Demographic dynamics and socio-economic development as drivers of deforestation in the Brazilian Atlantic Forest: a GIS integration of census and remote sensing data at different spatial scales

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Abstract:

In this paper, I present and discuss the methodology and the main findings of my PhD thesis, submitted in 2004 at University of Campinas-UNICAMP, Brazil. In this article, I develop an analysis on the socio-demographic factors associated with land cover change and deforestation processes in the Ribeira Valley watershed, a region that concentrates the largest remnants of the Brazilian Atlantic Forest.

The main objective of the paper is to analyze the role of demographic dynamics and socio-economic development upon deforestation processes over the last 15 years at regional, municipal and census tracts levels. I also look at the role of conservation units and topography on deforestation.

First, I present a description of the different factors associated with the processes of land cover change and deforestation (demographic and socio-economic factors, topography, road infra-structure, conservation units) in different spatial scales: sub-regions, municipalities and zoning categories. Afterwards, I analyze the factors associated with land cover change and deforestation processes at the level of census tracts.

The methodology for the analysis integrates socio-demographic data (from the Brazilian demographic census – 1991 and 2000) and land cover change data (from satellite images – Landsat TM), at different levels of aggregation (spatial scales), in a geographic information system (GIS).

1. Introduction

One of the key contentious issues in global environmental change research relates to the major human causes and drivers of land cover change in different geographical and historical contexts. In this sense, a great effort has been made to identify and explain the causes and drivers of deforestation, especially in tropical regions (Allen & Barnes, 1985; Walker, 1987; Rudel, 1989; Lambin, 1994, 1997; Lambin et al., 2001; Sponsel *et al.*, 1996; Rudel & Roper, 1996, 1997; Kaimowitz & Angelsen, 1998; Mather & Needle, 2000; Geist & Lambin, 2001, 2002).

In the same way, there has been considerable improvement concerning inter-disciplinary research on the so called human dimensions of environmental change, integrating methodologies, data bases and research groups from the natural and social sciences (Liverman et al., 1998). The land use and land cover change processes have been one of the main topics in this area working with an integrated approach for

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research, incorporating demographic and socioeconomic analysis to the land use cover change research agenda (IGBP-IHDP LUCC Project).

In this paper, I present an analysis of the drivers of deforestation in the Brazilian Atlantic Forest remnants, specifically in the Ribeira de Iguape River Basin, which covers an area of approximately 28 thousand square kilometers, 62% of it located in São Paulo State (involving 23 municipalities) and 38% in Parana State (distributed in 9 municipalities). Recognized for its biological diversity, the so-called Ribeira Valley region covers coastal, floodplain and mountain areas and represents the most significant fragment of the Atlantic Forest in Brazil. Twelve federal and state conservation units are located in this area. The region has been considered one of the most important international conservation priorities by agencies such as the International Union for the Conservation of Nature (IUCN), and the UNESCO/MAB Program.

My study will focus on the São Paulo portion of the Ribeira de Iguape River Basin, which represents 60% of the total area of the watershed. The Ribeira Valley is quite often seen as a single unit in comparison to other regions of São Paulo State. However, it is not a homogenous area, presenting significant internal diversity in terms of socio-demographic characteristics, biophysical and infra-structure attributes, presence of conservation units and land cover processes (deforestation and preservation of forest remnants).

As a consequence of this intra-regional diversity, the factors associated to land cover change processes are different for each sub-region or zoning category within the Ribeira Valley. Therefore, one has to incorporate the diversity found in the area in order to analyze these factors, as I will discuss along the paper.

Given these elements, the main research questions that I am trying to answer here are:

1) What has been the role of socio-demographic factors (drivers) upon land cover change processes (recent deforestation of Atlantic Forest remnants) in the Ribeira Valley region, at different spatial scales (sub-regions, municipalities, zoning categories and census tracts)?

2) What has been the role of conservation units, topography and access to infrastructure upon deforestation processes? How those three factors mediate the relationships between socio-demographic dynamics and deforestation in Ribeira Valley region?

In order to answer these questions, I developed a methodology that integrates socio-demographic data (from the Brazilian demographic census – 1991 and 2000) with land cover change data (from satellite images – Landsat TM, years 1990 and 1999) in different levels of aggregation (spatial scales), within a geographic information system (GIS).

In this sense, the two main objectives of this paper are:

1) To describe and analyze the different factors associated with the processes of land cover change and deforestation (demographic and socio-economic factors, topography, road infra-structure, conservation units) in the Ribeira Valley, at different spatial units and scales**:** sub-regions, municipalities and zoning categories.

2) To analyze the relationships (associations, correlations and causalities) between the factors mentioned above and the deforestation process, at the level of census tracts.

To achieve these objectives, this paper is divided into seven sections, described as follows.

Section 2 presents a general description and characterization of the Ribeira Valley region. In section 3, I explain the methodology and databases used for the analysis, which involves, mainly, the integration of census and remote sensing data within a Geographic Information System (GIS).

In section 4, I present a descriptive analysis of socio-demographic factors, conservation units, topography, road infrastructure and deforestation processes in the Ribeira Valley at the scales of sub-regions and municipalities.

In section 5, I analyze the same factors described in section 4, but instead of sub-regions, I develop an analysis at the scale of zoning categories.

In section 6, I carry out an analysis of the factors (drivers) associated with deforestation processes in the Ribeira Valley at the scale of census tracts. I analyze the relationships (associations and correlations) between deforestation and the factors described in sections 4 and 5, using, for this purpose, rural census tracts. At the end of this section, I propose a qualitative model of deforestation in the Ribeira Valley and point out some possible formal models of deforestation (with the support of regression analyses) that could be applied to the Ribeira Valley.

In section 7, I discuss the main results in comparison to other two recent reviews of case studies and models of deforestation.

Finally, in section 8, I synthesize the results and present final remarks.

At this point, it is important to say that most of the databases and methodologies used in my PhD thesis and also in this paper were developed during an one-year academic visit at Indiana University, in Bloomington, at the ACT research center (*Anthropological Center for Training and Research on Global Environmental Change*), having Professor Eduardo S. Brondízio as my adviser. The ACT research center is coordinated by Professor Emilio Moran and is internationally known for its research and training activities in the field of "human dimensions of global environmental change". The ACT is also the headquarters of the LUCC project Focus 1, which is a joint project between the IGBP and the IHDP.

This one-year training was made possible thanks to an international cooperation agreement between the ACT and two Brazilian research centers – the Population Studies Center (NEPO) and the Environmental Research Center (NEPAM), both located at University of Campinas (UNICAMP), São Paulo, Brazil.

2. The Ribeira Valley Region

The Ribeira de Iguape River Basin covers an area of approximately 28 thousand square kilometers, 62% of which is located in São Paulo State and 38% in Parana State. The Ribeira de Iguape River extends through 470 kilometers and is the last river in São Paulo State that has not been changed by dams, hydroelectric powders or other large engineering interventions. The Ribeira Valley region covers coastal, floodplain and mountain areas, and represents the most significant fragment of Atlantic Forest remaining in Brazil with twelve federal and state conservation units. The region has been considered one of the most important international conservation priorities by agencies such as the International Union for the Conservation of Nature (IUCN), and the UNESCO/MAB Program. Additionally, a single Landsat TM scene (220/77) covers almost the entire study area.

The Ribeira Valley encompasses the 'Estuarine Lagunar Complex of Iguape and Cananéia' (also known as 'Lagamar'), a vast estuary over 100 kilometers long and one of the five largest reproductive sites for South Atlantic marine species. This estuary is constituted of many coastal islands and extensive mangrove swamps, forming one of the most productive ecosystems in the world, where many species of fish and crustaceans feed and reproduce. The Ribeira de Iguape is the estuary's major river. There is, therefore, an inherent unity between the estuary and the Ribeira de Iguape River Basin, forming a single ecological and socio-environmental unit.

The Ribeira Valley Region is one of the six areas that form the Atlantic Forest Biosphere Reserve[1]. It is the most preserved area and concentrates the most extensive continuous remnants of tropical forest and associated ecosystems of all the six areas. The International Union for the Conservation of Nature (IUCN) considers this region as one of the highest priority areas for conservation in the world.

The São Paulo portion of the Ribeira de Iguape River Basin (Ribeira Valley) is divided into three main environmental compartments or sub-regions:

a) the costal and estuarine sub-region between the municipalities of Iguape, Ilha Comprida and Cananeia;

b) the floodplains along the bed of the Ribeira de Iguape river and the surrounding hilly region and

c) the mountain sub-region, encompassing the Carlos Botelho State Park, the Intervales State Park and the Alto Ribeira Tourist Park (PETAR).

In both environmental and sociological terms, these three segments form a single unit. The coastal sub-region encompasses an area of particular vegetation types such as mangrove, *restinga* (beach vegetation) and some dense forest in higher terrain. The sandy soil has a low potential for cultivation. On the other hand, the landscape is highly attractive for tourism activity. The establishment of conservation units on the coast has stimulated the tourism potential of the region, but has overlooked the existence of local communities living from slash-and-burn cultivation, fishing and forest extraction, which contributes to increase land conflicts in the region.

The second sub-region, the river valley, presents the highest agropastoral production in the region. Ecological opportunities have made this area the most dynamic in terms of land cover change. The two major systems – floodplain and plateau – have been historically preferred for intensive plantations. In the floodplain, the soil is enriched every year by alluvial sediments from major rivers, providing the ideal set up

[1] In the context of Unesco's *Man and the Biosphere – MAB – Program.*

necessary for annual and semi-perennial cash crops such as banana and rice. Frequent flooding, however, has proved to be a major limitation to agricultural development. In the plateau, perennial plantations such as tea and orchards dominate cultivation fields. More recently, perennial crops have been replaced by pasture for market-related reasons.

The third sub-region – mountain - is characterized by elevated areas reaching up to 1,200 meters. Due to geographical limitations, this region has been explored mainly for mining and, secondarily, for logging and cropping. Several conservation units have been established in this mountain ridge to preserve its extensive continuous Atlantic Forest remnants (Brondizio et al., 2000).

The Ribeira Valley region as a whole (including the São Paulo and Parana States areas) presents an extraordinary environmental heritage with over 2.1 million hectares of forests or approximately the equivalent to 21% of all the remaining Atlantic Forest in Brazil. It also includes 150 thousand hectares of *restingas* (beach vegetation) and 17,000 hectares of mangroves - all very well preserved – besides being one of the most important speleological heritages in the country. The region is also rich in ethnical and cultural terms as the population living in the Ribeira Valley includes communities of native Indians, *caiçaras* (community of seaside inhabitants), *quilombolas* (communities formed by descendants of black slaves) and small agricultural families, forming a cultural diversity that is quite rare to be seen in places so close to developed or urbanized regions (ISA, 1998; Lino, 1992).

In contrast with its rich environmental heritage, the Ribeira Valley is the least developed region of São Paulo, Brazil's most industrialized and wealthiest state. It presents the lowest rate of urbanization, the lowest levels of family income, years of schooling of the population and the highest infant mortality and fertility rates. Its economy is based on agriculture (bananas, tea), mining and extraction of forest products (hearts of palm). Historical factors, difficulties of access and natural conditions adverse to economic activities guaranteed, until recently, a relative isolation and preservation of natural resources in the Valley. This is valid even considering the proximity of the Ribeira Valley to urbanized areas. The regional capital, Registro, for example, is located less than two hundred kilometers from the São Paulo Metropolitan Area (ISA, 1998).

In other important aspects of the demographic dynamics of this region, the contrast with the rest of the State of São Paulo is also impressive. The infant mortality rate of the region in 1997 was 31.68 deaths per 1,000 live births, one-third higher than the average for the State. The region is perhaps the last in the State that has not gone through the "epidemiological transition". Its mortality profile is typical of a pre-industrial era, with a predominance of infectious and contagious over chronic and degenerative diseases. In terms of fertility, the regional health district (known as 'DIR of Registro') reports the highest rate in the State, 2.68 versus 2.26 children per woman (Hogan et al., 1999).

The Ribeira Valley is also the least urbanized region of the State – 65% vs 90%. Its population growth rate has been historically low, a situation reinforced nowadays by out-migration. Analysis of migration trends reveals three important aspects. First, the Ribeira Valley's net out-migration is considerable, indicating a lack of perspectives for jobs and socioeconomic insertion. Second, a large part of this mobility is restricted to surrounding municipalities. Adding these movements to the Valley's significant *internal* mobility, we see that the precariousness of employment provokes a considerable volume of population circulation. Third, the region's most 'qualified' residents (or the least unqualified) end up migrating to other areas and, consequently, the least qualified remain settled. In many of the municipalities of the Ribeira Valley, educational levels are extremely low (Hogan et al., 1999).

The Ribeira Valley, on the other hand, has had one of the most intensive political-institutional efforts to create protected areas for the last 30 years in Brazil. The distinct restrictions on land use (including forest use) imposed by the creation of conservation units, the lack of economic alternatives and infrastructure, together with land ownership conflicts have motivated diverse scenarios of environmental changes, making this region an ideal socioenvironmental microcosm for the study of processes of deforestation and land use and land cover change, derived from demographic and socio-economic dynamics and institutional (environmental) restrictions (Brondizio et al., 2000; ISA, 1998; Hogan et al., 1999).

3. Methodologies for the integration of census (socio-demographic) and remote sensing (deforestation) data: a study on the Ribeira Valley

As mentioned in the introduction, the general methodology for the analysis of the factors (drivers) of deforestation in the Ribeira Valley is the integration of socio-demographic data (from the Brazilian demographic census – 1991 and 2000) and land cover change data (from satellite images – Landsat TM, years 1990 and 1999), at different levels of aggregation (spatial scales), in a geographic information system (GIS).

The main methods used to integrate census and remote sensing data are:

i. classification of two Landsat TM images of the Ribeira Valley (scene 220/77, years 1990 and 1999);

ii. construction and organization of a demographic and socioeconomic database, from Brazilian census of 1991 and 2000, at the level of municipalities and census tracts;

iii. creation and organization of digital layers of road network, urban centers, topography, rivers, conservation units and municipal and census tracts boundaries;

iv. development of a GIS structure, integrating the three main sources of data mentioned above (satellite images, census data and digital layers);

v. creation of variables for land cover, topography, conservation units and road infrastructure, within a GIS.

Next I make a brief description of each of the methods listed above.

i. Classification of satellite images and creation of a transition matrix

I classified two Landsat TM images of the Ribeira Valley (scene 220/77, years 1990 and 1999). For each of the two images, I have distinguished seven land cover classes, which are: water, forest, mangrove, planted forest and non-forested areas (which include crops, pasture, bare soil and urbanized areas). However, for the purpose of this paper, I am going to look at two main land cover types: forest and non-forest.

After the classification was accomplished, I built a transition matrix, in order to capture and quantify land cover changes between the two dates of the images (time period of 1990-1999). The most important land cover trajectories (or changes) I want to look at are deforestation and preservation of forest remnants.

It is important to say that there is a great temporal correspondence between the land cover change/deforestation time period (1990 to 1999) and the census variables

(1991 and 2000). This correspondence allows a fine temporal association between land cover change and socio-demographic dynamics.

ii. Demographic and socioeconomic database

I organized a database with demographic and socioeconomic variables from the Brazilian census of 1991 and 2000, at the level of municipalities and census tracts (‘setores censitários’).

The census data are geo-referred to digital layers of municipalities and census tracts. This is an essential feature in order to make possible the spatial distribution of census data and the integration with remote sensing data and other spatial variables, all within a GIS structure.

iii. Creation and organization of digital layers

I built and organized biophysical, infrastructure and political-administrative maps (GIS vector and raster layers) with road network, urban centers, topography (Digital Elevation Model - DEM), rivers, conservation units and municipal and census tracts boundaries.

The digital layers, as well as the two Landsat images, are projected in the *Universal Transverse Mercator* (UTM) system. Some of the layers were especially built by us at the ACT – Indiana University and others were given by the Brazilian NGO *Instituto Socioambiental*.

iv. Development of a Geographic Information System (GIS)

I developed a GIS structure integrating three main sources of data:

1) Land cover maps derived from Landsat TM (scene 220/77) images (years 1990 and 1999).

2) Demographic and socioeconomic data from the Brazilian national census (years 1991 and 2000) at municipality and census tracts levels.

3) Biophysical, infrastructure and political-administrative maps (GIS vector and raster layers) with road network, urban centers, topography (Digital Elevation Model - DEM), rivers, conservation units and municipal and census tracts boundaries.

v. Creation of variables for land cover, topography, conservation units and urban and road infra-structure, integrated into a GIS

Besides the census variables, I also created a set of spatial variables integrated into a GIS. These variables were organized in four groups, which are: 1) land cover variables; 2) zoning categories and 'conservation units' variables; 3) topographic variables and 4) urban and road infra-structure variables.

The land cover change variables were created by a two-step procedure. The first step was overlaying the municipalities and census tracts layers with the already classified Landsat images (land cover maps). The second procedure was to extract land cover classes, which were then aggregated to the spatial units of analysis, namely census tracts and municipalities.

This procedure enabled us to estimate the total area (and the percentages) for each land cover class within every municipality and census tract of the Ribeira Valley, therefore, accomplishing the integration of census and remote sensing data. It became possible to estimate, for example, that the municipality of 'Eldorado' has 121 thousand hectares of forest (or 73% of the area of the municipality), 28 thousand ha without forest cover (17% of the municipality) and that the area deforested between 1990 and 1999 was of 10 thousand ha (or 6% of the municipality).

Map 1 shows how the land cover variables were created by overlaying the municipalities/census tracts layers with the land cover change maps.

The variables regarding zoning categories and conservation units were created by overlaying the conservation units layer with the municipalities/census tracts layers. For the municipalities, I estimated the area (and the percentages of the area) of the municipality under each type of zoning category, i.e., forest reserves/parks, areas of environmental protection (known as 'APAs') and non-protected areas. For the census tracts, I classified each one according to the zoning category that it belonged to: parks, APAs or non-protected areas. This was a very important accomplishment as it became possible to test the role of conservation units on deforestation processes, at the level of census tracts.

Map 2 shows how the zoning categories/conservation units variables were created by overlaying the layer of conservation units with the municipalities/census tracts layers.

The topographic variables were created with the support of a Digital Elevation Model (DEM). I overlayed the municipalities/census tracts layers with the DEM and calculated a series of descriptive statistics about the topography of each census tracts and municipalities, such as average elevation and slope, minimum, maximum and range of elevation/slope.

It is important to note that the topographic variables are important for my analysis, because the elevation and slope play a very significant role in the processes of land cover change and deforestation in the Ribeira Valley.

Map 3 shows how the topographic variables were created by overlaying the municipalities/census tracts layers with the Digital Elevation Model.

The last procedure was to create urban and road infra-structure variables by overlaying maps (layers) of urban centers and roads with the municipalities/census tracts layers. First, I created buffers around the main roads and urban centers. For the roads, I tested buffers of 100, 200, 500, 800 and 1,000 meters. For the urban centers, I tested buffers of 1, 3, 5, 8 and 10 kilometers. Afterwards, these buffers were overlayed with the municipalities/census tracts layers and thus I was able to calculate the area (and the percentages of the area) inside the buffers of roads and urban centers for every municipality and census tract. Therefore, these variables were considered as a proxy of access to urban markets and road infra-structure.

Map 4 shows how the urban and road infra-structure variables were created, through the overlaying of the buffers of urban centers and roads to the municipalities/census tracts layers.

After creating all the spatial variables mentioned above, the database was completed, so for every municipality and census tract the following groups of variables were available:

1) census variables (demographic and socioeconomic variables) (years 1991 and 2000).

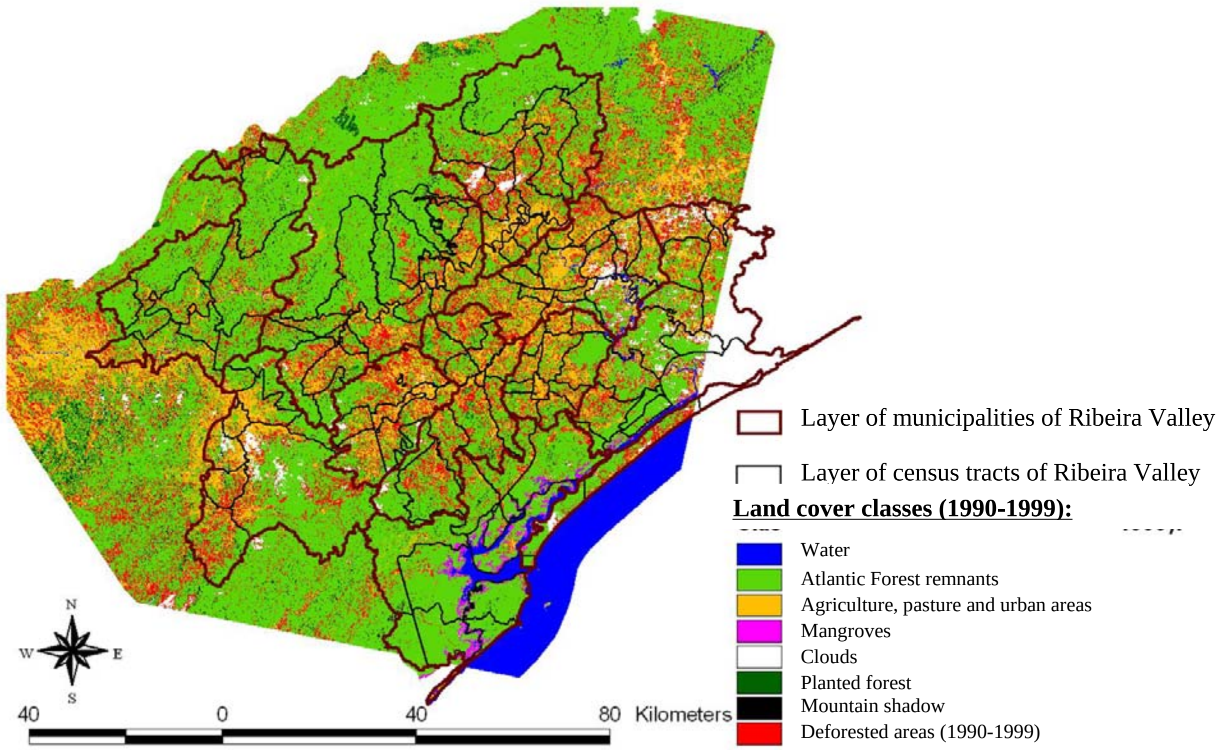
2) land cover variables (years 1990 and 1999).

3) zoning categories / conservation units variables.

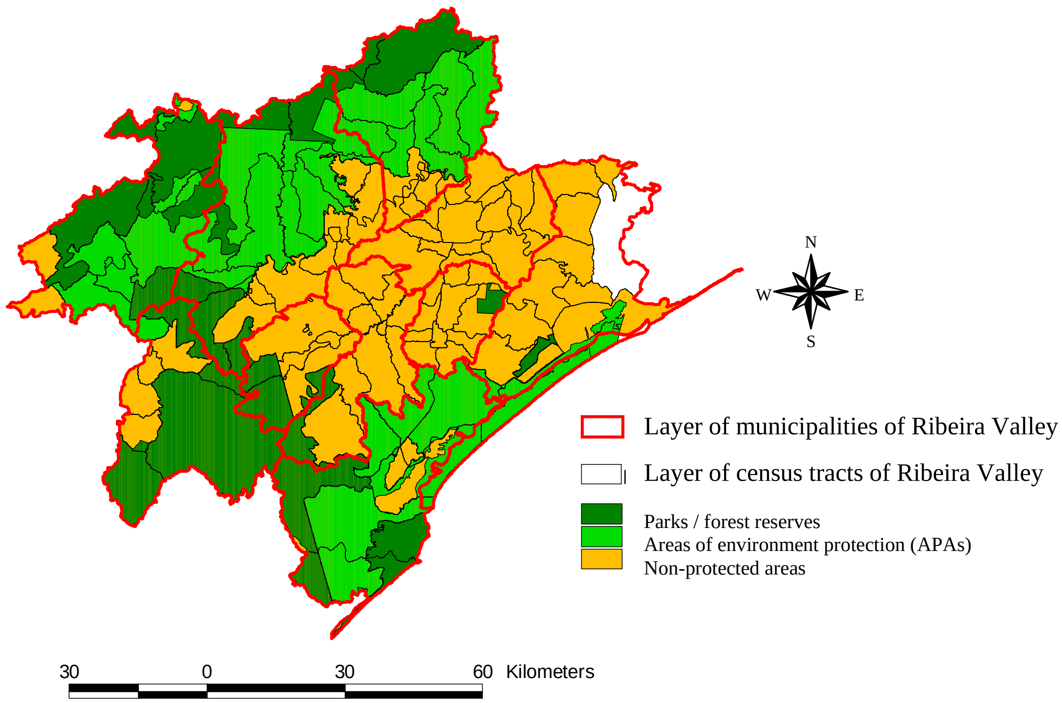
4) topographic variables.

5) urban and road infra-structure variables.

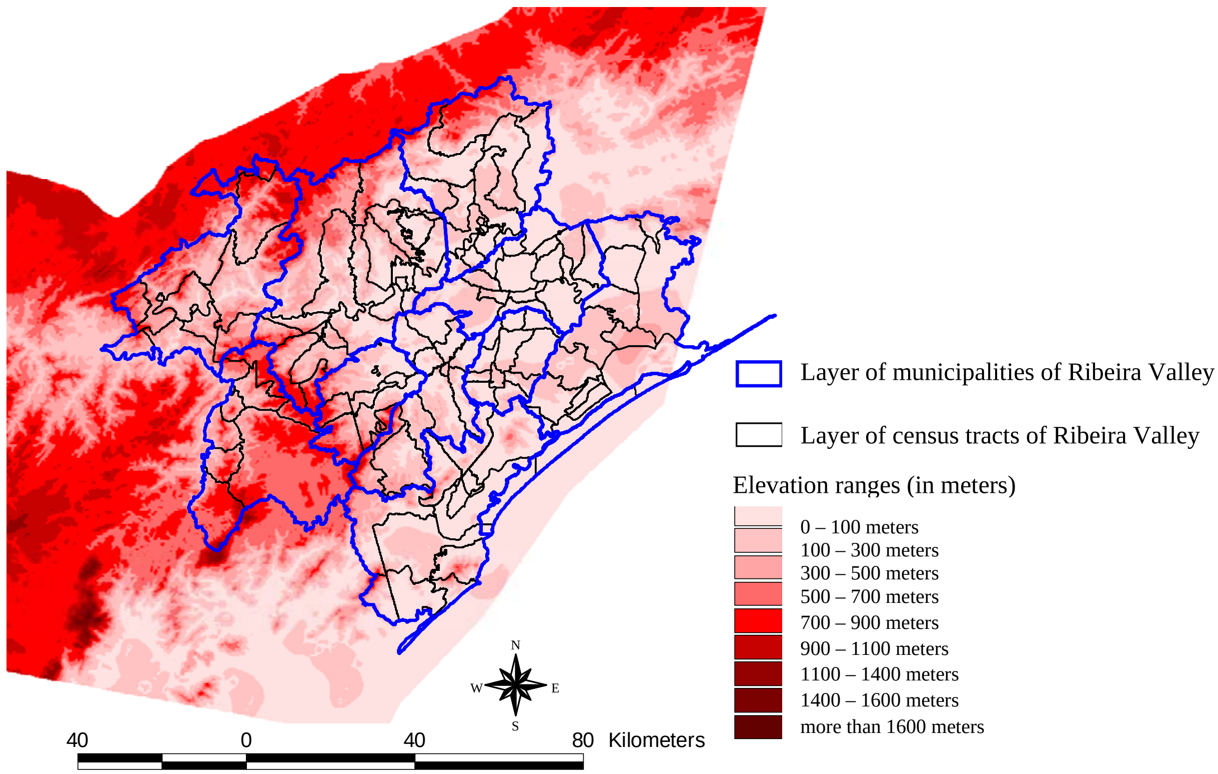
Map 1. Overlaying of the municipalities/census tracts layers of the Ribeira Valley with the land cover [change] maps (classified Landsat TM images)



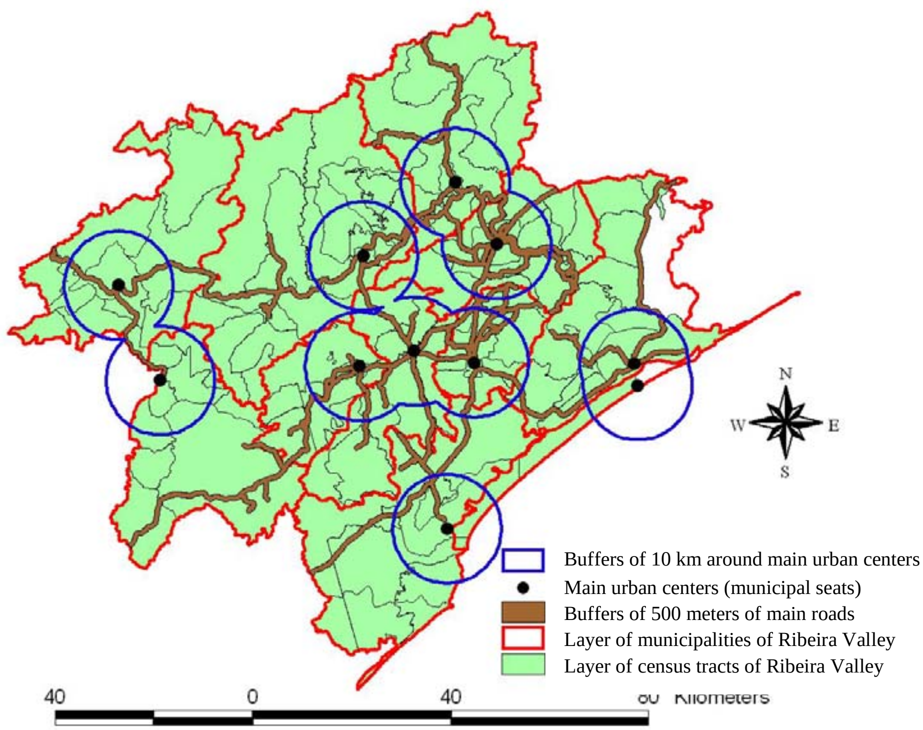
Map 2. Overlaying of the conservation units layer with the municipalities/census tracts layers of the Ribeira Valley



Map 3. Overlaying of the municipalities/census tracts layers with the Digital Elevation Model (DEM) of the Ribeira Valley



Map 4. Overlaying of the buffers of urban centers and roads to the municipalities/census tracts layers of the Ribeira Valley



4. Analysis of socio-demographic factors, conservation units, topography, road infrastructure and deforestation processes in the Ribeira Valley at the scales of the sub-regions and municipalities

The Ribeira Valley is known as a region covered by the Atlantic Forest and protected by parks and reserves, presenting very low population densities, low urban population rates and also very low socioeconomic and human development indicators in the context of São Paulo State.

This is valid for the region as a whole, but it does not apply to all municipalities and sub-regions within the Ribeira Valley. In fact, the Ribeira Valley is not a homogeneous area at all as it presents a great biophysical, demographic, socioeconomic and environmental diversity.

Considering this diversity, I proposed a division of the Ribeira Valley into sub-regions, which took into account the perimeters of the municipalities and the biophysical and topographic compartments of the region – mountain, river valley and coast.

As a result, I arrived at three sub-regions for the Ribeira Valley, according to the three topographic compartments mentioned above. The sub-regions can be seen in **map 5**.

Next, I make a brief description of each sub-region.

Mountain sub-region. It encompasses four municipalities (Barra do Turvo, Iporanga, Eldorado and Sete Barras). It concentrates most of the parks and forest reserves of the Ribeira Valley, such as the 'Carlos Botelho', 'Intervales', 'PETAR' and 'Jacupiranga' and also encompasses the APA 'Serra do Mar'. These conservation units represent 83% of the territory of this sub-region, which is the least urbanized one and with the lowest population densities in the Ribeira Valley.

River Valley sub-region. It encompasses four municipalities (Cajati, Jacupiranga, Registro and Pariquera-Açu). This sub-region is the most developed and urbanized one and has the largest concentration of population's volume and density, especially the city of 'Registro', which is the most populated and also the regional capital. The floodplains and plateaus of the Ribeira Valley have historically been preferred for intensive plantation and commercial agriculture, concentrating most of the region's annual and semi-perennial cash crops, such as banana, tea and rice. Besides, all the municipalities of this sub-region area are crossed by the BR-116 highway, which is one of the most important Brazilian highways. The presence of the BR-116 highway creates important economic and commercial dynamics for the municipalities of this sub-region.

Coastal / Estuary sub-region. It encompasses three municipalities (Cananéia, Iguape and Ilha Comprida). Since the 1970s – after the completion of the BR-116 highway - this sub-region, specially the municipality of Iguape, lost the status of the most important and dynamic area of the Ribeira Valley. The city of Iguape used to be, historically, the regional capital, including a very dynamic harbor in São Paulo State but it end up losing its importance for the city of Registro, which is located along the BR-116 highway. Nonetheless, Iguape is still the second most populated city of the Ribeira Valley. Despite suffering an economic and demographic stagnation during the 1970s and 1980s, the municipalities of the Coastal sub-region have shown a significant development and population growth during the 1990´s, mainly related to the exploration of tourist activities. As mentioned before, the coastal and estuary sub-region is highly suitable for tourism. However, unplanned urbanization processes, as a consequence of tourist activities, have become an important source of conflict in the municipalities within this Coastal sub-region, opposing eco-tourism and more conventional types of tourism.

I now proceed a comparative analysis of the three sub-regions described above. I found that there are great differences regarding socio-demographic factors, conservation units, topography, road infrastructure and land cover/deforestation processes.

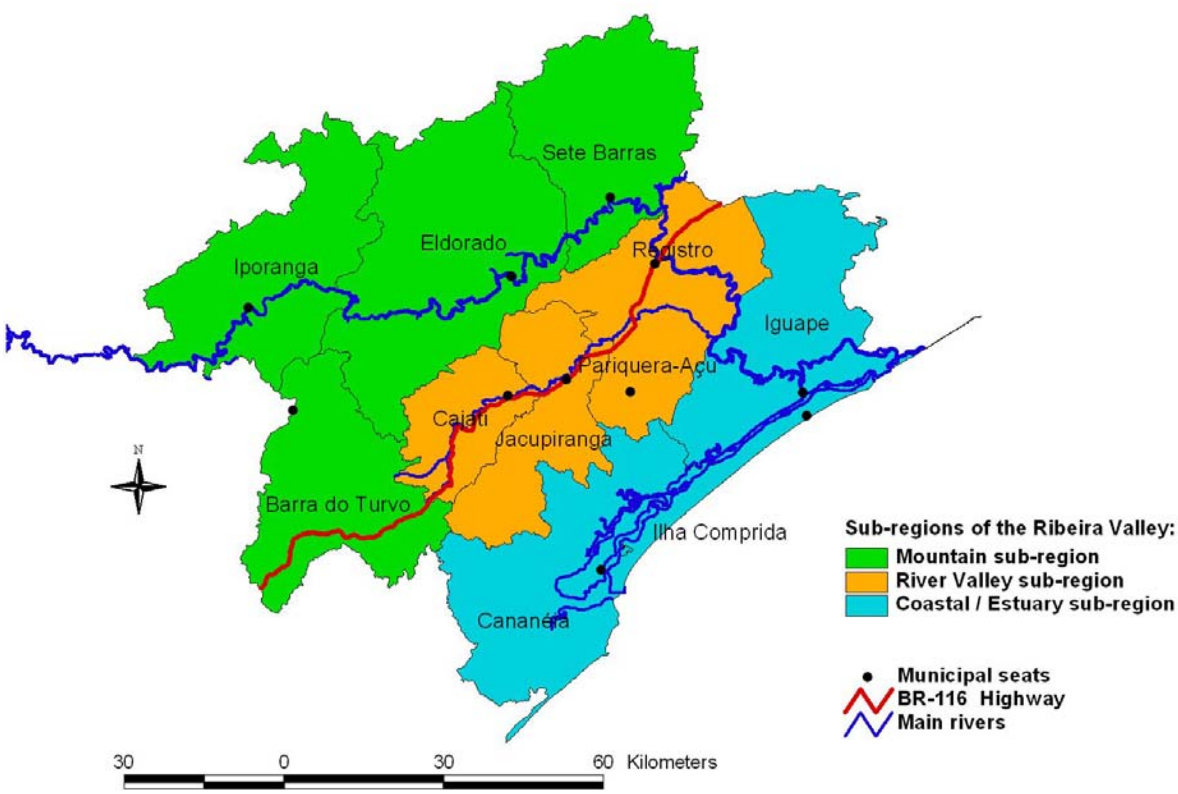
On one hand, the municipalities belonging to the first sub-region, the Mountain sub-region, are characterized by low urban population rates, small population size and density and low levels of population growth. On the other hand, most of the municipalities belonging to the second and third sub-regions - the River Valley and the Coastal sub-regions - present much higher urban population rates. The River Valley is the most populated sub-region and presented the fastest population growth during the 1970´s and 1980´s, although in the 1990´s its growth rate was smaller than the Coastal sub-region (see tables 2, 3 and 4 in Annex 1).

In 2000, almost 58% of the population living in the Ribeira Valley was concentrated in the River Valley sub-region. The Coastal and Mountain sub-regions concentrated 22.5% and 20% of the regional population, respectively.

The combination of a small population and a large territory results in very low population densities in the Mountain sub-region, with only 8.3 inhabitants per square kilometer, while in the Coastal sub-region the density is 18 inhabitants/km^2 and in the River Valley sub-region reaches 52.5 inhabitants/ km^2. The rural population densities are low in the three sub-regions: 14.2 inhabitants/ km^2 in River Valley, 4.9 inhabitants/ km^2 in the Mountain and only 2.8 inhabitants/ km^2 on the Coast (table 4 in Annex 1).

Therefore, one can see that there is a great diversity among the three sub-regions regarding population size, density and growth (see tables 2, 3 and 4 in Annex 1).

Map 5. Sub-regions and municipalities of the Ribeira Valley



It is true that the socioeconomic and human development indicators in the municipalities of the Ribeira Valley are fairly low in the context of São Paulo State. However, the levels of income, schooling, literacy and sanitation are not the same among the municipalities of the three sub-regions.

The municipalities of the Mountain sub-region have the worst living conditions, with high percentages of the head of households earning very low wages and presenting also very low levels of schooling, particularly in the rural areas. On the other hand, the municipalities of the River Valley sub-region have a better living condition, especially in the city of Registro. The municipalities of the Coastal sub-region stand in an intermediary situation (see table 5 in Annex 1).

Regarding the presence of conservation units, topographic and road infra-structure attributes and land cover/deforestation processes, there is also great diversity among the three sub-regions.

More than 80% of the territory of the Mountain sub-region is protected by conservation units, half of which are parks and forest reserves with strong environmental restrictions regarding the use of Atlantic Forest resources. The municipalities of this sub-region have a very irregular topography, being crossed by the 'Paranapiacaba' and 'Jacupiranga' mountain ridges, with steep slopes. The Mountain sub-region has a very low-density in terms of road network, especially in the northern part of the municipalities, where many areas have no road access at all.

The Mountain sub-region also concentrates almost 60% of the Atlantic Forest remnants of the Ribeira Valley and 69% of its territory is covered by forest, with a high level of conservation due to the presence of parks and reserves. However, despite the protection of the conservation units, approximately 32 thousand hectares of Atlantic Forest were deforested between 1990 and 1999, which represents almost 7% of the sub-region's territory and 9% of the forest cover in 1990 (see tables 6, 7 and 8 in Annex 1).

The River Valley sub-region is very different from the Mountain sub-region. Less than 12% of the River Valley is protected by conservation units and the municipality of Registro is not covered by any protected area. As mentioned before, the municipalities of this sub-region are located in the floodplains and plateaus of the medium and low course of the Ribeira River Basin, with very smooth slopes, historically preferred for intensive plantations. Since the BR-116 highway crosses all the municipalities of the River Valley, this sub-region concentrates the majority of the region's road network.

As a consequence of the development process in the Ribeira Valley region, which was more intense in the areas more suitable for agriculture and more accessible by roads, the land cover change processes in the River Valley sub-region have been very intense in the last decades. Between 1990 and 1999, almost 22 thousand hectares were deforested in the River Valley sub-region, which corresponds to 9.7% of its territory at a significant deforestation rate of 17.4% in 9 years (see tables 6, 7 and 8 in Annex 1).

In the Coastal sub-region, the conservation units encompass almost 60% of the territory, most of which are Areas of Environmental Protection (APAs), with private land ownership, something that makes more difficult to enforce environmental restrictions. The topography of the municipalities of the Coastal sub-region is very diverse, ranging from almost null elevation and slope in 'Ilha Comprida' municipality to steep slopes in 'Cananéia', a municipality that encompasses coastal mountain areas with important Atlantic Forest remnants and protected by two state parks ('Jacupiranga' and 'Ilha do Cardoso'). This sub-region has a very low-density in terms of road network, most of which are the roads that give access to the main urban centers.

As its territory is much smaller than the Mountain sub-region, the Coastal sub-region concentrates only 25% of the forest remnants of the Ribeira Valley. Nevertheless, 67% of the territory in the Coastal sub-region is covered by Atlantic Forest, particularly 'Cananéia', with 79% of its territory with forest cover and extensive areas of mangroves, very well preserved.

Besides that, the Coastal sub-region presented the lowest levels of deforestation among the three sub-regions of the Ribeira Valley in the 1990´s, with 10 thousand hectares deforested, which corresponds to 4.4% of its territory and a deforestation rate of 6.6% in 9 years (see tables 6, 7 and 8 in Annex 1).

As one can see, the Ribeira Valley region presents a great internal diversity, with striking contrasts and differences among the sub-regions and municipalities. Therefore, it is necessary to account for this socio-demographic, biophysical and environmental diversity when planning and implementing development projects and public policies suitable to the specificities of each sub-region and municipality. In this sense, one of the most important instruments for planning and managing the territory is the Ecological-Economic Macro-Zoning of the Ribeira Valley that, unfortunately, has not been implemented and enforced yet.

5. Analysis of socio-demographic factors, topography, road infrastructure and deforestation processes in the Ribeira Valley at the scale of zoning categories

Another way to analyze the diversity of the Ribeira Valley is to disaggregate the region into three main zoning categories: 1) parks and forest reserves; 2) Areas of Environment Protection (APAs) and 3) non protected areas.

Since 1991, the Brazilian census uses the perimeter of existing conservation units to define the borders of the census tracts. As a consequence, it is possible to classify the census tracts of the Ribeira Valley according to the zoning category in which it belongs, i.e., inside parks/reserves, inside APA or non protected area (see **map 6**).

In this sense, I aggregated the census tracts under the same type of environmental restriction to create the zoning categories and then to perform a comparative analysis among them. This comparative analysis will be a counterpoint to the comparative analyses of the sub-regions performed in the last section and that was based on municipal perimeters.

First, it is interesting to note that over 60% of the territory of the rural areas of the Ribeira Valley is inside conservation units, which can be classified in two main types according to the level of environmental restriction: forest reserves/parks and APAs.

The parks and forest reserves are under state jurisdiction. These areas are basically government property and its occupation by private dwellers is forbidden. The most important and preserved remnants of Atlantic Forest in the Ribeira Valley are located in these parks and reserves, which are ‘PETAR’, ‘Intervales’, ‘Carlos Botelho’, ‘Jacupiranga’, ‘Ilha do Cardoso’ and ‘Pariquera-Abaixo’[2].

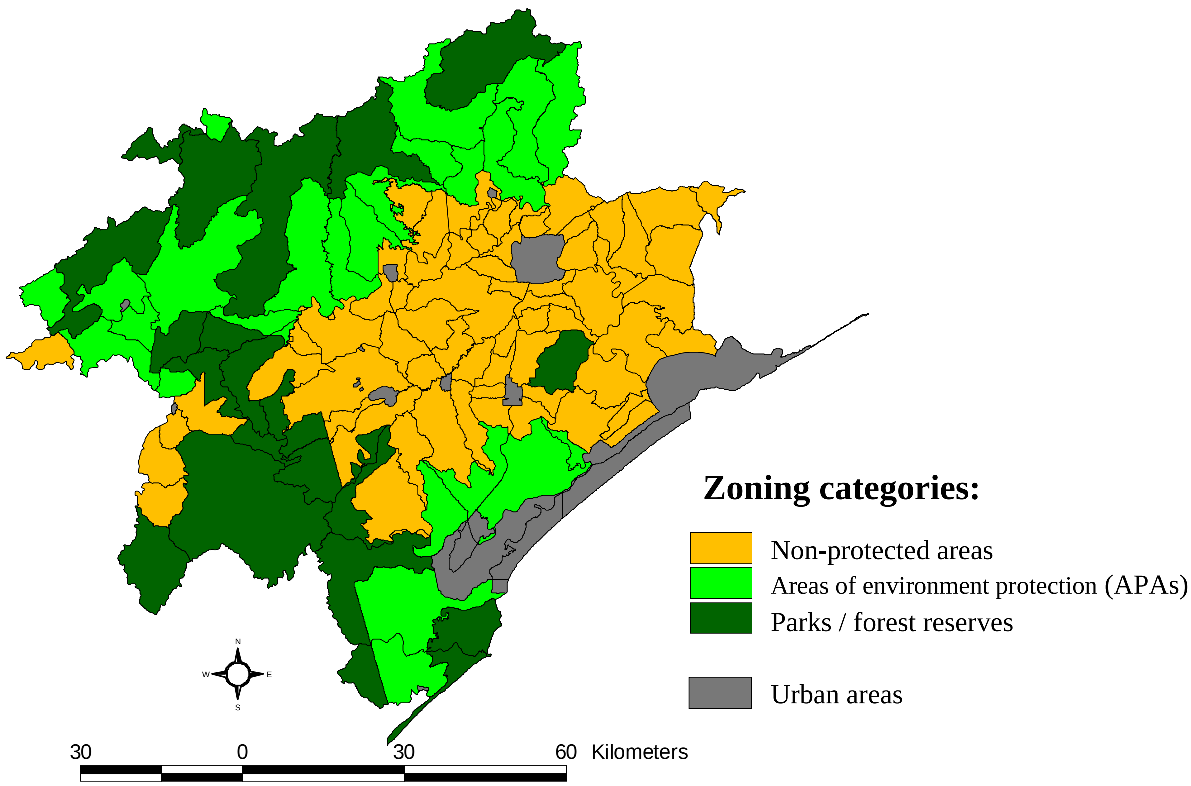
The Areas of Environmental Protection (*Áreas de Proteção Ambiental* – APAs) are a type of conservation area that allows private use of natural resources, according to the limitations of environmental laws. The APAs usually have a private land property status and land use is permitted under the terms of environmental regulation. Land use is enforced by the federal environmental government agency (IBAMA). The three

[2] One important conservation unit, the ‘Juréia-Itatins Ecological Station’, is located outside my study area, since it is not encompassed by the Landsat TM scene 220/77, and therefore will not be incorporated in my analysis.

APAs inside the Ribeira Valley are 'APA Serra do Mar', 'APA Cananéia-Iguape-Peruíbe' and 'APA Ilha Comprida'.

The three types of zoning categories in the Ribeira Valley have similar sizes: 298 thousand hectares covered by parks and reserves, 247 thousand hectares covered by APAs and 328 thousand hectares of non protected areas. In percentage, those areas correspond, respectively, to 34%, 28.3% and 37.6% of the Ribeira Valley territory[3] (see map 6).

Map 6. Zoning categories in the Ribeira Valley created by the aggregation of rural census tracts



[3] In this comparative analysis among the three zoning categories, I am considering only rural areas, which correspond to 92.8% of Ribeira Valley total area. The urban areas will not be included in the analysis because its socio-demographic and biophysical characteristics are very distinct from the rural areas, and therefore would bias the comparison among the areas. Besides, all the urban areas are outside conservation units.

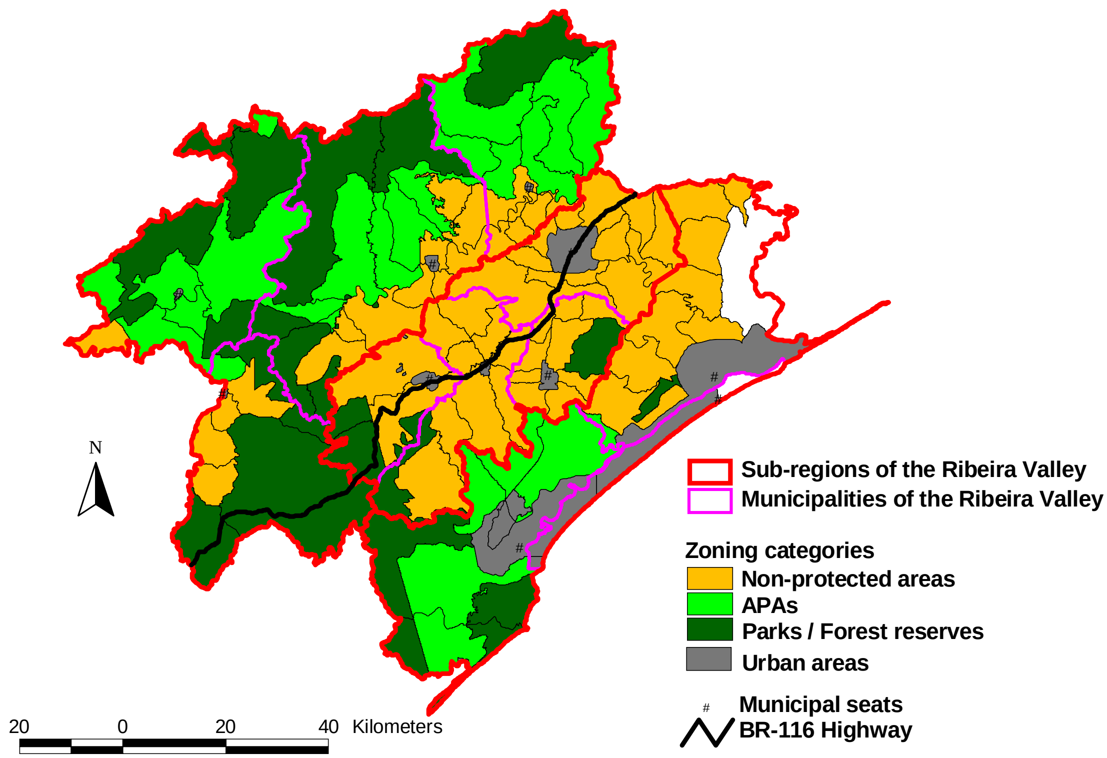
There are remarkable differences between the three zoning categories in terms of socio-demographic factors, biophysical and infra-structure attributes and land cover change processes (see tables 9, 10, 11 and 12 in Annex 1).

Almost 75% of the rural population of the Ribeira Valley lives in non-protected areas, with a population density of 13.7 inhabitants per square kilometer. In these non-protected areas, the socio-economic and human development indicators are significantly better in comparison to the areas inside conservation units. Despite the fact that these indicators can still be considered low in the context of the rural areas of São Paulo State, the levels of income, schooling, literacy and sanitation of the population living in non-protected areas are much higher than the ones inside APAs or parks/reserves, especially in this last zoning category (see tables 9 and 10 in Annex 1).

The non-protected areas are clustered in the medium and low course of the Ribeira River, with a smooth topography of floodplains and plateaus. It is important to say that there is a great spatial overlapping between the non-protected areas and the River Valley sub-region (described in the last section), as one can see in **map 7**. However, the non-protected areas cover a larger territory, encompassing parts of the municipalities of the Mountain and Coastal sub-regions, usually areas with smooth topography and suitable for agriculture. In this sense, one can see that an analysis based on zoning categories (using the aggregations of census tracts) captures much better the diversity of the Ribeira Valley than the analysis based on sub-regions (using the aggregations of municipalities) (see **map 7**).

Regarding land cover change processes, approximately 52% of the deforested area in the Ribeira Valley between 1990 and 1999 took place in non-protected areas, which represents only 26.6% of the forest remnants of the region. As a consequence, the deforestation rate in non-protected areas, in this nine-year period, reached almost 18% (see tables 11 and 12 in Annex 1).

Map 7. Overlaying of sub-regions and zoning categories of the Ribeira Valley



The areas inside conservation units show a very different pattern regarding socio-demographic factors, biophysical and infrastructure attributes and land cover change processes. Those areas concentrate only 26% of the rural population of the Ribeira Valley, with 15.6% living in APAs and 10.8% in parks and forest reserves. The population densities inside conservation units are very low, with 3.9 inhabitants per square kilometer inside the APAs and only 2.2 inhabitants per square kilometer inside the parks/reserves [4].

If the socio-economic and human development indicators of the rural population of the Ribeira Valley are low in general, the population living inside conservation units

[4] The socio-demographic factors, biophysical and infra-structure attributes and land cover change processes of the APAs and parks/reserves were calculated through the aggregation of all census tracts located inside APAs and parks/reserves, respectively. In map 6, the APAs can be seen in light green and the parks/reserves in dark green.

witnesses the worst living conditions of the whole region, with very low levels of income, schooling, literacy and sanitation. For example, the percentage of head of households earning less than a minimum wage per month (approximately 100 dollars) reaches 55% and 64% of the head of households in the APAs and parks/reserves, respectively (see tables 9 and 10 in Annex 1).

The vast majority of the conservation units are located in the mountain areas, with steep slopes as the ‘Paranapiacaba’ and ‘Jacupiranga’ mountain chains. Almost 75% of the Atlantic Forest remnants of the Ribeira Valley are clustered inside conservation units, being 42% of the remnants exclusively inside parks and forest reserves.

Approximately 48% of the deforested area in the Ribeira Valley between 1990 and 1999 occurred inside conservation units, 27.5% in APAs and 20% in parks/reserves, which represents high levels of deforestation for protected areas, especially in parks and forest reserves that present tight environmental restrictions and government land property. Having said that, the deforestation rates in the 1990’s inside APAs and parks/reserves (respectively, 8.8% and 5%) were still much lower in comparison to non-protected areas (17.8% in the same time period) (see tables 11 and 12 in Annex 1).

6. Analysis of the factors (drivers) associated with deforestation processes in the Ribeira Valley at the scale of the [rural] census tracts

In **table 1**, one can see that the factors positively associated with deforestation in the Ribeira Valley are the following:

- demographic factors (population size, density and growth);
- socio-economic conditions (levels of income, schooling and sanitation);
- access to urban markets and road infra-structure (proximity to urban centers and road network).

On the other hand, the factors negatively associated with deforestation are:

- poverty (percentage of head of households earning less than 1 minimum wage);
- topography (range of elevation inside the census tract);
- presence of conservation units.

As shown in table 1, the factor (independent variable) with the strongest positive association with recent deforestation is population density, presenting a linear correlation (Pearson coefficient) of 0.486. The second strongest factor associated with deforestation is the proximity to urban centers, with a linear correlation of 0.452.

Moreover, population density and proximity to urban centers are also highly correlated with each other[5]. So, it is possible to say that this quite strong correlation between population density and deforestation might be a consequence of the effect of the proximity to urban centers on the deforestation rates of the census tracts.

Table 1.
Linear correlation coefficients between the factors associated with deforestation (selected independent variables) and the rate of deforestation in 1990-1999.
Rural Census Tracts of the Ribeira Valley.

Factors associated with deforestation (selected independent variables)	**Linear correlation with rate of deforestation (Pearson coefficient)**
Population Density in 2000	0.486(**)
Percentage of the census tracts area within 10Km from the nearest seat of municipality	0.452(**)
Percentage of households with bathroom (in 2000)	0.405(**)
Average years of schooling of the heads of households (in 2000)	0.395(**)
Population size of census tract in 2000	0.362(**)
Percentage of census tracts area within the 1 Km buffers of road network	0.361(**)
Census tracts average income of the head of household (in minimum wages, 2000)	0.356(**)
Population Growth rate (1991-2000)	0.324(**)
Variation of the elevation in the census tract	– 0.490(**)
Percentage of head of households in poverty (in 2000)	– 0.382(**)
Restrictions in land use (presence or not of conservation units)	[0.452] (1)

Source: IBGE. Demographic Census 1991 and 2000 and Landsat TM images, 1990 and 1999 (scene 220/77).

** Significant correlation ($p < 0.01$).

(1) Coefficient of determination (R-square) in the analysis of variance.

[5] The linear correlation between population density and its proximity to urban centers is significant and positive, with a value of 0.538.

The socio-economic conditions of the population in the census tract (levels of income, schooling and sanitation) have also quite strong positive associations with deforestation, with linear correlations of 0.356 (income), 0.395 (schooling) and 0.405 (sanitation). One possible explanation for these associations is that better socio-economic conditions (therefore higher levels of income and consumption) imply on higher demands for agricultural and forest products and also a greater availability of economic resources to invest in agriculture activities, therefore increasing the probability of deforestation. But the causative pattern can also work in the opposite direction, i.e., the income generated by deforestation could have improved the socio-economic conditions of the population living in census tracts with higher deforestation rates.

After socio-economic conditions, the population size of the census tract is the variable with strongest association with deforestation (linear correlation of 0.362). The road network density is also positively associated with deforestation (Pearson's coefficient 0.361). Besides that, road network has a very high correlation with population density[6], revealing the important role of roads in the spatial distribution of the population, therefore suggesting that population density might be only a proxy of the effect of road network on deforestation in the Ribeira Valley.

At last, one can see that the population growth rate of the census tract has the lowest positive association with deforestation, among all the factors (independent variables) shown in table 1, with a linear correlation of 0.324. Different from its density, the rate of population growth does not seem to have an important effect on recent deforestation in the Ribeira Valley region.

In table 1, one can also see that the factors <u>negatively</u> associated with deforestation are the degree of poverty[7], the topography[8] and the presence of conservation units.

The degree of poverty presents a negative correlation with deforestation (Pearson coefficient of –0.382), showing that in the census tracts that present a higher percentage of poor head of households, the rates of deforestation are lower.

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[6] The linear correlation between road network and population density of the census tract is significant and positive, with a value of 0.699.
[7] Percentage of head of households earning less than 1 minimum wage (100 dollars) per month in the census tract.
[8] Range of elevation (minimum and maximum) inside the census tract.

The topography has a very important negative effect on deforestation, with a negative correlation between deforestation and the range of elevation of the census tract (Pearson coefficient of –0.490). It is important to highlight that, in absolute terms, the range elevation of the census tract is the variable with the strongest correlation with deforestation, even higher than the correlation between population density and deforestation.

The presence of conservation units has also an important negative effect on deforestation rates. In other words, higher rates of deforestation occur in census tracts outside conservation units.

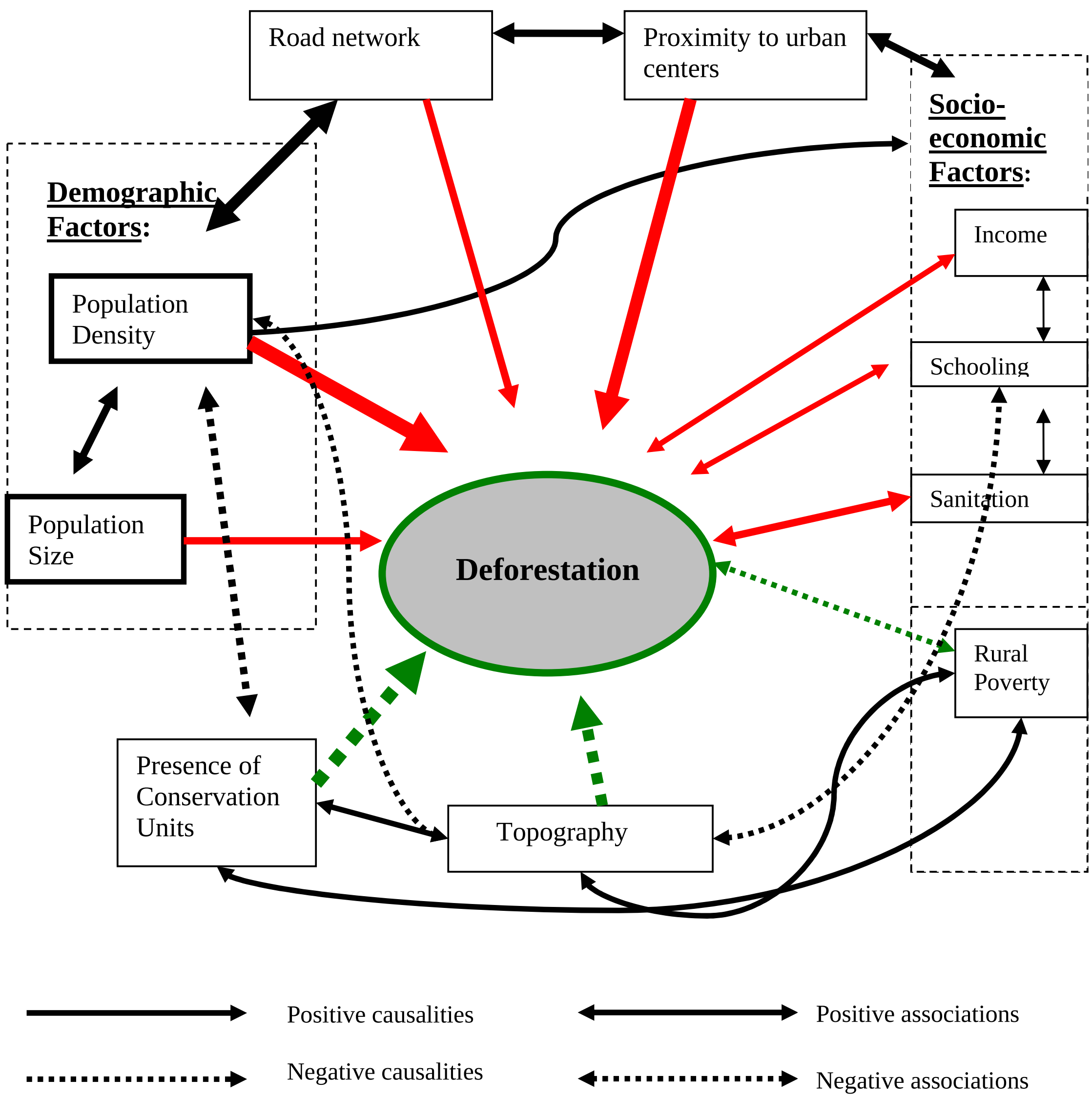
Based on my findings on the relationships between deforestation rates and the selected independent variables (factors) I can say that the rural census tracts with higher rates of deforestation have bigger population size and density, are located close to urban centers (within a 10 km radius), have a more dense road network, better socio-economic conditions and higher rates of population growth. Moreover, the census tracts with higher deforestation rates are located in areas with smoother topography and outside conservation units, and present lower levels of poverty.

In sum, the factors with the strongest positive association with deforestation are the population density and the proximity to urban centers, which are also positively correlated with each other. The factors with the strongest negative association with deforestation are topography (range of elevation of the census tract) and the presence of conservation units.

Besides that, the fact that many factors (independent variables) shown in table 1 are highly correlated with each other indicates that it is not possible to consider each variable as a single or isolated factor associated with deforestation, but instead it should be seen as a "network of relationships", with direct and indirect effects on deforestation processes in the Ribeira Valley.

Based on this "network of relationships" among the independent variables and the deforestation rates, I propose a qualitative (or graphic) model of correlation and causality between socio-demographic factors, topographic and infra-structure attributes, presence of conservation units and recent deforestation in the Ribeira Valley (see graphic 1).

Graphic 1.
Qualitative model of correlation and causality between socio-demographic factors, topography, access to infra-structure, conservation units and deforestation in the Ribeira Valley (network of relationships among the independent variables and deforestation rates of rural census tracts)



Graphic 1 shows the results for the qualitative model. It is possible to note a web of associations between a set of different factors (demographic, socio-economic, topography, road and urban infra-structure and conservation units) and deforestation processes in the Ribeira Valley.

Despite the fact that this qualitative model is derived from the observed correlations between the independent variables (the factors shown in table 1) and deforestation (the dependent variable), one can still infer some causal relationships from these correlations. Some of the causal associations are very evident, such as the association between topography and conservation units with deforestation. Other causal associations are not as clear but still very probable, such as the relationship between demographic factors and urban/road infrastructure with deforestation. From this point of view, population density and urban/road infrastructure can be seen as drivers of deforestation in the Ribeira Valley.

On the other hand, concerning the correlations between socioeconomic factors and deforestation it is more difficult to establish the causal relationships and, especially, its direction. In some cases, the deforestation could have generated income, therefore improving socioeconomic conditions of the population in the census tract.

At this point, it is important to say that in my study on the Ribeira Valley, I first aimed to work with a regression model in order to identify and analyze the factors that could explain deforestation rates in the Ribeira Valley. However, I found out that the regression analysis was not appropriate to deal with all the independent variables selected because of the occurrence of strong correlations among them, what is known as multicollinearity. **Annexes 2, 3 and 4** show some regression models that I tried to build for the Ribeira Valley[9].

Consequently, due to these restrictions to work with several independent variables in regression models, I decided to work, instead, with a qualitative model that could represent the network of relationships between the independent variables and the deforestation rates (the dependent variable). The major advantage of adopting a

[9] One can see in **Annex 2** that the first regression model that I tried to build, with all the factors associated with deforestation (eleven independent variables), presented strong multicollinearity among the independent variables. In this first model, only two independent variables were significant – population density and presence or not of conservation units. In this first regression model, the R-squared was 0.458.
Based on the results for this first regression model, I built a second regression model (see **Annex 3**) with only the two main factors associated with deforestation, namely population density (with positive association) and presence or not of conservation units (with negative association). Moreover, this last independent variable is a dummy, in which 0 is the absence and 1 is the presence of conservation units. It is interesting to note that even with only these two independent variables the R-squared is 0.426.
At last, I decided to test a spatial lag model, accounting for the deforestation rate in the neighbor census tracts (queen contiguity). In this third regression model the R-squared reached 0.532 (see **Annex 4**).

qualitative model is the possibility to map and represent graphically the diversity of factors associated with deforestation in the Ribeira Valley.

In future studies, I plan to build multivariate statistical models in order to perform quantitative analyses that are able to deal with all the selected independent variables of the qualitative model.

7. Discussion of the analysis of the drivers of deforestation in the Ribeira Valley based on two reviews of the deforestation literature

After presenting the analysis of the factors associated with deforestation processes in the Ribeira Valley, I now discuss my results based on two recent reviews of models and case studies of tropical deforestation. The two reviews are presented in Kaimowitz & Angelsen (1998) and Geist & Lambin (2001).

The literature on deforestation reflects the great effort of research and modeling in order to identify the factors associated with deforestation and to explain its causative patterns. Broadly speaking, the studies about land cover change and deforestation can be classified in two large groups: 1) the case studies and 2) the formal models.

There is a striking contrast between the complexity of descriptions of land cover change and deforestation processes for specific case studies and the relative simplicity of the mechanisms represented in formal models. However, in spite of the great precision and detail in describing deforestation processes, one of the case studies´ major drawback is the limited geographical coverage and the unfeasibility of generalization for larger areas, such as a region or a river basin (Lambin, 1997).

On the other hand, formal models usually work with regional, national or even global scales. Moreover, most of these models are empirical and one of the methodologies most used are regression analysis.

In the following, the discussion is organized according to the groups of factors associated with deforestation as shown in the qualitative model of the Ribeira Valley. All the factors I have analyzed for the Ribeira Valley are pointed out as drivers of tropical deforestation in the models and case studies described in the two reviews.

Demographic factors (population size, density and growth)

My results from the analysis of the factors associated with deforestation in the Ribeira Valley have shown that population density is the factor (independent variable) with the highest positive association with deforestation rates at the level of the rural census tracts. The population size also presented a significant and positive correlation with deforestation rates, although much lower than density.

The majority of the global models of deforestation show that demographic factors (mainly population size, density and growth) are the most important drivers of tropical deforestation (Mather & Needle, 2000; Allen & Barnes, 1985). However, the conclusions presented in the two recent reviews of models and case studies of deforestation show that population, specially its growth, is not the main factor associated with deforestation in the regional and local levels (Kaimowitz & Angelsen, 1998; Geist & Lambin, 2001).

In the review of 152 case studies, at regional and local levels, carried out by Geist & Lambin (2001), population factors are reported as drivers of deforestation in 93 cases (61% of all) but, although they present a significant impact on deforestation, they are not as important as other factors like socioeconomic, political, technological, institutional and socio-cultural factors.

Among the case studies reviewed by Geist & Lambin (2001), population is never seen as a single factor associated with deforestation, i.e., its effect on deforestation is always derived from inter-linkages with other drivers (socioeconomic, political, technological etc.). The same pattern was found in my model for the Ribeira Valley, with many factors affecting deforestation along with population, such as road network, proximity to urban centers and socioeconomic conditions.

I have also seen that the population density in rural census tracts is highly correlated with road network density and proximity to urban centers. In many deforestation models reviewed by Kaimowitz & Angelsen (1998), the population density, at regional and local levels, has a strong correlation with other factors, especially with road infrastructure and access to urban markets. Therefore, the strong correlation found between population density and deforestation in the rural census tracts of the Ribeira Valley could be seen as consequence of the effect of roads and urban centers on deforestation.

Another aspect of confluence between my results for the Ribeira Valley and the two mentioned reviews is the smaller importance of population growth upon deforestation processes. In my analysis for the Ribeira Valley, the correlation between population growth and deforestation is the weakest among all other factors associated with deforestation at the level of census tracts.

In fact, the evidences found in the models about the association between population growth and deforestation are very weak. The models and case studies reviewed do not support the idea – as put forward, for example, by Allen & Barnes (1985) – that population growth is the primary cause of deforestation, particularly population growth derived from high fertility levels (Geist & Lambin, 2001, 2002; Lambin et al., 2001).

Income levels and socioeconomic conditions

In my qualitative model for the Ribeira Valley, income levels and other socioeconomic conditions (e. g. schooling and sanitation) present positive associations with deforestation. Most global deforestation models reviewed by Kaimowitz & Angelsen (1998) also find a positive association between higher national per capita income and greater levels of deforestation (Capistrano & Kiker, 1995; Rock 1996).

Conversely, deforestation models based on a regional level and that have attempted to measure the relationship between income levels and deforestation have obtained contradictory results. On one hand, higher income levels are expected to increase pressure on forests by rising the demand for agricultural and forest products and by stimulating new access to virgin forests. But, on the other hand, in regions with higher per capita income (and therefore with higher wages), the logging and agriculture activities related to deforestation become less profitable and hence lead to lower forest depletion (Kaimowitz & Angelsen, 1998).

Moreover, deforestation may contribute to increase the population income levels, which could imply a causal relationship working in the opposite direction.

Poverty

My results for the rural census tracts of the Ribeira Valley oppose the conventional wisdom that says that rural poverty is an important driver of deforestation in the tropics. Among the census tracts of the Ribeira Valley, the degree of poverty of the heads of households is negatively associated with deforestation.

The review of deforestation models carried out by Kaimowitz & Angelsen (1998) goes in the same direction, showing that "there is little empirical evidence on the link between deforestation and poverty. If forest clearing requires investment, rich people may in fact be in a better position to clear new forest land” (Angelsen & Kaimowitz, 1999: 92).

In the review carried out by Geist & Lambin (2001), poverty appears as a factor associated with deforestation in only 15% of the case studies reviewed, located mainly in Asia.

Road infrastructure and access to urban markets

In my qualitative model for the Ribeira Valley, the proximity to urban centers is the factor (independent variable) presenting the second highest positive correlation with deforestation and is also highly correlated with population density. The road network density also shows a positive correlation with deforestation but the association is not as strong as with other independent variables. However, there is a very high negative association between road network density and the percentage of forest remnants in the census tract, suggesting that there was an important effect of road construction on deforestation in the past decades.

Deforestation models reviewed by Kaimowitz & Angelsen (1998) find that greater access to forests and markets accelerates deforestation. “Spatial regression models are well suited for studying the effects of access. Models of this type for Belize (Chomitz & Gray, 1996), Cameroon (Mertens & Lambim, 1997) and Costa Rica (Rosero-Bixby & Palloni, 1998) all show a strong relation between roads and deforestation. These results are also supported by nonspatial regression models from Brazil (Pfaff, 1997) and Ecuador (Southgate et al., 1991). Most studies show that forest clearing declines rapidly beyond distances of 2 or 3 kilometers from a road” (Angelsen & Kaimowitz, 1999: 85).

Concerning access to urban markets, Chomitz & Gray (1996), in a case study about Belize, show that areas closer to urban markets have less forest cover. Mertens & Lambim (1997), in a case study about Cameroon, show that deforestation rates fall remarkably beyond a 10 km distance from an urban center.

In the review of 152 case studies carried out by Geist & Lambin (2001), the presence of roads, especially road construction, is an important proximate cause of tropical deforestation, appearing in 61% of all case studies reviewed[10].

Topography

The topography plays a very important role in the land cover change and deforestation processes in the Ribeira Valley. As we have seen, the topography (elevation range inside the census tract) has a strong association with deforestation. In absolute value, the correlation between topography and deforestation is the highest among all the independent variables selected for my model, even higher than the correlation between population density and deforestation.

Nevertheless, topography is mentioned in only 5% of the case studies reviewed by Geist & Lambin (2001), most of them in Latin America. Those studies show that flat and gently sloping areas favor deforestation.

Conservation Units

My analysis also shows that the conservation units play a very important role in the preservation of Atlantic Forest remnants in the Ribeira Valley. The census tracts inside conservation units show significantly lower deforestation rates and significantly higher proportion of forest remnants than the census tracts outside conservation units.

However, only two models reviewed by Kaimowitz & Angelsen (1998) mention conservation units or protected areas as factors associated with deforestation, these two models conclude that the protection status reduces the probability of an area being deforested.

It is also interesting to highlight that an important study that analyzed 93 protected areas in 22 tropical countries concluded that the majority of the conservation units, specially the ones with stronger land use restrictions as parks and reserves, have been very successful in the protection of tropical forests, a fairly surprising finding in the context of chronicle lack of economic resources for environmental protection and the great land cover pressure in these areas. The conservation units have been particularly efficient in avoiding deforestation processes, which is considered the major threat to biodiversity in the tropics (Bruner et al., 2001).

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[10] Geist & Lambin (2001) compute any type of road, including unfinished penetration or feeder

8. Synthesis of results and final remarks

As we have seen, the factors positively associated with recent deforestation in the Ribeira Valley are population size, density and growth, socio-economic conditions (levels of income, schooling and sanitation) and access to urban markets and road infra-structure. The major drivers of deforestation are population density and proximity to urban centers. Besides, these two factors, together with road density, are very correlated with each other, implying that population density might be a proxy to access to urban markets and road infra-structure.

On the other hand, the main factors negatively associated with deforestation are topography and the presence of conservation units. As mentioned before, the rural census tracts inside conservation units show much lower deforestation rates and significantly higher proportion of forest remnants than the census tracts outside the conservation units.

Therefore, it seems clear that since its implementation in the 1980´s, the conservation units - together with topography - have been the most important barrier to deforestation of Atlantic Forest remnants in the Ribeira Valley. However, as mentioned in section 5, the conservation units are distinguished by very low population densities and low levels of living conditions. Thus, if, on one hand, the conservation units have been quite successful in the preservation of forest remnants, on the other hand there has been a great out-migration from these areas and the perpetuation (or even worsening) of poverty and low socioeconomic conditions for the population still living inside or nearby the conservation units.

In this sense, the questions raised are: What type of environmental conservation program is taking place in the Ribeira Valley? Are poverty and out-migration of the local population, living in conservation units, a prerequisite for the preservation of Atlantic Forest remnants? Is this type of environmental conservation sustainable?

At last, it is important to mention that my analysis [of the relationships between deforestation rates and the independent variables] was not able to incorporate all the complexity of the factors involved in the processes of land cover change and deforestation in course in the Ribeira Valley region. As discussed in the literature,

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roads, logging roads and oil and mining company roads.

deforestation processes do not proceed linearly. In other words, they are not dependent on one exclusive factor (e.g. population growth or road construction), nor are ahistorical. Instead, it is a combination of many factors (social, economic, demographic, political, institutional etc.), operating in different spatial and temporal scales and interacting in specific environmental, social and historical contexts.

Quoting Lambin (1997: 389), “the most fundamental obstacle to progress in the understanding and prediction of human impacts on terrestrial ecosystems lies in the lack of a comprehensive theory of land-use changes. The role of a theory is to explain experimental findings and to predict new results”. In this sense, there has been a great effort from the scientific community in the search for new theories and methods of analysis that could enable a better balance between geographic coverage, analytical precision and realism for the analysis and models of deforestation.

In my study on the Ribeira Valley, I also faced a dilemma to find the best balance between geographic coverage and analytical precision. On one hand, the simplicity of the correlation analyses and qualitative model limited the analytical power of my analysis of the factors associated with deforestation. But, on the other hand, these analyses enabled us to work with a relatively large numbers of variables and to incorporate all the rural census tracts of the Ribeira Valley (109 census tracts). This geographic coverage would not be possible to achieve in a case study using fieldwork and in-depth analysis.

Therefore, my analysis of the factors associated with deforestation in the Ribeira Valley was able to incorporate three important aspects: 1) it presents a wide geographic coverage; 2) it uses very disaggregated spatial unit of analysis (census tracts); and 3) it integrates a large and diverse number of variables for the analysis (census variables, remote sensing/land cover variables and other spatial variables as topography and road infrastructure).

In this sense, maybe the most significant contribution of this study is the application of a methodology that integrates census and remote sensing variables, all information aggregated at the level of census tracts, for the development of an analysis of the associations between socio-demographic factors and deforestation. Hence, this is one of the first studies in the field of “Population and Environment” to use this kind of methodology at the level of census tracts.

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Annex 1. Tables for sections 4 and 5

Table 2. Population per household status (urban / rural) and urban population rate Sub-regions of Ribeira Valley, 1991 and 2000

Sub-regions	1991				2000			
	Urban	Rural	Total	Urban population rate	Urban	Rural	Total	Urban population rate
Mountain	13,794	23,591	37,385	36.90	16,574	23,944	40,518	40.91
River Valley	67,394	32,799	100,193	67.26	85,827	31,842	117,669	72.94
Coast / Estuary	29,313	8,768	38,081	76.98	38,842	7,587	46,429	84.60
Ribeira Valley	**110,501**	**65,158**	**175,659**	**62.91**	**141,243**	**62,856**	**204,099**	**69.20**

Source: IBGE. Brazilian demographic census of 1991 and 2000.

Table 3. Geometric annual population growth rate (urban, rural and total) Sub-regions of Ribeira Valley, 1970-1980, 1980-1991 and 1991-2000

Sub-regions	1970/1980			1980/1991			1991/2000		
	Urban	Rural	Total	Urban	Rural	Total	Urban	Rural	Total
Mountain	5.62	0.15	1.41	3.76	0.23	1.37	2.06	0.17	0.90
River Valley	9.33	-0.06	5.03	2.35	1.86	2.19	2.72	-0.33	1.80
Coast / Estuary	7.34	-4.55	2.09	2.63	-0.31	1.86	3.18	-1.59	2.23
Ribeira Valley	**8.46**	**-0.82**	**2.95**	**3.26**	**0.23**	**1.94**	**2.36**	**0.55**	**1.68**

Source: IBGE. Brazilian demographic census of 1970, 1980, 1991 and 2000.

Table 4. Spatial Distribution and population density (total e rural population). Sub-regions of Ribeira Valley (year 2000)

Sub-regions	Total population 2000	Spatial distrib. 2000	Population density 2000 (inhab/km2)	Rural populati on 2000	Rural spatial distrib. 2000	Rural population density 2000 (inhab/km2)	Area (hectares)	% over Ribeira Valley total area
Mountain	40,518	19.85	8.31	23.944	38.09	4.91	487,767.07	50.46
River Valley	117,669	57.65	52.52	31.842	50.66	14.21	224,059.07	23.18
Coast / Estuary	45,912	22.49	18.02	7.070	11.25	2.78	254,741.00	26.36
Ribeira Valley	**204,099**	**100.00**	**21.12**	**62.856**	**100.00**	**6.50**	**966,567.14**	**100.00**

Source: IBGE. Brazilian demographic census of 1991 and 2000.

Table 5. Socio-economic indicators (income and schooling)
Sub-regions of Ribeira Valley (year 2000)

	Sub-regions			
	Mountain	River Valley	Coast / Estuary	**Ribeira Valley**
% No income	14.37	10.25	12.13	**11.76**
% Pour (1)	45.75	31.04	35.48	**36.13**
% Not pour (2)	54.25	68.96	64.52	**63.87**
% Illiterate	21.42	13.17	13.51	**16.18**
% Low schooling (3)	46.51	33.04	32.79	**38.6**
% Medium-high schooling (4)	53.32	66.75	67.06	**61.23**

Source: IBGE. Brazilian demographic census of 2000.
(1) Pour: Head of households earning less than a minimum wage per month (approximately 100 dollars)
(2) Not pour: Head of households earning more than a minimum wage per month
(3) Low schooling: Head of households with less than 3 years of schooling
(4) Medium-high schooling: Head of households with more than 4 years of schooling

Table 6. Presence of conservation units (parks/reserves and APAs).
Municipalities and sub-regions of Ribeira Valley

Municipalities and sub-regions	**Total Area (hectares)**	**Area conservation units (ACU)**	% ACU over area of municipality	**Area parks and forest reserves (APR)**	% APR over area of municipality	**Area APAs**	% APAs over area of municipality
Barra do Turvo	100,540.10	79,378.81	78.95	76,456.08	76.05	2,922.73	2.91
Iporanga	115,713.24	110,776.27	95.73	59,050.98	51.03	51,725.29	44.70
Eldorado	165,918.58	122,008.34	73.54	37,618.20	22.67	84,390.14	50.86
Sete Barras	105,595.15	90,727.48	85.92	27,614.43	26.15	63,113.05	59.77
Mountain sub-region	**487,767.07**	**402,890.91**	**82.60**	**200,739.69**	**41.15**	**202,151.22**	**41.44**
Cajati	45,551.33	15,238.33	33.45	15,238.33	33.45	0.00	0.00
Jacupiranga	70,980.48	8,366.78	11.79	8,366.78	11.79	0.00	0.00
Pariquera-Acu	35,934.59	2,473.02	6.88	2,473.02	6.88	0.00	0.00
Registro	71,592.67	0.00	0.00	0.00	0.00	0.00	0.00
River Valley sub-region	**224,059.07**	**26,078.13**	**11.64**	**26,078.13**	**11.64**	**0.00**	**0.00**
Cananéia	124,520.30	114,134.82	91.66	37,063.98	29.77	77,070.84	61.89
Iguape	111,330.69	14,919.38	13.40	2,312.91	2.08	12,606.47	11.32
Ilha Comprida	18,890.02	18,890.02	100.00	0.00	0.00	18,890.02	100.00
Coastal/Estuary sub-region	**254,741.00**	**147,944.22**	**58.08**	**39,376.89**	**15.46**	**108,567.33**	**42.62**
Ribeira Valley region	**966,567.14**	**576,913.25**	**59.69**	**266,194.71**	**27.54**	**310,718.54**	**32.15**

Source: Geographic Information System constructed with databases from ACT-Indiana University and the NGO Instituto Socioambiental.

Table 7. Topography and Road Infra-structure.
Municipalities and sub-regions of Ribeira Valley

	Topography		**Road infra-structure**	
Municipalities and sub-regions	Elevation (average) (in meters)	Slope (average) (in percentage)	% area inside *buffer* roads of 500m	% area inside *buffer* roads of 1 km
Barra do Turvo	643.13	6.35	6.34	12.51
Iporanga	462.61	10.26	5.61	11.66
Eldorado	312.82	7.02	6.07	11.62
Sete Barras	214.51	4.07	10.22	18.92
Mountain sub-region	**395.11**	**7.01**	**6.92**	**13.39**
Cajati	355.17	7.56	13.78	24.85
Jacupiranga	191.79	4.97	12.72	25.86
Pariquera-Acu	80.63	1.41	26.96	46.22
Registro	75.90	0.96	19.14	33.02
River Valley sub-region	**169.95**	**3.64**	**17.27**	**31.21**
Cananéia	135.54	5.20	6.45	12.56
Iguape	123.41	2.27	10.94	21.55
Ilha Comprida	0.00	0.00	0.00	0.23
Coastal/Estuary sub-region	**120.62**	**3.63**	**7.93**	**15.58**
Ribeira Valley Region	**685.68**	**14.29**	**9.58**	**18.10**

Source: Geographic Information System constructed with databases from ACT-Indiana University and the NGO Instituto Socioambiental.

Table 8. Land cover change (1990-1999).
Municipalities and sub-regions of Ribeira Valley

	Forest Remnants 1999		Deforestation 1990-1999		
Municipalities and sub-regions	Area (hectares)	% over area of municipality and sub-region.	Area (hectares)	% over Forest cover area 1990	% over area of municipality and sub-region.
Barra do Turvo	61,000.11	60.67	6,371.82	9.46	6.34
Iporanga	89,082.81	76.99	6,841.17	7.13	5.91
Eldorado	120,987.27	72.92	10,036.80	7.66	6.05
Sete Barras	64,293.84	60.89	9,165.42	12.48	8.68
Mountain sub-region	**335,364.03**	**68.75**	**32,415.21**	**8.81**	**6.65**
Cajati	19,264.05	42.29	4,283.91	18.19	9.41
Jacupiranga	40,741.29	57.40	7,733.34	15.95	10.89
Pariquera-Acu	17,716.95	49.54	3,381.84	16.03	9.41
Registro	25,123.14	35.40	6,326.28	20.12	8.84
River Valley sub-region	**102,845.43**	**46.04**	**21,725.37**	**17.44**	**9.70**
Cananéia	89,695.08	78.78	3,633.30	3.89	2.92
Iguape	43,524.45	51.70	4,827.06	9.98	5.60
Ilha Comprida	8,952.66	60.01	1,547.37	14.74	9.82
Coastal/Estuary sub-region	**142,172.19**	**67.17**	**10,007.73**	**6.58**	**4.42**
Ribeira Valley Region	**580,381.65**	**62.95**	**64,148.31**	**9.95**	**6.84**

Source: Two Landsat TM images from years 1990 and 1999 (scene 220/77).

Table 9. Spatial Distribution and population density in 1991 and 2000 and population growth 1991-2000.
Aggregations of [rural] census tracts by zoning category

	Zoning Category			**Rural areas of Ribeira Valley**
	Non protected areas	Areas of Environment Protection (APAs)	Parks and Forest Reserves	
Population size in 1991	44,288	9,013	7,314	60,615
Population distribution 1991	73.06	14.87	12.07	100.00
Population Density in 1991	13.48	3.65	2.46	6.94
Population size in 2000	45,023	9,544	6,579	61,146
Population distribution 2000	73.63	15.61	10.76	100.00
Population Density in 2000	13.70	3.86	2.21	7.00
Population Growth (1991-2000) (absolute numbers)	735	531	-735	531
Population Growth (1991-2000) (percentage)	1.66	5.89	-10.05	0.88
Number of households 1991	9,781	2,154	1,716	13,651
Number of households 2000	11,063	2,453	1,670	15,186
Growth in the number of households 1991-2000 (%)	13.11	13.88	-2.68	11.24

Source: IBGE. Brazilian demographic census of 1991 and 2000.

Table 10. Socio-economic indicators (income and schooling) 1991 and 2000
Aggregations of [rural] census tracts by zoning category

	Zoning Category			**Rural areas of Ribeira Valley**
	Non protected areas	Areas of Environment Protection (APAs)	Parks and Forest Reserves	
1991				
% No income	10.75	6.26	20.80	11.25
% Pour people (1)	42.20	39.55	59.01	43.80
% Not Pour people (2)	57.56	60.31	40.86	55.98
% Low schooling (3)	64.68	70.45	76.17	66.98
% Medium-high schooling (4)	35.32	29.55	23.83	33.02
% Illiterate population	38.16	40.09	48.18	39.66
2000				
% No income	12.61	15.94	24.95	14.51
% Pour people (1)	46.32	55.00	63.79	49.64
% Not Pour people (2)	53.68	45.00	36.21	50.36
%Average income (min. wages)	2.06	1.74	1.44	2.07
% Low schooling (3)	50.46	58.21	59.74	52.73
%Medium-high schooling (4)	49.54	41.79	40.26	47.27
% Average years of schooling	3.53	3.03	2.83	3.38
% Illiterate population	29.43	32.58	36.74	30.71

Source: IBGE. Brazilian demographic census of 1991 and 2000.
(1) Pour: Head of households earning less than a minimum wage per month (approximately 100 dollars)
(2) Not pour: Head of households earning more than a minimum wage per month
(3) Low schooling: Head of households with less than 3 years of schooling
(4) Medium-high schooling: Head of households with more than 4 years of schooling

Table 11. Topography and Urban and Road Infra-structure.
Aggregations of [rural] census tracts by zoning category

	Zoning Category			Rural areas of Ribeira Valley
	Non protected areas	Areas of Environment Protection (APAs)	Parks and Forest Reserves	
Area in hectares (ha)	328,663.17	247,194.69	297,898.53	873,756.38
Distribution of areas	37.61	28.29	34.09	100.00
Average elevation (meters)	155.15	210.14	510.97	291.93
Average slope (percentage)	3.45	6.02	8.00	-
% area inside 500 meters buffers of main roads	13.89	7.98	4.09	8.88
% area inside 1 km buffers of main roads	26.24	15.44	8.46	17.12
Distribution of road network	57.65	25.51	16.84	100.00
Percentage of the area within 8 Km from the nearest seat of municipality	50.07	29.74	11.12	31.04
Percentage of the area within 10Km from the nearest seat of municipality	61.05	25.99	6.08	32.39

Source: Geographic Information System constructed with databases from ACT-Indiana University and the NGO Instituto Socioambiental.

Table 12. Land cover change (1990-1999).
Aggregations of [rural] census tracts by zoning category

	Zoning Category			Rural areas of Ribeira Valley
	Non protected areas	Areas of Environment Protection (APAs)	Parks and Forest Reserves	
Forest remnants (area in hectares – ha)	146,783.52	172,313.91	232,500.78	551,598.21
Distribution of forest remnants	26.61	31.24	42.15	100.00
Percentage of area with remnants	44.82	69.71	78.05	63.21
Area deforested in 1990-99 (ha)	31.759.29	16.712.28	12.226.77	60.698.34
Distribution of deforested area 1990-99	52.32	27.53	20.14	100.00
Deforestation rate1990-99	17.79	8.84	5.00	9.91
Percentage of deforested area in 1990-99 over area of category	9.70	6.76	4.10	6.96

Source: Two Landsat TM images from years 1990 and 1999 (scene 220/77).

Annex 2: First Regression Model – considering all factors (independent variables) associated with deforestation

Dependent variable:

- PFLO_DESMA Deforestation rate between 1990 and 1999 (%)

Independent variables:

DENSID_200	Population Density in 2000
PBFCITY10K	Percentage of the census tracts area within 10Km from the nearest seat of municipality
PCBANHEIRO	Percentage of households with bathroom (in 2000)
MEDIA1_ANO	Average years of schooling of the heads of households (in 2000)
POPRESI	Population size of census tract in 2000
PBFROAD1KM	Percentage of census tracts area within the 1 Km buffers of road network
CRESC_91_0	Population Growth rate (1991-2000)
ELEV_RANGE	Variation of the elevation in the census tract
POBRES2000	Percentage of head of households in poverty (in 2000)
DUMMY_UC	Presence or not of conservation units (*dummy variable*)

REGRESSION

SUMMARY OF OUTPUT: ORDINARY LEAST SQUARES ESTIMATION

Dependent Variable : **PFLO_DESMA**	Number of Observations: 109
Mean dependent var : 14.9316	Number of Variables : 11
S.D. dependent var : 9.05654	Degrees of Freedom : 98
R-squared : 0.458448	F-statistic : 8.29614
Adjusted R-squared : 0.403188	Prob(F-statistic) :1.26494e-009
Sum squared residual: 4841.63	Log likelihood : -361.419
Sigma-square : 49.4044	Akaike info criterion : 744.837
S.E. of regression : 7.02882	Schwarz criterion : 774.442
Sigma-square ML : 44.4186	
S.E of regression ML: 6.66473	

Variable	Coefficient	Std.Error	t-Statistic	Probability
CONSTANT	16.68531	6.283559	2.655392	0.0092467
DENSID_200	**0.1796163**	**0.08622023**	**2.083227**	**0.0398338**
PBFCITY10K	-0.005465693	0.02571725	-0.2125302	0.8321371
PCBANHEIRO	0.01797709	0.03749503	0.4794527	0.6326831
POPRESI	0.0029043	0.001806728	1.607492	0.1111638
PBFROAD1KM	-0.03021472	0.0433779	-0.6965464	0.4877361
MEDIA1_ANO	0.05964127	1.156851	0.05155484	0.9589888
CRESC_91_0	0.00889898	0.0111959	0.7948428	0.4286249
ELEV_RANGE	-0.005654678	0.003978719	-1.421231	0.1584242
POBRES2000	-0.01954043	0.04344333	-0.4497912	0.6538528
DUMMY_UC	**-5.423307**	**2.016608**	**-2.689321**	**0.0084161**

REGRESSION DIAGNOSTICS

MULTICOLLINEARITY CONDITION NUMBER 28.48721

TEST ON NORMALITY OF ERRORS

TEST	DF	VALUE	PROB
Jarque-Bera	2	25.38758	0.0000031

DIAGNOSTICS FOR HETEROSKEDASTICITY

RANDOM COEFFICIENTS

TEST	DF	VALUE	PROB
Breusch-Pagan test	10	27.59633	0.0020942

Annex 3: Second Regression Model – considering only two main factors (indep. variables) associated with deforestation – population density and conservation units

Dependent variable:

- PFLO_DESMA Deforestation rate between 1990 and 1999 (%)

Independent variables:

DENSID_200 Population Density in 2000
DUMMY_UC Presence or not of conservation units (*dummy variable*)

REGRESSION
SUMMARY OF OUTPUT: ORDINARY LEAST SQUARES ESTIMATION

Dependent Variable	**PFLO_DESMA**	Number of Observations	109
Mean dependent var	14.9316	Number of Variables	3
S.D. dependent var	9.05654	Degrees of Freedom	106
R-squared	**0.426097**	F-statistic	39.3501
Adjusted R-squared	0.415269	Prob(F-statistic)	1.6536e-013
Sum squared residual	5130.85	Log likelihood	-364.581
Sigma-square	48.4043	Akaike info criterion	735.162
S.E. of regression	6.95732	Schwarz criterion	743.236
Sigma-square ML	47.072		
S.E of regression ML	6.86091		

Variable	Coefficient	Std.Error	t-Statistic	Probability
CONSTANT	15.60513	1.341112	11.63596	0.0000000
DENSID_200	0.2299799	0.06010256	3.826458	0.0002201
DUMMY_UC	-7.722522	1.570706	-4.916592	0.0000032

REGRESSION DIAGNOSTICS
MULTICOLLINEARITY CONDITION NUMBER 3.76745
TEST ON NORMALITY OF ERRORS

TEST	DF	VALUE	PROB
Jarque-Bera	2	43.38495	0.0000000

DIAGNOSTICS FOR HETEROSKEDASTICITY
RANDOM COEFFICIENTS

TEST	DF	VALUE	PROB
Breusch-Pagan test	2	5.499227	0.0639526
Koenker-Bassett test	2	2.696993	0.2596303

Annex 4: Third Regression Model – spatial lag model with two independent variables

Dependent variable:

- PFLO_DESMA Deforestation rate between 1990 and 1999 (%)

Independent variables:

W_ PFLO_DESMA	Deforestation rate in neighborhood areas (Queen Contiguity)
DENSID_200	Population Density in 2000
DUMMY_UC	Presence or not of conservation units (*dummy variable*)

REGRESSION
SUMMARY OF OUTPUT: SPATIAL LAG MODEL - MAXIMUM LIKELIHOOD ESTIMATION

Dependent Variable : **PFLO_DESMA**	Number of Observations: 109
Mean dependent var : 14.9316	Number of Variables : 4
S.D. dependent var : 9.05654	Degrees of Freedom : 105
Lag coeff. (Rho) : 0.470584	

R-squared : 0.532633	Log likelihood : -356.215
Sq. Correlation : -	Akaike info criterion : 720.431
Sigma-square : 38.3339	Schwarz criterion : 731.196
S.E of regression : 6.19144	

Variable	Coefficient	Std.Error	z-value	Probability
W_PFLO_DESMA	0.4705844	0.09191826	5.119596	0.0000003
CONSTANT	8.433295	1.925243	4.380381	0.0000119
DENSID_200	0.1729602	0.05436117	3.181686	0.0014643
DUMMY_UC	-5.537701	1.524437	-3.632621	0.0002806

REGRESSION DIAGNOSTICS
DIAGNOSTICS FOR HETEROSKEDASTICITY
RANDOM COEFFICIENTS

TEST	DF	VALUE	PROB
Breusch-Pagan test	2	14.80708	0.0006091

DIAGNOSTICS FOR SPATIAL DEPENDENCE
SPATIAL LAG DEPENDENCE FOR WEIGHT MATRIX : **peso_queen_1order.GAL**

TEST	DF	VALUE	PROB
Likelihood Ratio Test	1	16.73091	0.0000431