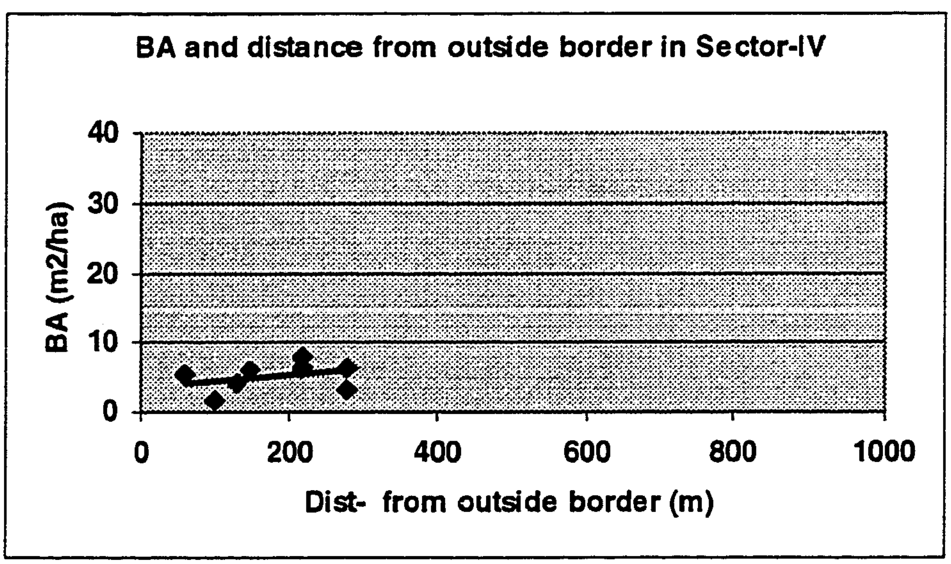
I. Acariaquara



II. Nova Republica



III. Ouro Verde



IV. Coroado

Figure 5.4- Relationship between basal area (m^2/ha) and distance from outside border (m) by forest fragment sectors: I. Acariquara (15 years of isolation), II. Nova Republica (10 years of isolation), III. Ouro Verde (4years of isolation), and IV. Coroado (25 years of isolation).

Figure 5.5. Spatial distribution of three upland cover classes derived from supervised classification of Landsat MSS 1977 for Campus Forest , Manaus, AM, Brazil.

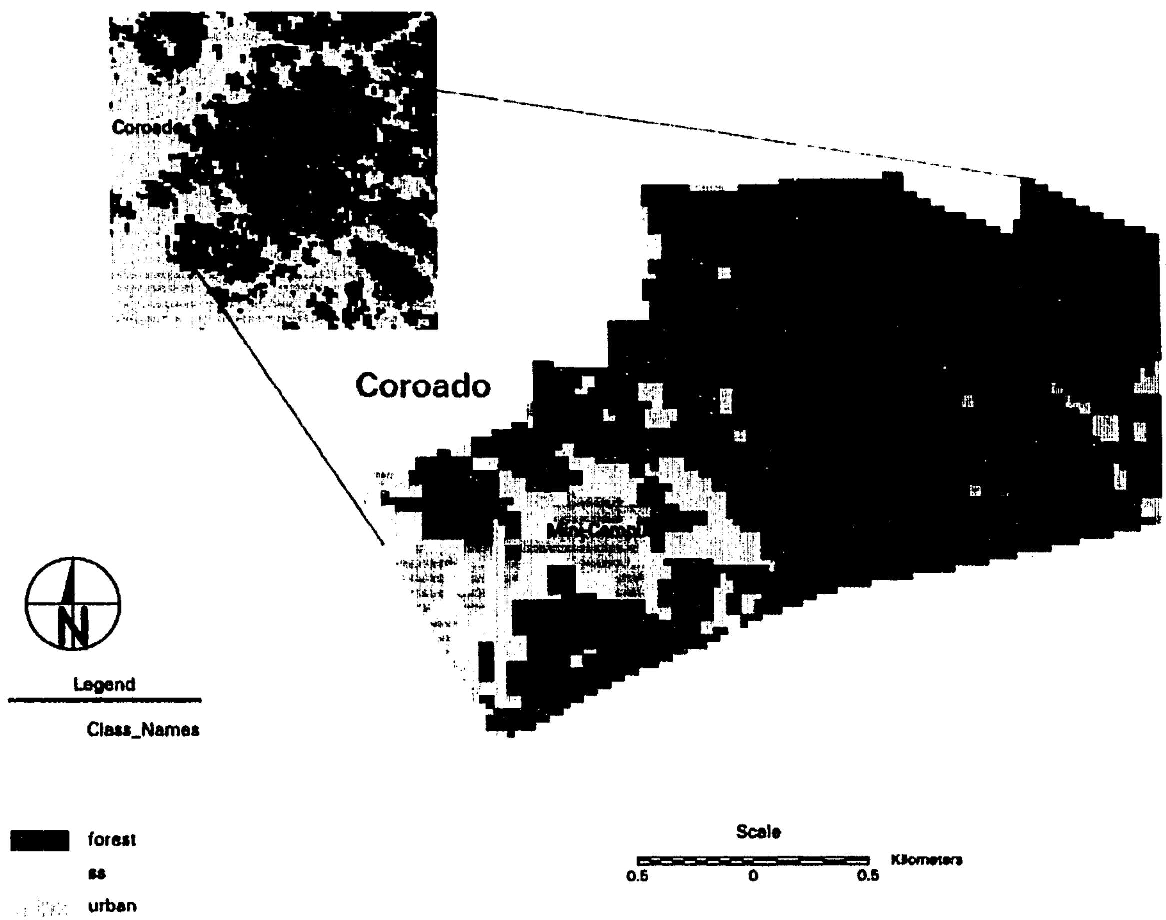


Figure 5.6. Spatial distribution of land cover and land cover change classes derived from Landsat MSS1977 and TM 1988 for Campus Forest, Manaus, AM, Brazil.

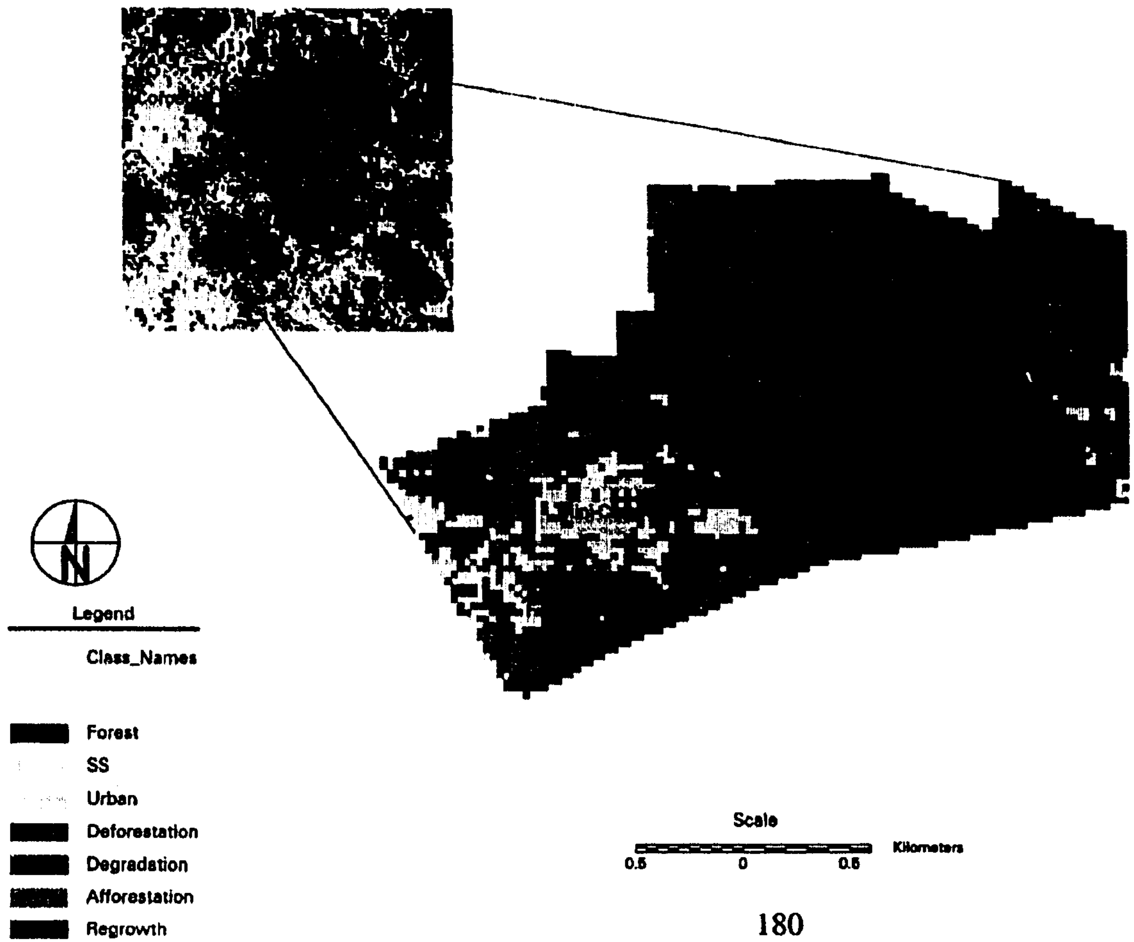


Figure 5.7. Spatial distribution of land cover and land cover change classes derived from Lansat TM 1988 and 1995 for Campus Forest, Manaus, AM, Brazil.

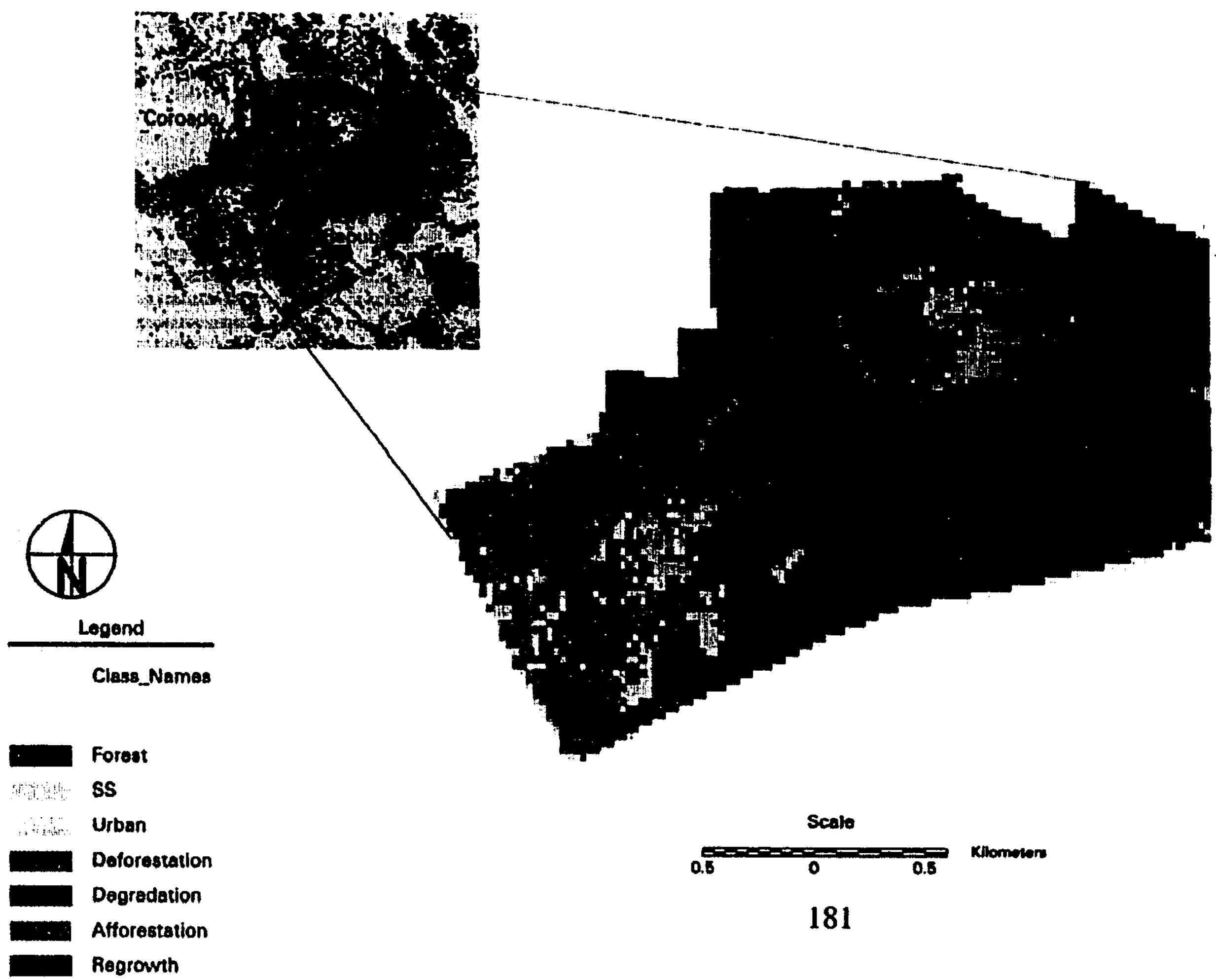


Figure 5.8. Spatial distribution of three upland cover classes derived from supervised classification of Landsat TM 1995 for Campus Forest, Manaus, Am, Brazil.

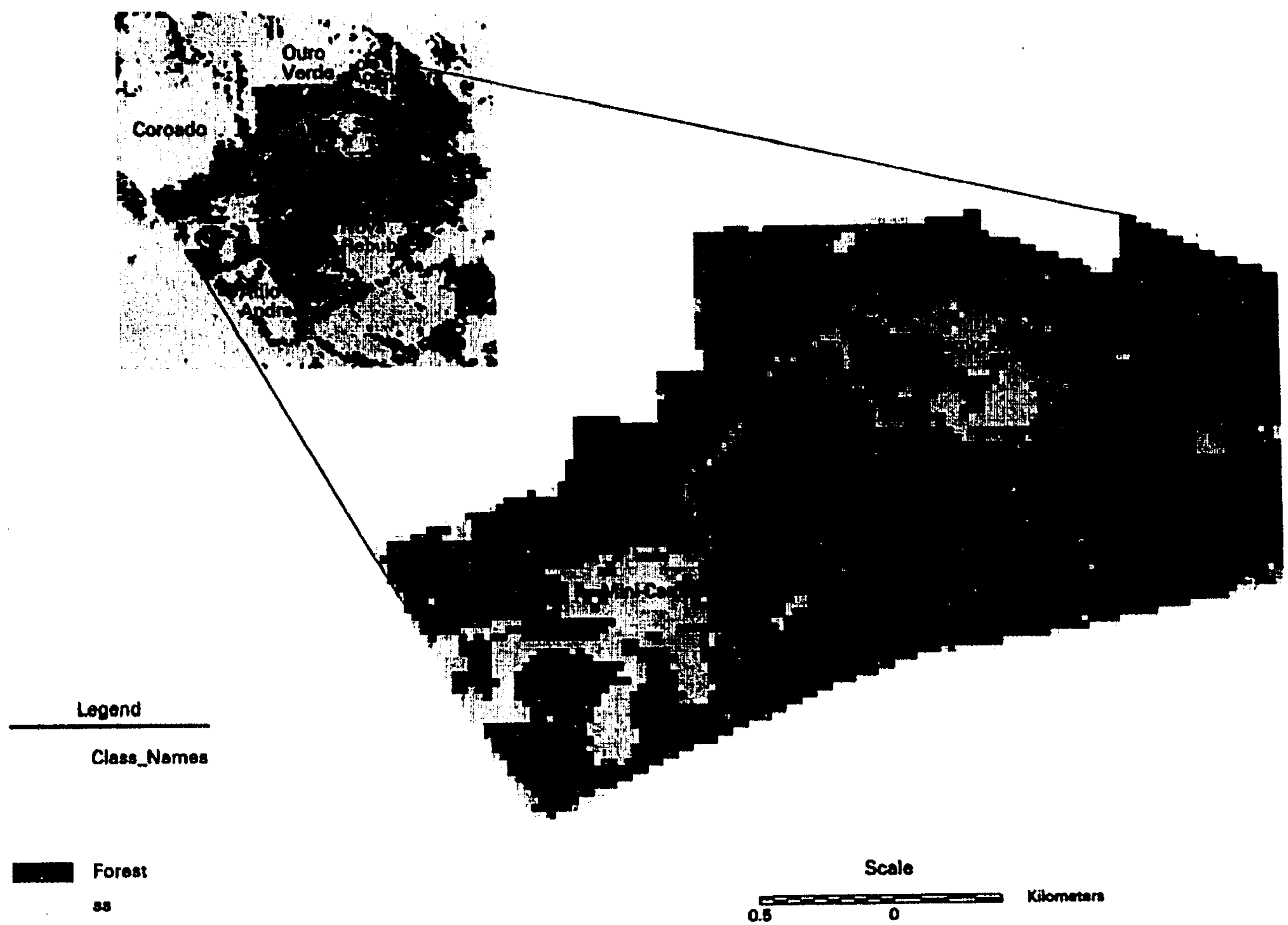


Figure 5.9. Campus Forest management zoning map

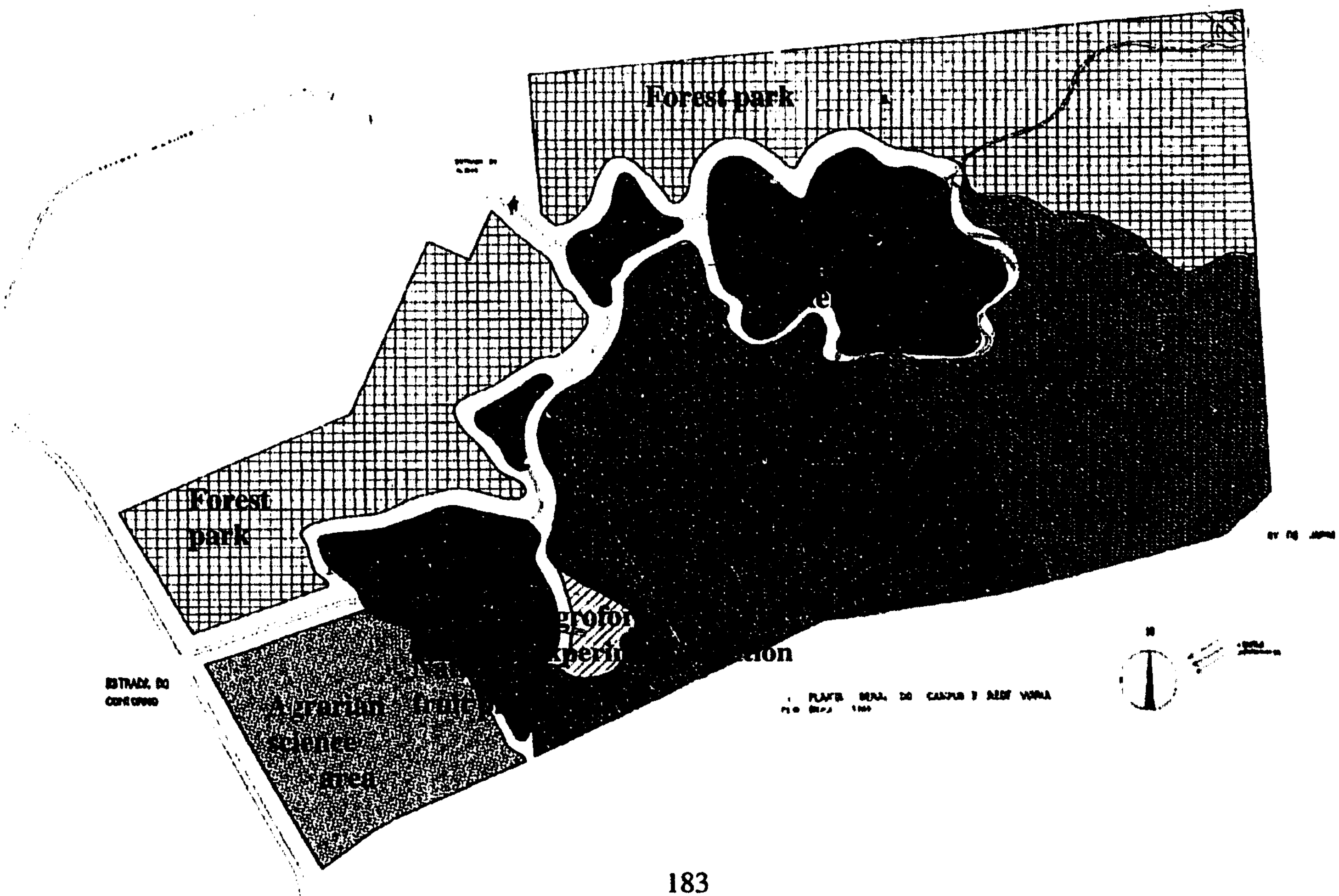


Table 5.1- Regressions on basal area and distance from both the Campus Forest mainroad, and the outside border

Basal Area (m^2/ha)							
INDEPENDENT VARIABLE Distance from mainroad (m)				INDEPENDENT VARIABLE Distance from outside border (m)			
	R^2	p	n		R^2	p	n
SS-OD	0.01	0.62	15	SS-OD	0.00	0.81	15
OD	0.00	0.56	36	OD	0.02	0.34	36
CC	0.10	0.17	19	CC	0.12	0.14	19
Sector I	0.70	0.01	7*	Sector I	0.62	0.03	7*
Sector II	0.11	0.15	20	Sector II	0.12	0.11	20
Sector III	0.00	0.98	11	Sector III	0.00	0.95	11
Sector IV	0.00	0.96	8	Sector IV	0.09	0.44	8

* Statistically significant at the 0.05

Table 5.2. Summary of the Land Cover Change in the Campus Forest, 1977-1988-1995

Classes	1977-1988			1988-1995		
	# pixels	HA	%	# pixels	HA	%
forest-forest	4047	364.23	69.46	4412	397.08	75.72
forest-ss	431	38.79	7.39	21	1.89	0.36
forest-urban	273	24.57	4.68	67	6.03	1.15
ss-forest	431	38.79	7.39	591	53.19	10.14
ss-ss	305	27.45	5.23	114	10.26	1.95
ss-urban	69	6.21	1.18	161	14.49	2.76
urban-forest	22	1.98	0.37	94	8.46	1.61
urban-ss	130	11.7	2.23	140	12.6	2.40
urban-urban	118	10.62	2.02	226	20.34	3.87
total	5826	524.34	100	5826	524.34	100

Table 5.3. Distribution of land cover change and land cover classes in campus Forest, 1977-1988-1995.

Classes	1977-1988			1988-1995		
	pixels	HA	%	pixels	HA	%
deforestation	342	30.78	5.87	228	20.52	3.91
degradation	431	38.79	7.39	21	1.89	0.36
afforestation	453	40.77	7.77	685	61.65	11.75
regrowth	130	11.7	2.23	140	12.6	2.40
forest	4047	364.23	69.46	4412	397.08	75.72
ss	305	27.45	5.23	114	10.26	1.95
urban	118	10.62	2.02	226	20.34	3.87
total	5826	524.34	100	5826	524.34	100

Table 5.4. Distribution of the three upland cover classes in Campus Forest, 1977, 1988 and 1995

Classes	1977			1988			1995		
	pixels	HA	%	pixels	HA	%	pixels	HA	%
forest	4751	427.59	81.54	4500	405	77.23	5097	458.73	87.48
ss	805	72.45	13.81	866	77.94	14.86	275	24.75	4.72
urban	270	24.3	4.63	460	41.4	7.89	454	40.86	7.79
total		524.34	100	5826	524.34	100	5826	524.34	100

Table 5.5. Effective Monitoring on Campus Forest Borders

Date	Number of guards	Principal event	Institutional arrangement phase
1973	4	Beginning of Coroado land invasion	Invasion and institutional establishment (1973-1975)
1974	25	Controlling land invasion	
1975	80	Conflict resolution with squatters and former owners	Institutional consolidation of the Campus (1975-1977)
1977	80	Creation of GT Biota	Conservation concerns: designing a preliminary management plan for the CF (1977-1985)
1985	20	Creation of the Zoning Commission	Designing and implementing a management plan for the Campus Forest (1985-1992)
1992	6	Activities of the Zoning Commission end, and this commission became a working group structured as part of the Center for Environmental Science (Centro de Ciências Ambientais-CCA)	Construction of the Center for Environmental Science building
1994	6	Workshop Sobre a Area do Campus Universitário	Improvement of the infra-structure of the security system

CHAPTER 6

THE EFFECTS OF SURROUNDING NEIGHBOR COMMUNITIES ON CAMPUS FOREST STRUCTURAL ATTRIBUTES: USE, PERCEPTION AND ATTITUDES OF LOCAL RESIDENTS

In Chapter 5, the biophysical and institutional edge effects of forest fragmentation on the structural attributes of Campus Forest were analyzed. By using basal area as a biomass indicator derived from forest data collected in 1996, and land cover change analysis over time as an indicator of forest change derived from a set of three Landsat images, I concluded that basal area in the Campus Forest does not depend on distance from the forest edges. The spatial distribution of land cover changes shows forest changes within the campus areas and several small patches on the borders at the north side. However, changes on the borders are not consistently associated with forest degradation, which could show biophysical and institutional edge effects. Instead of degradation, results have shown a progressive afforestation around the whole Campus Forest.

In this chapter, the effect of consumptive forest use by residents is tested on the Campus Forest structural attributes by using basal area as an indicator. The effect of residents' consumptive use is tested, using basal area as the dependent variable and the distance from non-forest areas[1] as the independent variable by considering the four fragment sectors associated with each neighborhood (Table 4.9). Since monitoring

[1] Non-forest areas here mean any easy access areas such as cleared areas around the forest, and roads and trails distributed inside of the forest from where it would be easy to extract forest products.

currently does not seem to be a constraint to people's use of the forest, it is expected that they would be collecting forest products, using less costly access such as nearby non-forest areas, including any trail or shortcut access, instead of the outer or the main road edges.

The use of Campus Forest's products and services by the neighborhood residents is also analyzed. How they perceive and value the forest, and the sources which could explain the residents' positive or negative attitudes toward Campus Forest conservation are also evaluated, using both the results of a household survey undertaken in two neighborhoods (Coroado and Nova Republica) in 1997, and other information gathered in 1996 through interviews, group discussion and meetings carried out with key informants from the four neighborhoods and Campus Forest officers (see Chapter 2). Coroado and Nova Republica were selected for household interviews because these two areas contrast in terms of time since establishment, socio-economic features, and origin of the residents. Thus, they represent the whole spectrum of residents' uses and attitudes in regard to Campus Forest.

Conflicts between local residents and managers are good indicators of unsuccessful management strategies and forest degradation in reserves. Studying the attitudes of rural residents in Machalilla National Park, Ecuador, Fiallo and Jacobson (1995) found that the principal source of negative attitudes of villagers included: (1) lack of public participation in the park's creation and misunderstanding of the parks' concept, (2) perceived restriction on resource-use outweighing perceived benefits from the park, and (3) conflicts between local inhabitants and the park staff. At the same time, positive attitudes tended to increase with an increase in respondents' level of education and knowledge about conservation issues, perceived benefits from the park, good relations with park staff, and participation of younger residents. Since people's perception are, in general, associated with their past experiences (Metha & Kellert, 1998), I hypothesized that I would find a much more negative attitude towards Campus Forest conservation in Coroado than in Nova Republica because Coroado residents experienced conflicts with Campus Forest officers concerning forest land invasion and use of forest products.

In order to evaluate the attitude of the neighborhood residents toward conservation of the Campus Forest, questions related to the use of forest products, demography, socio-economic activities, origin of household heads, mobility, access to urban facilities, knowledge about the reserve, level of education and relation with reserve staff were asked (see Appendix 2.1).

6.1. Effect of Residents' Consumptive Use on the Structural Attributes of Campus Forest

The relationship between basal area and distance from non-forest areas in the four forest fragment sectors is shown in Figure 6.1, and the statistical results are also given in Table 6.1. The statistical results indicate that basal area does not depend on distance from non-forest areas in the four fragment sectors. However, there is a clear but not statistically significant trend in sector III- Ouro Verde (Figure 6.1-III) where the basal area is smaller close to the non-forest area's edge. This trend may be a result of the settlement phase of Ouro Verde. As described earlier, Ouro Verde was established through land invasion on the border of Campus Forest. Residents claim to have used forest products during the invasion process (Lima, 1997). During the forest survey, in two plots inside of sector III, several trees were observed in phases of regrowth that were cut years ago, showing human use of that forest area. In sector I-Acariquara, there is also an opposite trend, however, as shown in Figure 6.1-I, basal area is higher close to the non-forest area's edges than deeper in the forest. Acariquara's residents do not use forest products. Nevertheless, they complain about neighboring residents who come close to their Campus Forest area to use its products. The opposite trend shown in the Acariquara sector may also be a result of the Ouro Verde residents using that forest sector since Ouro Verde is the closest neighborhood to Acariquara (see Chapter 5).

In the Coroado and Nova Republica forest sectors (IV and II, respectively), the distribution of basal area does not show trends related to the distance from non-forest area edges. Basal area in the Nova Republica sector varies mostly from 10 to 30 m^2/ha independent of the distance from non-forest area. In Coroado, basal area also varies independently from distance from the non-forest areas, but from 1 to 10 m^2/ha, since the Coroado sector is covered by younger secondary succession with low biomass. These results may indicate that even without systematic patrolling, the Coroado and Nova Republica residents are still not using the Campus Forest for consumptive use. In the next section, the behavior of these residents is analyzed in regard to their attitude and use of the Campus Forest.

6.2. The Use of Campus Forest by Coroado and Nova Republica Residents

A total of 235 households was visited and 233 agreed to be interviewed. In some cases, informants refused to answer certain questions, particularly those related to income. From the 233 households, 115 were interviewed in Coroado and 118 in Nova Republica.

The use of the Campus Forest products by residents and the restrictions on using them were evaluated based on several statements that followed the two first questions related to their perception of the Campus Forest (see next section). The followed up questions and statements were asked sequentially: 1) "Who in your family uses the area of the Campus Forest for any reason? Could you tell us her/his age, sex, types of product and use, and the location where the products are collected or used? ; 2) Do you or your family members use the Campus Forest products with the same intensity that you did five, ten, fifteen, or twenty years ago?; 3) Do you or your family members have any intention to continue using the Campus Forest products?; 4) Are you able to use any products from Campus Forest? If not, what kind of constraints prevent you?; 5) What do you or your family do to overcome these constraints?; 6)Someone told me that during the installation of Coroado, the University of Amazonas had a strong and restrictive control over the forest. Did those measures in some way influence the decisions made by your family regarding the use of Campus Forest products?; 7) Did you observe any change concerning Campus Forest patrolling during the last twenty years? If so, what kind of changes?; 8) How does the Campus Forest monitoring work now?; 9) What should the University of Amazonas be delivering to you and your family that it is not doing?"

The number of households using the forest was very similar in both neighborhoods -- 40 (35%) households in Coroado and 43 (36.5%) in Nova Republica (see Figure 6.2). The proportion of types of use was a little different between them. Most households use the Campus Forest for non-consumptive purposes such as recreation (i.e., trails, streams, and soccer fields), however in Coroado consumptive use was slightly higher than in Nova Republica. In 10 (8.7%) Coroado households, residents admitted collecting some forest products (i.e., vine, pole, palm leaves and fruits, ornamental and medicinal plants, and game) (Figure 6.2).

Even though used consumptively, the intensity of the forest use in the Coroado and Nova Republica sectors has been light enough to leave few traces on the structural attributes of the Campus Forest (Figure 6.1). Of those forest products collected, only the extraction of poles could contribute to a measurable decline of the biomass in these sectors. Harvesting of vines, palm leaves and fruits, ornamental and medicinal plants, or game would not be captured by the biomass measurement of trees equal to or higher than 10 cm of dbh.

Given the similarity of the socio-economic and historical characteristics of Ouro Verde, one could expect that Ouro Verde residents use the Campus Forest similarly to Coroado residents, and that Acariquara resembles Nova Republica's profile of non-consumptive use. The decline in basal area related to the distance from non-forest area edges found in Ouro Verde seems to be an effect of its time of establishment. Ouro Verde residents in that time (1992) used many more poles and trunks in order to build their houses, fences and other facilities. With time, the demand for those products has declined.

Palm leaves are used during June and July to decorate areas in celebration of St. John and St. Peter festivities, while the use of medicinal plants has been substituted increasingly by pharmaceutical products.

6.3. The Attitudes of Coroado and Nova Republica Residents Towards Campus Forest Conservation

The attitudes of Coroado and Nova Republica residents toward conserving the Campus Forest was evaluated based on several statements. First, a general question was asked about the importance of the Campus Forest: "Please, could you tell us whether the Campus Forest has any importance for you and/or for your family, yes or no? If so, why?" All "yes" answers were considered a positive attitude regarding the maintenance of the Campus Forest as a reserve whether they used utilitarian explanations or not. Depending on their answers, people were asked to elaborate a little more about the reasons underlying their attitude toward Campus Forest conservation. Another question used to evaluate residents' perception was stated as "Could you please tell us what you think about having the University of Amazonas as a neighbor located inside of that large forest?" When necessary, other open questions were asked to help us understand the residents point of view in regards to the forest and its issues. Other questions following up these two (see section above), also helped in evaluating residents' perceptions toward Campus Forest conservation.

In Nova Republica, 101 household heads (85.6%) answered "yes", regarding conserving the forest, while just 13 had complaints about it. In Coroado, 67 (58%) answered positively and 43 (35.4%) negatively; 5 did not answer (Table 6.2). These results show that the majority of residents from these two neighborhoods have a positive attitude towards the forest.

Coroado residents exhibited less positive attitudes toward maintaining Campus Forest, but this was not a result of the historical conflicts that started in the beginning of the 1970s when migrants invaded the campus area where Coroado is now. During the campus installation, the conflicts between new settlers and officers were intense. However, this conflict was resolved. In several households the relationship between the residents and University officers was described thus: "in the past we were enemies but now we have no problems." Two factors contributed to the conflict resolution between the Campus Forest managers and the residents. First, the invaders of Campus Forest were permitted to formally maintain their land and receive title to property through a negotiation process undertaken between the Universidade do Amazonas and Habitation Agency of the Amazon (COHAB/AM), which paid back the University for the invaded area. Second, Coroado residents also opened areas for soccer fields (a total of seven soccer fields were built inside the Campus Forest borders) and they have used them informally without any constraints for a long time. Many residents argued, however, that it was not fair to maintain a huge forest in the middle of the city when so many people needed land to build their houses, more space for recreation and for other community affairs.

Most of the Coroado residents' complaints are associated with the lack of intense patrolling around the forest, making it an open area that gives access to criminals, thus impede them from using the campus. However, most residents interviewed know the restrictions on the use of consumptive forest products. Most indicated that the restricted products are poles, tree trunks and game. Nevertheless, they are asking for intense patrolling in the area to be able to use the recreational potential of the Campus Forest since they have informal permission to do that. In both neighborhoods, residents seem very frustrated that the Campus Forest cannot be used much more.

Actually, several cases of violence occurred inside the forest during the fall of 1997. Being a 600-hectare native forest located in the middle of an urban area without any buffer zone or any intense monitoring, several parts of the Campus Forest have become a refuge for people to hide stolen items, do drugs, and commit sexual violence. The main reason mentioned by Coroado residents who do not wish to maintain the forest was their perception of the Campus Forest as a dangerous place (Table 6.3). A murder and several cases of robbery and rape were reported by the residents.

The image of Campus Forest as a refuge for criminals is not a new issue in the history of this reserve. Several minutes of the GT biota (1977-1985) cited the need to increase the security facilities in the campus because of the frequent presence of criminals around the forest who could even endanger the guards' lives. However, it seems that these problems have increased lately and have affected the residents' perceptions of the Campus. For example, a child was murdered and two women were raped in the campus area close to Coroado just two months before these household interviews were undertaken. These three cases were repeated constantly by the majority of the residents who described the campus as a dangerous place.

Several residents who identified the forest as a big problem for the community suggested that the University should split the forested land and give it to the community. Others suggested urbanizing it, transforming the forest into a urban park, cleaning the forest ground, and increasing the number of guards or the type of monitoring to assure the residents' security. The presence of poisonous animals (i.e., snakes, spiders, scorpions) (Table 6.3) on the forest border that have invaded several house gardens was another reason indicated by several households for changing the use of the forest. In many parts of the campus, the forest limits border resident gardens. In the Coroado limits, several residents have cut the campus fences and cleaned the forest ground to expand their gardens. According to them, this was a way to control animal invasion and trespassers. Thus, most of the negative attitude of Coroado residents was related to their perceived restriction on non-consumptive resource use outweighing their perceived benefit from the Campus Forest.

The issue about conservation *per se* was rarely mentioned. About 10 households in both neighborhoods cited preservation as the main reason to maintain the forest (Table 6.3). On the whole, Nova Republica residents are more interested in preserving the forest than Coroado residents. However, residents of both neighborhoods mentioned spontaneously that climate balance[2] was the principal reason to maintain that forest,

[2] Climate balance was a category created to put together the answers related to: "to freshen the air," "pollution control," "air renovation."

followed by preservation and recreation, regardless of the issues associated with violence. Most of them did not see any relationship between climate balance and preservation.

The sources which could explain the residents' attitudes (e.g., origin and socio-economic attributes) were analyzed. Of the 233 households, 71 were composed of rural native Amazonian families, most of them (58) living in Coroado. No relationship was found between origin and attitudes of the residents. Of the 58 rural native Amazonian[3] households found in the two neighborhoods, exactly half (29) showed positive attitudes and the other half (29) negative attitudes. However, among the non-rural, only 33% presented negative attitudes. Residents' origins were also directly correlated with levels of education and socio-economic status. Rural Amazonians, on average, had less formal education and received lower income than non-rural Amazonians (Table 6.4). Even the few rural native Amazonians from Nova Republica, who spent as many years in school as the non-rural, had, on average, lower incomes than non-rural Amazonians (Table 6.4). Thus, in this urban context, the origin and level of education of the residents were not the main factors in explaining their behavior with regard to the reserve.

In Coroado, where residents presented more negative attitudes, population density is higher, urban infra-structure is poorer, and the level of education and income of the residents is lower than in Nova Republica. The combination of socio-economic attributes of the residents, the lack of urban infrastructure in the neighborhood, and lack of intense patrolling around Campus Forest seems to make a difference in the their attitude.

[3] The interviewees were classified according to their origin. All residents who come from legal Amazon rural areas were classified as "rural native Amazonian", and all the remaining, including those who come from Manaus and other Amazonian urban areas, were classified as "non-rural native Amazonian."

Coroado is a poor and very densely populated area without any ecological or urban barrier protecting it from the other urban areas. Residents do not depend economically on the forest, but the campus is one of the few areas to be used for recreational purposes. However, as stated previously, its area around the forest is accessible and security is almost non-existent. The police rarely patrol the area, and forest guards from the campus patrol the forest border just twice a week, leaving it prone to poaching activities. In contrast, Nova Republica is located in a reserved area where access to outsiders is more difficult (Figure 1.1). Living in a higher level socio-economic neighborhood, Nova Republica residents also possess other alternatives for their leisure time. For them, the forest is still worthwhile because of its "ecological services." This context can explain the different proportion of using consumptive and non-consumptive Campus Forest products by the residents of Coroado and Nova Republica.

6.4. Conclusions and final remarks

In this chapter, the effect of consumptive use by neighborhood residents on the attributes of the Campus Forest was analyzed, using basal area as a biomass indicator on the distance from non-forest areas in the four forest fragment sectors. No significant statistical relationship between basal area and distance from non-forest area was found. However, in sector II, the Ouro Verde neighborhood area, a trend where basal area declines with the distance from the non-forest area was found. Ouro Verde is the youngest neighborhood around the Campus. It was established in 1992 as the result of a land invasion on the border of the Campus. Although, because of limited spatial resolution, land cover change analysis was not able to capture the effects of trees cut around that sector, those cuttings could, however, be captured through the basal area measurement. In the three remaining sectors, no consistent trends were detected.

Residents of both Coroado and Nova Republica have used consumptive forest products such as vines, poles, ornamental and medicinal plants and game, even though traces from these activities were not captured through the analysis of basal area. In Coroado, twice as many households collect forest products than in Nova Republica. However, the percentage of households that use consumptive forest products is small in both neighborhoods, just 8.7% in Coroado, and 4.2 % in Nova Republica. Non-consumptive uses, however, are mostly indicated. They have used and want to use that area much more for recreational purposes. Nevertheless, it is not the patrolling activities that is impeding them, rather it seems that it is the presence of criminals who have transformed the area into a dangerous place. Complaints about violence in the Campus Forest are higher in Coroado as well, and violence has been one of the reasons for their negative attitudes towards the preservation of that forest reserve.

Although the majority of Nova Republica and Coroado residents presented a positive attitude regarding conservation of the Campus Forest, around 35% of Coroado residents complained about the lack of systematic patrols that has transformed the forest into a dangerous place that causes serious problems for the surrounding communities. In this regard, most of the resident's negative attitudes of the were associated with their perceived restriction on non-consumptive resource use outweighing the perceived benefits from the reserve.

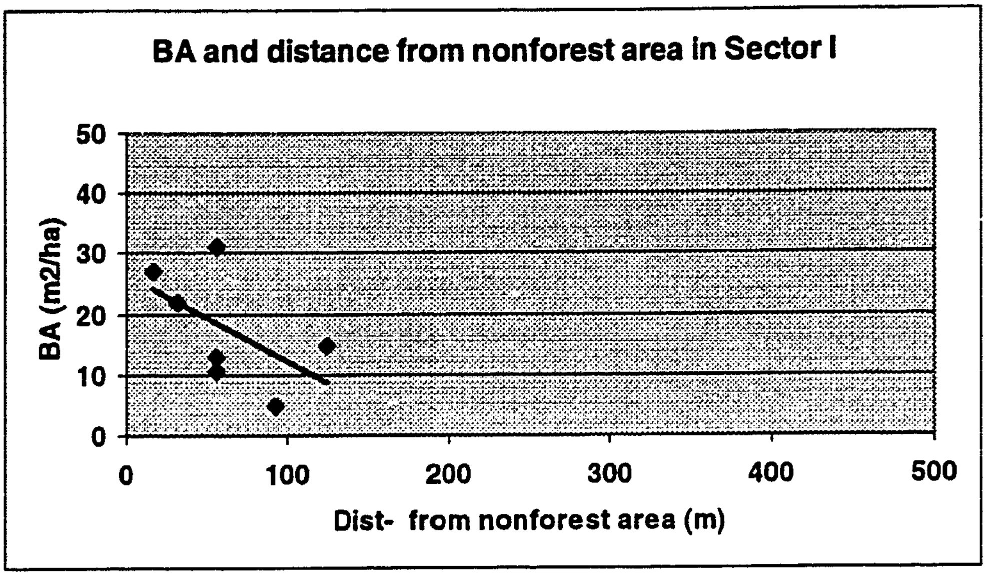
Analyzing residents' origins and socio-economic attributes to understand the sources which could explain their attitudes in regard to the preservation of the reserve, no relationship was found between origin and attitudes of the residents. Origin was, however, directly correlated to level of education and socio-economic status. Hence, in this urban context, the origin and level of education of the residents were not the main factors in explaining their behavior in regard to the reserve. Indeed, the predominance of negative attitudes by the residents was found in Coroado, where the population density is higher, the urban infra-structure is poorer, and the income of the residents is lower. The combination of socio-economic attributes of the residents, the lack of urban infrastructure in the neighborhood, and the lack of intense patrolling on Campus Forest is making the difference in the attitude of the residents.

Thus, urban reserves are prone to population pressures, conflict between local residents and reserve staff, and other urban pressures. However, the source of conflicts and environmental degradation is different from rural areas. Rapid urban growth and poor urban infrastructure added to the socio-economic attributes of the residents are pushing people to use forest areas, in Manaus' case, currently, for recreational purpose. In Manaus, in addition to the lack of urban services such as security and recreational options, the current patrolling system used by the University of Amazonas on the 600-hectares of native forest is affecting the residents' attitudes in regard to the forest. The Campus Forest patrolling system may be efficient in preventing the forest from being consumptively over used, but it may not be enough to prevent the area from becoming a refuge for criminals. If the University wants to be successful in preserving the Campus

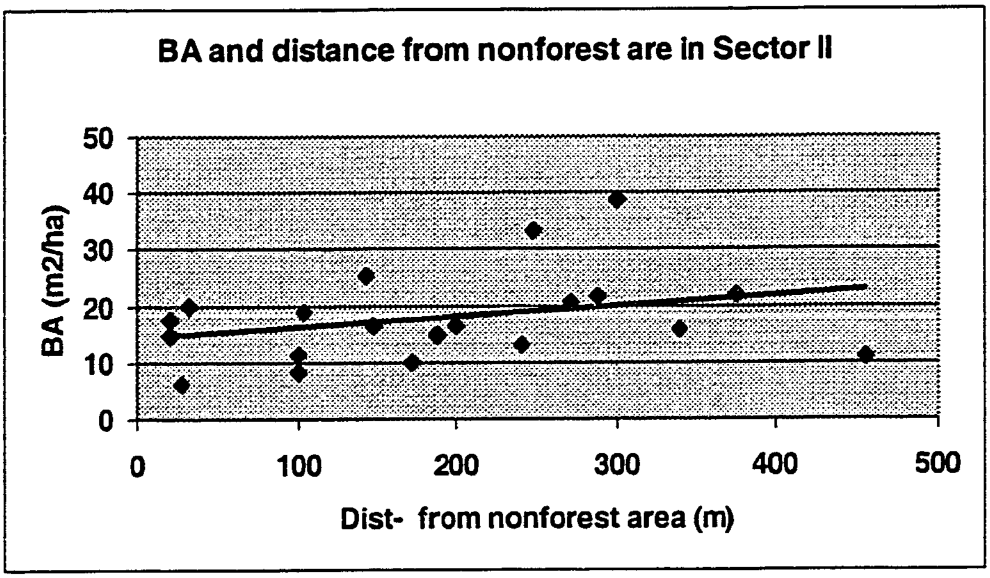
Forest, that area should be managed, taking into consideration the concerns of the local residents and solving the problems of violence and invasion of wild animals in urban forested communities. Also, although the University officers have constantly complained that the communities have been disturbing the forest, the indicators used by them to evaluate degradation have been based on the visual analysis of the forest guards, which is not an appropriate means of evaluating the status of preservation of a forest.

Finally, the issues raised by the communities are very important to improving the partnership between residents and campus managers and must be considered in order to protect the forest. Also, constant property right forest use enforcement must be undertaken on Campus Forest. Strong patrolling around some national parks has been a key factor in decreasing the local resident incentive to use non-allowed products (Gibson & Marks 1995; Albers & Grinspoon, 1977). Different from some rural contexts, an urban environment offers more economic options to people for making a living, thus decreasing the potential pressure on urban forests. In addition, the Campus Forest currently does not offer valuable products which could stimulate local residents to start harvesting more intensely, and residents do not depend economically the forest products.

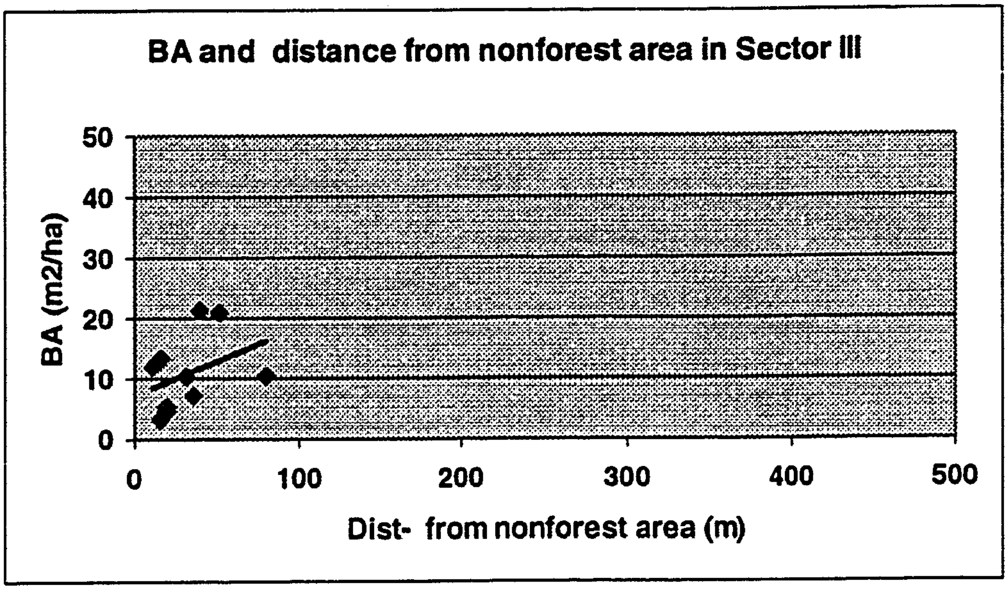
However, land invasion is still a possibility in the Manaus area. Campus Forest still has a valuable commodity: Land. Campus Forest's land is very valuable in the Manaus real estate market and can be invaded again. For example, the political environment generated during gubernatorial and mayoral elections is critical to land invasions because political instability and rivalry among political parties increases. During the last mayoral election in 1997, the Campus Forest managers were very worried about land invasions. One of the candidates encouraged some Manaus residents to talk with the President of the University in order to solve some of their community's problems in regard to urban space. Arguing that the University still had a large amount of "empty forest," the candidate made a point of reminding these people that Campus Forest is still an area that could be taken and used. Invasion in Manaus urban forest lands is not a rare event. In the beginning of 1996, a forest area owned by the Association of the Amazonas Comercio located around 1km from Campus Forest was invaded. The invasion was controlled and invaders were expelled, but some forest patches were cut down. Thus, systematic monitoring around Campus Forest is a crucial measure to protect this reserve, not only transforming it into a safe environment for the campus community and surrounding residents but also avoiding potential invasion that could have a serious negative ecological impact on the structure of the forest.



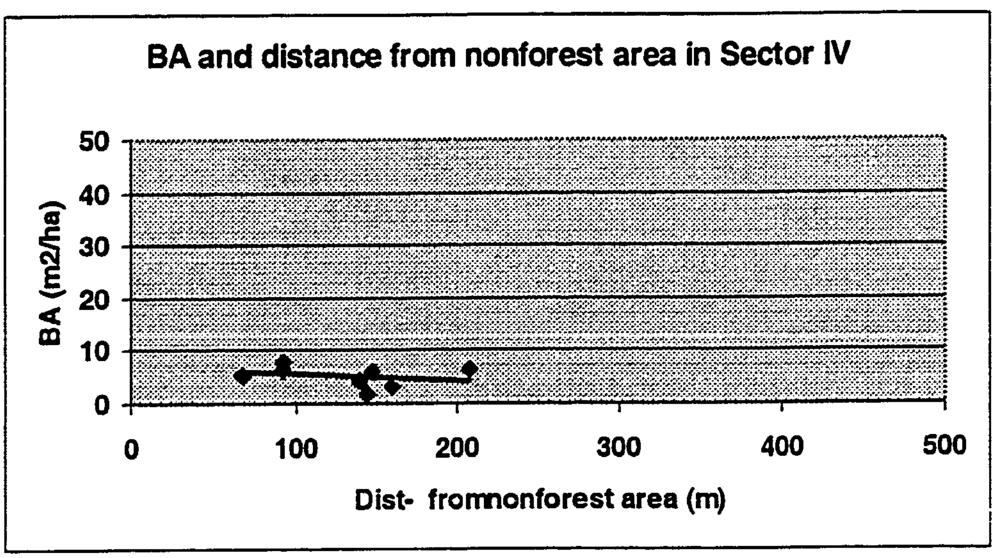
I. Acariquara



II. Nova Republica



III. Ouro Verde



IV. Coroado

Figure 6.1- Relationship between basal area (m²/ha) and distance from nonforest area (m) by Sectors: I. Acariquara (15 years of isolation), II. Nova Republica (10 years of isolation), III. Ouro Verde (4 years of isolation), and IV Coroado (25 years of isolation).

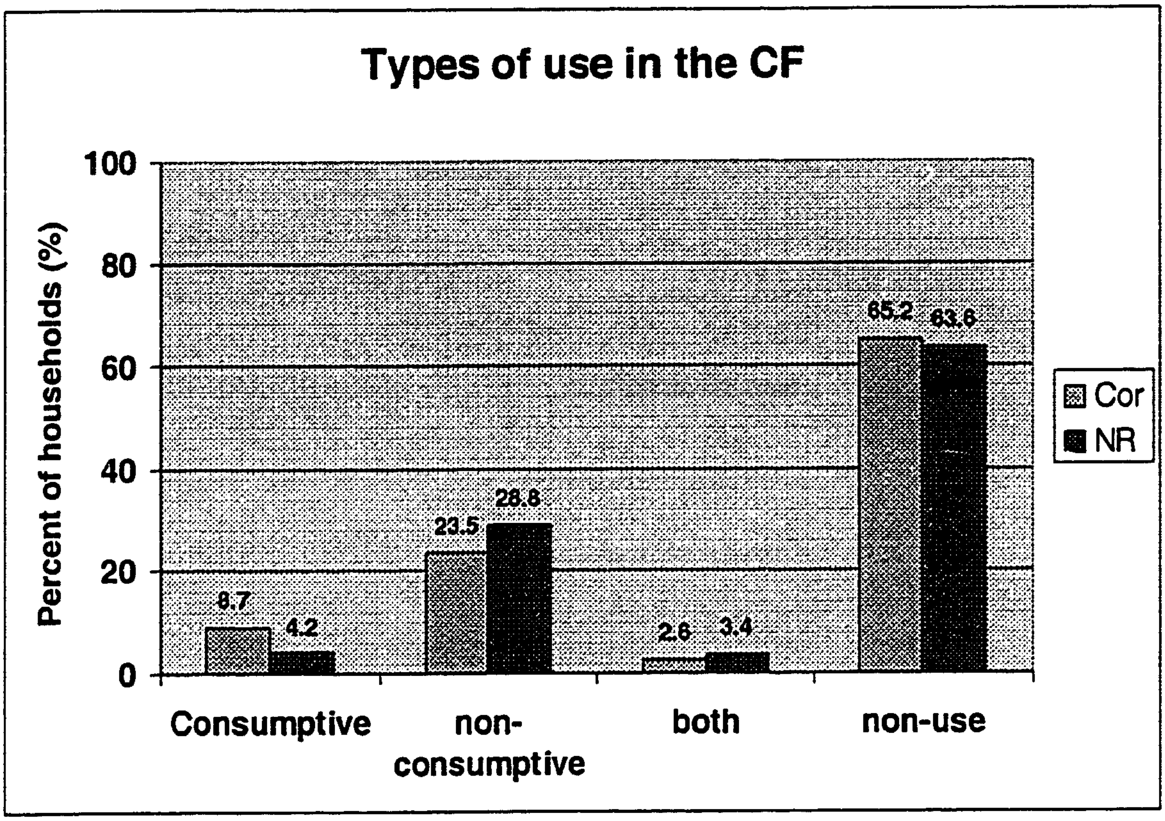


Figure 6.2. Percent of households in each neighborhood (Cor: Coroado, n=115); NR: Nova Republica, n=118) by types of use: **Consumptive** includes vine, pole, palm leaves and fruits, ornamental and medicinal plants, and game; **Non-consumptive** includes recreation, nature contemplation and knowledge (i.e., education); **Both uses** (consumptive and non-consumptive); and **non-use.**

Table 6.1- Regressions on basal area and distance from non-forest area in Campus Forest

	R^2	p	n
Sector I (Acariquara- 15 yrs of isolation in dense forest)	0.42	0.15	6
Sector II (N. Republica- 10 yrs of isolation in dense forest)	0.07	0.24	19
Sector III (O. Verde- 4 yrs of isolation in dense forest)	0.13	0.32	9
Sector IV (Coroado)- 25 yrs of isolation in secondary succession	0.07	0.5	7

Table 6.2. Attitude of Coroado and Nova Republica Residents toward Campus Forest conservation

Attitude	Coroado		Nova Republica	
	n	%	n	%
Positive	67	58.2	101	85.6
Negative	43	37.4	13	11
No answer	5	4.3	4	3.3
Total	115	100	118	100

6.3. Reasons used by Residents to explain their positive and negative attitude towards Campus Forest conservation

Reasons	Coroado		Nova Republica	
Positive	n	%	n	%
Climate balance	**35**	**31.8**	**56**	**49.1**
Preservation	12	10.9	13	11.4
Recreation	7	6.3	9	7.9
Avoid land invasion	1	0.9	7	6.1
Good for the community	4	3.6	2	1.7
To leave without use	2	1.8	12	10.5
No reason	6	5.4	2	1.7
Total	**67**	**60.9**	**101**	**88.6**
Negative	n	%	n	%
Dangerous place	27	24.5	4	3.5
Poison animals	0	0	3	2.6
Disadvantage for the community	3	2.7	0	0
No infrastructure	1	0.9	0	0
Do not know	6	5.4	0	0
No reason	6	5.4	6	5.2
Total	**43**	**39**	**13**	**11.4**
Totals	110	100	114	100

Table 6.4. Educational and socioeconomic profile of the household interviewed in Coroado and Nova Republica, Manaus, AM, Brazil.

	Coroado					
	rural native (n=58)			non-rural native (n=57)		
	Y-S[1]	HHh[2]	HHt[3]	Y-S	HHh	HHt
average	5.36	3.42	5.95	7.44	4.64	7.5
SD	3.09	2.37	3.69	3.65	4.25	5.77
	Nova Republica					
	rural native (n=13)			non-rural native (n=105)		
	Y-S	HHh	Hht	Y-S	Hhh	Hht
average	10.5	7.5	9.25	9.88	10.09	15.1
SD	4.43	5.54	9.23	5.04	6.03	9.83

[1] Number of years in school

[2] Household head income (number of MW- minimal wage. 1MW= $120)

[3] Household income

CHAPTER 7

CONCLUSION

This dissertation examined causes and degrees of degradation in an urban restricted-use forest reserve created in recent decades. By drawing on the case of the Campus Forest of the University of Amazonas, the process of reserve installation and establishment and its impact on forest preservation were examined. The previous chapters have shown how historical, social, economic and biophysical contexts are involved and how, over time, they contribute to forest degradation in and around the reserve, and how those factors have influenced the current conditions of the forest.

A considerable number of restricted-use reserves have been created in recent years in order to protect endangered species, biodiversity and natural ecosystems. However, the conservation literature and a host of agencies' reports often show the dilemma of growing degradation in protected areas. Scholars dealing with conservation issues have used different approaches to understand and explain degradation in protected areas. Some ecologists use biophysical aspects of the reserves such as habitat fragmentation and edge effects (e.g., Lawrence, 1991, 1997). Others explain degradation through population pressure and human activities (Green & Sussman, 1990; Vandermeen & Perfecto, 1995; Shaffer, 1995; Godway, 1997). In contrast, institutional failure and conflicts between indigenous people and conservation agencies (Raval, 1991, Guimire, 1991, Colchester, 1994; Silva-Forsberg, 1996) are examined by many social scientists. However, these three approaches explain only part of the processes of change in the Campus Forest.

First, most of the scholars dealing with forest conservation never mention what they mean by conservation or what they use as indicators to evaluate whether a forest is preserved or degraded. Second, studies evaluating forest reserve preservation have basically focused on the social and economic context in and around reserves, or on the institutional profile and capability of the agencies in charge of the reserves' management. They rarely connect those factors and processes with measurements of the forest attributes.

To approach the complexities and multi-level factors related to reserve preservation, I drew on a framework that examines the direct and indirect causes of forest reserve changes. Locating these causes spatially and temporally, the study shows different factors and processes that have shaped the degree of preservation in the study reserve. Considering the historical, economic and social factors affecting the forest areas around the reserve, it has been possible to conclude that its current ecological attributes were shaped not only by the proximate and underlying factors acting at the local level but also by those affecting forested lands regionally and over time. Edge effects, whether biophysical or institutional, may affect the preservation performance of a forest reserve but they do not explain ecological degradation or improvement on their own. The history of land use inside and outside of the reserve, government incentives motivating in-migration, which resulted in forest land invasion, conflict between squatters and reserve managers, and the creation and evolution of the reserve's institutional arrangements proved to be key variables explaining such change.

7.1. Empirical findings

This dissertation tested three hypotheses derived from the main approaches used to explain forest degradation in restricted-use reserves (edge effects result from fragmentation, population pressure and inequalities, and institutional failure). The following section discusses the results from testing the three hypotheses.

7.1.1. H1: Forest degradation is caused by edge effects

Overall, the Campus Forest analysis showed no influence of biophysical and/or institutional edges' effects on the forest structural attributes. As a whole, Campus Forest edges are not much poorer in biomass than the forest interior, as is predicted by the two models.

Biophysical edge effects

In the Central Amazon region where Campus Forest is located, permanent study plots within 100 meters of newly fragmented edges lost more than 30% of their biomass in the first 10 to 17 years after isolation (Laurance et al. 1997). Laurance and colleagues predict that it is unlikely that forest edges will return to their original condition, because fragmented forest is prone to wind disturbance that can kill and damage many trees. Thus, in the presence of fragmenting processes, old-growth rain forest tends to be replaced by shorter, scrubby forests with smaller volume and biomass (1997).

In the Campus Forest case, however, no edge effects on the total forest biomass were found. Nevertheless, these results do not mean that Campus Forest has not been affected by biophysical edge effects. Chapter 4 shows that Campus Forest is as rich in species as any Central Amazon forest, but this forest has lower basal area when compared with other Central Amazon mature forests. The basal area of mature forest ranges between 20 and 50 m^2/ha in the Central Amazon, showing on average figures around 35 m2/ha (Section 3.3, Table 3.3.2). The Campus Forest basal area of around 21.5 m2/ha is located at the lowest end of the range.

The principal cause of the lower distribution of basal area around the Campus Forest is associated with the history of land use of that area. Before the creation of the reserve, the former owners had used several parts of that forest for agriculture and timber activities. Small holders were using their areas for slash and burn agriculture while the larger farmers were using their areas for timber extraction. Those activities impacted differently the Campus Forest ecological attributes. Overlaying the Campus Forest patrimonial map (Figure 4.1), which shows the spatial location of the former landowners areas, with the location of forest plots surveyed in 1996, it was possible to show that the current number of mature forest species and basal area is statistically higher ($p< 0.01$, $t=2.1$. $df=40$) in the larger landowner plots than in the smaller ones. Past slash and burn agriculture within the small owners' lots had a greater negative impact on the forest than timber activities undertaken by larger owners. Also, during the 25 years of the reserve's existence, the Campus Forest as a whole gained biomass throughout, even at the edge areas. Hence, changing the land-use regime, due to the creation of the Campus Forest reserve, the different vegetation around the campus could regrow very fast, overcoming even the influence of biophysical edge effects.

Institutional edge effects

In the Campus Forest case, no institutional edge effects were found on the forest structural attributes. As already described above, the forest biomass was not lower on the forest edges than in interior areas. This result could mean that the monitoring has not been enforced in this forest as assumed by institutional edge effects, and consequently the whole forest would lose biomass since the forest property rights rules have not been enforced and local residents used products not only on the edges but in any place accessible. However, the forest has been regrowing instead of losing biomass. At the same time, both monitoring activities undertaken around the campus have been very mild without any kind of sanctions on non-allowed users in the last 10 years or so. The surrounding residents have been using consumptive and non-consumptive forest products for a long time. Like biophysical edge effects, it seems that both a lack of strong monitoring and the residents' use of the forest have not significantly affected the attributes of the forest. However, population pressure and a poor monitoring system during its creation and establishment had significant impact on the Campus Forest.

7.1.2. H2: Forest degradation is caused by population pressure and inequalities

Starting in the 1970s, fast population growth in Manaus, motivated by policies and governmental incentives through industrialization and urbanization, caused irreversible changes around Manaus and Campus Forest land. Immigration of thousands of rural natives and non-rural natives to Manaus caused high rates of deforestation, forest fragmentation and human invasion in Manaus' rural and peri-urban forested lands (Chapter 3). Thus, at the regional level, population pressure caused forest destruction and degradation in Manaus, having a serious impact even on the Campus Forest area. Rural landless native Amazonians arrived without much education and means to settle in the new area. They invaded several forest patches around Manaus to build their housing. The north part of the Campus Forest was invaded at that time, and 119 hectares of forest were lost during this process. No Campus Forest land was lost during and after the invasion because the University started to patrol and monitor the area.

At the local level, however, Campus Forest has not been significantly affected by population pressure and inequality. Since 1977, the forest has been recovering its ecological attributes by gaining biomass. Residents surrounding Campus Forest use this forest mostly for non-consumptive purposes. The current level of extraction of forest products used for consumption is very low. Only 8.7% of the households in Coroado use the forest for any consumption use. However, during the installation of two neighborhoods (Coroado and Ouro Verde), the new settlers relied on some Campus Forest products to build their houses, fences and other facilities. With time, the demand for those products has declined. However, the demand for non-consumptive use such as recreation has increased.

Thus, population pressure has caused a great deal of large forest destruction in Manaus in the last three decades. The fast demographic change experienced in this region also had serious impact on the Campus Forest by shrinking its forested land by 119 hectares in the beginning of the 1970s. At the local level, however, no significant influence of population pressure on the forest ecological attributes was found.

7.1.3. H3: Forest Degradation is a Result of Institutional Failure

Considering the ecological performance of the Campus Forest since 1977, I would say that the University of Amazonas is doing a good job of preserving the Campus Forest. The Campus Forest's species richness is similar to the average of Central Amazon dense forest vascular plant diversity (Chapter 4). No forest degradation has been identified since 1977. In contrast to what Campus Forest managers have argued about forest deterioration, the Campus Forest has not only maintained its structural attributes, but also as a whole, has gained biomass since the late 1970s (Chapter 5).

The loss of 119 hectares of forested land during the land invasion at the north part of the campus occurred because the University did not have the staff to avoid and control the invasion of hundreds of squatters on its land. The University was in a period of expansion and it had just acquired the Campus Forest land a couple of years before. In that time, they also did not have total property rights of the area. They gained full property control only in 1975 when the last former landowner left the area.

Between the time the University bought the land in 1969 until 1975, they also faced two conflicts. First there was the conflict with 16 small landowners who did not want to leave the Campus Forest land. Second, squatters migrated from rural areas during the beginning of the industrial boom of Manaus (Chapter 5). These two conflicts affected differently the preservation of Campus Forest. Conflicts with the landowners delayed changes in land use regime in several parts of the campus where those plots were located. Instead, the forest in these parts continued to be cleared and used for agriculture. Conflicts with squatters affected mostly the north part of the campus at Sector IV- Coroado. Squatters trying to take more campus land, cleared several parts of that area. Even after being expelled from the area, they left traces of forest destruction. The forest area around Sector IV is currently characterized as secondary succession where basal area does not reach 10 m^2/ha (Figure 5.3).

Nevertheless, to consider institutional failure in regard to these two conflicts, it is necessary to differentiate between them. Conflicts with former Campus Forest residents were more related to the options that were almost forced upon them. Several of the residents left their homes without land payment and also without a place to live. Resistant to leave, some of them just continued to do on their properties what they had always done. In this case, the University negotiation system was not able to solve the land conflict with the residents promptly and several patches of the forest were cleared after the creation of the reserve. This can be considered an institutional failure of the University since one of goals of a restricted-use reserve is to maintain the integrity of its ecosystems.

Conflicts with and sanctions on squatters who invaded the current Coroado area were, however, a way to enforce campus land property rights. People who invaded the Coroado area were not local residents but migrants coming from different rural areas. They came in waves due to the industrial frontier area that Manaus became in the beginning of the 1970s. That invasion, and others around Manaus forest areas, were exceptional events. Most people living in Manaus could not have forecasted the invasions in advance. The migration was so fast and strong that most of the agencies in Manaus could not cope successfully with the challenge it posed at that time.

7.2. Theoretical contribution

In this section, the three theoretical approaches to forest destruction and degradation will be discussed to assess the usefulness of each in explaining the changes in the pattern of forest structural attributes.

7.2.1. The edge effect

In the Campus Forest, the biophysical edge effect does not seem to be the most appropriate approach to explaining changes in forest attributes in this restricted-use reserve. The human activities developed by former owners who cut down patches of the forest better explain the current ecological attributes of the forest. The problem with using the edge effect model to explain forest degradation in restricted use reserves is related to the assumptions made about the forest reserves' ecological conditions. Restricted-use reserves are considered pristine forest areas barely touched by anthropogenic factors until the start of isolation due to fragmentation. Since most of the well-known old growth forests have been shaped by humans for a long time, and especially in the last five decades, the explanatory power of this model is weak in explaining degradation in this restricted-use reserve.

The edge effect model may, however, help us understand changes in forest attributes in isolated reserves that are not currently being used by human communities, or at least in the last fifty years. However, it is difficult to picture a forest reserve isolated due to fragmentation without human activities inside it and in its surrounding areas. Today, forests are fragmented due to open access into human activities. However, trails and other access routes to forest core areas are not taken in consideration by researchers who apply the edge effect model. Fragmentation is mostly associated with anthropogenic activities.

Nevertheless, there are some cases in which reserves are still part of a continuous forest, or isolated forest reserves are located inside large commercial farm enclaves where human activities have not been found in the last century. The best known examples are the forest reserves managed by the Smithsonian Institute in collaboration with the National Institute for the Amazonian Research (INPA), located 80 km north of Manaus. The Biological Dynamics of Forest Fragments Project (BDFFE) reserves were created in a relatively undisturbed upland dense forest to test the effect of habitat fragmentation on rainforest ecosystem. The BDFFE reserves are located inside four large farms where the access of outsiders or potential squatters is very limited (Lovejoy & Bierregaard, 1990). In those reserves, most of the anthropogenic factors that could explain forest degradation are relatively well controlled. Nevertheless, the case of the BDFFE, again, has become more an exception than a general pattern. It has been estimated, for example, that 11.1 million hectares within federal conservation units in the Legal Amazon (38% of the total area) overlap with Amerindian territories (Capobianco, 1995).

In conclusion, the biophysical edge effect is a model that could explain degradation in reserves that have no past or current influence of human activities. Or, in cases where human influence is so mild that they cannot mask the influence of biophysical effects of fragmentation. The best way to use this model is in combination with other approaches, given the rarity of a reserve's biological isolation from human history.

7.2.2. Population pressure and inequality

This study shows that population growth does explain the deforestation and forest degradation that the Manaus region experienced in the last three decades. Indeed, population pressure through migration stimulated by government incentives was the underlying force responsible for the initial forest destruction around Manaus, and was also responsible for decreasing the Campus Forest land area in the beginning of the 1970s.

This trend, however, only explains forest land cover change at the regional level, and is mostly associated with the fast transition which Manaus faced during the installation of the Zona Franca when that city, and a good part of Amazonian rural areas, became a frontier. Linking the human occupation around the Campus Forest with the ecological attributes of the forest, we do not find a pattern of forest degradation with the growing of the population at the local level.

Thus, a neo-Malthusian approach in this case has explanatory power only when applied to a regional context. At the local level, where the forest is smaller, settlement pattern and income inequality are the two interdependent variables explaining degradation in the forest. The two neighborhoods established through land invasion headed mostly by poor, landless and non-educated people impacted the forest during their installation process. With time, the settlers grew more stable, made urban improvements through neighborhood associations, and the pressure on the forest decreased. Hence, it is not only important to highlight the validity of the neo-Malthusian approach in explaining forest destruction and degradation across time and space at regional level, but also the role of institutions in mediating the relationship between population and environment at the local level. The government incentives pushing migration to specific areas of the Amazon have been repeatedly observed in the last three decades (Moran, 1981; Fearnside, 1985; Schmink, 1988; Wood & Schmink, 1993; Wood & Skole, 1998). Manaus was no different. However, at the local level, the role of the creation and evolution of institutional arrangements for using the Campus Forest was a key factor in keepimg squatters from taking more forest land and products from the Campus Forest reserve over time. The use of population pressure and inequality is still a worthwhile approach as an analytical tool in understanding forest degradation in and around restricted-used reserves, but it should be used while taking into consideration the multi-scale nature and complexity that underlies this problem.

7.2.3. Institutional failure and conflicts between reserve managers and residents

In the Campus Forest, the examination of institutional failure and conflicts between reserve managers and residents seems to be a strong factor explaining forest degradation during its installation and establishment. The inability of the University of Amazonas to enforce Campus Forest property rights resulted in a land invasion and the loss of 119 ha of forested land in the beginning of the 1970s. Conflicts which lasted for at least 5 years with squatters also had a negative influence on the ecological characteristics of the forest, as well as did conflicts with former land owners (Chapter 5).

But in 1975, when an institutional arrangement was initialized by defining and enforcing rules concerning the use and management of the Campus Forest, degradation was controlled and a forest restoration process began. Intense control inside of the forest by integrating roles and activities of the University of Amazonas with forest conservation goals, as well as intense patrolling on the forest borders until 1985, were key factors explaining forest protection and restoration.

Effective capability to monitor, sanction and arbitrate property rules in regard to the use of CPRs are indeed essential to accomplishing long-term sustainability of those systems. But these measures have to be undertaken systematically and constantly. In the Campus Forest case, patrolling around forest borders has decreased in the last decade. Decreasing patrolling activities does not seem to have influenced the protection and restoration of the forest. However, lack of forest monitoring has indeed affected the local residents' attitude in regard to Campus Forest conservation. Even with a murder and two cases of rape happening in the forest close to the Coroado neighborhood, the attitudes of the majority of the residents in regard to conserving it are still positive. Nevertheless, if criminal cases increase in the forest area, residents could display offensive attitudes by clearing and burning areas on the forest borders to limit danger, or favoring opening up the area to urban development, thus greatly affecting the preservation of the forest.

Finally, it is important to highlight the fact that institutional failure is not only a strong approach to understanding degradation and/or successful conservation achievement in restricted-use reserves, but also in multi-use reserves. In general, multi-use reserves have complex institutional arrangements since they are co-governed by both conservation agencies and local user communities, which have rights to utilize and monitor property right uses. Thus, there is a strong need to study this type of conservation unit.

7.3. Importance of this study and its implications for conservation policies and opportunities for future research agendas

Besides its empirical and theoretical findings, this study attempted to integrate methods (remote sensing, archives, interviews, site inventories), scales (meso-regional, micro-regional, and site-specifics) and theoretical approaches from, ecology, anthropology, demography and political science. This integration provides useful insights to understand, evaluate and overcome complex environmental problems related to forest degradation and conservation in tropical areas.

7.3.1. Overcoming interdisciplinary "blindness" The growing awareness of the close links between social and environmental problems has led researchers and policy makers to look for interdisciplinary ways to understand and solve such problems.. Environmental issues are by their very nature interdisciplinary because of their multi-scale complexity. During at least the last three decades, a great number of scholars from different disciplines have been trying to contribute to the "marriage" of theories and methodologies to understand and solve complex questions. However, to break disciplinary barriers and overcome interdisciplinary "blindness" is not a easy task. Information and knowledge gaps have been used to explain our inability to understand complex processes related to, for example, land cover change (Schweik, 1998).

This study shows a case where information was partially available, but to be useful it had to be approached with a set of theoretical and methodological tools encompassing its temporal and spatial complexity. In the Campus Forest case, to evaluate its current preservation status and understand the cause of its degradation or recuperation, it was necessary to develop a hierarchical research design and use a well structured, but flexible framework to integrate theoretical and methodological tools from different academic fields. First, since current and historical ecological forest data were not available to evaluate the reserve forest attributes', forest inventory was undertaken and compared with data available from similar types of mature forest found in the Central Amazon, overcoming the lack of baseline comparative forest inventory data. Second, advanced remote sensing analysis, combining data from fully calibrated MSS and TM images, provided information needed for undertaking image classifications and developing land cover change matrices. With these procedures and products, forest change over time was followed and information from interviews, analysis of archives, literature, maps and agencies reports were integrated to provide detailed information to track back variables and processes that influenced forest changes at regional and local levels. Thus, when appropriate theoretical and methodological tools are used, new and existing information can be integrated to answer and solve environmental puzzles.

7.3.2. Other theoretical contributions of this study

Although not directly emphasized in the chapters, this dissertation touched one of the most significant, and often overlooked, process responsible for land cover changes in the Amazon: urbanization. Although important, studies on Amazon urbanization have been scarce (but Penteado, 1968; Benchimol, 1977; Mitschein et al. 1989; Browder et al. 1994) since the 1970s, the Amazon has also became an urban frontier (see Becker, 1985; Sawyer, 1987; Depres, 1991 Browder & Godfrey, 1997), and Manaus, as was shown in this study, is the most extreme example of this trend. Currently, 58 % of the Amazon's population lives in urban settings and the city of Manaus hosts almost half of the population of the state of Amazonas (IBGE, 1999).

This study has shown how the rapid urbanization process in Manaus has affected land cover change (deforestation, forest fragmentation, and forest degradation) in its surroundings. However, the broad effect of urbanization on Amazon forested lands needs to be measured and the linkages between rural and urban areas concerning the behavior of individuals and groups making decisions in regard to land use needs to be studied.

According to Browder and Godfrey (1997), Amazon urban development does not replicate the North American or European models, instead it follows locally specific contexts (disarticulated urbanization) (1997:3). Becker (1990) also argues that urbanization in the Amazon is not a consequence of agricultural expansion. Looking at the Manaus case, one may agree with B. Becker. However, we have a long way to go before making generalizations about the development of Amazon urban areas and its implications. A logical step for understanding the rural-urban-rural socio-environmental dynamics in Central Amazon region, is to investigate how the fast urban growth of Manaus has affected its surrounding rural areas. It is expected that when urban population grows, the demand for agricultural and other products will increase, consequently increasing population pressure on rural lands. Thus, important issues need to be considered concerning the urbanization process in the Manaus region. First, the sustainability of food production around Manaus: how many facilities and products Manaus produces locally and how much it still relies on imported products from other Brazilian regions? And, second the linkages between urban households and rural areas: in which ways urban households are linked to rural activities and vice-versa, and how their decision affects land use changes in rural settings are also questions to be examined. The integration of these analyses will greatly contribute to increasing our understanding of the urbanization process and its dynamics in the Amazon.

7.3.3. Policy recommendations on managing the Campus Forest and other Brazilian conservation units

As described above, the University of Amazonas is managing its Campus Forest with relatively good success. However, several improvements of its monitoring system and a clear conservation program need to be designed and implemented in order to accomplish long term protection for that reserve. In regard to the monitoring system, it is necessary to increase the number of guards patrolling the reserve limits. This is an urgent measure in order to avoid criminal activities around the forest. It is also necessary to construct a better physical infrastructure, particularly better transport and communication systems, to help the staff to perform their duties.

Several improvement also need to be made regarding the boundaries of the area by opening a buffer zone from the fence line to the dense forested area. This buffer zone along the outside borders should be at least wider than 10 meters and be managed as an open forest area such as in urban parks. The creation and management of this zone will not only help guards to control the entrance of trespassers into the forest, but will also give more of a sense of security for the neighboring residents while increasing the scenic beauty of the area.

Conservation and environmental education programs need to be encouraged in the area. Campus Forest is one of the few remaining fragments of the Central Amazon forests located in the middle of a very densely populated urban area. Manaus residents and other tourists do not need to go far away to enjoy and learn about tropical moist forest ecosystems. They can have these experiences inside of the University of Amazonas campus. For the conservation program I mean to create infrastructure inside the forest and provide trained professionals to offer public visits using descriptive trails and plant and animal observation activities. Through these programs the University can both raise funds to manage the forest and increase the positive attitude of residents and other agencies towards Campus Forest conservation.

Financial constraints have always been a barrier to developing more effective monitoring in Campus Forest, and this situation has not changed. Partnership with other public agencies and non-governmental organizations to manage the reserve is a way to solve same of the problems. Furthermore, it is time to incorporate the Campus Forest as part of the National System of Conservation Units (SNUC). Historically, the University of Amazonas community has avoided linking the Campus Forest to the National Conservation Units network in order to maintain its autonomy in governing this forest reserve. However, since 1996, with the creation of the *Reservas Particulares do Patrimônio Natural* (Private Reserves of Natural Patrimony) (RPPNs) (Decree 1.922/96), a restricted-use reserve can be managed by private owner or agency without losing its ownership status or total control over the area. In addition, many advantages can be gained by legally transforming Campus Forest into an RPPN. It can have: 1) priority on the analysis of projects and resource concession from FNMA (National Fund for the Environment); 2) more access to rural credits in official banks; 3) help on protecting the forest against fire, poaching and deforestation from governmental agencies since any RPPN is under integral protection status; 4) the full support of the Brazilian Environmental Agency (IBAMA) on monitoring and managing the reserve; 5) the opportunity to raise funds by developing eco-tourism, recreational and environmental activities; 6) the support, cooperation and respect from other environmental agencies and organizations; and 7) tax exemption on both rural properties (ITR) and the development of a wildlife management business (Decree 1.922/96) . Thus, with legal status as a RPPN, Campus Forest will be able to attract more opportunities and material incentives to improve its conservation.

Nevertheless, the National System of Conservation Units is not only composed of RPPNs. In Brazil, most restricted-use reserves, such national parks, ecological and biological reserves, and multi-use reserves, are under the national conservation agency control and governance. According to Jorge Padua (1993), 40% of the national parks are not regularized, as well as 15% of the biological reserves. A great amount of land still needs to be legally acquired in order to have total public control over the Brazilian conservation units created at the national level. Using the effective amount of funds invested by the federal government to manage national conservation units, Padua estimated that it would take Brazil 400 years to buy all lands that integrate the national conservation system. In addition to the land ownership constraint, the IBAMA is an agency that lacks the staff needed to accomplish its mission, indeed, the ratio of officials-to-area is 1: 48,000 hectares, and most of these officials are allocated in clerical work rather than monitoring national conservation units.

Given the IBAMA's institutional inability to manage the Brazilian conservation units, partnership with local communities and other national and international organizations is almost the only possible solution to accomplish conservation in these reserves. From the Campus Forest case, we learned that conflicts between local communities and conservation managers affected negatively the ecological attributes of that reserve. However, effective patrolling and monitoring activities are key factors in enforcing forest product property rights, and consequently improving its preservation status. Also, the faster land ownership problems are solved, the better for conservation goals. Thus, a general diagnosis concerning the social, economic and political context enveloping Brazilian conservation units would help in designing strategies to build partnerships and programs with local communities and other private and civil organizations to manage those units.

It is time to undertake a more empirical analysis of the conservation performance of the Brazilian conservation units using clear biological and economic indicators based on a set of methodological tools such those used in Campus Forest. This evaluation can be made by comparing two conservation networks, a new one like the Amazon conservation units, which has been developed in the last two decades with an older one such as those installed in the Mata Atlantica. Based on the lessons learned from the Campus Forest experience, a broad research design would categorize the conservation units in terms of status of use (restricted- and multi-use), population pressure (urban, peri-urban, and rural area), institutional level (federal, state, and municipal) and type of management and governance (single- only national, state, or municipal conservation agency; double- co-management with local NGOs or local communities; and triple- co-management with both inter-or national NGOs and local communities). Through a integrated analysis of the preservation status of the conservation units, as well as the causes of their successes and problems, will teach us important lessons about maintaining these areas preserved for the current and future generations.

7.3.4. Refining methodologies for multiple-scale analysis: lessons from the Campus Forest

As shown in Chapter 3, 4, 5 and 6, in order to understand the complexity underlying environmental problems related to forest change, it is necessary to approach these problems across space and time. This study is a singular example of how to use a multi-scale analysis to understand these issues. The methodological approach used in this dissertation is a good example of how to integrate scientific methods essential to understanding the human dimension of environmental change (see Moran, Ostrom & Randolph, 1998; Gibson, Ostrom & Ahn, 1997). However, the integration of different methodologies toward this endeavor is still a challenging task.

Through remote sensing analysis it was possible to trace back changes affecting Campus Forest attributes. Since all images were fully calibrated, by combining MSS and TM images it was possible to follow the spatial distribution of land cover changes back to 1977. This study used a broad image classification to follow the forest temporal changes, where all types of forests, including mature and intermediary secondary succession, were assembled in just one land cover class named forest. A finer classification discriminating between different forest types and ages would be very useful for analyzing in more detail the effects of history of land use and institutional changes on the forest attributes over time, or the effects of neighboring communities', behavior on Campus Forest products. By refining these analyses, the power of the policy's prescription to conserve this and other forest reserves will be stronger.

This dissertation proposed a set of methods to measure both the effect of institutions over time (i.e., their "institutional edge effect", and the effect of neighbor communities on harvesting forest products on the attributes of the forest. These methods proved to be very useful on capturing those effects and discriminating the biophysical from other anthropogenic edge effects on the forest attributes. However, some improvements can be made to refine them. I used random forest plots to inventory Campus Forest, and this design gave me flexibility in testing different hypotheses and integrating several methods to investigate the human dimensions of Campus Forest environmental change. Biophysical and institutional edge effects were first tested on the current attributes of the forest by measuring the relationship between basal area and distance from the forest edges. Since the forest inventory plots were selected randomly, the basal area and distance from cleared areas, such as the outside border and the principal road, were coded and analyzed. That relationship was later measured over time through land cover change analysis. To capture the effect of forest consumptive use by neighboring residents, however, I measured and analyzed the relationship between basal area and distance of any non-forest area, including the trail networks inside of the forest which are areas not affected by biophysical or institutional edge effects.

To understand the effect of institutions on the forest conditions and to develop the institutional analysis for the Campus Forest, many interviews and archives were searched. However, the integration of remote sensing data and information about the creation and evolution of institutions can be better linked if the remote sensing dates can be connected with the principal institutional events that seem to make a difference on the history of the forest. Thus, a exploratory institutional analysis of a forest to be studied can provide useful information by indicating how many and what image dates should be acquired for the study area. Nevertheless, it is important to highlight that decisions about levels of analysis and methodologies to answer specific questions need to be made in relation to the nature of the problem to be studied, and changes, in general, are necessarily made during the development of the project.

Appendix 2.1. Household questionnaire administrated in Coroado and Nova Republica neighborhoods

HOUSEHOLD SURVEY

MANAUS: CAMPUS FOREST PROJECT

HH #: ______________
DATE: ____/____/_____
NEIGHBORHOOD: ____________________
DISTANCE FROM THE FOREST: ___________

I- DEMOGRAPHIC

1. Resident ID:__________________

2. Address:

____

____

3. Marital status:_____________

4. Age: ___________________

5. # of children: ______________________

6. # of HH members _______________

7. Description of HH members:

#	relation to the HH head	Sex (f, m)	age	work (yes, no)	occupation	income

II- SOCIOECONOMIC

1. HH head occupation:______________________________
2. Years in school :______________________________
3. Current job: ______________________________
4. HH head income: _______________ 5. HH income:_______________

III- ORIGIN

1. Where are you from? (town/state)

____

2. If not from Manaus, when did you arrive in Manaus?:_______________
3. Rural ( ) or Urban Area ( )
4. Why did you come to Manaus?: work ( ), education ( ), health ( ), find better life ( ), other ( )

IV- MOBILITY IN MANAUS

1. Where did you live when you arrived in Manaus? ( ) friends, ( ) relatives, ( ) rent a house, ( ) bought house, ( ) others ______________________________
2. Which neighborhood ______________________________
3. First Job: - location:_______________, Type:_______________
4. How did you get?______________________________

V- CURRENT HOUSE

1. Occupation:

( ) own, ( ) rented , ( ) invaded , ( ) borrowed, ( ) heritage, ( ) friends, ( ) relatives

VI- URBAN FACILITIES

1. Water supply

( ) municipal system , ( ) well system, ( ), well, ( ) other

What do you use to fetch potable water?

Have you fetched water from Campus Forest? ( ) yes, ( ) no

2. Power supply
2.1- ( ) yes, ( ) no
2.2- What kind? ( ) ELETRONORTE , ( ) " gato" , ( ) other ______________

3. Sewer System
3.1- ( ) yes, ( ) no
3.2- What kind? - ( ) municipal system , ( ) River system , ( ) "fossa septica", ( ) "fossa rudimentar" ( ) others ____________________________

4. Trash destination
( ) municipal system, ( ) burn , ( ) dump in specific place, ( ) others ______________

VII- RELATION WITH THE CAMPUS FOREST (CF)

1. Does the CF have any importance for your family? ( ) yes, ( ) no.
If so, Why ?

____

____

____

2. Has anyone in your family used the CF in the five years?

# ID	age	sex	Product	Use	location in the forest

3. Nowadays, are you using the CF in the same intensity that have you used in the past, such as
( ) 5 years ago, ( ) 10 years ago, ( ) 15 years ago, ( ) 20 years ago, ( ) 25 years ago.

4. Are you planning to use the CF in the future? ( ) yes, ( ) no.
Why?

____

____

5. Do you have permission to use any product from the CF? ( ) yes , ( ) no

6. If not, what kind of constraints do you face for using forest products?

---

7. How have you solved the constraints?

---

8. Someone told me that in the past the University of Amazonas had strict control. Is it true? ( ) yes , ( ) no. Has that policy influenced how your family has used the CF?

---

9. Have you noticed any change in the management and use of the CF in the last 20 years?
( ) yes, ( ) no. What has changed?

---

10. How do the controls works now ?

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VITA

MARIA CLARA SILVA-FORSBERG

Born: March 2, 1959 Imbituba, Santa Catarina, Brazil.

EDUCATIONAL

Attended elementary and high school in Santa Catarina, Brazil.

1982 Biologist, Faculdade de Biologia, Centro de Ciencias Biologicas, Universidade Federal de Santa Catarina, Florianopolis, Santa Catarina, Brazil.

1991 **Master in Ecology**, Instituto Nacional de Pesquisas da Amazonia (INPA), Manaus, Amazonas, Brazil.
Thesis: "Subsistence Ecology of a Brazilian Amazonian Caboclo Population" (Ecologia de Subsistencia de uma Populacao Cabocla na Amazonia Brasileira), 103 p.

PROFESSIONAL AND ACADEMIC POSITIONS

1992-1994 Visiting Professor, College, Department of Biology, Institute of Biological Science, University of Amazonas, Manaus, Brazil.

1984-1992 Assistant Professor, College, Division of Ecology, Department of Biology, Center of Biological Science, Fed. University of Santa Catarina, Florianopolis, Santa Catarina. Brazil.

1984-1985 Professor, High School (biology), State Institute of Education, Florianopolis, Santa Catarina, Brazil.

MOST RECENT PUBLICATIONS

- Silva-Forsberg M.C. and Fearnside, P.M. 1997. Brazilian Amazonian Caboclo agriculture: effect of fallow period on maize yield. **Forest Ecology and Management** 97: 283-91.

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