Land Cover Change Analysis from Historical Remote Sensing Images: Case Study Itaipú

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Hiermit versichere ich, daβ ich die vorliegende Dissertation selbständig und ohne fremde Hilfe - mit Ausnahme der im Verzeichnis angegebenen Literatur – angefretigt habe.

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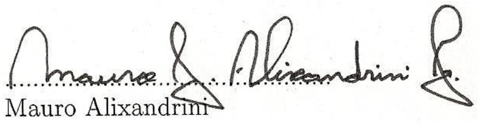

This work is dedicated
to my wife Vivian.

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Contents

List of Figures

List of Tables

ABSTRACT

On the basis of the increasing demand of energy in Brazil, a series of projects involving large hydroelectric power plants will be settled in the next decade. In spite of the renewable energy generated by these enterprises, some phenomena can be observed in the regions where these hydroelectrics are established, for example, reorganization in the land structure, changes in typical economic activities and rural estate appreciation. Accordingly, the analyses of old cases is crucial for planning and management of future projects. In this work we investigate the evolution of the forest distribution in areas with strong deforestation in the period since the construction of the Itaipú hydroelectric power plant until the current day. The focus of this research are the analyses of the forest distribution and its relation to historical aspects regarding the socio-economic reorganization and the construction of the Itaipú hydroelectric. In order to recognize the phenomena responsible for these changes, we proposed the use of sensing as the investigation tool. The scenes available for this work are restricted to the medium resolution of 20 to 80 m and are derived from the following sensors: LANDSAT 1, 2, 5 TM, 7 ETM e CBERS II. In the first stage we performed the spatial and thematic association of the different sensors. For that we defined a methodology based on classical techniques, like the Maximum Likelihood classifier and the Thematic Map comparison. The evaluation of the results of the automatic classifications considers two principles developed in this work: i) the random selection into the reference groups for the training and evaluation samples, and ii) the images of evidence. The images of evidence define a minimum situation of acceptance for the thematic maps, which allows the generation of consistent classifications among the applied sensors. In the next step we performed a comparison between these maps. The compatibility of the spatial resolutions takes place with the generalization of these maps. The historical context of the region was compared to the results obtained from the set of adopted images. Based on the analyzed documents we can define the main anthropogenic phenomena responsible for the changes in the vegetation cover in the region. We identified the Paraguayan agricultural expansionism and the predominantly agricultural Brazilian migratory movements to the border region between Brazil and Paraguay. The results show that the systematic process of deforestation had already been established before the beginning of the construction of Itaipú. Migratory processes associated with previous factors to the construction of hydroelectric show mainly correlations with the deforestation observed in the region. Furthermore, the analysis verifies the incoherent documentation about the current situation in the protected areas. The conclusions prove the characteristics of the employed method showing that its use is valid in a context of the analysis of the regional development.

KURZFASSUNG

Um die steigende Energienachfrage in Brasilien zu decken, wird im nächsten Jahrzehnt eine Reihe von Projekten einschließlich des Baus großer Wasserkraftwerke festgesetzt. Diese erzeugen zwar erneuerbare Energie; es werden jedoch, in den Regionen, in denen solche Wasserkraftwerke gebaut werden, eine Reihe von Phänomenen beobachtet, beispielsweise die Umverteilung des Landes, Veränderungen typischer wirtschaftlicher Aktivitäten und die Aufwertung ländlicher Immobilien. Daher ist die Analyse älterer Projekte für die Planung und Verwaltung künftiger Vorhaben von entscheidender Bedeutung. In dieser Arbeit wird die Entwicklung der Waldbedeckung in Regionen untersucht, in denen in den letzten 30 Jahren starke Abholzung zu verzeichnen ist. Dieser Zeitraum entspricht dem Ausbau des Itaipú Wasserkraftwerks. In dieser Periode erlitt insbesondere die paraguayische Seite eine intensive Transformation. Der Schwerpunkt dieser Forschung liegt auf der Analyse der Waldverteilung und seine Beziehung zu historischen Aspekten bezüglich der Reorganisation des Landes und des Ausbaus des Itaipú-Wasserkraftwerkes. Die Fernerkundung wird für diese Untersuchung eingesetzt, um die räumlichen Phänomene erkennen zu können, die für diese Veränderungen verantwortlich sind. Die für diese Arbeit verfügbaren Szenen liegen lediglich in mittlerer Auflösung von 20 bis 80 m von folgenden Sensoren vor: LANDSAT 1, 2, 5, TM, 7 ETM und CBERS II. Im ersten Schritt wurde die räumliche und thematische Vereinigung der verschiedenen Sensoren durchgeführt. Dafür wurde eine Methodik definiert, die auf klassischen Techniken beruht, wie dem Maximum-Likelihood-Klassifikator und dem Vergleich thematischer Karten. Die Auswertung der Ergebnisse der automatischen Klassifizierung verwendet zwei Prinzipien, die in dieser Arbeit entwickelt wurden: a) die zufällige Auswahl von Referenzgruppen für die Trainings- und Kontrollgebiete und b) die Beweisbilder. Die Beweisbilder bestimmen einen Mindest-Akzeptanz-Zustand für die thematischen Karten, was die die Erzeugung kompatibler Klassifizierungen zwischen den untersuchten Sensoren ermöglicht. Im nächsten Schritt wurde der Vergleich zwischen diesen Karten durchgeführt. Die Anpassung der räumlichen Auflösungen erfolgt durch ihre Generalisierung. Nach dem Erhalt der Ergebnisse aus dem Satz der verwendeten Bilder folgte die Korrelation mit einer historischen Sicht der Region. Basierend auf den analysierten Aufnahmen ist es möglich, die wichtigsten anthropogenen Phänomene einzugrenzen, die für die Entwicklung der Vegetationsbedeckung in der Region verantwortlich sind: die paraguayische landwirtschaftliche Expansion und die brasilianische Migrationsbewegung, insbesondere in die Landwirtschaft, in die Grenzregion zwischen Brasilien und Paraguay. Die Ergebnisse zeigen, dass der systematische Entwaldungsprozess bereits vor dem Beginn des Ausbaus von Itaipú begann. Vor allem Migrationsprozesse, die mit Faktoren zusammenhängen, die vor dem Ausbau von Itaipú zu suchen sind, korrelieren mit der Entwaldung in der Region. Weiterhin zeigt die Analyse die Inkoheränz der offiziellen Dokumentation über die aktuelle Situation in den geschützten Gebieten. Die Schlussfolgerungen bestätigen die Gültigkeit der Methodik in der Regionalentwicklungsanalyse.

RESUMO

Com a crescente demanda de energia no Brasil, uma série de projetos envolvendo grandes hidroelétricas será concretizada na próxima década. A despeito da energia renovável gerada por esses empreendimentos, uma série de fenômenos são observados nas regiões onde essas hidrelétricas se instalam como, por exemplo, a reorganização fundiária, a alteração de atividades econômicas típicas e a valorização imobiliária rural. Dessa forma, a análise de casos mais antigos é fundamental para o planejamento e administração desses futuros projetos. Esse trabalho investiga a evolução da cobertura florestal em áreas que sofreram um forte desflorestamento nos últimos 30 anos, período correspondente a construção da usina hidroelétrica de Itaipú. Neste periodo principalmente a região do lado Paraguaio sofreu uma intensa transformação. O foco dessa pesquisa é a analise da distribuição florestal e sua relação com aspectos históricos ligados à reorganização territorial e à construção da referida hidroelétrica de Itaipú. Com o objetivo de reconhecer os fenômenos responsáveis por essas modificações propoõem-se o uso do sensoriamento como ferramenta para essa investigação. As cenas disponiveis para esse trabalho estão restritas a media escala com GSD(Ground Sampling Distance) ente 20 - 80 m são derivadas dos seguintes sensores: LANDSAT 1, 2, 5 TM, 7 ETM e CBERS II. Na primeira etapa foi realizada a associação espacial e temática dos diferentes sensores. Para isso, foi definida uma metodologia baseada em técnicas clássicas, como o uso do classificador de máxima verossimilhança e a comparação de mapas temáticos. A avaliação dos resultados das classificações automáticas utiliza dois princípios desenvolvidos nesse trabalho: i) a seleção aleatória nos agrupamentos de referência para as amostras de treinamento e avaliação e ii) as imagens de evidência. As imagens de evidência definem uma situação mínima de aceitação para os mapas temáticos, o que possibilita gerar classificações compatíveis entre os sensores estudados. Na etapa seguinte é efetuada a comparação desses mapas. A compatibilização das resoluções espaciais acontece com a generalização desses mapas. Após a obtenção dos resultados oriundos do conjunto de imagens utilizado, procedeu-se o correlacionamento com uma perspectiva histórica da região. Baseado nos registros estudados é possível delimitar os principais fenômenos antrópicos responsáveis pela evolução da cobertura vegetal da região. Foram identificados o expansionismo agrícola paraguaio e o movimento migratório brasileiro, predominantemente agrícola, para a região de fronteira do Brasil com o Paraguay. Os resultados revelam que o processo de desflorestamento sistemático já havia se estabelecido anteriormente ao inicio da construção de Itaipú. Principalmente os processos migratórios associados a fatores anteriores a construção da hidroelétrica mostram-se correlações com o desflorestamento observado na região. Além disso, a análise verifica a não coerência de documentação sobre a situação atual nas regiões protegidas. As conclusões evidenciam as características do método empregado mostrando que sua utilização é válida num contexto de análise do desenvolvimento regional.

THESIS OUTLINE

This thesis is presented in seven chapters. Chapter 1 focuses briefly on the background of the project, the objective and the state of the art. Chapter 2 concentrates on showing and discussing the main aspects concerning data characteristics and change detection through thematic map comparison, the method used in this work. Chapter 3 describes the study area and its physical characteristics, historical background and development of the Brazilian and Paraguayan region near the Itaipú reservoir. Chapter 4 refers to the data used in this project as well as the field research realized in 2008. The methodology that was applied will be discussed in Chapter 5 whereas Chapter 6 exhibits the results obtained from this project. At the end, the conclusion in Chapter 7 demonstrates the implications to region development and supplies recommendations for future projects.

Chapter 1

1. Introduction

Brazil is one of the world's leading producers of hydroelectric power, with a current capacity of about 108,000 megawatts. Despite the global financial crisis, the Inter-American Development Bank (IADB) reports that Brazil will increase investments in infrastructure projects. In recent years, Brazil has progressively reactivated plans for the use of its potential energy sources, such as large scale hydroelectric power plants.

According to the Brazilian Ministry of Mines and Energy (MME), Brazil has 773 hydroelectric power plants in operation, 88 under construction, and a further 239 are planned to be built by 2017 (MME,2009). Such demand raises questions about the real impact of hydroelectric power plants.

Since hydroelectric power plants do not burn fossil fuels, they also do not directly produce carbon dioxide. However, hydroelectric projects may be linked with many other disadvantages such as:

- Environmental damage;
- Indirect greenhouse gas emissions;
- Relocation of populations;
- Dam failures;
- Problems due to flow shortages.

This study proposes to investigate long-term environmental impacts of such hydroelectric power plants. In order to achieve this, the Itaipú power plant was chosen as a case study due to its large historical database. The analysis of historical remote sensing data was chosen as the main methodological tool.

The study is based on the analysis of a multi-temporal data set composed of 46 satellite images (seen Chap. 4, 4.1) taken with four different orbital sensors. The data's characteristics will be detailed in Chapters 2 and 4. This data set has been used to recognize land-cover change related to large hydroelectric power stations and their reservoirs. The main challenge is to compare classification results from the images, since their differences in geometric and radiometric quality are very relevant.

The study area is located in the Paraná River basin on the border between Brazil and Paraguay, where the Itaipú hydroelectric power station was built. Itaipú is known worldwide as one of the largest electric power generation enterprises (I.H.A., 2006). There are 16 Brazilian and 5 Paraguayan municipalities located in southern Brazil and at the eastern border of Paraguay where flooding occurred during the formation of the reservoir.

Some changes were related to the physical dimensions of the above-mentioned municipal districts, where agricultural areas have decreased since the formation of the reservoir. Other changes were related to the environment itself, which was transformed from fluvial to lacustrine (Loch&Bernardy, 2005). These changes have had a direct impact on the regional economy, territorial redistribution and the environment.

This study proposes a new approach for analyzing these issues based on remote sensing imagery in order to describe regional development in a land border context.

1.1 Objectives

The first main objective of this research was to develop a methodology suitable for regional territorial distribution analysis based on remote sensing images. The second objective was to verify the proposed methodology in a case study. The use of case studies is a widely accepted means of bringing theoretical concepts and practical situations together.

The specific goals of this work are associated with regional science and the area of remote sensing:

a) To integrate the results from different mid-resolution optical sensors.
b) To improve the methodology of classification evaluation.
c) To provide error modeling for dynamic land-cover changes.
d) To approach the environment and socio-economic development questions associated with the case study: Itaipú power plant.
e) To use share-shift analysis on the results.
f) To analyze future scenarios for a specific region.

1.2 State of the Art

There is plenty of literature on different aspects of Itaipú, but most of it emphasizes Itaipú's economic and political influence on Brazil and Paraguay rather than its global aspect. The purpose of this study was to research its regional impact, which involves the municipalities.

Some studies have focused on Itaipú's consequences on a regional level, for Brazil or Paraguay separately, without analyzing the structural context of where Itaipú was built.

The first regional-level study was done before the construction of the power plant for IPARDES[1] in Brazil and ANDE[2] in Paraguay (IPARDES, 1980). These were feasibility studies for Brazil and Paraguay respectively. However, contemporary authors such as Kohlhepp and Nickson (Kohlhepp,1987; Nickson,1981) noted that these studies seemed rather superficial.

In the 80s, Kohlhepp outlined possible impacts of Itaipú on the region. (Kohlhepp,1987,1983,1984;Kohlhepp&Karp,1984a). Kohlhepp's work emphasized Brazilian issues such as the migration of Brazilians to Paraguay, forest policy in Brazil, rural exodus, etc. Since then many authors (Nickson,1981;Sprandel,1997;Souchaud,2001;Fogel,2008) have

[1] *Instituto Paranáense de Desenvolvimento Econômico e Social* (IPARDES)- Institute of Economic and Social Development of the State of Paraná http://www.ipardes.gov.br/

[2] *Administración Nacional de Electricidad* (ANDE) - The National Electricity Administration that controls the entire Paraguayan electricity market, including generation, transmission and distribution http://www.ande.gov.py/

frequently published articles concerning the social impacts of Itaipú, especially regarding migration between Brazil and Paraguay. Publications on the Itaipú regional environment in the last decade have dealt with monitoring the reservoir's riparian zone (Loch&Bernardy,2005;Bastos&Loch,2005;Fernandes, et al.,2007).

If the aim is to rationally manage the situation instead of formulating basic emergency action, information on land cover and its dynamics is essential. Information derived from remote sensing data has often been used to provide insights into land cover and land-use patterns, examine multi-temporal trends and to assist in policy formulation (U.S.A.,1990;F.R.G., 2007;Ridley et al.,1997;Vogt&Teka,2007). Furthermore, as technologies have improved, so have the range and opportunity for the remote sensing of structures, dynamics, and ecosystem processes (Lunetta&Elvidge,1998). These aspects have received attention from resource management and planning agencies.

Land-cover mapping as a tool for regional planning is a recent innovation. Formerly, while resources were abundant, planning was demand oriented. However, with quickly decreasing resources, planning based on statistical surveys has become popular in regional development projects. Spatial planning has been improved through spatial analysis, which was initially based on topographical maps or aerial photography, but is now supplemented with a variety of sensors on aerial and spatial platforms. The application of this technology over large areas was hampered by a lack of suitable technology and the absence of a user community with a strong need for such information (Bähr,1992;Sturm, et al.,2007). Thus, for a number of years, land-cover data sets compiled from ground surveys or various national sources were the major source of information on a global level.

Land cover, e.g. the composition and characteristics of land-surface elements, is the key environmental information. It is important for geoscientific studies, resource management, and policy purposes as well as for a range of human activities (Bähr&Vögtle,1999). It is an essential determinant of land use and, thus, land value for society. Land cover varies with a range of spatial scales from local to global and with temporal frequencies from days to millennia (Barnsleyand et al., 2001). As the need for environmental planning and management grew, an accompanying call for land-cover information also emerged.

This is a matter of special importance for many international UN[3] organizations as well as for national administration. One example is the UN initiative Organizations: FAO[4],IPCC[5] and WMO[6] to provide the world with a clear scientific view on the current state of climate change and its potential environmental and socio-economic consequences.

In 1993, UNEP and FAO organized a meeting aimed at harmonizing data collection and management and taking a first step towards an internationally agreed-upon reference base for

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[3] The United Nations (UN) http://www.un.org/

[4] Food and Agriculture Organization (FAO). http://www.fao.org

[5] The Intergovernmental Panel on Climate Change(IPCC) is the leading body for the assessment of climate change, established by the United Nations Environment Program}, UNEP\footnote{The United Nations Environment Program (UNEP) is the voice for the environment in the united nations system. http://www.unep.org/

[6] World Meteorological Organization -http://www.wmo.int

land-cover and land-use monitoring (IPCC,2003;UNEP&FAO,1994). In 2003, IPCC published a technical report to assist countries in producing inventories for land use, land use change and the forestry sector. So far, that report has proven to be neither an over- nor underestimate, and uncertainties have been reduced in it as far as practicable.

As these methods mature, there is an increased need for remote sensing data and associated analysis techniques for detecting and monitoring change, particularly in the areas of resource management and planning (Bähr&Vögtle,1999;Vogt&Teka,2007). With the parallel expansion of computer processing capabilities and software specifically developed to handle image and spatially explicit data (e.g., image analysis systems [IAS] and geographic information systems [GIS]), spatial data products have become widely accepted outside the remote sensing community.

Meaningful and consistent measures of thematic map reliability are necessary for the map user to assess the appropriateness of map data for a particular application; moreover, the accuracy of thematic maps may significantly affect the outcome of an application (Foody,2004). Measures of map accuracy are important so that the thematic map maker can allow for analysis of error sources and of the weaknesses of a particular classification strategy. Documenting map accuracy, however, is not a straightforward task. While individual measures of map accuracy are well-established in the literature (Congalton&Green,2008; Foody&Atkinson,2002; Goodchild&Gopal,1994), considerable ambiguity remains concerning the implementation and interpretation of thematic map accuracy assessment. Uncertainties include selecting which accuracy measures to report, how to interpret them, and the nature and quality of reference samples. As a result, map quality remains a difficult variable to consider "objectively" (Foody&Atkinson,2002).

Fundamental to the challenge of assessing accuracy, according to Gopal & Woodcock (1994), is the problematic nature of thematic maps themselves, since thematic maps segment continuous landscapes into discrete, mutually exclusive classes.

While many distinct boundaries may exist in a landscape (e.g., a forest at the bank of a river), virtually all environments include land-cover classes that represent segments of a continuum (e.g. in the tropics, pasture to second-growth forest to primary forest). The extremes of such classes may be spectrally distinct and therefore easily separated; however, the boundaries between such classes can be arbitrary, and distinguishing between the two classes becomes increasingly difficult near the boundary.

Even if classes are clearly defined and spectrally distinct, a thematic map is based on the assumption that each region represents a single land-cover class. Yet all satellite imagery used to derive thematic maps - regardless of the spatial resolution of the sensor - will include mixed pixels in three basic situations. According to Bähr(2005) and Schiewe & Gähler(2006) at the border of features, in the transition zone between classes and finally, as a result of sub-pixel objects - such as a road, a building, or a tree. This may cause problems, not only in interpreting the thematic map product, but also in collecting reference data samples for accuracy assessments. Regardless of the source of reference samples (e.g. ground surveys, aerial photographs), human interpretation is almost always required to assign a class label to the reference sample.

Estimating the thematic accuracy of land-cover maps by a set of labeled reference samples is based on several assumptions (Congalton&Green, 2008; Gopal & Woodcock, 1994; Lunetta & Elvidge, 1998; Powell et al., 2004):

1. that the reference data set is a statistically valid sample of the mapped area;
2. that the reference samples are accurately co-registered with the map;
3. that the samples can be consistently and unambiguously labeled as one of the map classes;
4. that each map pixel corresponds to a single land-cover type; and
5. if time has elapsed between the acquisition of the map and reference data sets, that land cover has not changed in the interim.

A special challenge in image classification is isolating and minimizing, if possible, the role of human interpretation in the classification process. This is important because reproducibility is a fundamental requirement for any method or product (Cihlar&Jansen,2001). When the operator's sample input criterion is propagated throughout the classification procedure, the result is not reproducible. On the other hand, as long as discrete (thus artificial to some degree) classification legends continue to be used, the analyst's role cannot be eliminated because the class distinctions do not necessarily correspond to equivalent actual distinctions. It is, however, possible to assign a more precise role to the analyst and to limit his input to specific portions of the classification procedure. This improves the reproducibility of the entire process, and highlights the impact of analyst decisions.

To augment historical records, specialists use growing repositories of satellite-derived land cover data sets, which record a broad spatial picture of human land-use and land-use change over the past years. However, the quality and the limits of these historical records must be observed.

There is currently a real concern about the benefits and importance of land-use mapping. This is explained by the international interest in climate change, food emergencies and the preservation of the environment, in all of which land use is a significant variable. It is possible that the use of temporal knowledge can test theses about the regional development. However, the methodology of land use mapping and accuracy assessment must be consistent in order to support decisions and planning

Chapter 2

2. Fundamental Concepts

2.1 Introduction

Firstly, the function of remote sensing images in this methodology should be explained. In Brazil, as in other South American countries, the availability of territorial information is very restricted. Territorial planning began to gain importance only in the seventies with the urbanization of the population. Until the present day, regional questions have been omitted or subjected to questions of the national development. Studies dealing with the history of the regional development especially suffer from a lack of data that prove one or another hypothesis.

Remote sensing data thus provide support for studies on physical territory realignment. In Brazil, images of average resolution derived from Landsat and CBERS are the most widely available free of cost data offered by The National Institute for Space Research (INPE) for research purposes. Another important characteristic of the Landsat data is that it presents a historical record in orbital images for a period of over 30 years.

There exists a continuous set of Landsat data from mid-1972 until 2003[7], which provides an indispensable history of the state of the land surface. Data at these spatial resolutions can provide high potential mapping accuracy for natural vegetation and alterations.

The National Aeronautic and Space Administration (NASA) has sponsored the creation of open global land data sets, namely Landsat Multispectral Scanner, Thematic Mapper, and Enhanced Thematic Mapper (see Table 2.4) to support a variety of scientific studies and educational purposes (Ryan&Freilich,2008).

By the late 1980's in Brazil, advances in the MECB[8] satellite program boosted research in the area of space technology. The interest in using space technology for industrial applications was due to a desire to strengthen the internal economy and facilitate the search for new international partners (INPE,2009).

Chinese know-how for the construction of satellites and launch systems became a great strategic asset for the Brazilian government. Meanwhile, Brazil contributed its background in high technology and modern industrial facilities to its new partner.

The CBERS family of remote sensing satellites[9] (see chapter 2.2.2) brought significant scientific advances to Brazil. According to the INPE[10], their significance is attested to by the over 1,500

[7] still functioning, but with faulty scan line corrector.
[8] *Missão Espacial Completa Brasileira* (MECB)- the Complete Brazilian Space Mission was created in 1981 to coordinate launch vehicles, launch sites, and the manufacturing of satellites.
[9] The China-Brazil Earth Resources Satellite program (CBERS) is a technological cooperation program between Brazil and China that develops and operates Earth observation satellites. By 2009, CBERS 1, CBERS 2 and CBERS 2B had been successfully launched.

organizations registered as active CBERS users as well as by the 300,000 CBERS images that are being distributed at the approximate rate of 250 per day.

Its images are used in deforestation and fire control in the Amazon Region, water resource monitoring, urban growth, soil occupation and education. It is also fundamental for large national and strategic projects like PRODES - the real-time evaluation of Amazon deforestation, CANASAT - the monitoring of sugar-cane areas, and DETER - real-time detection of Amazon deforestation, among others (INPE,2009).

In this chapter the properties of the sensor used in this research project will be described and recent improvements in Change Detection based on data from passive Remote Sensing will be briefly presented.

2.2 Sensor Systems

2.2.1 Characteristics of the Landsat System

In the mid-1960s, NASA, the Department of Agriculture, and other agencies embarked on an initiative to develop and launch the first civilian earth-observing satellite to meet the needs of resource managers and earth scientists (Williams,2009). The USGS[11] assumed responsibility for archiving the data acquired by the program as well as for distributing the data product.

On July 23rd, 1972, NASA launched the first in a series of satellites designed to provide repetitive global coverage of the Earth's land masses. Landsat, originally named Earth Resources Technology Satellite has continued to provide high-quality, moderate-resolution data depicting the land and coastal regions of the planet(Bähr,1973). As a result of its initial success, subsequent satellites were launched over the course of the Landsat project.

Landsat 1 through 3 operated in a near-polar orbit at an altitude of 920 km with an 18-day repeat coverage cycle (Chander et al.,2009). These satellites circled the Earth every 103 minutes, completing 14 orbits a day. Eighteen days and 251 overlapping orbits were required to provide nearly complete coverage of the Earth's surface with 185 km wide image swaths. The amount of swath overlap or sidelap varies from 14% at the Equator to a maximum of approximately 85% at 81 degrees north or south latitude. Landsat 1 through 3 carried return beam vidicon (RBV) cameras and a multispectral scanner (MSS) sensor; however, the RBV cameras did not achieve the popularity of the MSS sensor.

The MSS sensor scanned the Earth's surface from west to east as the satellite moved in its descending (north-to-south) orbit over the sunlit side of the Earth. Six detectors for each spectral band provided six scan lines in each active scan. A detector was sampled every 9.958μs. During this time frame, the ground projection detector advanced 56 m in the sweep. Thus, the data is about 40% oversampled in the cross-track direction and the effective sampled pixel size is considered to be 56 x 79 m. The radiometric coverage is in four spectral bands,

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[10] *Instituto Nacional de Pesquisas Espaciais* (INPE) - The National Institute for Space Research is a research unit of the Brazilian Ministry of Science and Technology. http://www.inpe.br/.

[11] The United States Geological Survey (USGS) is a scientific agency of the United States government. http://www.usgs.gov/

from the visible green to near-infrared (near-IR) wavelengths. The combination of scanning geometry, satellite orbit, and the Earth's rotation produced the global coverage necessary for studying land-surface change.

Landsat 4 and 5 carried both the MSS and the TM sensors; however, the routine collection of MSS data was terminated in late 1992. The satellites orbited at an altitude of 705 km and provided a 16-day, 233-orbit cycle with a swath overlap that varied from 7 percent at the equator to nearly 84 percent at 81 degrees north or south latitude. These satellites were also designed and operated to collect data over a 185 km swath. The MSS sensors aboard Landsat 4 and 5 were identical to those carried on Landsat 1 and 2.

The MSS and TM sensors primarily detected reflected radiation from the Earth's surface in the visible and infrared (IR) spectrum; the TM sensor provided more radiometric information than the MSS sensor. The wavelength of the TM sensor range is from the visible (blue) through the mid-IR into the thermal-IR portion of the electromagnetic spectrum. The sixteen visible and mid-IR wavelength band detectors in the TM sensor provide 16 scan lines in each active scan. The four thermal-IR band detectors provide 4 scan lines in each active scan. The TM sensor has a spatial resolution of 30 m for the visible, near-IR, and mid-IR wavelengths and a spatial resolution of 120 m for the thermal-IR band.

Landsat 7 carries the enhanced Thematic Mapper Plus (ETM+), with 30 m visible and IR bands, a 60 m spatial resolution thermal band and a 15 m panchromatic band. Failure of on-board electronics halted data collection by Landsat 4 in 1993. The spacecraft was maintained in orbit as a test bed until it was decommissioned in June, 2001. Landsat 5 and 7, the two remaining operating satellites, orbit at an altitude of 705 km, each providing a 16-day, 233 orbit cycle. (The two orbits are offset, allowing 8-day repeat coverage.)

All Landsat satellites have maintained sun-synchronous orbits with equatorial crossing times ranging from:

- 8:30 a.m. for Landsat 1,
- 9:00 a.m. for Landsat 2,
- and 9:45 a.m. for Landsat 5 and 7.

2.2.2 Characteristics of the CBERS System

The China Brazil Earth Resources Satellite (CBERS) or ZY satellite series is a cooperative program of the People's Republic of China CAST[12] and Brazil's INPE. The program was initiated in July 1988 to establish a complete remote sensing system (space and ground segment) in order to serve both countries with multispectral remotely sensed imagery(INPE,2009).

CBERS-1, the first satellite that was developed, was successfully launched on October 14th, 1999 by the Long March 4B launcher from the Taiyuan Satellite Launch Center in China. CBERS-2 was successfully launched from the same center on October 21st, 2003 with a payload

[12] Chinese Academy of Space Technology-The China Academy of Space Technology develops and manufactures Chinese spacecraft, including scientific research satellites and application satellites. http://www.cast.cn.

identical to CBERS-1. The third satellite, CBERS-2B, was launched on September 19th, 2007. The design of CBERS-2B was similar to that of the two previous satellites but included a new camera: a High Resolution Panchromatic Camera (HRC).

The two governments decided in November 2002 to give continuity to the CBERS program by signing a new agreement for the development and launch of two more satellites, CBERS-3 and 4. It was agreed that Brazilian participation in this program would increase to 50%, putting Brazil on an equal footing with its partner. The CBERS-3 launch was projected for 2010 and CBERS-4 for 2013.

CBERS-1	October 14th 1999 - operations terminated in August 2003.
CBERS-2	October 21st 2003 - operational as of 2006.
CBERS-2B	September 19 th 2007
CBERS-3	Planned in 2010.
CBERS-4	Planned in 2011.

Table 2.1: Dates of Launch [Source: (INPE,2009)]

The CBERS satellites are designed for global coverage and include cameras for optical observation as well as a data collection system for gathering data on the environment and resources. They are unique systems using specially designed on-board sensors to resolve the broad range of space and time scales related to monitoring and preserving the ecosystem.

A unique characteristic of CBERS is its multi-sensor payload with different spatial resolutions and data-collecting frequencies:

- Wide Field Imager (WFI)
- Charge-coupled device Camera (CCD Camera)\footnote{pushbroom sensors}
- Infrared Multispectral Scanner (IR-MSS)\footnote{only in CBERS 1 and 2}
- High-Resolution Panchromatic Camera (HRC)\footnote{only in CBERS 2B}

The WFI ground swath is 890 km wide, which provides a synoptic view with a ground sampling distance (GSD) of 260 m. The Earth's surface is completely covered in about 5 days in two spectral bands: 0.66 (green) and 0.83 (near infra-red).

Parameters	WFI	CCD	IR-MSS	HRS
Field of view	60°	8.3 °	8.8 °	2.1 °
Ground sampling distance	260 m	20 m	56 m	2.7 m
Swath width	890 km	113 km	120 km	27 km
Temporal resolution	5 days	26 days	26 days	130 days

Table 2.2: CBERS senors parameters [Source: (INPE,2009)]

The CCD camera is a linear array, or pushbroom sensorconsisting of 3 CCD segments aligned in the focal plane. It provides images of a 113 km wide strip with 20 m spatial resolution. Since this camera has a sideways pointing capability of ± 32 °, it is capable of taking tracking images across a certain region. The CCD camera operates in 5 spectral bands that include a panchromatic band from 0.51 to 0.73 µm (see table 2.3). The two WFI spectral bands are also incorporated into the CCD camera in order to complete the data for the two types of remote sensing images. The CCD sensor is composed of 3 arrays and has a complete coverage cycle 26 days (see figure 2.1).

Band	Band limts µm
pan	0.51 - 0.73
blue	0.45 - 0.52
green	0.52 - 0.59
red	0.63 - 0.69
near infrared	0.77 - 0.89

Table 2.3: Spectral bands of CCD-CBERS [Source: (INPE,2009)]

The raw CCD/CBERS images in each band are composed of five parts (three arrays and two overlap regions). The first array captures only columns 1 to 1886; columns 1887 to 2040 are a result of the overlap of array 1 and array 2. This also occurs in the interval 3773 to 3926, which is an overlap of arrays 2 and 3. These arrays are positioned inside the camera as a *divoli* construction(Lillesand,2002), guaranteeing complete and continuous cross-track imagery. This is the same scheme used in the High Resolution Visible sensor (HRV) of SPOT satellites.

Its setup produces an effect from radiometric response differences. The effect generates three regions with differences in brightness and two gradient regions in the image. The graphic in Figure 2.2 shows the three gain arrays for “line 1” of the side image. Such an effect is partially eliminated by the INPE's relative calibration process.

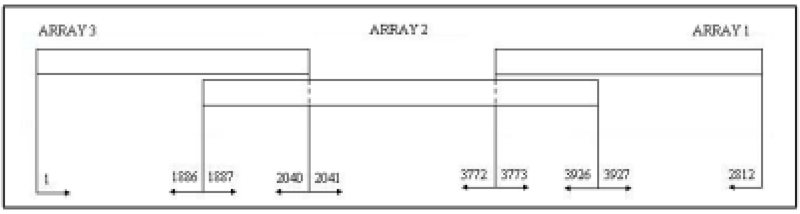

Figure 2.1: CCD Array device consists of three arrays and two overlap regions. [Source: (Anjos, 2007)]

The even and uneven detector inputs are stored in a disconnected manner, which causes differences in detector gain and offsets (Anjos,2007).

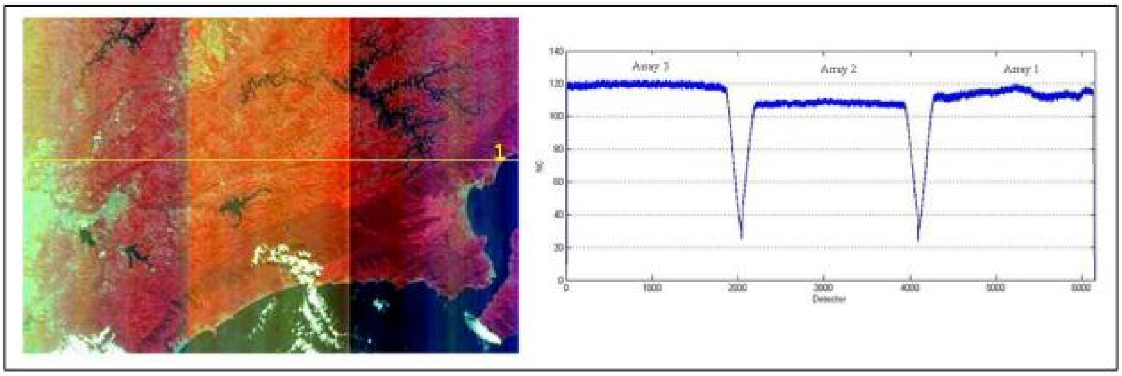

Figure 2.2: CCD radiometric response discrepancies verified in one Image and measured for on line in laboratory. [Source:(Bensebaa, 2006)]

The IR-MSS operates in 4 spectral bands, extending CBERS spectral coverage to the thermal infrared range. It images a 120 km swath with a resolution of 56 m (160 m in the thermal channel). In 26 days it obtains complete coverage of the Earth that can be correlated with the CCD camera images.

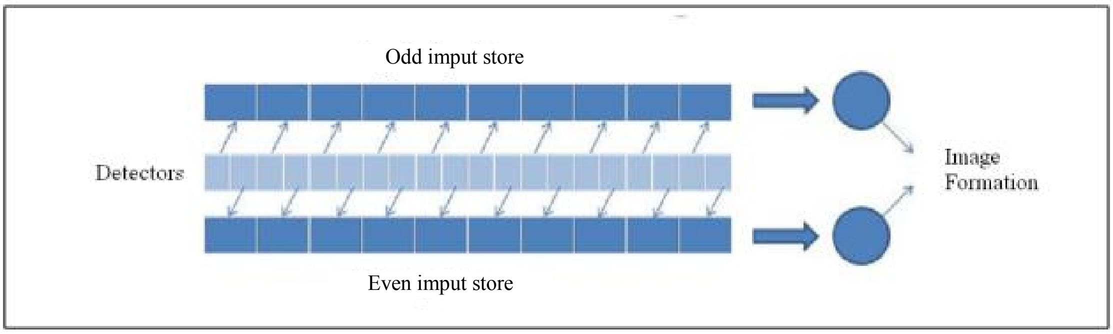

Figure 2.3: CBERS image stored process [Source:(Fonseca et al., 2004)]

The CBERS satellite is composed of two modules. The payload module houses the optical and electronic systems used for Earth observation and data collection. The service module incorporates the equipment that ensures power supply, control, telecommunications and all other functions needed for the satellite to operate.

The CBERS has a sun-synchronous orbit at an altitude of 778 km and completes about 14 revolutions per day. Local solar time at the equator crossing is always 10:30 a.m.

The CBERS programs represent an important source of development in Brazilian and Chinese satellite engineering. However the know-how acquired before CBERS 2 regarding absolute and relative sensor calibration was insufficient (Bensebaa, 2006). Because of this some effects such as the difference between even and odd columns in the final image were not totally eliminated. In the future we expect greater effectiveness in this area.

2.2.3 Sensor comparison

Historically, research has required a multi-sensor approach because sensor development was much slower in the past than today. In the case herein presented, the most useful images came from the Landsat and CBERS programs. Therefore comparing the sensors used in these two programs is important.

The comparison consisted of two parts: first the spatial, then the spectral and radiometric considerations. The temporal characteristics are restricted in this project to the available dates.

Spatial comparison

This is the critical point for data compatibility. The pixel size can be a parameter for evaluating the spatial resolution of an image and it was presented as the available parameter for this comparison. For the Landsat 7 ETM+ sensor, data is often reported in 30 m increments; however, light from up to approximately 90 m from the center of each pixel contributes to the pixel value (Townshend et al., 2000).

Another possibility is evaluating the geometric characteristics of the sensors by positional accuracy as well as band-to-band registration.

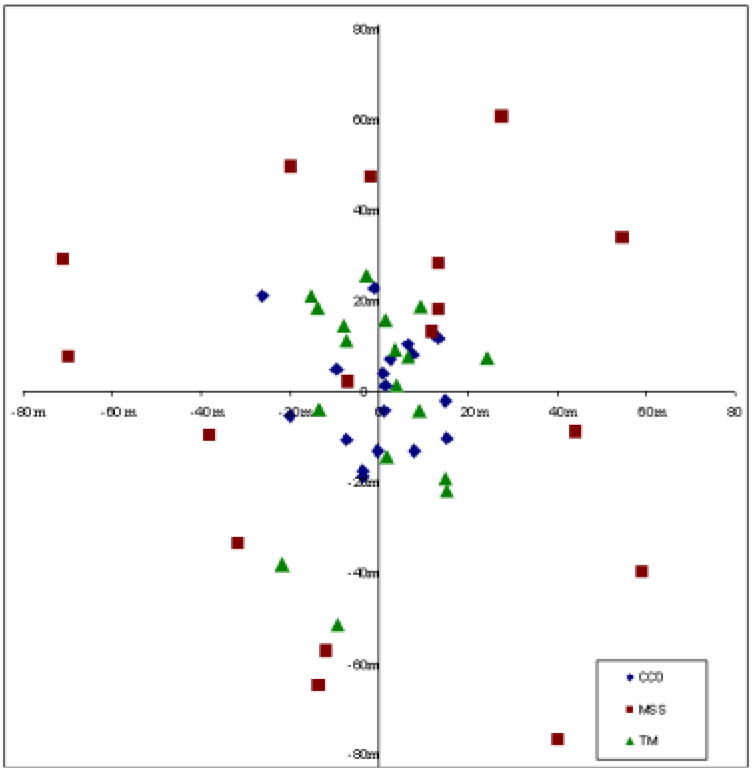

Figure 2.4: Residuals after geometrical correction [Source: study data set]

Positional accuracy was chosen as a parameter to test the relationship between the sensors. Figure 2.4 shows the residuals from MSS, TM and CCD sensors, which were correlated based on the orthorectified 15 m panchromatic ETM+ from the year 2000.

The RMS found for the three images were 16 m, 23 m and 55 m respectively, for CBERS, Landsat-5 and Landsat-1. On average, 20 points were measured per scene. The scenes were adjusted using only first-order polynomial coefficients. This decision was based on the desire to prioritize robust solutions over highly precise ones in cases where control over the scenes could not be well established. This occurred mainly in the 1970s image data set.

The area comparison was restricted to the largest pixel size and the worst positional accuracy. Thus, for an area comparison between a CBERS and a Landsat-1 thematic map, the thematic of CBERS map would be resampled to the same pixel size as that of Landsat-1.

Spectral and radiometric comparison

When all CBERS sensors were compared with the Landsat TM spectral bandwidth, the results were highly similar (figure 2.5). However the spatial resolution of CBERS sensors was restricted to allow this comparison. Subsequently, only the CCD sensor at approximately 20 m was considered.

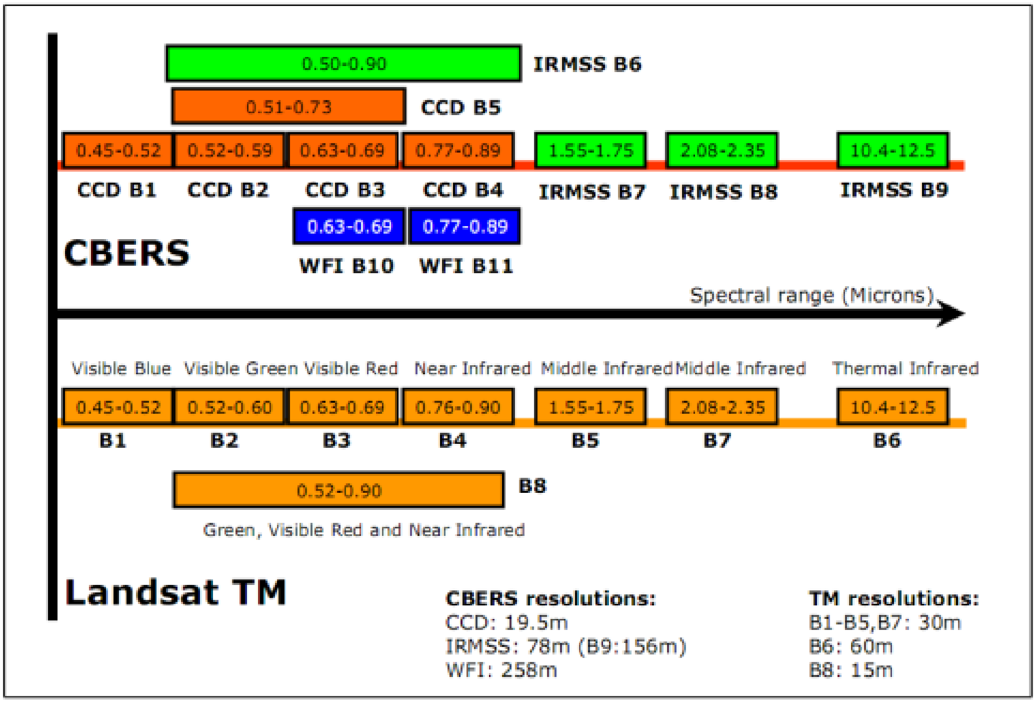

Figure 2.5: Sensor bandwidth comparison between CBERS and Landsat TM [Source:(Wu et al., 2006)]

The CCD-CBERS 2B spectral range between 0.45 and 0.89 µm brings with it technical difficulties in meeting the project specifications of INPE or CAST. The wider the spectral band, the greater the radiance seen by a detector. Thus, saturation was reached at a much lower point than expected and decreased the instrument's dynamic range in the spectral bands. The bandwidths ranges are illustrated in Table 2.5.

Table 2.4 shows that the four sensors have a common spectral region between 0.52 and 0.89 µm, which corresponds to visible green and red as well as to the near infrared spectrum.

MSS revealed a high autocorrelation between the two infrared bands, although only one of these bands was used. In the case of Landsat TM and ETM, there are also bands in the near- and thermal infrared. Only the visible and near-infrared bands were adopted for classification, which was due to the need to compare thematic maps. For this reason, the images came from passive sensors; the same bandwidth collaborated to a more homogeneous result.

Satellites	Landsat 1,2	Landsat 5	Landsat 7	CBERS II
Sensor	MSS	TM	ETM	CCD
launched in	1972	1982	1999	2003
pixel size (m)	56	30	30	20
pixel size PAN (m)	-	-	15	20
Band 1 (μm)	-	0.45-0.52	0.45-0.52	0.45-0.52
Band 2 (μm)	0.5 - 0.6	0.53-0.61	0.53-0.61	0.52-0.59
Band 3 (μm)	0.6 - 0.7	0.63-0.69	0.63-0.69	0.63-0.69
Band 4 (μm)	0.7-0.8	0.78-0.90	0.78-0.90	0.77-0.89
Band 5 (μm)	0.8-1.1	1.57-1.78	1.57-1.78	-
Band 6 (μm)	-	10.42-11.66	10.42-11.66	-
Band 7 (μm)	-	2.08-2.35	2.08-2.35	-
Band PAN(μm)	-	-	0.5-0.9	0.51-0.73

Table 2.4: Systems Characteristics: Landsat and CBERS [Source:(USGS, 2006)]

Image entropy is a convenient measure for comparing differences in the radiometric proprieties of the four sensors (Malila, 1985; Jeffrey et al., 2001). According to Shannon's information theory (Jeffrey et al., 2001), entropy (E) can be defined in terms of information content as:

$$E = -\sum_{i=0}^{N} x(i) log_2 x(i) \qquad (2.1)$$

Where x indicates the probability that a specific numerical value i will occur (e.g. a specific digital number) in the range of 0 to N. In practice, $x(i)$ is simply the normalized value of the i^{th} bin of the image in a digital number histogram. For the case of Landsat, $N=2^8=256$, a histogram in which all values are equally filled (flat histogram) yields E= 8, which is the maximum possible information content. In Figure 2.6 the entropy response of the study samples is shown. Alternatively, if all values resided in one bin, E= 0, which is the lowest possible information content (Jeffrey et al., 2001).

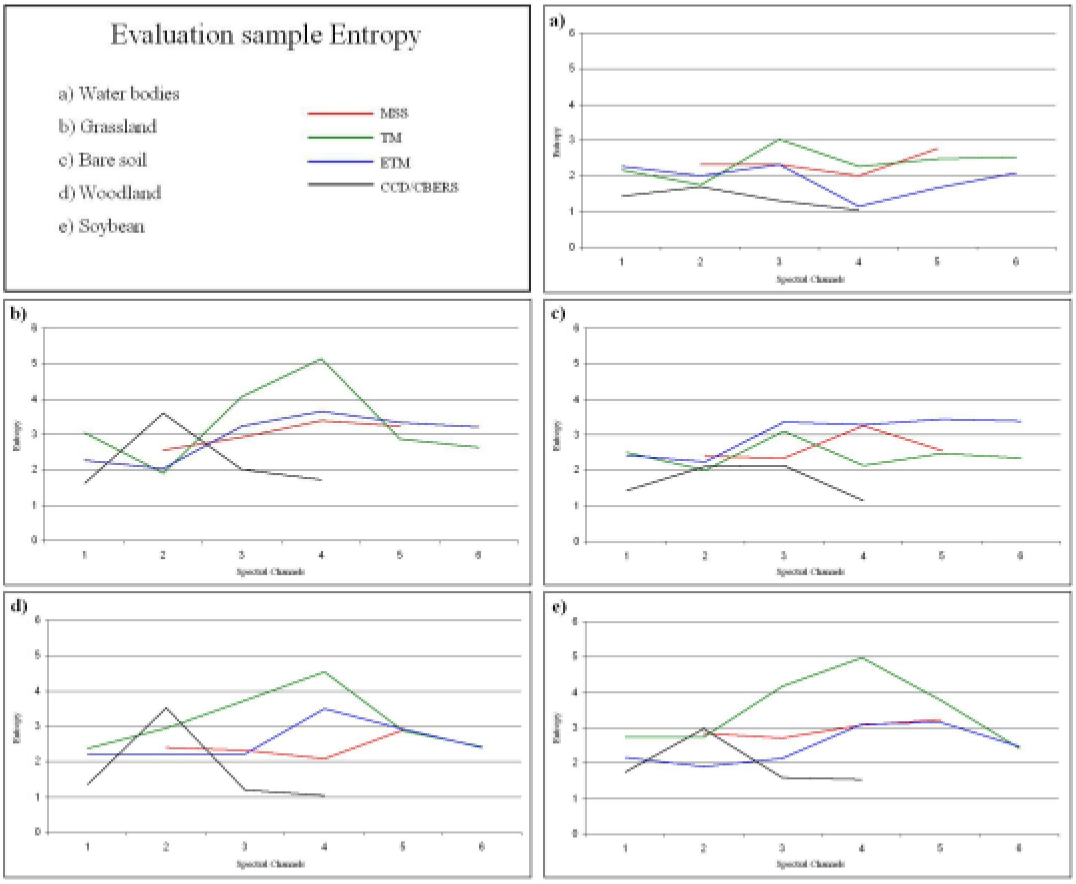

Figure 2.6: Entropy MSS, TM, ETM and CCD for owner samples [Source: study data set]

The relative spectral response function (Figure 2.7) of an electro-optical sensor describes the responsiveness at each wavelength for the sensor's signal output per unit flux incident (Schott,1997).

One factor that is often overlooked is the effect of a sensor's relative spectral response (RSR), or spectral response function (SRF), in broadband spectral measurements.

The RSR describes the quantum efficiency of a sensor at specific wavelengths over the range of a spectral band. Currently, general descriptors such as bandwidth and average band pass are often the only spectral characteristics considered in an analysis of sensor spectral measurements. However, cross-sensor wavelength variations in RSR can lead to measurement discrepancies between sensor measurements that prohibit their direct comparability (Schott,1997). In order to provide consistent quantitative spectral measurements of vegetation land cover and derived metrics, such as the spectral vegetation index, the effect of a sensor's SRF must be considered and understood.

The main problem when comparing spectral measurements between sensors is that the magnitude of the RSR effect varies with the spectral signatures of the land features being observed.

The result is variability in measurements between different sensors even after inter-calibration techniques have been applied. This variability may lead to reduced accuracy, precision, and consistency of land cover measurements.

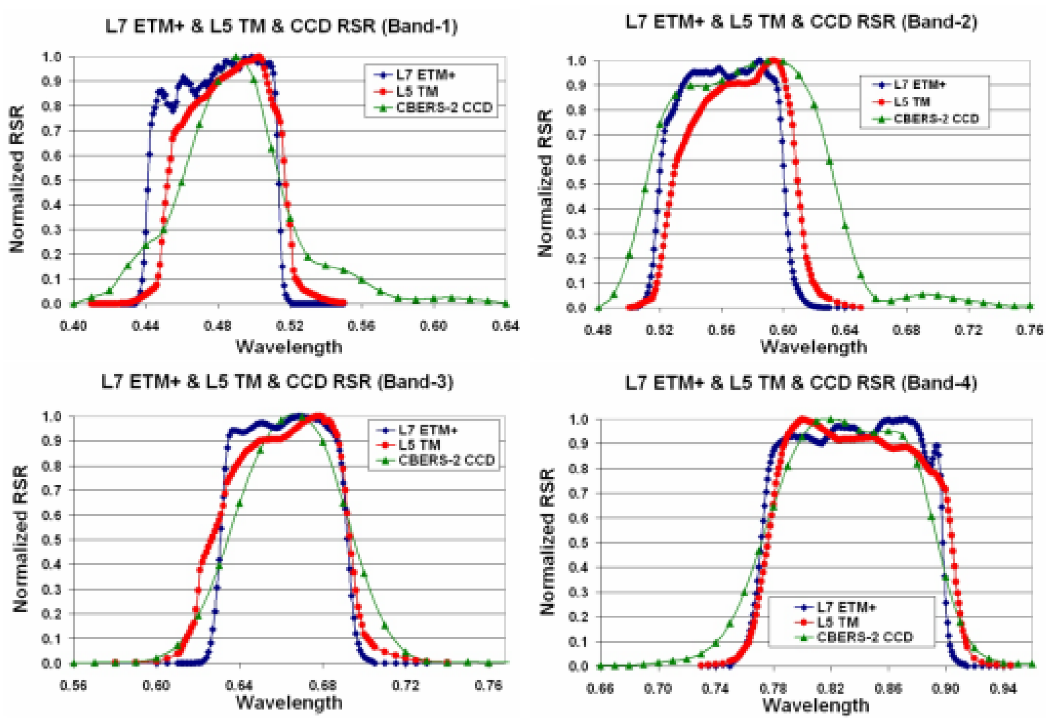

Figure 2.7: Relative Spectral Response for CCD, TM and ETM. [Source:(USGS,2006)]

The relative spectral response function (Figure 2.7) of an electro-optical sensor describes the responsiveness at each wavelength of the sensor's signal output per unit flux incident (Schott,1997). These curves originated from spectral measurements in the laboratory13 and take into account the response per radiance unit. The graph shows the closeness of spectral response functions for the sensors.

[13] A comparison of CBERS-2 and Landsat data. U.S. Geological Survey (2006).

2.3 Change detection techniques

The traditional methods of detecting change based on remote sensing data can be broadly divided along these lines: image differentiation and post-classification change detection.

Change detection approaches can be divided into two broad groups, namely, bi-temporal change detection and temporal trajectory analysis (Figure 2.8).

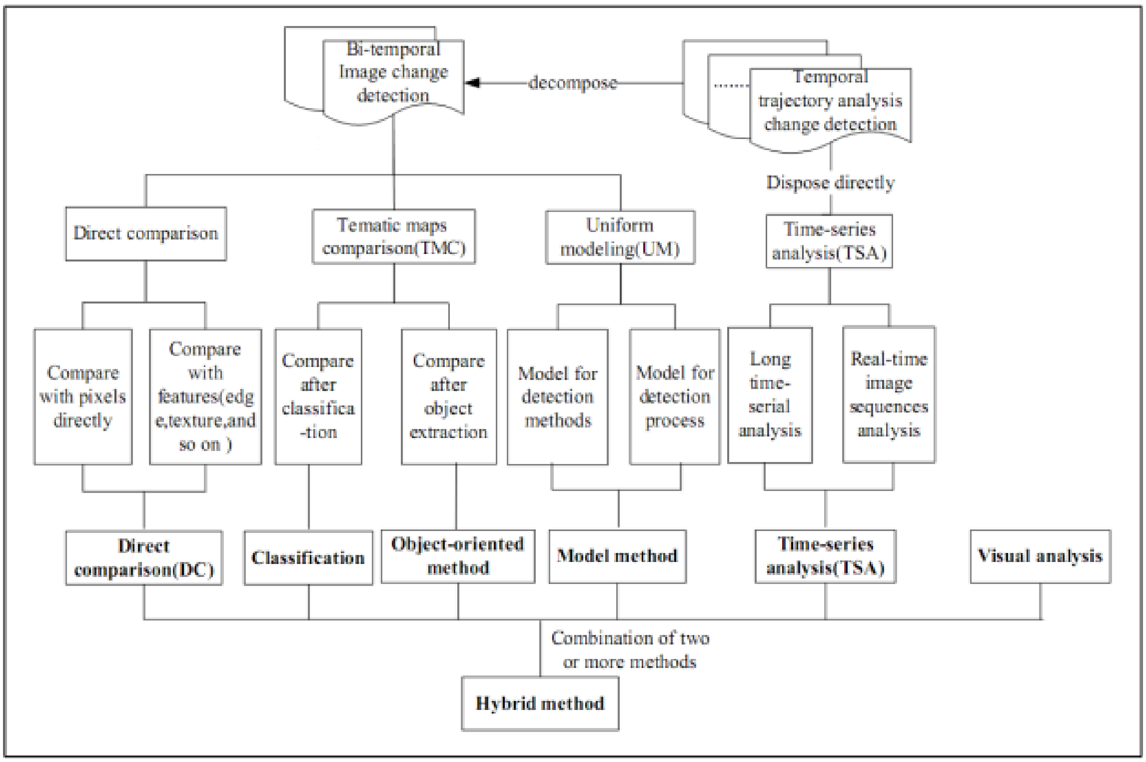

Figure 2.8: Classification concept of change detection methods. [Source:(Jianya et al., 2008)]

Image differentiation, although mathematically simple, allows for only one band of information to be processed at a time, whereas other techniques incorporate multiple data bands for change detection.

Previous studies have confirmed that smaller components successfully detected land cover changes (Byrne et al.,1980) when the areas affected by the change occupy a small proportion of the study area (Macleod&Calgoton,1998).

Image differentiation using band ratios or vegetation index is another technique commonly employed for land cover change detection. For example, the normalized difference vegetation index (NDVI) was developed both to identify the health and vigor of vegetation and to estimate green biomass. The NDVI, the normalized difference of brightness values from the near infrared and visible red bands has been found to correlate highly with crown closure, leaf area index, and other vegetation parameters (Singh, 1989).

Knowing which data set from the NDVI is coupled with which display color, the analyst can visually interpret the magnitude and direction of biomass changes in the study area over the three dates. Automated classification can be performed on three or more NDVI dates by unsupervised cluster analysis (Cihlar&Jansen,2001).

Change and no change categories are labeled and dated through interpreter analysis of the cluster statistical data and guided by visual interpretation of RGB-NDVI color composites.

2.3.1 Thematic Map Comparison

In order to overcome the limitations of an unsupervised approach, techniques based on a supervised classification of multitemporal images can be employed. The simplest technique in this category is Thematic Map Comparison (TMC) (Pacifici,2007).

It detects change in thematic maps by independently classifying and comparing two remote sensing images of the same area acquired at different times. Thus it is possible to detect changes and understand the types of transition that have taken place. Furthermore, the classification of multitemporal images obviates the need to normalize atmospheric conditions and sensor differences between acquisitions. However, the accuracy of the thematic maps is critical for adequate TMC performance. The accuracy of the final change detection map is close to the product of the accuracies of the two involved times (Yuan&Elvidge,1998).

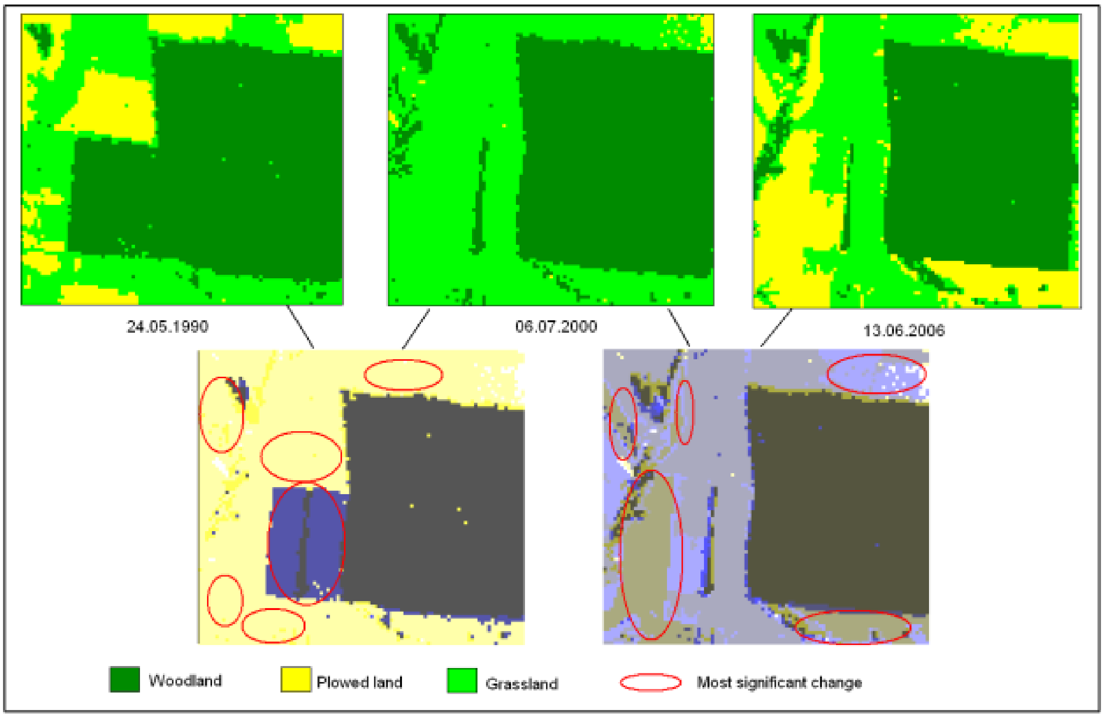

Figure 2.9: Change detection based on Thematic Map Comparison techniques. [Source: study data set]

This is due to the fact that TMC does not take into account the existing dependence between two images of the same area acquired at two different times, while Direct Multidata Classification (DMC) can overcome this problem (Pacifici,2007). With this technique, pixels are characterized by a vector obtained from stacking the feature vectors related to the images acquired at two times. Change detection is then performed by considering each transition as a class and by training a classifier to recognize the transitions. Appropriate training sets are required: The training pixels from the two different times should be related to the same points on the ground and should accurately represent the proportions of all the transitions in all of the images. Nevertheless, in real applications, it is usually difficult to employ training sets with such characteristics (Treitz&Rogan, 2004).

The above-mentioned methods are mainly pixel based, while (Lunetta&Elvidge, 1998) is a region-based change detection algorithm, in which specific user requirements are introduced into the change detection chain by means of a cost function that takes them into account. In general, an approach based on supervised classification is more flexible than one based on a comparison of multi-temporal raw data.

Chapter 3

3. The study area

3.1 Introduction

In order to understand the specificities of the presented case, this chapter will show the results of historical research on the processes that interfered in the territorial reorganization of the region.

The construction of the Itaipú hydroelectric plant on the Paraná River reflects cooperative aspects between two nations. The project was preceded by a long discussion centered on political gain rather than on its possible far-reaching consequences for future economic and social development or on the ecological conservation of the entire Paraná River hinterland.

The Paraná River basin is among the five largest water systems in the world, in South America second in size only to the Amazon basin. With a length of 4,500 km, it consists of three main rivers, the Paraná, Paraguay and Uruguay, as well as their tributaries. It covers an area of 5,128,000 km^2 and contains an estimated population (2006) of more than 100 million people(Rosa et al.,1988). Brazil encompasses the largest share of the basin at 46%, followed by Argentina at 28% and Paraguay at 13%, with the remainder belonging Bolivia and Uruguay.

Brazil's share of the basin includes some of the relatively more progressive and industrialized southwestern, southeastern, southern states: Mato Grosso, Goias, São Paulo, Paraná, Santa Catarina, and Rio Grande do Sul.

Until the completion of a paved road and the international bridge over the Paraná River, Paraguay's connection to world markets depended exclusively on the Paraguay and Paraná Rivers(Fogel,2008). This road and bridge where built in the 1960s, permitting direct access to the Atlantic coast of Brazil. This reveals the strategic importance of the river for Paraguay.

The study area (figure3.1) is located in the center of South America and consists of the Paraguayan districts Ciudad del Este, Hernadárias, Mbaracayu, San Alberto and Minga Porá, and the Brazilian municipalities Foz do Iguaçú, São Miguel do Iguaçú, Itaipúlândia, Santa Helena, Santa Terezinha de Itaipú, Missal and Santa Inês. The study area covered 7,820 km^2, of which 4,659 km^2 belongs to Paraguay and 3,161 km^2 to Brazil.

The districts and municipalities are equivalent in administrative function. The administrative organization shows more historical than political discrepancies. In Brazil, each municipality usually contains the seat of local government. During Spanish colonial rule in Paraguay, the involved regions were mainly designated as ‘districts’ and had neither been formally organized into provinces nor incorporated into existing ones. Nowadays, they also contain the lowest-level seat of government like Brazilian municipalities.

3.2 Physical Characteristics

A brief description follows of the physical aspects of the region and their impact on economic characteristics. It is a climate that allows a high regional productivity of grains such as soy and wheat.

The Itaipú region can be divided into two parts: an eastern part, which is the slope of the southern Brazilian uplands between the Piquirí River and the Iguaçú River in the state of Paraná, and a western part including a portion of the Paraguayan Amambay plateau in the Alto Paraná and Canendiyú Departments of eastern Paraguay.

3.3 Geological Characteristics

Much of western Paraná and eastern Paraguay are covered by an extrusion of Paraná flood basalts (137-132 Ma) called the Paraná plateau or the Guarapuava plateau. It extends over the border to form the Amambay plateau.

It mainly consists of upper Triassic trap sheets of basalt with scattered diabase intrusions. This Mesozoic plateau slopes down from approx. 1,100 m above mean sea level at the centre of Paraná State in Brazil to less than 200 m above mean sea level at the edge of the Pleistocene valley of the Paraná River.

This valley cuts to a depth of less than 50 m above mean sea level. Vertically jointed diabase sheets of trap-rock and melaphyres are interspersed with thin deposits of inter-trap sandstone (Comin-Chiaramonti&Gomes,2005).

Figure 3.1: Study Area

The slope of the plateau is continuous and without tectonic disturbances, reaching to the low ridge between the cities of Cascavel and Foz do Iguaçú. The erosion products of the lava sheets range in color from dark red to reddish-brown, including deeply weathered and dark-red soils (Maack,2002).

In the northwest, north of the Piquirí River, the diabase and melaphyre sheets are covered by Jurassic Caiuá sandstone, which is also extremely susceptible to erosion(IAP,2009).

To the west of the tectonically aligned Paraná River valley, which runs along one of the rupture fissures at the edge of the trap-rock cover, the Amambay plateau in eastern Paraguay forms the geological continuation of the Mesozoic plateau of southern Brazil (Comin-Chiaramonti&Gomes,2005). The Amambay plateau region is bound in the north by the Mbaracayú Mountains, which border the Brazilian state of Mato Grosso do Sul.

The Itaipú Dam and its reservoir are located on the basaltic outpourings of the Paraná Basin, which is part of the Serra Geral formation, whose origin goes back to the Jurassic Period. The basaltic sheets are essentially horizontal, with a thickness varying from 20 to 60 m, and include discontinuities in parallel planes. There are heterogeneous breach layers between the sheets from 1 to 30 m thick that are usually less resistant and more deformable than the basalt. The basaltic sheets are relatively uniform, and vary both in tones of dark gray and in particle size in the central portion, changing to vesicular, amygdale and breciaceo in the transition zones (IAP,2009).

The thickness, lithology and porosity of the breach layers vary widely. Between the sheets, the land surface was subject to weathering, suffering erosion and sediment deposition from wind and water. The subsequent sheet remodeled that material, thus shaping the breach layers of each outpouring (Comin-Chiaramonti&Gomes,2005).

Another characteristic of the region’s basaltic sheets is the presence of a discontinuity under the vesicular-amygdale layer of each outpouring (Tha,2007).

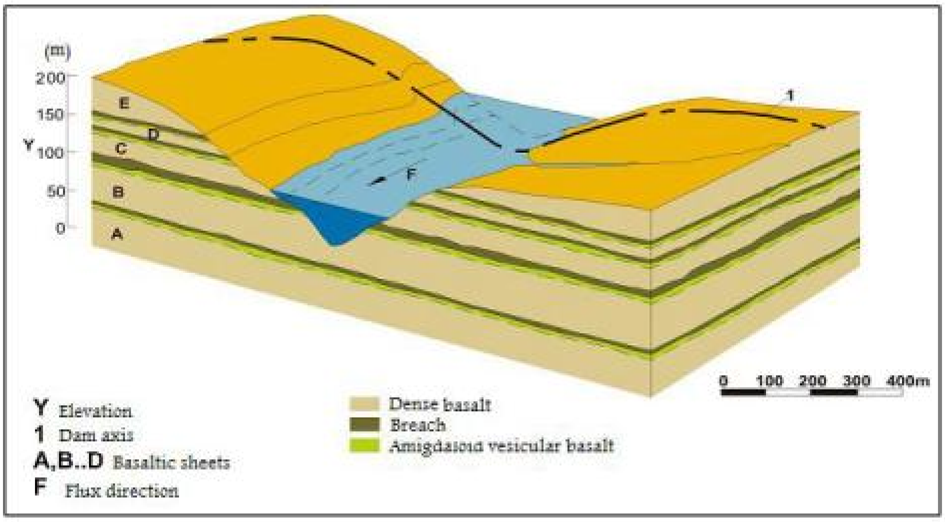

Figure 3.2: Basaltic sheets in the region of the Itaipú Dam. [Source:(Tha,2007)]

In the area of the dam, five different sheets were identified that submerge three grades toward the northeast. Those sheets were denominated, ascending vertically: A, B, C, D and E(Tha,2007). The thickness of each outpouring varies between 30 and 70 m and the sheets include three different types of basalt (Tha,2007):

1. Dense basalt, which is characterized by microcrystalline texture, high relative density (2.95) and a high modulus of deformability (> 20 GPa). Due to their high rigidity, such layers are highly fractured.
2. Amygdaloidal Vesicular basalt, which has a similar texture to dense basalt, but presents veins and is much less fractured than dense basalt. Its relative density varies between 2.6 and 2.7 and its modulus of deformability between 10 and 15 GPa. It doesn't present permeable zones.
3. Breach, which is a mixture of vesicular lava, blocks of basalt, sandstone, siltstone and other materials. It has partially irregular cavities filled with carbonate and amorphous and crystalline quartz. Its relative density varies between 2.1 and 2.4, but was locally less than 2. The modulus of deformability is on the order of 7 GPa.

Figure 3.2 shows the successive outpourings of basalt in the Itaipú Dam region.

3.4 Climatic Characteristics

The study area belongs to the humid marginal tropical-subtropical climatic region (Maack, 2002). The climatic conditions are characterized by the region's position in an immediate transition zone between a marginal humid tropical to a dry winter area, which is characterized by hot summers and cool winters with occasional night frost.

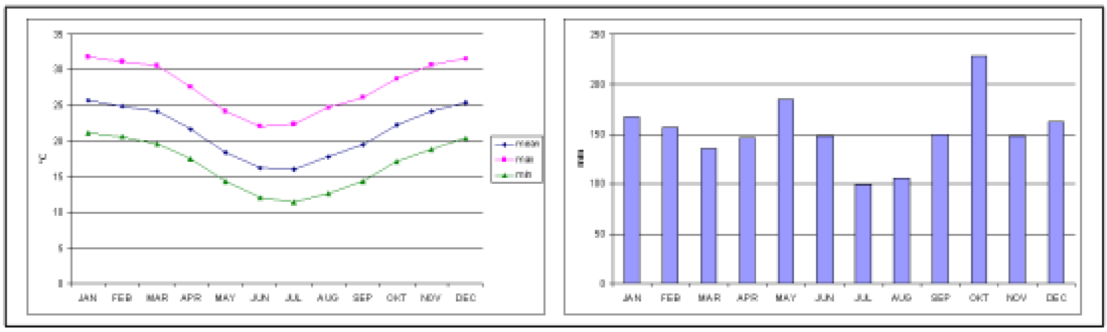

Figure 3.3: The average monthly temperature and rainfall at the Foz do Iguaçu sation over the last five years. [Source:(IAP,2009)]

The average annual temperature and rainfall at the Paraná River's Iguaçú Falls can be seen in Figure 3.3. The variation in temperature between the warmest and coolest months of the year is approximately 10-11˚C. The highest monthly temperatures, recorded in January and February, are around 26˚C in Guaíra and Foz do Iguaçú and 22˚C in Cascavel, where the altitude is 750 m.

The lowest monthly temperatures occur in June/July, with 15-16˚C along the Paraná River and 13˚C in higher regions. While the absolute maximums reach nearly 40˚C, insurgences of cold air between June and August can lead to night frost. While this is very rare in the Paraná River area (0.3 - 0.5 days a year), it is a regular occurrence in the uplands (10 - 15 days a year). The absolute minimum recorded in Guaíra (265 m above mean sea level) is – 5˚C (IAP,2009). The rainfall situation characterizes the region as year-round humid. Even in the less wet southern winter (June - August), the monthly averages do not drop below 60 mm.

Annual rainfall figures are between 1,650 mm and 1,800 mm, with maximum rainfall from December to March and maximum monthly averages of around 230 mm (IAP,2009). Due to the fact that the climate is humid all year round, the water balance is very constant, with no field moisture deficiency. The average regional relative air humidity is approximately 80%.

3.5 Vegetation Characteristics

The natural vegetation is also transitional, in accordance with the climatic conditions. An evergreen subtropical rain forest covers the river valleys and the slopes of the southern Brazilian uplands less than 500 m above mean sea level. Above 500 m the dominant natural vegetation is Araucaria forest (Araucaria angustifolia).

The natural forest vegetation in western Paraná (as in the rest of state in general) has been largely destroyed by burning and clearing during the great agricultural colonization process that has been ongoing since the latter half of 1950s.

Figure 3.4: Itabo Reserve in Mbracayu - Paraguay

3.6 Socio-economic conditions and regional development processes of western Paraná - Brazil

The first settlements in western Paraná occurred in the latter half of the 19^{th}century. Small ports were developed on the Paraná River by English and Argentinean timber and maté companies (Pereira,1974). The collection posts for maté tealeaf production provided the first impetus for regional economic development. In 1888, Brazil set up a small and completely isolated military base at Foz do Iguaçú for strategic reasons.

The 1940's saw the first efforts to open up western Paraná by Luso-Brazilians and immigrants of Slavonic origin from settled areas of eastern Paraná (Pereira,1974). The typical farming method in this pioneering phase was shifting cultivation (land rotation) with maize-growing and pig farming.

In the early 1950s, the southwest of Paraná was colonized area by the farming population, which was mainly of German and Italian origin from the Rio Grande do Sul area. Some of these immigrants had been displaced from their settlement areas in Rio Grande do Sul and western Santa Catarina due to land division between heirs. Others were attracted by the prospect of cheap land.

In western Paraná (see Figure 3.5) an initiative by the Rio Grande do Sul Settlement Company Maripá led to the first attempts of colonization in the Toledo area, as well as to a model colonization project similar to a former English Company project in 1950. This first phase of development was characterized by a regular arrangement of settlements, schools, churches, roads and a system of isolated strip farms with guaranteed access to water, as well as by colonies segregated according to national origin and religion (Fogel,2008). This example of serious development activity stands in contrast to the numerous conflicts over landowner status in other parts of the region. In return for political support and favors, state-owned land had been given (in some cases on a large scale) to individuals in the capital, Curitiba, most of whom had never seen their undeveloped property.

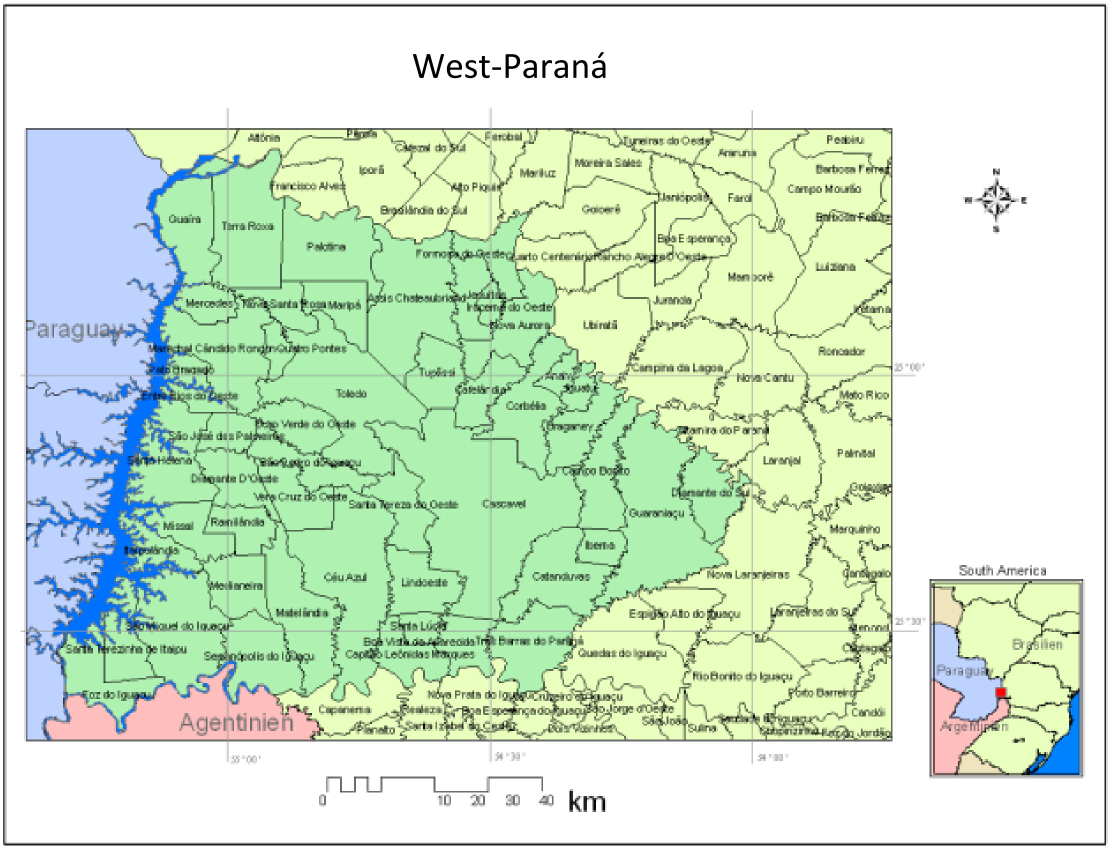

Figure 3.5: The western Paraná region – Brazil [Source:(IPARDES,2007)]

The stream of immigrants in the 1950s considerably increased the value of the subtropical rain forest area by their efforts in clearing it, building roads and establishing settlements. This drew the attention of economic interests. Numerous violent disputes and land conflicts characterized the second half of the 1950s, when during Governor Lupion's term there was a spate of incorrect sales, with many owners of false land titles proceeding to drive settlers away (Pereira,1974). In 1962, the Brazilian government was compelled to establish a special commission to end the violence and the chaotic ownership conditions.

In the 1960s a second wave of migration came to the western Paraná region from the north. These migrants were mainly Luso-Brazilians who had come to Paraná for the purpose of coffee-growing and built a small financial base as tenant farmers and subcontractors[14]. Speculative investment, especially first-time land buying, and an associated improvement of agricultural and social status characterize this phase. South of the coffee-growing frontier, farming was characterized in particular by the cultivation of traditional basic foods (beans, hill rice, manioc, maize) as well as cotton and peanuts (Nickson,1981). However, only a small number of those settlers succeeded in establishing themselves as landowners on a lasting basis in western Paraná.

In the 1960s the very poor transportation infrastructure of the region had also placed tight economic limits on traditional family farms. The settlers practiced the polyculture system[15] and pig farming. Under these conditions there could be no question of specialized market production. Although the protein rich soybean was known to the immigrants from Rio Grande do Sul, it was initially a low priority manual cash crop in maize cultivation and used for feeding pigs.

Once wheat-growing in the Toledo area had its first successes, the early 1970s saw the start of an abrupt and drastic restructuring of agriculture in western Paraná. The predominant subsistence economy changed towards market-oriented production based on soybean farming. This was aided by cheap agricultural loans made available through the agricultural modernization program.

For the first time, the purchase of agricultural machinery made possible the mechanical clearing of roots and stumps and the establishment of large-scale fields. It became possible to use modern resources such as artificial fertilizers, high yield seed and pesticides. The new financing facilities formed the decisive instrument for state-controlled development of market and export-oriented cash crop production. Federal agricultural consultants and development banks brought the small cooperatives together. They formed a small number of large cooperatives which operated under official supervision and created substantial storage capacity.

These large cooperatives, through their activities in the advisory field and in the social sector, improved the farmers' operating standards and quality of life and acquired a monopoly in the allocation of loans on behalf of the state. The crucial factor in the soybean "breakthrough"'

[14] The named in Brazil ``*empreiteiros*'' are subcontractors in the coffee-growing industry who specialize in setting up coffee plantations.

[15] Polyculture is agriculture using multiple crops in the same space, in imitation of the diversity of natural ecosystems, and avoiding large stands of single crops, or monoculture. It includes crop rotation, multi-cropping, inter-cropping, companion planting, beneficial weeds, and alley cropping.

was, besides the agricultural credit facilities, the sharp rise in the world market price from US$ 100/ton (1968/69) to US$ 260/ton (1973/74)(Kohlhepp,1987). The region was also favored because of its fertile soils and a topography which lent itself to mechanization, a comparatively well balanced middle-class social structure, and the willingness to innovate by immigrants, particularly those from Rio Grande do Sul and Santa Catarina.

Until the early 1970s, urban development in western Paraná took on the form of colonization bases and unassuming trading centers in the face of what was still predominantly a subsistence economy.

Industrialization was confined mainly to sawmills and agricultural produce handling. Two totally different population groups contributed to the main body of population growth in the towns Kohlhepp,1984):

1. Farm workers and small tenant farmers displaced by mechanization and squatters[16] who had lost the fight for their land titles; these groups were responsible for the creation of expansion slums in urban districts that were socially and spatially marginal.

2. Owners of medium-sized and large farms who had come in search of the advantages of urban life and wanted to give their children the benefits of better schooling. Not all of them, however, were absentee landlords who entrusted the running of their farms to managers. What happened was that motorization had brought most of the farms to within commuting distance of urban areas. This group frequently bought urban properties as a speculative investment.

The impact of the Itaipú dam was felt in this region's economy, society and environment. However, at this time the Brazilian side of the region substituted coffee growing for a soybean-wheat cash-crop alternation. This change in production also produced a land exodus that was linked to rising land prices, which only aggravated the conflict between squatters and the speculative land owners.

3.7 Socio-economic conditions and regional development processes of Alto Paraná - Paraguay

The Alto Paraná region remained almost totally unexploited until the beginning of 1900s. The indigenous Mbya, Ache and Pai-Tavytera peoples who formerly populated the region lived fromhunting and beekeeping since they had no access to arable land (Pangrazio,1999).

> *"During the early colonial period, there were attempts to establish Jesuit settlement near the present day town of Saltos del Guaira on the Brazilian border. This first settlement was abandoned due to attacks from Brazilians Bandeirantes(Brazilian explorers). Jesuit settlements were subsequently established in the southeast of Paraguay, and the dense forest of the region remained largely unexplored, except by occasional military expeditions to fend off Brazilian penetration.*

[16] the named ``*posseiros*'' are people that working the land without legal title.

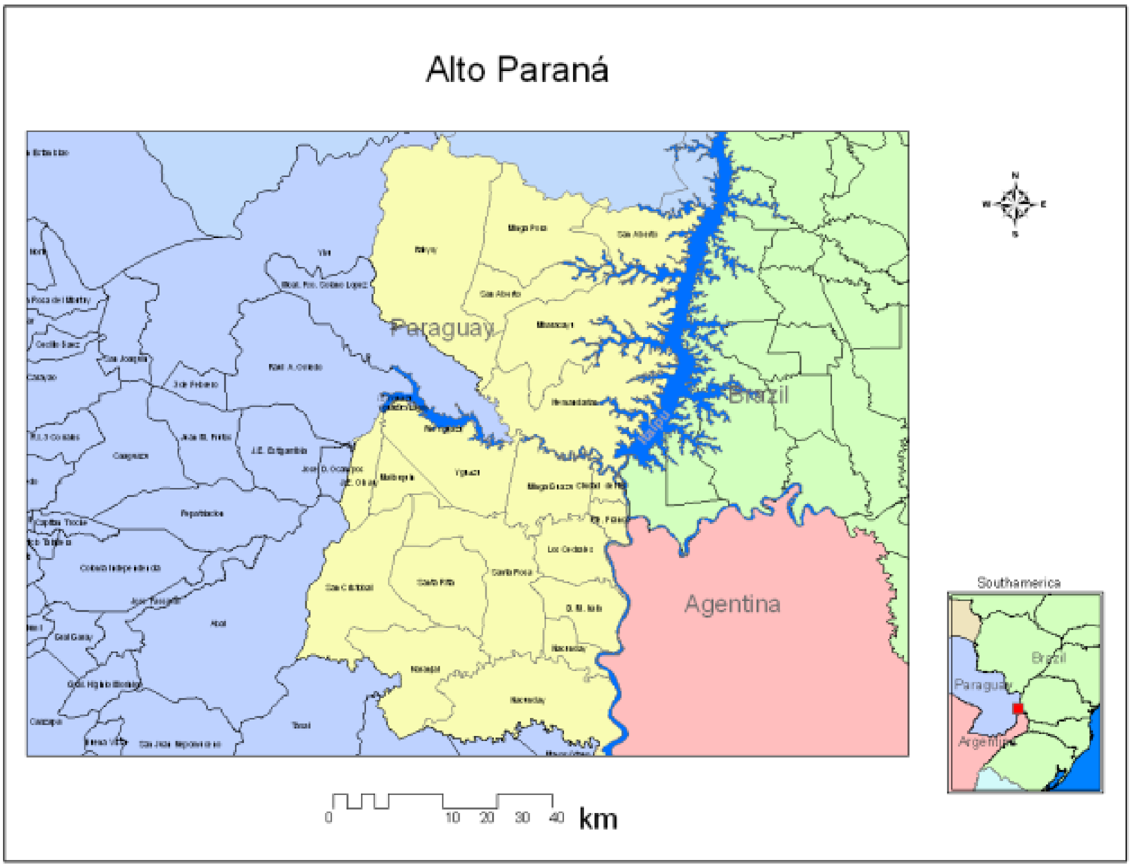

Figure 3.6: The current Alto Paraná Department[Source:(DGEEC,2008)]

Economic activity in the border region during the colonial period and the post-war nationalist period (1814-1870) was connected to the collection of yerba(Paraguayan tea). Following Paraguay's defeat in the Triple Alliance War (1865-1870), the widespread sale of public lands by post-war governments in 1883 and 1885 led to a rapid increase in private exploration of regional yerba resources (Pereira,1974). A large part of the eastern border of Paraguay was sold to foreign buyers, most of them Argentinian tea companies. This established a highly unequal system of land tenure which remained virtually unchanged for the next 80 years. Prior to this (1871), a law had been passed forbidding contracted workers from leaving the yerbales without permission and providing for capture and fines if they escaped.

Paraguay retained its independence and some viable territorial integrity mainly because Argentina and Brazil could not agree on a total partition. Paraguay emerged from the war with its first democratic constitution and a new generation of politicians who tried with some success to play Argentina and Brazil against each other until all foreign troops left Paraguayan territory. This diplomatic strategy became known at the time as Paraguay's pendulum diplomacy and was used repeatedly in its dealings with these two neighbors.

The reconstruction of Paraguay after 1870 was primarily based on the natural link that the Paraná and Paraguay rivers provide between Asunción and Buenos Aires. By means of the rivers came manufactured goods, capital, technology, ideas, and the individuals that brought them." (Translated from Pereira,1974.)

After the last Brazilian soldiers left Paraguay in 1876, the influence of Brazil was felt only by a few border posts separated from Asuncion by the dense and unpopulated forests of eastern Paraguay. Mindful of the unresolved ownership problems about a portion of the seven falls of Guaira or Sete Quedas, the bitter lessons of their past history, and language and culture differences, Paraguayans remained distrustful of Brazil. The geopolitical ideas that inspired Brazil in the 1950s to resume its march to the west and move its "living frontiers" beyond its conventional "legal" borders did little to calm the fears of most Paraguayan politicians and intellectuals regarding Brazilian imperialism (Pangrazio,1999).

In the early 1940s, a military dictatorship took power in Paraguay after dissolving and outlawing the Liberal party, which had been in power since 1904. The new Paraguayan military regime wanted closer links with Brazil to ensure greater security against its opponents. Brazil found the time promising to gain influence and establish a new presence in Paraguay (Pangrazio,1999).

Economic forces outside Paraguay were largely responsible for "opening up" the region. The westward moving frontier of agricultural settlement in the Brazilian state of Paraná began to extend into Paraguay as a result of a growing disparity in land prices on either side of the Paraná River. From a steady trickle in the mid-1960s, the immigration of Brazilian colonists into the Paraguayan border region turned into a flood from 1972 onwards. There are now an estimated 300,000 Brazilian colonists in Paraguay, equivalent to 60% of the population of the region(Kohlhepp,1983).

Due to the impact of Brazilian colonization, the Alto Paraná region underwent a process of rapid economic growth that was largely separated from the rest of the Paraguayan economy. Although nominally within the Paraguayan nation, the economy of the region is now closely linked with that of Brazil.

The two streams of internal migration in Brazil converged in Paraná, and as a result of the situation were diverted to eastern Paraguay. On the one hand, coming from the north, there were the Luso- and Afro-Brazilian farm workers from the coffee growing areas of São Paulo and Paraná, where fundamental structural changes had taken place in the agricultural sector as a result of the frost problems.

On the other hand, small farmers of German and Italian descent engaged in the production of basic foods were coming from the smallholding areas of the southern states.

As a result of these developments, large areas of eastern Paraguay became completely dominated economically and socio-culturally by Brazil. In the initial phase of Brazilian immigration, the average size of farms was between 25 and 60 hectares(Souza,2005). The most common form of settlement was a row of isolated farms with a broad strip field pattern, and poorly consolidated central "town sites".

Even though only some of the Brazilian colonists displayed a particular receptiveness to innovations in the agricultural sector and the majority of the Brazilian immigrants had a relatively poor standard of education, there was still a large discrepancy between them and the rural Paraguayan population, especially regarding practical experience with the techniques and cultivation methods of “forest colonization”. Although the number of Brazilian settlers for whom Paraguay represented a haven from the competitive pressures of the mechanized market-oriented farming system in western Paraná was by no means small, there was also an inferiority complex evident among the Paraguayan population, and their resulting disapproval of the foreigners gave rise to problems in contact zones. On the other hand, since the immigrants settled in more or less self-contained settlement areas, and in view of the official interests and harmonious relations between the two countries, especially in the neighboring Itaipú area, outbursts of such latent conflicts of interests have so far only occurred on an isolated scale.

In the meantime the soybean-wheat boom got underway in eastern Paraguay (Kohlhepp,1983). The enormous expansion of these new cash crops was due almost entirely to the Brazilian immigrants. This means a two-phase process of displacement was taking place in eastern Paraguay:

1. The Brazilian settlers who had themselves been displaced from western Paraná were displacing Paraguayan colonists from large areas of the Amambay plateau.

2. The soybean growing boom and the associated trend towards soybean-wheat crop rotation or even soybean monoculture has been developing in eastern Paraguay along virtually the same lines as in western Paraná.

Although an initially large number of small and medium-sized farms joined this new system, there were soon signs that these farms were being displaced by a subsequent influx of large Brazilian establishments that imported the mechanization cycle into Paraguay including its tendency to concentrate farms and the labor market.

The relatively low land prices led to a veritable rush of land buyers to secure the remaining areas still under forest. Following the Brazilian small farmers and mid-sized and large establishments, multinational agro-business operations in the soybean sector moved into eastern Paraguay. This was the situation in which Itaipú was built in the latter half of the 1970s and the early 1980s, which led to further structural changes in the region, triggering a broad spectrum of repercussions for settlement, economic geography, socioeconomics and ecology.

3.8 Itaipú power-station and reservoir

Following numerous preliminary studies to the signing of the “Act of Iguaçú” (June 1966), a joint Brazilian-Paraguayan technical commission was set up in February 1967 (Kohlhepp,1987). In April 1970 an agreement was reached with two state-owned electricity companies (Eletrobras - Brazil and Andes - Paraguay) to prepare the necessary studies for a bi-national power station on Paraná River.

In November 1970 a joint venture was formed with the International Engineering Company (San Francisco, USA), an offshoot of Morrison Knudsen, and Electroconsult (Milan, Italy) was commissioned to carry out a three-year feasibility study of the technical and economic aspects of water resource exploitation along the common Brazilian-Paraguayan stretch of the river between *Sete Quedas/Saltos del Guairá and Foz do Iguaçú*, a length of approximately 180 km(Souza,2005). The findings covered 10 alternative sites and 50 types of project.

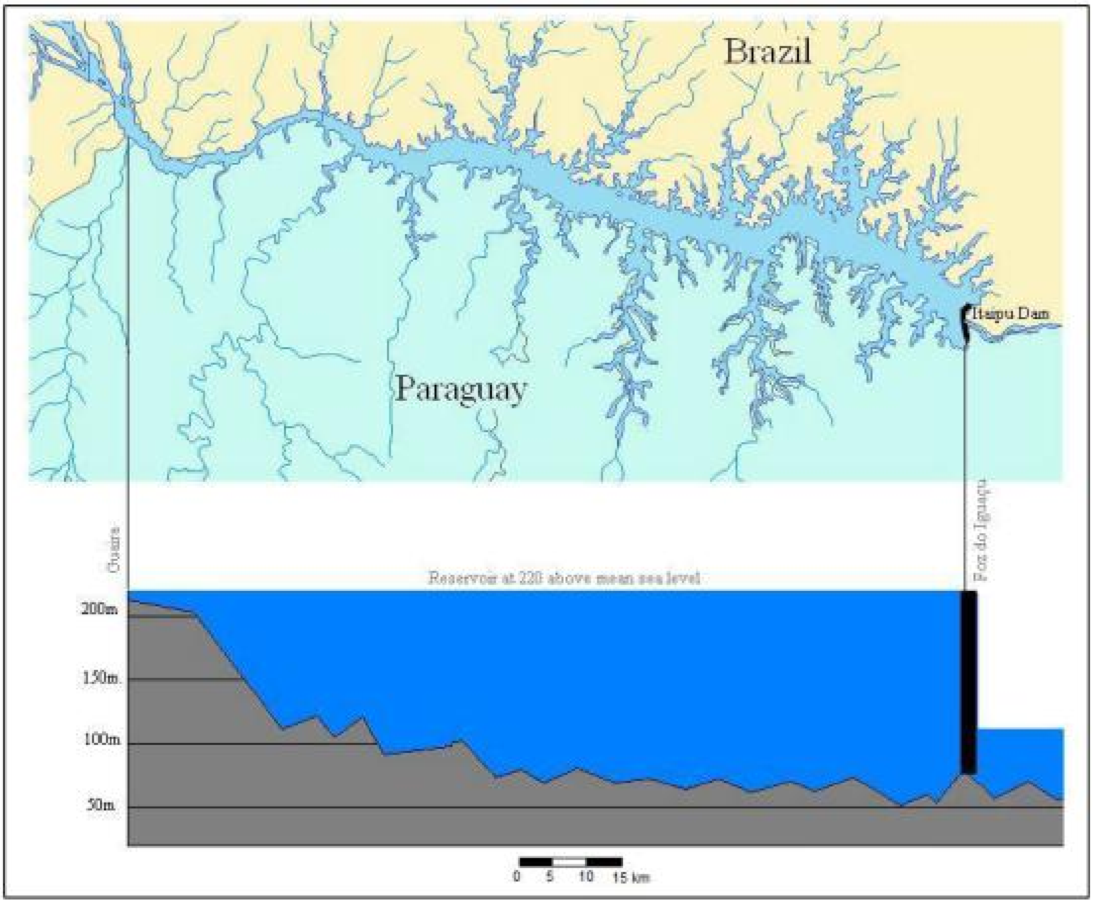

Figure 3.7: Itaipú reservoir [Source:(Itaipú,1994)]

The present site, which is 15 km upstream from Foz do Iguaçú at a point where the Paraná River is only 450 m wide, proved to be the best site, offering the cheapest energy production. Moreover, it was possible to build a high dam with very good geological conditions both for the foundations of the structure and for diverting the river. The reservoir created behind the Itaipú dam was to have a large capacity, a prerequisite for technical aspects of flow control. The site also proved favorable with respect to the existing infrastructural development of the region and the nearby towns of Foz do Iguaçú (Brazil) and Puerto Presidente Stroessner (currently Ciudad del Este - Paraguay), which were important logistically.

On April 26th, 1973 the Itaipú Agreement was concluded by the governments of Brazil and Paraguay and was signed by Presidents Médici and Stroessner (Pangrazio,1999). The project was officially inaugurated in May 1974 under Itaipú Binacional, the company set up to implement the entire project.

By early 1983 the Itaipú reservoir had been formed by backing up the the Paraná River to a height of 220 m above mean sea level. It not only flooded the 60 km long fault valley of the Paraná River but also submerged the famous Sete Quedas waterfalls on the Paraná River near Guaíra.

In 1984, the first of the 20 generator units began to operate (ITAIPÚ,2009). In 2006, the 19th unit began to operate and the 20th was officially inaugurated in 2007.

The reservoir stretching from Itaipú to Guaíra has a total length of 170 km, but due to the local morphology it is relatively narrow, with a maximum width of 7 km. The extremely deep incision was carved by the Paraná River into the melaphyre and diabase covering of the sloping plateau of southern Brazil. The Paraná River, whose level in this valley used to vary by nearly 50 m, has been cut down some 115 m to a height of 50 m above mean sea level. The distance between the upper edges of the valley between Guaíra and Itaipú rarely exceeded 600 m.

At a normal storage level, the water of the Itaipú reservoir covers an area of 1,350 km^2 (Kohlhepp,1987). At high water the area increases to 1,460 km^2, covering 835 km^2 in Brazil and 625 km^2 in Paraguay.

The financial compensation outlined in the Itaipú Treaty and included in the Yacyreta Treaty is to be interpreted as rent earned by the partners for their water (ITAIPÚ,1994). A rent payment is due whether the partner sells or buys power, and the bi-national corporation is supposed to charge this from the owners. This compensation is known as “Royalties from Itaipú”.

Chapter 4

4. Data and field research

This chapter discusses the data set, the temporal characteristics and, in the final section, the field research.

4.1 Data

The data was gathered from many institutions and organizations: IBGE[17] , INPE[18], the DGEEC[19], SEMA[20], ANDE[21] and ANEEL[22].

The image data displayed in the Table below is derived from the INPE and includes 46 scenes from the Landsat and CBERS series. The scenes that were chosen had a maximum cloud coverage of 10%. The images were co-registered (see section 5.2.5 on chapter Methodology) through semi-automatic pixel correlation based on the panchromatic band from Landsat ETM+ March 3rd, 2001. Duplicated pixels were replaced with null values (zero-fill) and thus the image contains alternating strips of missing data.

Data	Date	Scene	Data	Date	Scene
Landsat 1 - MSS	12.03.1973	239/78	Landsat 5 - TM	24.05.1990	224/77
Landsat 1 - MSS	23.02.1973	240/78	Landsat 7 - ETM	05.08.1999	224/78
Landsat 1 - MSS	24.02.1973	241/78	Landsat 7 - ETM	06.07.2000	224/78
Landsat 1 - MSS	16.12.1975	240/77-78	Landsat 7 - ETM	03.03.2001	224/77-78
Landsat 2 - MSS	19.07.1976	240/78	Landsat 7 - ETM	25.05.2002	224/77
Landsat 2 - MSS	21.10.1977	240/77-78	CBERS 2 - CCD	01.08.2004	161-162/127-128
Landsat 2 - MSS	14.03.1978	240/77-78	CBERS 2 - CCD	31.07.2005	161-162/127-128
Landsat 2 - MSS	11.10.1979	240/77-78	CBERS 2 - CCD	25.08.2006	161-162/127-128
Landsat 2 - MSS	12.08.1980	240/77-78	CBERS 2B - CCD	02.09.2008	162/128-129
Landsat 2 - MSS	09.05.1981	240/77-78	CBERS 2B - CCD	10.08.2008	161/129
Landsat 2 - MSS	16.01.1982	240/77-78	CBERS 2B - CCD	12.07.2008	162/128-129
Landsat 5 - TM	14.03.1987	223/77	CBERS 2B - CCD	16.06.2008	162/128-129
Landsat 5 - TM	19.04.1989	224/78	CBERS 2B - CCD	29.03.2009	162/128-129

Table 4.1: Available Landsat MSS TM and ETM data and CBERS CCD data.

[17] *Instituto Brasileiro de Geografia e Estatistica* (IBGE) (The Brazilian Institute of Geography and Statistics) is the agency responsible for statistical, geographic, cartographic, geodetic and environmental information in Brazil; http://www.ibge.gov.br

[18] *Instituto Nacional de Pesquisas Espaciais* (INPE) - (The National Institute for Space Research) is a research unit of the Brazilian Ministry of Science and Technology; http://www.inpe.br/

[19] *Dirección General de Estadísticas, Encuestas y Censos*(DGEEC) (The General Management of Statistics Information and Cartography) is the agency responsible for statistical, geographic and cartographic information in Paraguay; http://www.dgeec.gov.py/

[20] *Secretaria de Estado do Meio Ambiente e Recursos Hídricos*(SEMA)- (The Environment Bureau of Paraná); http://www.sema.pr.gov.br

[21] *Administración Nacional de Electricidad*}(ANDE)- (The National Electricity Administration) controls the entire Paraguayan electricity market, including generation, transmission and distribution. http://www.ande.gov.py/

[22] *Agencia Nacional de Energia Elétrica* (ANNEL) - (The Brazilian Electricity Regulatory Agency). http://www.aneel.gov.br

The Landsat MSS data (table 4.1) were acquired for each year (+/- 1 year) from 1973 until 1982. However, good homogeneity was not possible for the same season. According to Albertz (2007), images taken during the same season in different years minimize the seasonal changes in reflectance of specific features. From the MSS data set, 6 of the 11 images were taken from December to March, which is when the wet season begins in this region. The other 5 images correspond to the dry season, i.e., the winter and fall in the Southern Hemisphere. The reduction of class was a way to minimize this problem.

Landsat TM and ETM+ data were acquired every 5 years since 1985 (table 4.1). CBERS images with a maximum cloud cover of 10% were acquired every 4 months in 2008. The acquisition of a cloud-free image of this region in 2007 was impossible. This reveals a common problem concerning passive sensors in South America- the annual cloud covering of regions. For rainy regions such as these there are few cloud-free images for long periods of time.

4.2 Field research

The field research, whose aim was to collect additional data in order to interpret the images from the data sets as well as to solve doubts about the classes, was carried out in December 2008.

An important issue was the lack of control samples for the historic data from the MSS sensor. For example, figure 4.1 shows a region recognized since 1973 as São Miguel do Iguaçú. Sites such as these were found in the region near the National Park and international airport.

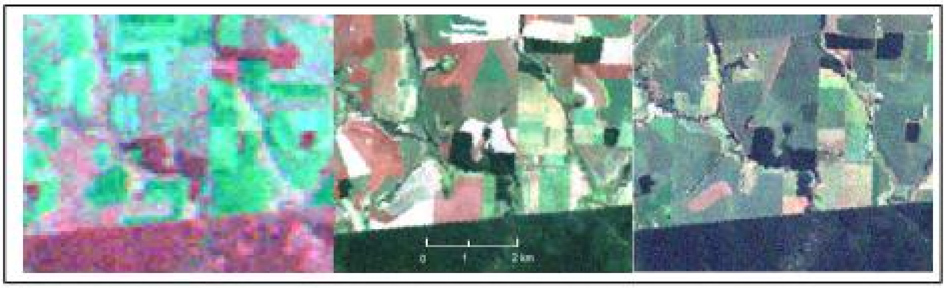

Figure 4.1: A feature recognized in 1973, 1990, 2004.

The field survey was done with a GPS receiver, a digital camera and a tablet PC equipped with GIS software for dimensional sketching. The GPS receiver was linked to the PC and the data were stored using the GIS software. GPS then lead the way to the selected sites and measured the azimuth of the investigator while taking a photograph of the selected site. Furthermore, either a dimensional sketch could be recorded or the field information could be queried from the Tablet PC. Accordingly, the results of the field investigation, including the pictures and the description of land usage, were prepared with the GIS system for future use as control or training samples for remote sensing tasks.

Finally, photos were collected for interpretation that identified features and controlled areas, such as regions without wooded cover at the reservoir. Figure 4.2 shows an example of an soybean area in Foz do Iguaçú.

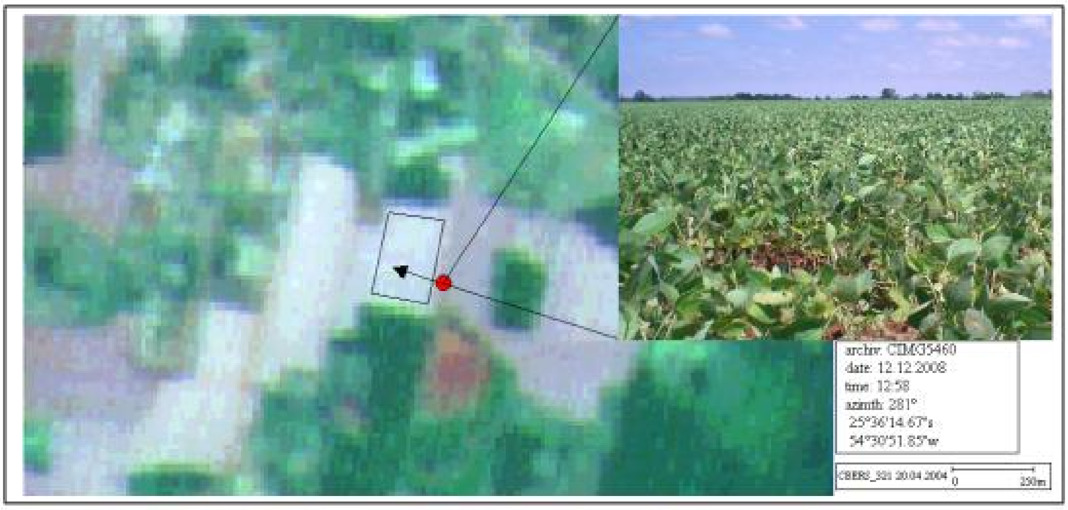

Figure 4.2: Area acquired soybean area in the field research.

Sites were sampled only on the Brazilian side due to logistical problems. However, it was established in chapter three that the land use differences do not conflict since the agricultural culture in the border region was heavily influenced by Brazilian migration from the neighboring regions. For this reason the coverings and the land use verified on the Paraguayan side are assumed to be similar to those on the Brazilian side.

Twenty sites were visited in the course of the research, in which important partners were identified. One of them was an area management and distribution center for crops such as soybean and manioc.

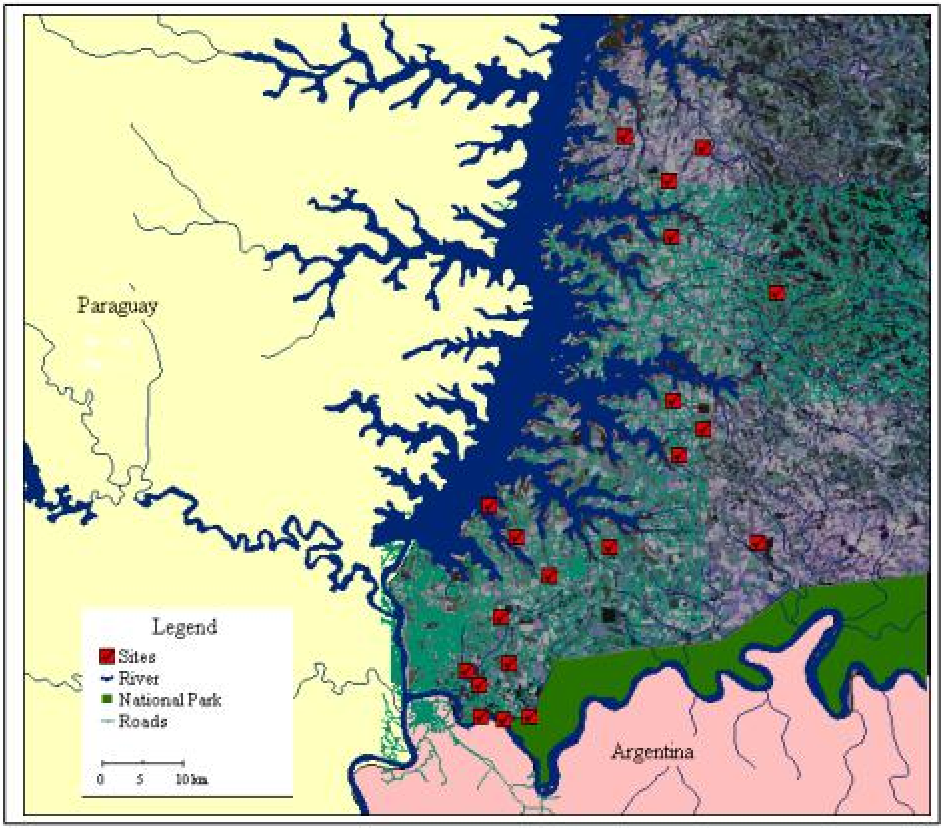

Figure 4.3: Field research sites.

The field areas were identified soybean, pasture, bare soil, ploughed soil, crop areas, triticale (a hybrid of wheat and rye), corn, tobacco, grass, sand, eucalyptus and sugarcane.

The IBGE provides a systematic monthly survey of agricultural production information for the forecast and monitoring of agricultural harvests, with estimates for production, average yield and planted and harvested areas, with municipal districts as collection units.

Chapter 5

5. Methodology

The overall objective of this study was to determine the effects of territorial redistribution in South America, making use of available resources such as remote sensing data as well as Brazilian and Paraguayan statistical surveys. Case study Itaipú refers to a hydroelectric power plant and reservoir on the Brazil-Paraguay border. The dam was constructed between 1975 and 1982 and created an artificial lake that extends approximately 170 km^2, partially covering many municipalities in Brazil and Paraguay.

Despite being the second largest operational hydroelectric power plant in world, Itaipú is hardly an exception in South America, where it is possible to find reservoirs larger than Itaipú's. Nevertheless the development of any such projects impact many regional aspects. For example, a huge population group must be relocated in the first stage. In the second stage, the creation of the reservoir reduces both productive areas and forested zones.

This study examines the validity of these assumptions regarding the accurate assessment of land-use maps derived from satellites images. The methodology was arranged according to the flow chart in Figure 5.1 and was started with the image data set. Than this data set was classified using an evaluation methodology based on random reference separation and validation. The result thematic maps were analyzed and compared with statistical date and historical sources.

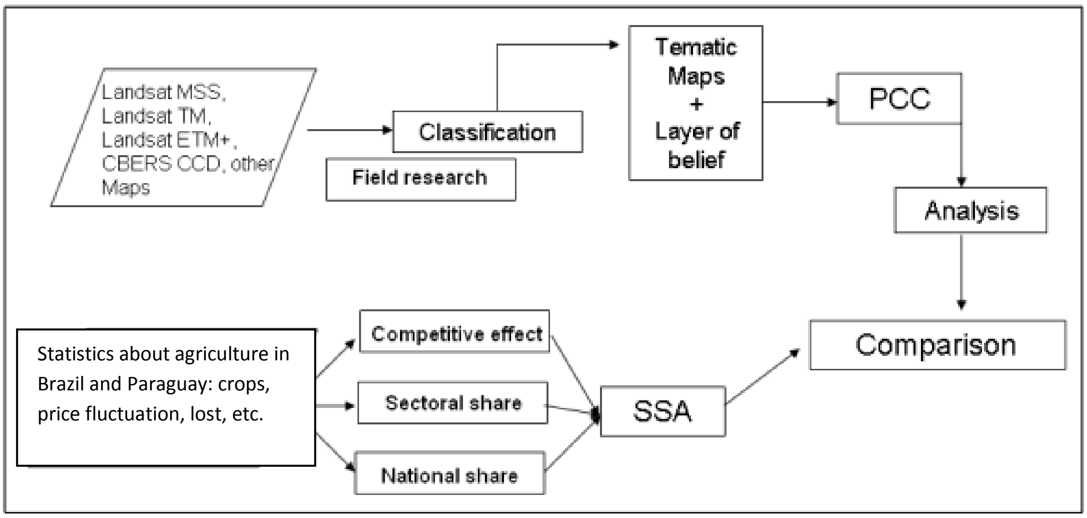

Figure 5.1: Arrangement of methodological steps.

The initial data are the result of a large survey on the history and development of the region where the Itaipú Dam was erected and the Itaipú reservoir is located. Research on this region was carried out to allow for both the selection and homogeneity of relevant information. This means that some sources were unreliable and others were incomplete.

The image data set required a separate research endeavor about technical aspects and sensor characteristics, since sensor imagery such as the multispectral scanner requires specific pre-processing, comparable to an ETM sensor.

5.1 Temporal sampling

Another important issue is appropriate temporal sampling when monitoring vegetation: under-sampling may not accurately describe the phenomenon being considered, whereas over-sampling would increase the cost of the project without additional benefit.

The goal is to estimate the optimum temporal resolution for long-time vegetation monitoring on a regional scale by means of annual images and composites. The idea is also expressed as an investigation into the optimum temporal resolution for monitoring vegetation conditions during the wet season using time-series analysis of medium resolution sensors (20 - 80 m) that distinguish between the two major vegetation categories: natural and managed vegetation. A quality assessment of multi-temporal composites following the proposed optimum temporal resolution was carried out.

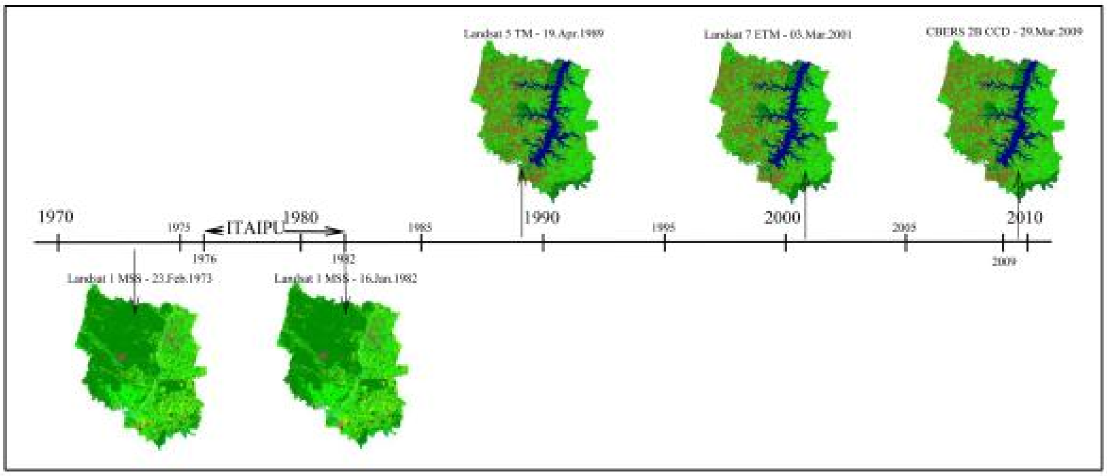

Figure 5.2: Distribution of main data series (10 ± 2 years)

The temporal approach proposed here employs a transition graph to describe the temporal dependencies between the pertinent classes. Such a strategy enables the user to formulate a priori temporal knowledge and to use it during the automatic analysis in order to help classify the scene. Structural knowledge about temporal dependencies can thus be exploited to refine decisions during the interpretation process. Temporal knowledge is used in the statistical classification process and directly influences the results of the interpretation. In a previous study (Müller et al. ,2004; Pakzad, 2002), the use of temporal knowledge was limited to hypothesis making for possible new states of the region, and not the formulation of real probabilities.

The study started with two images but increased at regular intervals 10±2, 5±2, 2±2 years series. Figure 5.2 shows the 10±2 year time series. In this example, the time interval of the scenes is 10 years with a 2-year maximum variation.

5.2 Classification

To carry out the classification process, predefined spectrally characterized classes were determined. The resulting images that have been classified along these lines may be treated as a thematic map depicting the land cover of the region.

5.2.1 Maximum Likelihood Classification

The Maximum Likelihood Classifier (ML) is one of the most widely used supervised classification techniques with remote monitoring data. It quantitatively evaluates both the variance and covariance of the class spectral response patterns when classifying an unknown pixel.

It is assumed that the distribution of the cloud of points forming the category training data is Gaussian (normally distributed). This assumption of normality is generally reasonable for common spectral response distributions (figure 5.3)(Lillesand&Kiefer,2002). Under this assumption, the distribution of a class response pattern can be completely described by the mean vector μ_i and the covariance matrix C_i. Within these parameters, the statistical probability of a given pixel value being a member of a particular land cover class can be computed. The resulting bell-shaped surfaces are called probability functions, and there is one such function for each spectral class.

This classifier evaluates the a posteriori probability that a certain pixel x in the image belongs to one of the study classes. The classifier attributes pixel x to the class Ω_i in which it has the highest probability of belonging. This is *Classification Law (*Bähr&Vögtle,1999) expressed by the equation:

$$x \in \omega_i, if p(x \mid \omega_i)p(\omega_i) > p(x \mid \omega_j)p(\omega_j) \quad (5.1)$$

According to Tjan and Nandy (2006), this classification also takes into consideration the a priori probability of differentiated occurrences of the study classes Ω_i . But, surprisingly, this prior knowledge is almost always neglected in the classification process, assuming that all classes have an equal possibility of occurrence. Consequently, the likelihood function, considering $p(\Omega_i)$ and p(x) constant, becomes

$$p(x \mid \omega_i)p(\omega_i) \approx p(x \mid \omega_i) \quad (5.2)$$

The normal distribution for i- dimensions is adopted for the ML to represent the distribution function $p(x|\Omega_i)$. It is expressed (Bähr&Vögtle,1999) as:

$$p(x \mid \omega_i) = \frac{1}{\sqrt{2\pi^n |C_i|}} \exp\left(\frac{-1}{2(x-\mu_i)^T C_i^{-1}(x-\mu_i)}\right) \quad (5.3)$$

Figure 5.3 presents the principle of the ML method, where each pixel is attributed to one of the two classes according to its probability of being distributed in two spectral bands.

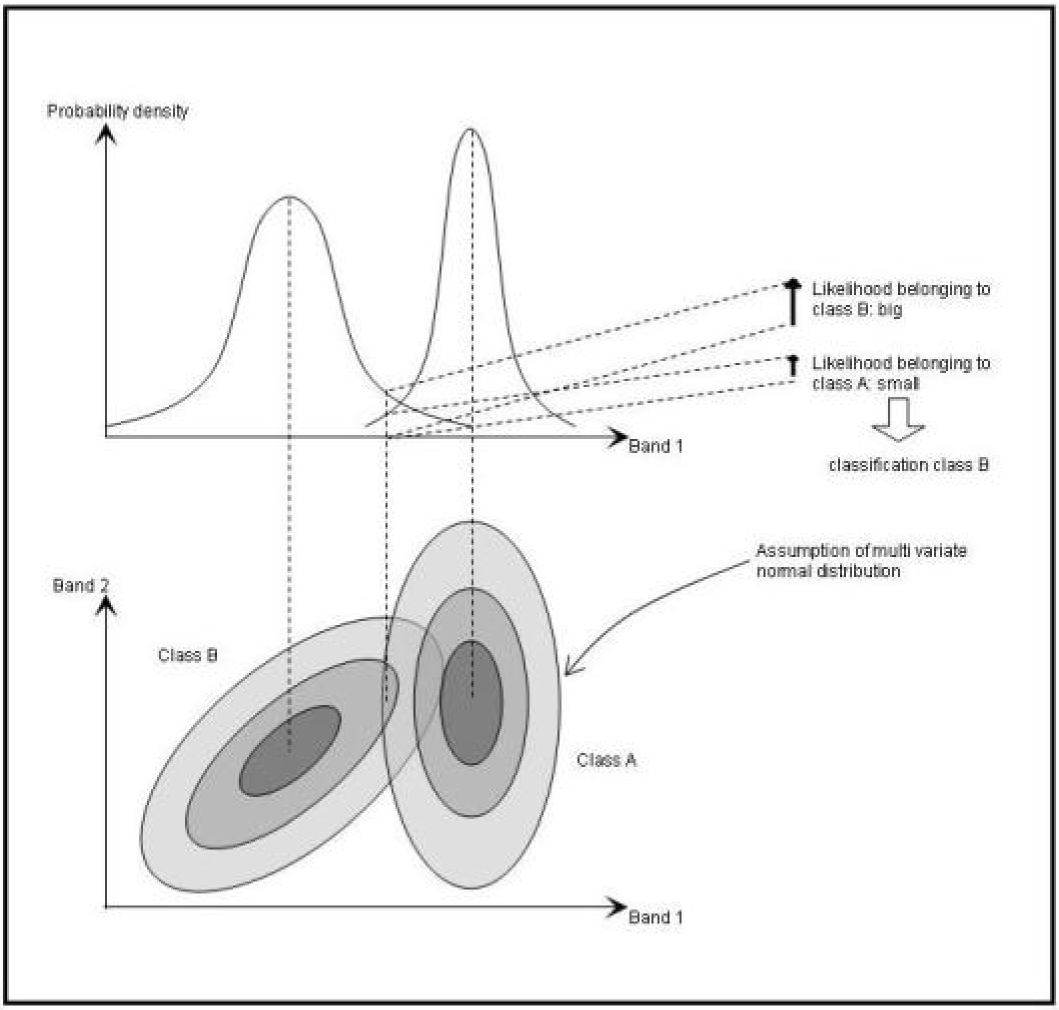

Figure 5.3: Concept of Maximum Likelihood Method [Source:(Lillesand & Kiefer, 2002)]

5.2.2 Layer of belief

The Theory of Evidence (Guan&Bell,1991) proposes the use of certain concepts like belief and plausibility which may be applied to create a so called "layer of belief" "*layer of belief*".

The derivation of evidence theory is based on propositions for representing subsets of the set of all possible values (numeric or not) for some variables of interest. The advantage of the theory is that it explicitly represents uncertainty. It takes into account what remains unknown directly and represents what is known exactly.

Evidence theory is a generalization of Bayesian statistics, which also aims to provide a theory of partial belief. The theory assigns "masses" to subsets of a set of values which some quantities of interest can take, while in Bayesian statistics "densities" are linked to the elements.

In evidence theory, evidence is described in terms of evidential functions. The *belief-interval or evidence-interval bi* was defined as the difference between belief bel(X) and plausibility plau(X). This can be interpreted as an estimation of uncertainty between accepting and rejecting the classification of pixel x in a class Ω_i. If, for the classification of maximum likelihood it associated,

$$bel(\omega_i) \sim N(\mu_n, \sigma_n^2) \therefore P(x \mid \omega_i) \tag{5.4}$$

it results in the following normal function (FN), describing the distribution behavior of pixels in a given class:

$$FN(x, \mu_n, \sigma_n^2) = \frac{1}{\sigma_n \sqrt{2\pi}} \exp \frac{-X - \mu_n}{2\sigma_n^2} \tag{5.5}$$

For every Ω_i class there is a $N(\mu_n,\sigma_n^2)$ normal distribution that every x pixel in the image receives a value, then there is one $p(x|\Omega_i)$ probability that a pixel will to belong to Ω_i class, such that the classified maximum likelihood attributes the x pixel to the Ω_i class that satisfies the condition of maximum value of $p(x|\Omega_i)$, independently of the value of $p(x|\Omega_i)$. It was determined in this study, therefore, to add not only the pixels, but also a value generated in function of the relevant probabilities $p(x|\Omega_i)$.

$$f(x) = \frac{p(x \mid \omega_i)}{\sum_{i=1}^{m} p(x \mid \omega_i)} \tag{5.6}$$

The values of the function will depend on the maximum value of $p(x|\Omega_i)$and on the difference among the values attributed to the other classes. Thus, there would be two classes with normalized functions that are described by the curves in Figure 5.4a , with values of f(x) presented in Figure 5.4b:

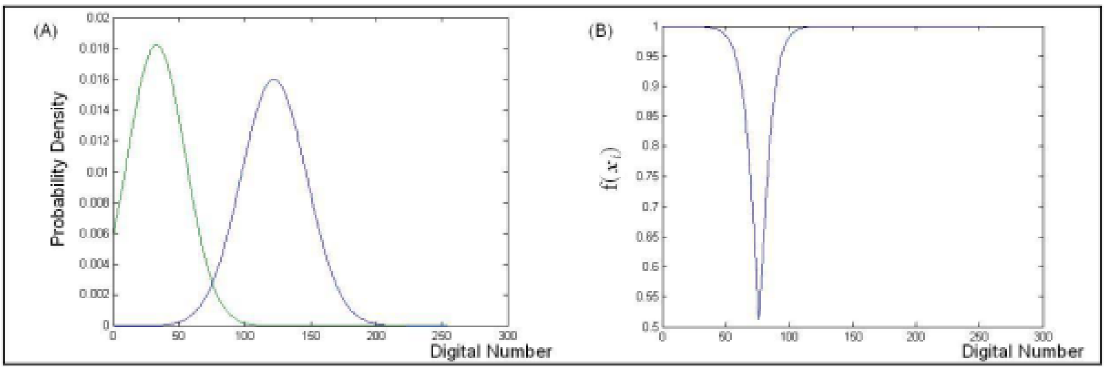

Figure 5.4: Distribution of probability for two classes in one spectral band.

The values tend toward 1 when one of the probabilities of relevance is superior to the other. The values tend toward a minimum value, in the case of two half classes, when the difference of the relevance probability would be minimal.

This variation in the value of $p(x|\Omega_i)$refers to the non-correspondence of very low values of a class; pixels in which the difference of this function is similar to that of another pixel cannot be simply added to the class. Although this is only one criterion of decision, it is possible to effectively evaluate regions in the image that have low values in this function and effectively resulted from a mixture of classes or display regions belonging to a possible new class.

5.2.3 Sampling Design

When researchers assess the accuracy of maps derived from remote sensing data and cannot check the entire mapped area, sampling becomes the default means for determining the accuracy of land-cover maps. Any sampling scheme should satisfy three criteria (Congalton&Green:2008):

1. A map of low accuracy should have a low probability of being accepted.

2. A map of high accuracy should have a high probability of being accepted.

3. A minimum number N of ground truth samples should be required.

Researchers have published formulas for calculating the number of necessary sample plots depending on the objectives of the project (Rosenfield et al.,1982; Rosenfield,1982; Congalton,1991). Some types of sampling schemes are:

- Simple Random Sampling (SRS).
- Stratified Random Sampling (STRAT).
- Systematic Sampling (SYS).
- Stratified Systematic Unaligned Sampling (SSUS).
- Cluster Sampling (CLUSTER).

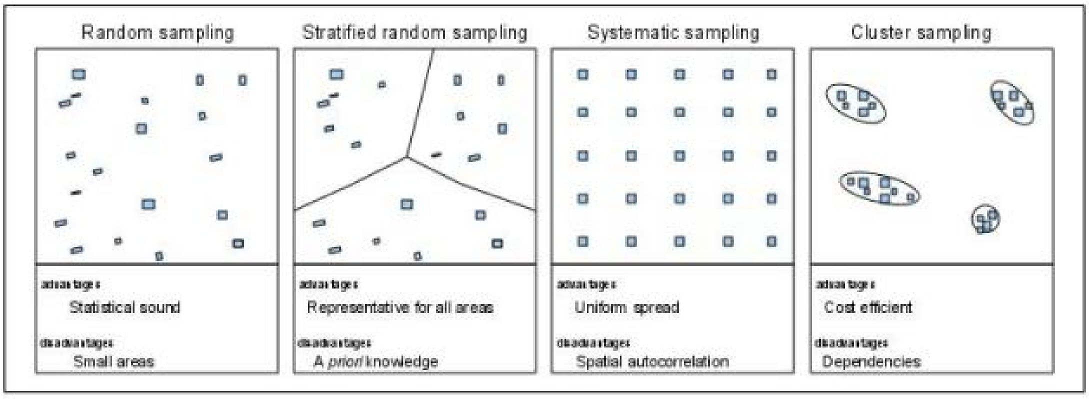

Figure 5.5: Sampling Schemes. [Source:(Banko,1998)]

Figure 5.5 (Banko,1998) illustrates the various sampling approaches and lists their major advantages and drawbacks. The choice of sampling technique will depend upon several factors, including the size of the study area, the type and distribution of features being mapped, and the costs of acquiring verification data.

Both random and systematic sampling were impractical in this study due to the 7,800 km^2 coverage and the distribution of recognizable features in each image. Instead, cluster sampling was chosen, although it was necessary to reduce the dependencies. To accomplish this, the application of random divisions of the evaluation and training data was decided upon. The operator extracted only reference samples, which were randomly divided into training data sets and one evaluation data set.

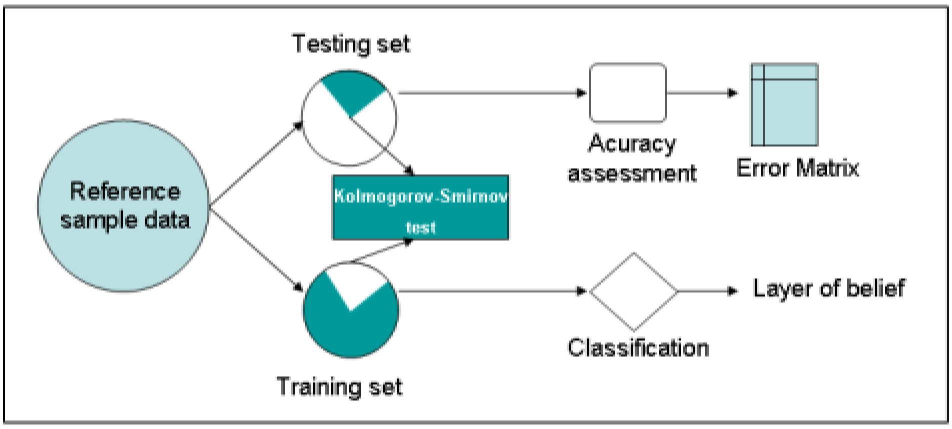

Figure 5.6: Applied sampling.

Sampling required a statistical test to verify consistency. The Kolmogorov-Smirnov test verified if a subset has the same population distribution as Gaussian, Binomial or Chi-square. Then the evaluation data set was used in the error matrix and the training data set for classification and layer of belief.

Number of samples

Once the sample scheme was decided upon, the correct number of samples to be included was determined. The sample size is a compromise between effort expenditure and minimum sample requirements.

In general, the larger the available sample size, the greater the confidence one can have in assessments based on that sample. Depending on the goal of the accuracy assessment, the minimum sufficient number of sample plots can be calculated by different methods.

Fitzpatick-Lins (1981) used the normal approximation equation to compute the sample size for assessing a land use/land cover map. He suggested that the sample size N could be used to assess the accuracy of a land-use classification map by using the formula in a binomial probability theory:

$$N = \frac{Z^2(p_{accur} q_{accur})}{E^2} \qquad (5.7)$$

where,

p_{accur} is the expected percent accuracy,

$q_{accur} = 100 - p_{accur}$,

E is the allowable error, and

Z = 1.96 of the standard normal deviation for the 95% two-sided confidence level.

An expected accuracy of 85% was selected because the land-use classification system specifies that each category should be mapped to at least 85% accuracy. An allowable error of 2% was used by Fitzpatrick-Lins (1981) in a study that involved very little field verification. In this study the allowable error of 5% reflects a low level of confidence in the supervised classification process. Substituting these values into equation 5.7, N = 75 samples.

5.2.4 Class definition

The classes were defined based on limitations imposed by older data. The decision regarding whether to use samples as training or evaluation was limited to theoretical knowledge of the region and the field research carried out in 2008. Four main classes were defined: urban areas, woodland, bodies of water and agricultural areas which, due to diversity of responses, was defined as comprising all other areas.

Spectral Separability pairs	JM distance	Spectral Separability pairs	JM distance
Urban areas and Cultivated areas	1.38	Woodland and Cultivated areas	1.87
Urban areas and Grassland	1.50	Ploughed soil and Cultivated areas	1.99
Urban areas and Ploughed soil	1.75	Woodland points and Ploughed soil	1.99
Urban areas and Woodland	1.76	Grassland and Ploughed soil	1.99
Water and Ploughed soil	1.81	Water and Cultivated areas	2.00
Grassland and Cultivated areas	1.83	Water and Grassland	2.00
Woodland and Grassland	1.86	Woodland and Water	2.00

Table 5.1: Class separability using Transformed Divergence for bands 123, MSS 23.Feb.1973.

Table 5.1 shows spectral separability by means of the Jeffries-Matusita (JM)[23] distance between pair classes for the 10-year series. The calculation of JM distance results in a value between 0 and 2, with higher values representing better separability of class pairs. Even good distances between the pairs did not necessarily reveal a real distinction among the classes because this assessment depended on sample quality.

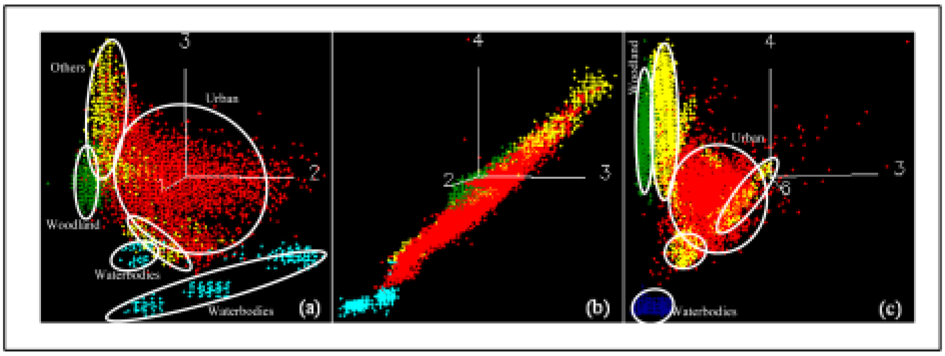

Figure 5.7: Scatterplots from samples of epoch 23.Feb.1973.

Figure 5.7 shows the behavior of class samples in different band combinations. In picture 5.7(a), bands 123 of the MSS sensor show a good differentiation among the proposed classes. In (b) a high correlation can be observed between bands 34 for the same sensor. This

[23] Formula described by (Schowengerdt,2007) third ed. page 398.

encouraged the use of only 3 of the 4 available bands for the MSS data. Figure 2(c) shows the class distribution in TM sensor bands 437. This was determined to be a better definition of the proposed category boundaries than the MSS.

5.2.5 Accuracy Assessment

The procedures for accuracy assessment were conducted in two parts: geometric and thematic evaluation. The geometric correction or registration was based on a Landsat ETM+ panchromatic scene. The registration of the entire data set was made from this base image taken on March 3rd, 2001.

Geometric Accuracy Assessment

The images were co-registered through semi-automatic pixel correlation with an initial manual identification of 4 to 8 points based on the Landsat ETM+ 03.Mar.2001.

In this method the sampled radiometric values of a (target) image with dimensions (mxn) of a reference point belongs to reference image T. By sampling the radiometric values of a fraction of image S with equal dimensions (mxn) in the search window, a reference point can be found. The fraction (mxn) scans the search window whose size has been previously defined. The value of the correlation ρ can be determined with the following formula:

$$\rho = \frac{\sum x_t x_s - mn\bar{x}_t\bar{x}_s}{\sqrt{(\sum x_t^2 - mn\bar{x}_t{}^2)(\sum x_s^2 - mn\bar{x}_s{}^2)}} \tag{5.8}$$

where:

mn- number of pixels of the target image; x_t , x_s the grey scale values of the target image and the corresponding fraction; $\bar{x}_t$, $\bar{x}_s$ average of the grey scale values of the target image and the corresponding fraction.

The target image was compared with fractions of the search window to find the location (i,j) of the highest correlation ρ. The manual identification of the initial point is easily following the automatic search. Image registration was carried out with a first order polynomial transformation because its reference was another image with similar geometric resolution.

The reference data from March 3rd, 2001 were orthorectified using geodetic and elevation control data to correct for positional accuracy and relief displacement. The geometric accuracy was in the order of 1 pixel.

Ground Control Points (GCPs) were used to calculate a transformation from an image coordinate system to the specific ground coordinate system. Accuracy was assessed by calculating the root-mean-square (RMS) error, which is a combination of the error in x-direction (RMS_x) and y-direction (RMS_y):

$$RMS_{xy} = \sqrt{RMS_x^2 + RMS_y^2} \tag{5.9}$$

where the RMS error in one direction can be calculated as:

$$RMS_x = \left[\frac{1}{n}\sum_{i=1}^{n}\left(\delta_{xi}^2\right)\right]^{\frac{1}{2}} \tag{5.10}$$

where, δ_{xi} is the residual of the i^{th} GCP and n = the number of GCPs. Statistically, it is more sound to calculate a standard deviation. The sum of the residuals is divided by the redundancy (r), which depends on the degree of freedom determined by the applied polynomial for large numbers of GCPs, the RMS error and the standard deviation.

The use of uncorrelated CGPs is necessary for an independent assessment. The extraction of supplementary control points is also helpful. In this stage the random process was chosen for select the points to accuracy assessment.

Graphic RMS_{set} 5.8 refers to the results of data set registration. The bars show the planimetric RMS obtained for the region of a correspondent year image. Until 1982 the MSS with a mean RMS of 65 meters enjoyed a proportionally high variation in RMS values. The variability of conditions in each scene (humidity, season, shade) made the identification of control points difficult. For these scenes, the control points were linked to rivers where possible instead of roads, which do not produce optimal distribution throughout the scene. However, the results were compatible with a pixel size equivalent to 56x79 m of land.

The data sets after 1990 obtained a 25-meter positional accuracy or better, which is related to the higher resolution of the sensor as well as control point feature identification.

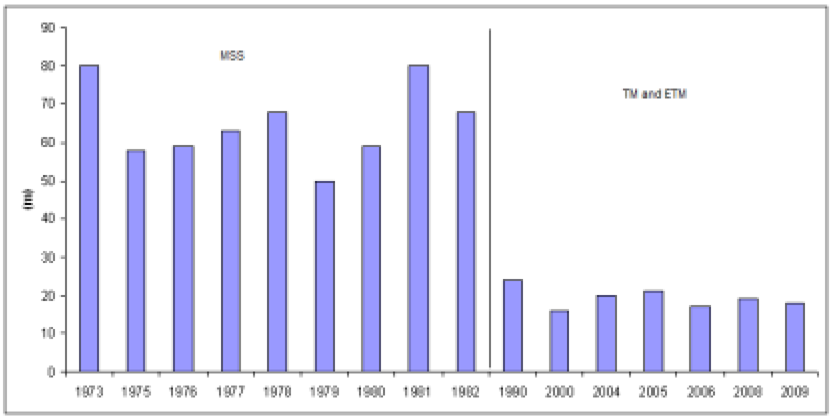

Figure 5.8: RMS acquired for data series.

The geometric evaluation used supplementary sample points based on the 1:25,000 map from Foz do Iguaçu, Cidad del Este, São Miguel do Iguaçú, Santa Terezinha de Itaipú, Hernandarias and Itaipúlândia.

Figure 5.9 shows an example of the behavior of one MSS image. The residual errors in the adjustment (RMSt) and control points (RMSe) were plotted on the graph. There were about 45% more matchings points than were estimated by RMS in the registration.

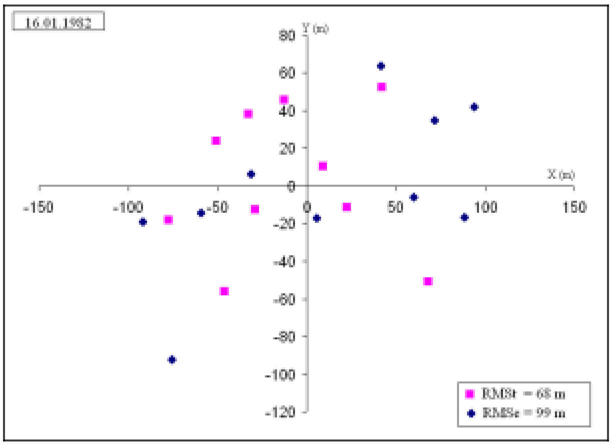

Figure 5.9: Planimetric residuals from supplementary sample points (MSS data).

5.3 Shift share analyses

Shift-share analysis tries to explain changes in a local phenomenon by breaking-down changes into three main sources: national, structural share, and competitive effect (Gaigné et al.,2005). The national share corresponds to the result of the national growth parameter (e.g. population, soybean production). The structural share and competitive effect were calculated from the changes in the region as well as its neighbors.

If we denote with V_{ij} the initial value of the considered economic magnitude that corresponds to the sector in the spatial unit j, V'_{ij} being the final value of the same magnitude, then the change experienced by this variable can be expressed as follows:

$$V'_{ij} - V_{ij} = \Delta V_{ij} = EN + ES + ER \qquad (5.11)$$

The three terms of this identity correspond to the shift-share effects:

- EN $\rightarrow$ National share
- ES $\rightarrow$ Regional or structural share
- ER $\rightarrow$ Competitive effect

Thus the structural share indicates positive or negative influence on the growth of specialization in productive activity in sectors with growth rates over or under the average. The competitive effect indicates the special dynamics of a regional sector compared to the dynamics of the same sector on a national level.

The shift-share analysis has some limitations, however. First, it uses an arbitrary selection of weights that are not updated with changes in productive structure. Second, the results are sensitive to the degree of structural aggregation. The growth attributable to secondary multipliers is assigned to the competitive effect instead of the structural share, resulting in the interdependence of both effects.

5.4 Scenario Building

The need for anticipatory conjunctures has led to the development of methodologies that produce insights on future scenarios. The two main forms are forecasts and foresights. The distinction between forecasts and foresights is that, in general, the aim of a forecast is to obtain precise values of the future based on extrapolations of past variable relations, while foresight is mostly qualitative in nature; its aim is to provide a scenario of the future based on radical breaks or structural effects that destroy past tendencies. Contrary to forecasts, foresights do not address the dynamic processes that will produce the final state. Instead, they explore the general consistency of the final scenario by analyzing all the adjustment processes that are likely to happen.

Two steps are involved in scenario building for foresights. In the first, a hypothesis is developed involving a main element or driving force that influences and regulates the system. The second step inserts changes to this element into the thematic view of the region and establishes a structural relationship between the basic purpose and thematic variables.

Because forecasts extrapolate from past tendencies, they yield the best results in a short-term perspective. Foresight provides parameters for the future based on radical structural breaks with the past and generally assumes a long-term perspective (decades).

The intention is not to provide precise estimates of certain future levels, but rather to highlight the main tendencies, major adjustments to change, and relative behavioral paths that will be at work, given some conditional assumptions about the influence of the main driving forces.

Scenario building involves aspects of foresight, specifically the recognition that many factors may combine in complex ways to create future development stages. The method also allows the inclusion of factors that are difficult to formalize, such as novel insights about the future market, unprecedented regulations or inventions and climate change.

Chapter 6

6. Results and Discussion

The quantification and assessment of the Itaipú project's ecological effects are hampered by a lack of long-term observations and measurements in the area. Remote sensing results are thus used as additional information.

Figure 6.1: The Study Area and current political divisions.

The results demonstrate the thematic map comparison suggested in the fifth chapter. The methodology was applied to the Itaipú region in order to better describe the changes that have occurred, including an outline of the contributions of regional agents to the changes verified in the region. Subsequently, environmental questions regarding wooded area coverage are discussed. The distribution and coverage area of woody vegetation and the areas cleared for farming are associated with a structural change in regional and national economy. The consequences of this change are evident in demographic transformations. Thus, we were surveying social and environmental data that both described regional development demonstrated the reasons for land cover change. In the final section, the implications of the changes in regional social structure are discussed. The analyzed period spans 1973 through 2009.

The researched area consists of five Paraguayan districts and six Brazilian municipalities. Chapter three describes how the Paraguayan administrative structures which are organized in a system of districts and departments, while in Brazil there are states and municipalities. In this region the two types of structure are geometrically and economically comparable.

Figure 6.1 shows the study region, municipalities and districts that were selected for this study. The districts in Paraguay were Minga Porá, San Alberto, Mbaracayú, Hernandarias and Ciudad del Este; in Brazil the included municipalities were Santa Helena, Missal, Itaipúlândia, São Miguel, Santa Terezinha de Itaipú and Foz do Iguaçu.

6.1 Thematic Map comparison

The results were analyzed in three ways: first, the initial and final conditions of the region were compared; second, the progression of modifications each 10 years was studied, narrowing the list of probable change agents; third, using the section classification described in chapter five, precise issues that exemplify regional dynamics were identified.

The left and right sides of Figure 6.2 show the initial and present conditions of the region. In the Brazilian part of the region, east of the Iguaçu River, it can be observed that the process of agricultural expansion is in its advanced stage. Few regions remain unexploited; one of these is 100 km north of Foz do Iguaçu and another is a part of the Iguaçu National Park, near the southern edge of the region.

In Paraguay, west of the Paraná River, there is dense forest cover mainly in the districts north of Hernandarias. The areas used for agriculture are concentrated in Hernandarias and Ciudad del Este. These areas form an axis starting in Hernandarias that passes through the districts of Mbaracayú and San Alberto. This axis corresponds to the highway that connects the region to the north of the Department and the district of Salto del Guairá.

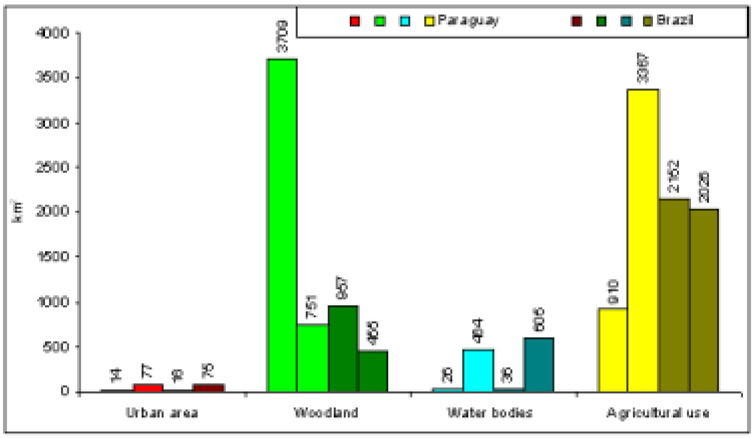

Figure 6.2: Results for 23.Feb.1973 and from 29.Mar.2009.

The first map (figure 6.3) from 1973 corresponds to a stage at which the feasibility study had already been completed and the site for the Itaipú dam had been chosen by the governments of Brazil and Paraguay. Construction was officially started in 1974. At that time there was a dense forest on the Paraguayan side of the Paraná River. Deforestation began in the south at the Paraná River along the road that links Hernandarias and Salto del Guairá.

On the Brazilian side, in the extreme west of Paraná, aggressive policies of agricultural expansion have been implemented since the 1950s. Little remains of the original forest apart from two large wooded areas: one southwest of Foz do Iguaçú in the Iguaçú National Park and another about 100 km north of Foz do Iguaçú in the border region near the Paraná River.

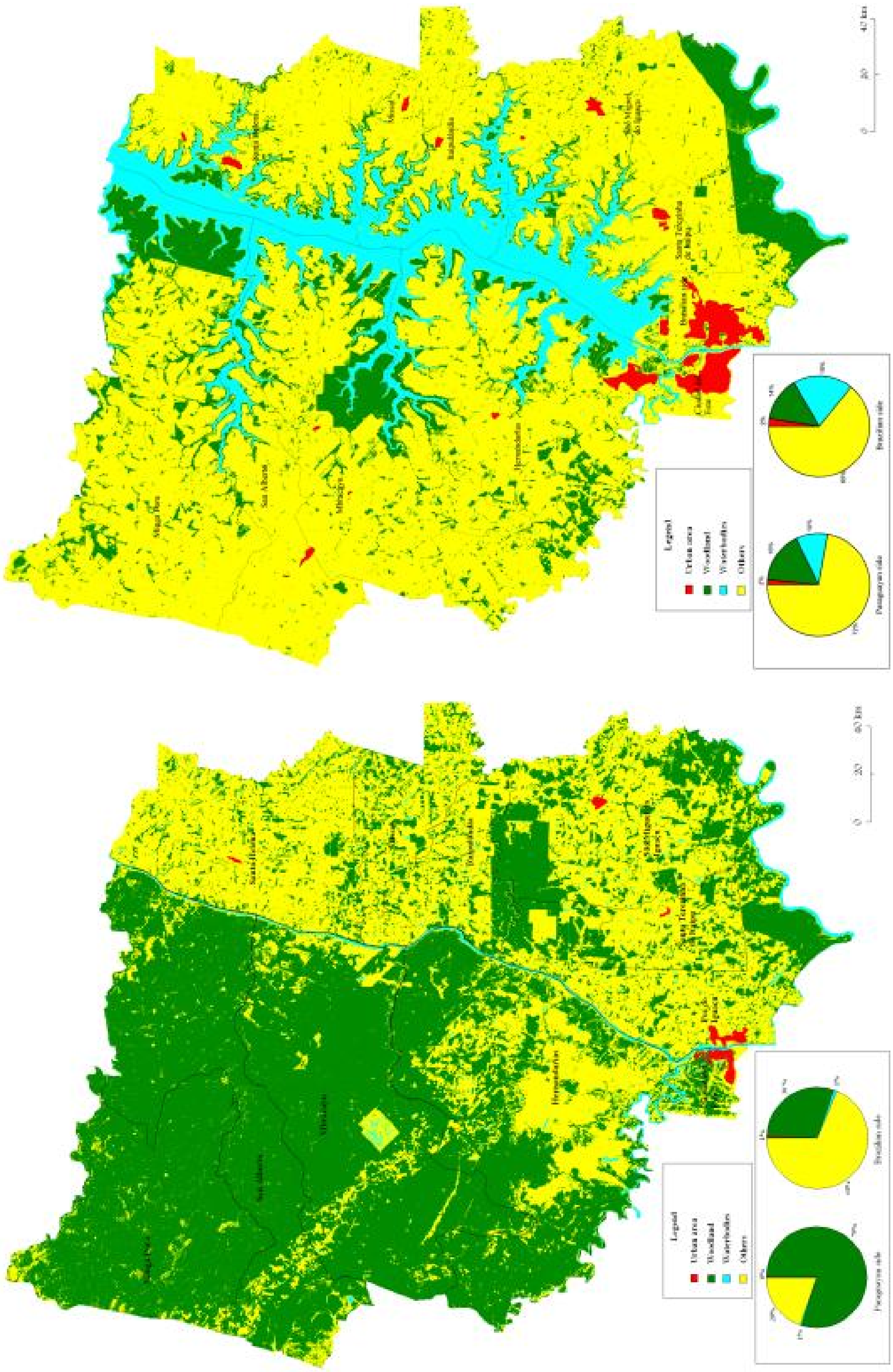

Figure 6.3: Thematic Map from 23.Feb.1973 and from 29.Mar.2009.

The areas with the greatest change are on the Paraguayan side. A dense original forest was displaced by agricultural use (ploughed land and grassland). The woodland area has decreased from 3,709 km^2 in 1973 to 751 km^2 in 2009.

		Initial Condition			1973
Paraguay	Urban area	Woodland	Water bodies	Agricultural use	Class Total
Final Condition: Urban area	**12**	26	1	38	**77**
Final Condition: Woodland	1	**645**	3	102	**751**
Final Condition: Water bodies	0	302	**18**	144	**464**
Final Condition: Agricultural use	1	2,736	4	**626**	**3,367**
Final Condition: Class Total 2009	**14**	**3,709**	**26**	**910**	**4,659**
Image Difference	**+63**	**−2,958**	**+438**	**+2,457**	

		Initial Condition			1973
Brazil	Urban area	Woodland	Water bodies	Agricultural use	Class Total
Final Condition: Urban area	**14**	6	6	49	**75**
Final Condition: Woodland	1	**246**	2	206	**455**
Final Condition: Water bodies	0	186	**26**	395	**605**
Final Condition: Agricultural use	1	519	2	**1,504**	**2,026**
Final Condition: Class Total 2009	**16**	**957**	**36**	**2,152**	**3,161**
Image Difference	**+59**	**−502**	**+569**	**−126**	

Table 6.1: Change area matrix (km^2) for Paraguay and Brazil 1973-2009.

Table 6.1 shows the so-called "change matrix", or the areas changed between an initial condition (the thematic map from February 23rd, 1973), and the final condition (the thematic map from March 29th, 2009). The columns contain the results for the final condition of the class, and the rows contain the results for the initial condition. The row sum is the total class area in 2009. The column sum is the total class area in 1973. The main diagonal matrix shows the unchanged areas and the other values the changed areas. The difference between the total area in initial and final condition was observed in the row Image Difference.

The matrix also shows changed area and total increased or decreased area in the final condition in the two last rows, respectively.

Nevertheless, Table 6.1 shows that there was not only a substitution of woodland by agricultural use, because approx. 315 km^2 had new forest cover (for Paraguayan side $1+3+102=106km^2$, for Brazilian side $1+2+206=209km^2$). This same table also shows that bodies of water covered approximately the same area as woodlands and agriculture, 468 km^2 and 516 km^2 respectively. Bodies of water, however, have since grown to 1,007 km^2.

Smaller localized changes can also be observed in the marginal region of the reservoir as well as in Iguaçu National Park (southeast region). The construction of Itaipú was one of many factors that produced these changes. The analysis of more scenes could better track these changes over time.

The 10-year series comparison (figure 6.4) included five thematic maps: 1973, 1980, 1990, 2000 and 2009.

A comparison between 1973 and 1980 was the first in this 10-year series. The Itaipú reservoir had not yet formed, but the resettlement phase had already progressed during this period.

The second map shows the area in 1980, two years before the Itaipú dam was completed. Most of the people who would be affected had already been removed from the flood zone but Paraguayan law 752 of 1979 modified the compensation process, guaranteeing fair compensation for the remaining Paraguayans that were affected.

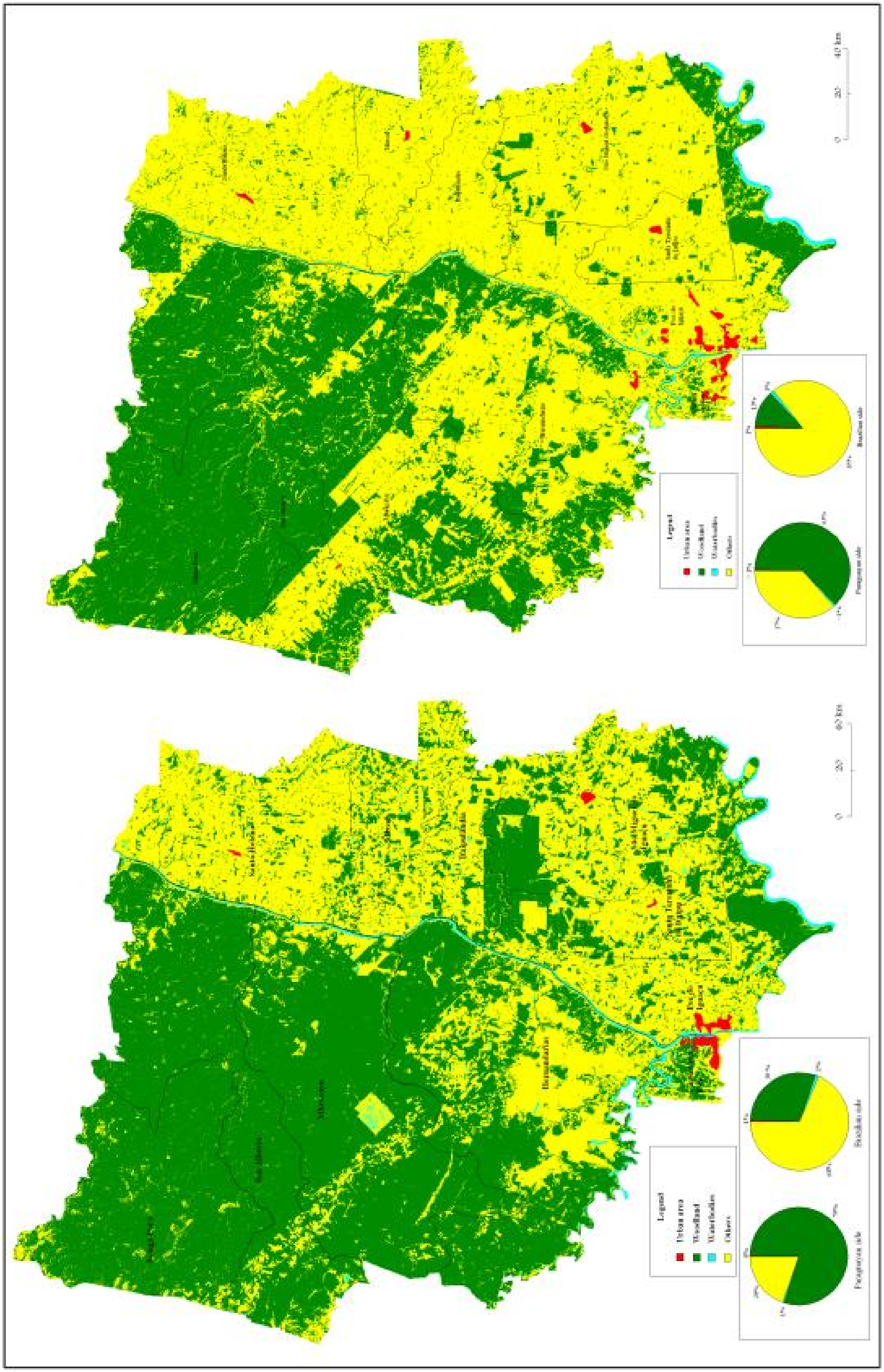

Figure 6.4: Study Region Thematic Map from 23.Feb.1973 and 12.Aug.1980 .

The area changes can be seen in Table 6.2, where the columns show the initial condition and the rows the final condition.

		Initial Condition				1973
	Paraguay	Urban area	Woodland	Water bodies	Agricultural use	Class Total
Final Condition	Urban area	**12**	0	0	2	**14**
	Woodland	1	**2,680**	2	229	**2,912**
	Water bodies	0	3	**13**	3	**19**
	Agricultural use	1	1,021	11	**681**	**1,714**
	Class Total 1980	**14**	**3,704**	**26**	**915**	**4,659**
	Image Difference	**0**	**−792**	**−7**	**+799**	
		Initial Condition				1973
	Brazil	Urban area	Woodland	Water bodies	Agricultural use	Class Total
Final Condition	Urban area	**11**	2	1	9	**23**
	Woodland	0	**254**	2	137	**393**
	Water bodies	0	3	**22**	10	**35**
	Agricultural use	5	675	11	**2,019**	**2,710**
	Class Total 1980	**16**	**954**	**36**	**2,175**	**3,161**
	Image Difference	**+7**	**−541**	**−1**	**+535**	

Table 6.2: Change area matrix (km^2) for Paraguay and Brazil 1973-1980.

The greatest change occurred in woodland area, which decreased by 1,903.8 km^2 in the region. The Paraguayan side shows a major decrease close to the road between Hernandarias and Asunción and near Santa Helena. The greatest losses on the Brazilian side were in northern Foz do Iguacú due to flooding by the reservoir.

An important factor in explaining these changes was the start of construction on the Itaipú project in 1975. There are strong indications that Brazilian migration to eastern Paraguay has intensified since 1972, which is the last time a national population census was carried out.

Since the mid-1960s, the Paraguayan Government has made a series of decisions that have greatly facilitated Brazilian migration, including the construction of roads linking Asunción and the Brazilian border and the construction of bridges across the Paraná River between Puerto President Stroessner and Foz do Iguaçu.

Furthermore, the *Instituto de Bienestar Rural* (IBR) was established in 1973 in order to remove squatters and other poor farmers from the Central Zone and resettle them in new agricultural colonies in the north and east of the country. However, a survey of seven colonies in the Department of Alto Paraná in 1978 showed an average cultivated area per family of only 4-6 ha and showed that only 6% had legal titles (IBR,1978).

This occurred because the titles issued to colonists on arrival were only provisional and did not constitute legal ownership of the land. Colonists were given seven years and a two-year grace period to pay for their land in order to obtain a legal title. Without a legal title, colonists could not receive agricultural credit. This resulted in the program's failure.

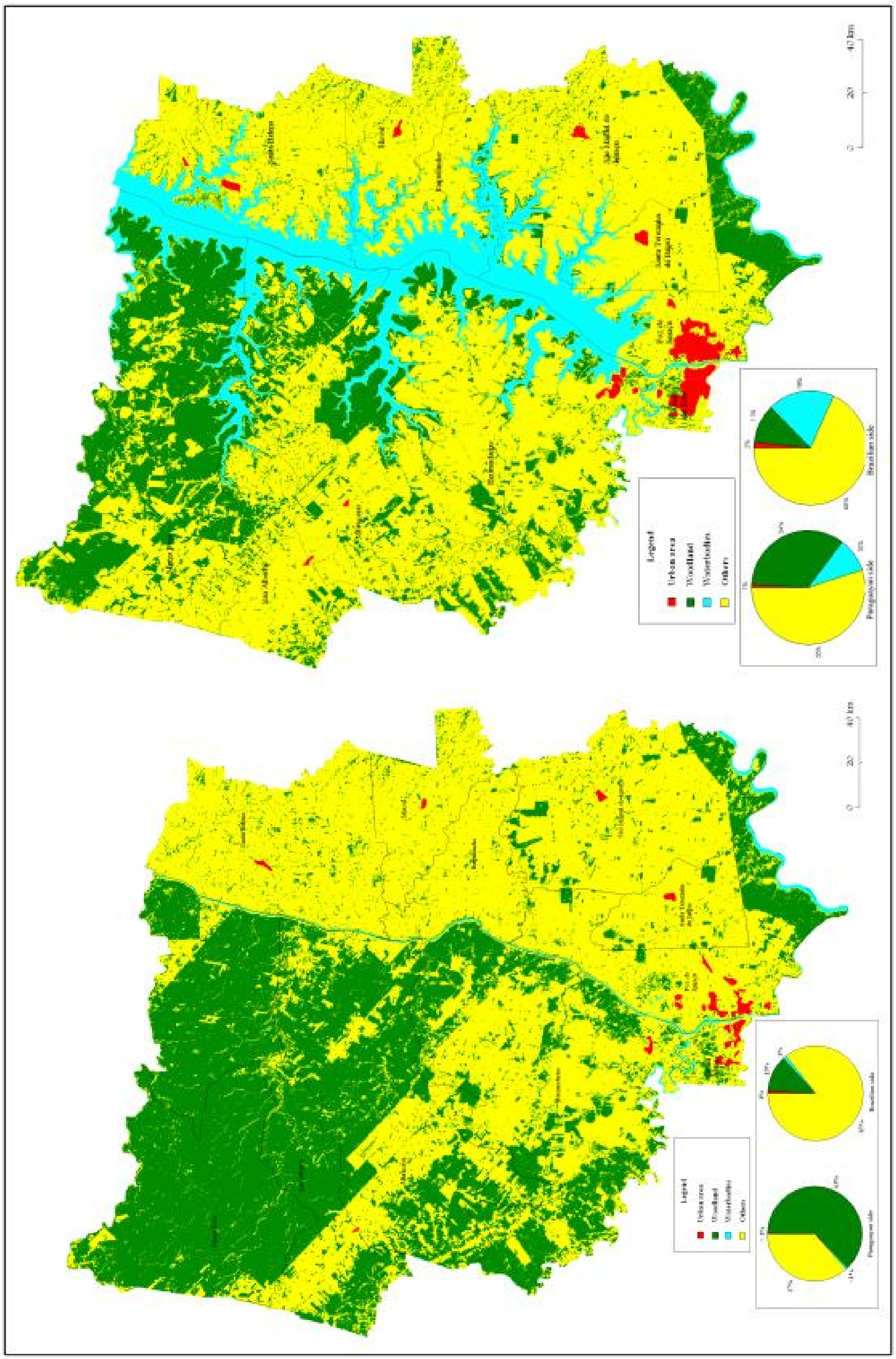

Figure 6.5: Study Region Thematic Map from 12.Aug.1980 and 24.May.1990.

The failure of the IBR program opened the way for increased Brazilian migration. The sale of their land in Brazil enabled Brazilian colonists to arrive in Paraguay with considerable liquid capital, which was sufficient for both a much larger amount of land and the equipment necessary for mechanized production.

Paraguay	Urban area	Woodland	Water bodies	Agricultural use	1980 Class Total
	Initial Condition				
Final Condition					
Urban area	**12**	10	1	19	**42**
Woodland	1	**1,405**	0	197	**1,603**
Water bodies	0	253	**17**	181	**451**
Agricultural use	1	1,244	1	**1,317**	**2,563**
Class Total 1990	**14**	**2,912**	**19**	**1,714**	**4,659**
Image Difference	**+28**	**−1,309**	**+432**	**+849**	

Brazil	Urban area	Woodland	Water bodies	Agricultural use	1980 Class Total
	Initial Condition				
Final Condition					
Urban area	**16**	2	0	33	**51**
Woodland	0	**201**	1	153	**355**
Water bodies	3	47	**32**	513	**595**
Agricultural use	4	143	2	**2,011**	**2,160**
Class Total 1990	**23**	**393**	**35**	**2,710**	**3,161**
Image Difference	**+28**	**−38**	**+560**	**−550**	

Table 6.3: Change area matrix (km^2) for Paraguay and Brazil 1980-1990

According to Nickson(1981), the typical price ratio in 1977 was about 1:8. Another attractive point was that both taxes on Paraguayan soybean exports and income tax were far lower than in Brazil.

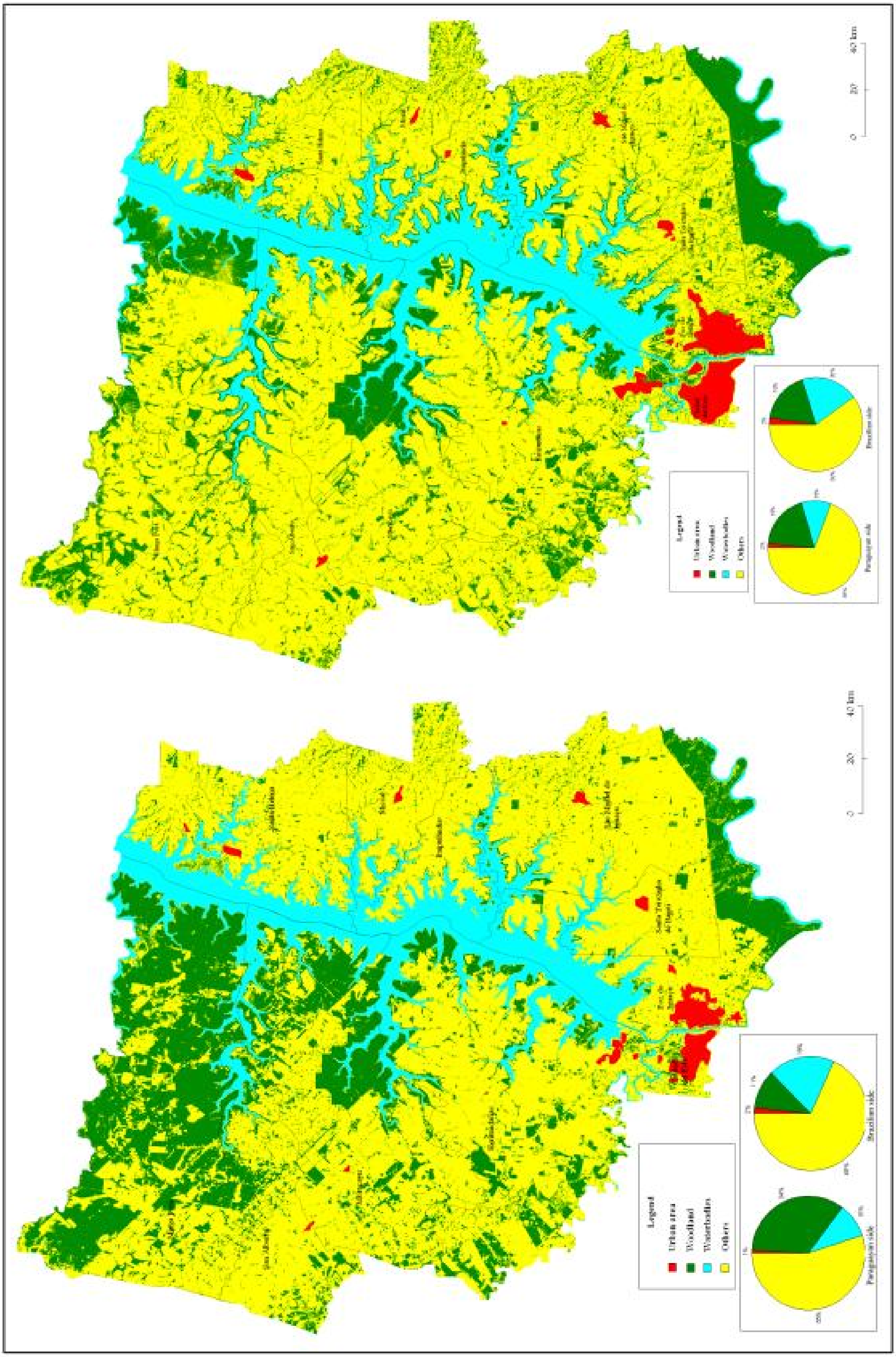

Figure 6.6: Study Region Thematic Map from 24.May.1990 and 06.Jul.2000.

The following comparison between 1980 and 1990 shows increases in both the reservoir and deforestation in San Alberto, Minga Pora, Mbaracayu and northern Hernandarias. On the Brazilian side, the area was totally covered by ploughed land or grassland, which indicates complete deforestation in the region.

Paraguay	Urban area	Woodland	Water bodies	Agricultural use	1990 Class Total
	Initial Condition				
Final Condition: Urban area	**40**	5	0	25	**70**
Woodland	0	**725**	0	161	**886**
Water bodies	0	1	**450**	25	**476**
Agricultural use	2	872	1	**2,352**	**3,277**
Class Total 2000	**42**	**1,603**	**451**	**2,563**	**4,659**
Image Difference	**+28**	**−717**	**+25**	**+664**	

Brazil	Urban area	Woodland	Water bodies	Agricultural use	1990 Class Total
	Initial Condition				
Final Condition: Urban area	**46**	1	0	24	**71**
Woodland	0	**315**	1	257	**573**
Water bodies	0	0	**592**	29	**621**
Agricultural use	5	39	2	**1,850**	**1,896**
Class Total 2000	**51**	**355**	**595**	**2,160**	**3,161**
Image Difference	**+20**	**+218**	**+26**	**−264**	

Table 6.4: Change area matrix (km^2) for Paraguay and Brazil 1990-2000

The changes seen in Figure 6.6 refer to the 1990s (from May 24th, 1990 until July 6th 2000). The most important change is forest clearance in the north of the study region, including the Paraguayan districts of San Alberto and Minga Porá. The largest remaining forested areas where the previously-mentioned Itaipú Reserve and the Iguacú National Park near Foz do Iguacú.

According to Table 6.4 the total woodland area decreased by 499 km^2 [the sum of increased area in Brazilian side (+218km^2) and decresed area in Paraguayan side(−717 km^2)] In this period the Asunción Treaty was signed by Brazil, Paraguay, Argentina and Uruguay on March 26th, 1991, creating *Mercosul* "*Mercado Comum do Sul"*, a common market for Central South America. This included not only a common market but a common environmental policy as well. Paraguay established in 1991 an Environmental Impact Assessment through law 294/93, like Brazil had done in 1987, obliging both the EIA and public scrutiny

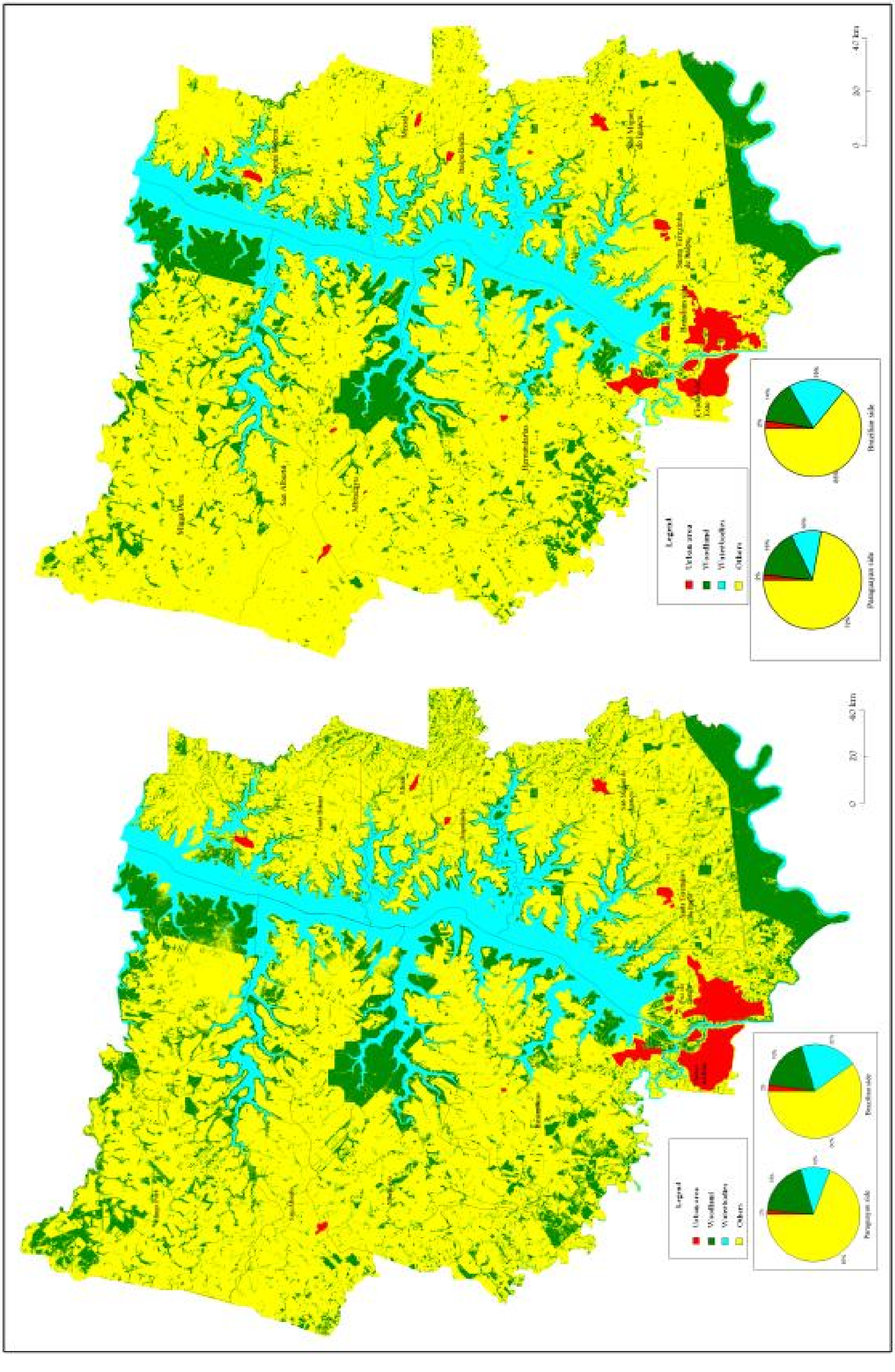

Figure 6.7: Study Region Thematic Map from 06.Jul.2000 and from 29.Mar.2009.

	Paraguay	Initial Condition: Urban area	Woodland	Water bodies	Agricultural use	2000 Class Total
Final Condition	Urban area	**45**	12	1	19	**77**
	Woodland	1	**545**	7	198	**751**
	Water bodies	2	10	**446**	6	**464**
	Agricultural use	22	319	22	**3,004**	**3,367**
	Class Total 2009	**70**	**886**	**476**	**3,227**	**4,659**
	Image Difference	**+7**	**−135**	**−12**	**140**	

	Brazil	Initial Condition: Urban area	Woodland	Water bodies	Agricultural use	2000 Class Total
Final Condition	Urban area	**57**	4	2	12	**75**
	Woodland	1	**362**	5	87	**455**
	Water bodies	1	4	**591**	9	**605**
	Agricultural use	12	203	23	**1,788**	**2,026**
	Class Total 2009	**71**	**573**	**621**	**1,896**	**3,161**
	Image Difference	**+4**	**−118**	**−16**	**+130**	

Table 6.5: Change area matrix (km^2) for Paraguay and Brazil 2000-2009.

In the 2000s, there were no drastic changes visible in the comparison, although the progressive decrease of woodland area continued. The new environment policies and a host of plans did not lead to a reforestation proposal. Instead the tendency was that forest fragments disappeared and the agricultural area became homogenous. Woodland area decreased a further 253 km^2 (118 km^2 in Brazil and 135 km^2 in Paraguay) in this period, as can be seen in the change matrix in Table 6.5.

Since 2000 Itaipú and the municipalities have tried to protect and recover the so-called Environmental Protection Zone (EPZ), an area approximately 200 m wide to reduce the effects of erosion. In 2000 Itaipú developed a Master Environment Plan and organized a project called "*Cultivando Agua Boa*"(CAB) in 2003. The program proposed, among other goals, to protect the reservoir's riparian forest and to create a biological corridor linking forests in Paraguay, Brazil and Argentina. Based on the program's results to date, CAB seems far from its goals. Itaipú reports (Itaipú,2009) indicate that the PEZ should be 98% recovered. Even though the study area did not include the entire reservoir, it was possible disprove this statement.

	1973 Area (km^2)	1980 Area (km^2)	1990 Area (km^2)	2000 Area (km^2)	2009 Area (km^2)
Urban area	30	37	93	141	152
Woodland	4,666	3,605	1,958	1,459	1,206
Water bodies	62	54	1,046	1,097	1,069
Agricultural use	3,062	4,424	4,723	5,123	5,393

Table 6.6: Classification Results for 10 year series

The same master plans created by the municipalities of Foz do Iguaçú, Itaipúlândia and São Miguel do Iguaçú have as of yet obtained poor results.

When the overall results are compared (Table 6.6), a progressive and drastic reduction of woodland area is evident, as well as a progressive increase of urban area and agricultural land.

The changes seem to relate more to national agricultural policies and the construction of Itaipú. Itaipú catalyzed Brazilian migration into Paraguay and has ineffectively handled its Environmental Protection Zone.

Figure 6.8 shows the class development since 1973 for the two sides. The first class, urban area, presents similar growth on both sides. The same is true for the total area of bodies of water, which increased due to the formation of the reservoir as well as to seasonal variations in the preconstruction period. The graph demonstrates a great difference in woodland area between the Brazilian and Paraguayan sides; however, Paraguay systematically lost its wooded cover in the region whereas the Brazilian side varied during the period.

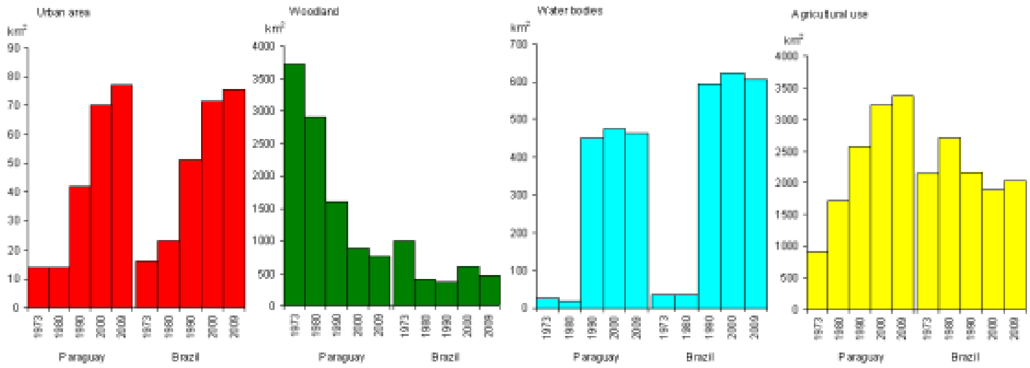

Figure 6.8: Results from 23.Feb.1973 to 29.Mar.2009 .

When the class areas are compared, the difference is obvious. Figure6.8 shows the progressive reduction in Paraguayan forest. On the Brazilian side, all areas remained at the same level except for the urban area.

Four areas described in Figure6.9 were selected to clearly exemplify the changes verified in the region.

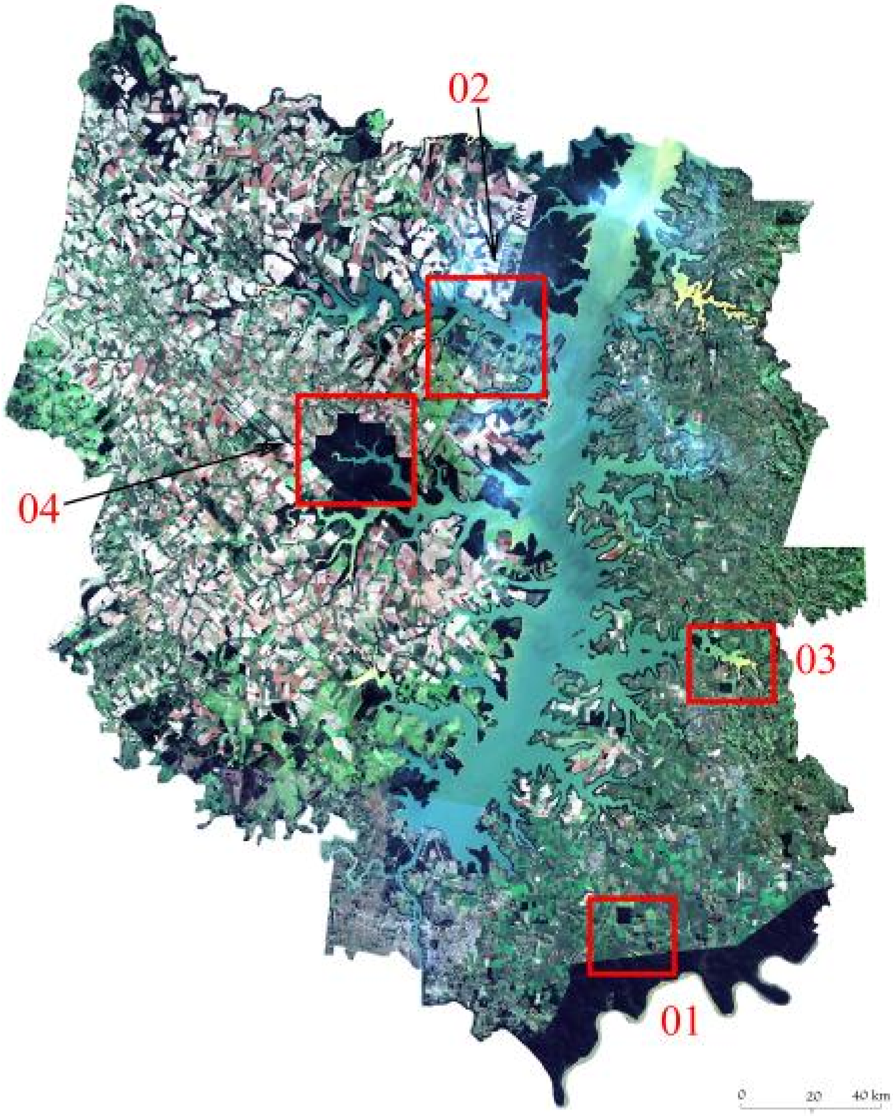

Figure 6.9: Index selected areas.

Figure 6.10 shows the northern border of Iguaçu National Park, near the Brazilian municipality of Santa Terezinha de Itaipú. Area 1 also shows a group of small wooded areas near the park border.

As observed in the thematic map time series, 1973-80 marked a rapid decrease in woodland area, especially the more fragmented regions. In the park region, an increase in wooded area can be noted during that same period, which continues progressively until the final map of 2009. It should be emphasized, however, that outside of the park reduction continued from 1990-2007. Nevertheless it is possible to identify the same woodland regions on different dates, which shows that those regions tended to stay intact.

Figure 6.11 presents four images of a region at the division between the Paraguayan districts of San Alberto and Mbaracayu.

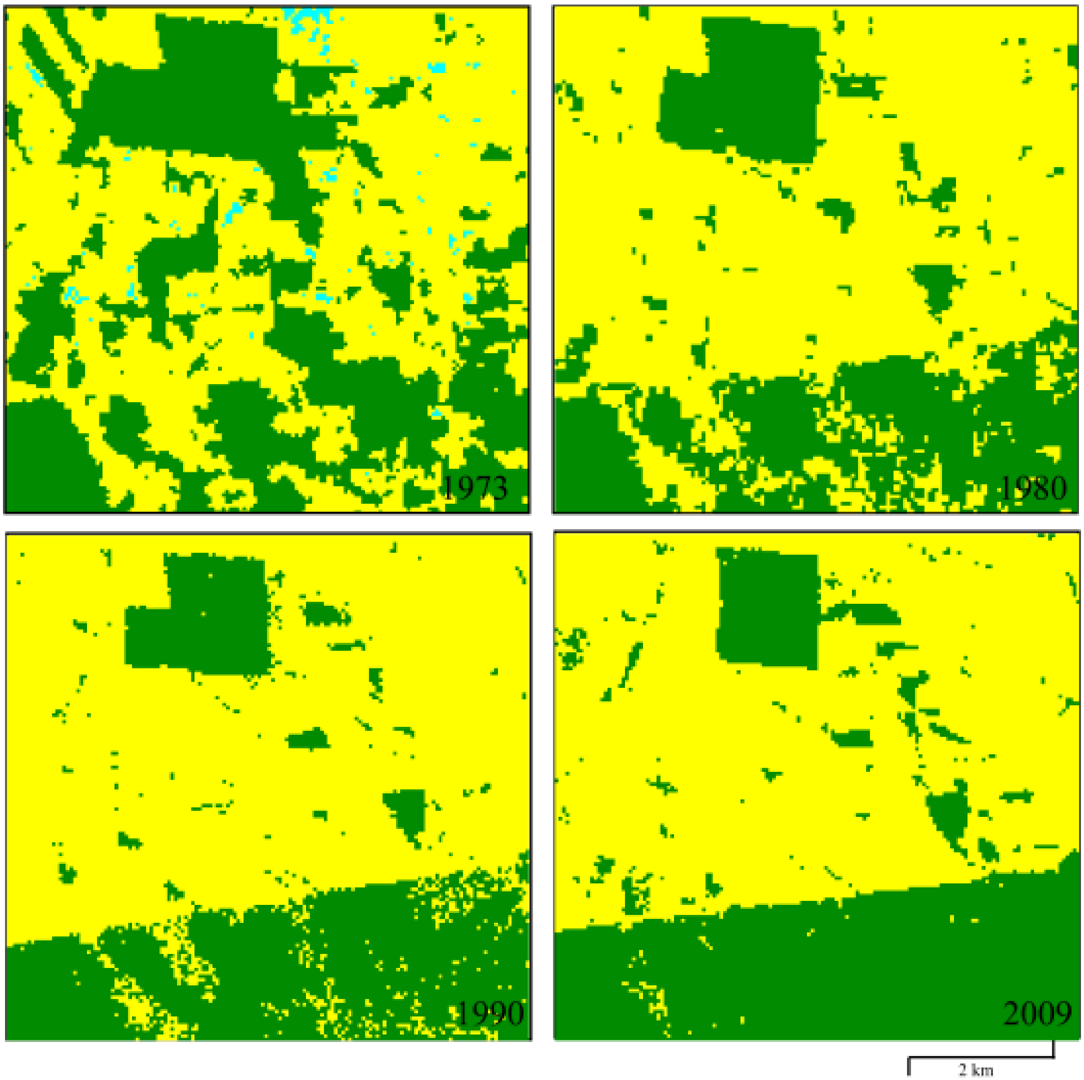

Figure 6.10: Area 1.

This area shows the region of the river that divides the two districts. In the northwest of the area is the southern border of the Limoy Ecological Reserve, which was created as ecological compensation for the area flooded by the reservoir. In the image progression, two periods of deforestation can be distinguished.

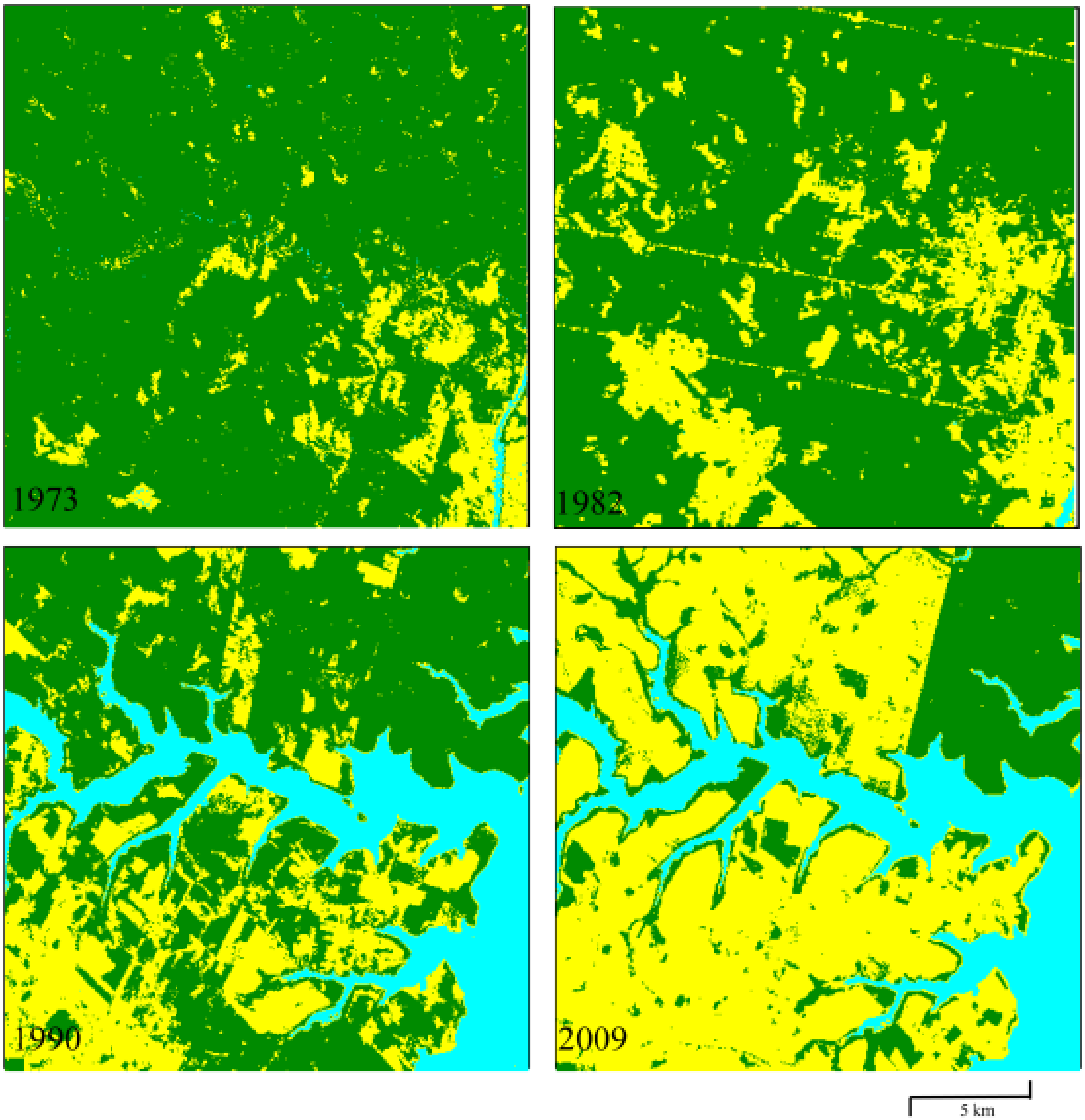

Figure 6.11: Area 2.

In the initial period (1973-1982), we clearly observed the occurrence of deforestation in the central region of the area before flooding by the reservoir.

In the next period (1990-2009), a continuous reduction in forest cover is evident, due principally to agricultural expansion. It can be observed that the park area includes original forest remnants. In the southwest border of Iguaçu National Park there is an area tending towards deforestation, contrary to the general forest regeneration trend.

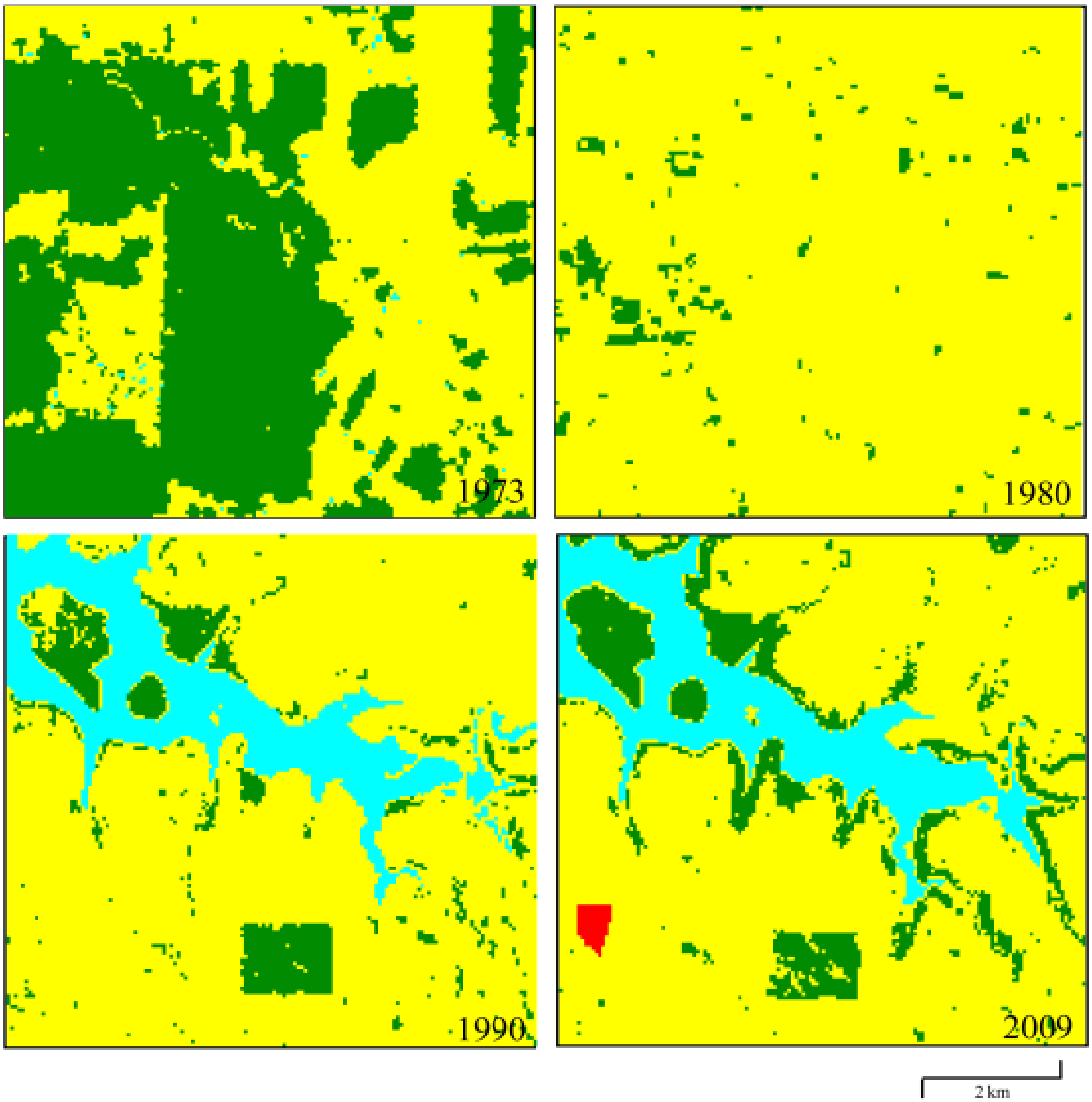

Figure 6.12: Area 3.

In Figure 6.12 area 3 shows a region near the municipalities of Missal and Itaipúlândia. It was verified that deforestation was much more acute in this area than in some regions of Paraguay. Here, the remaining vegetation has been almost completely cleared away in an attempt to prevent the eutrophication of the reservoir. Such deforestation can also be observed in areas 2 and 4, although with less intensity.

From 1982 until 1990, the recovery of the first woodland regions can be observed. After 1990 the forest areas increase around the reservoir's riparian forest, a region that became protected after the formation of the reservoir. A new urban area, the municipality of Itaipúlândia, can be observed toward the end of the 1990s to the north of São Miguel do Iguaçu.

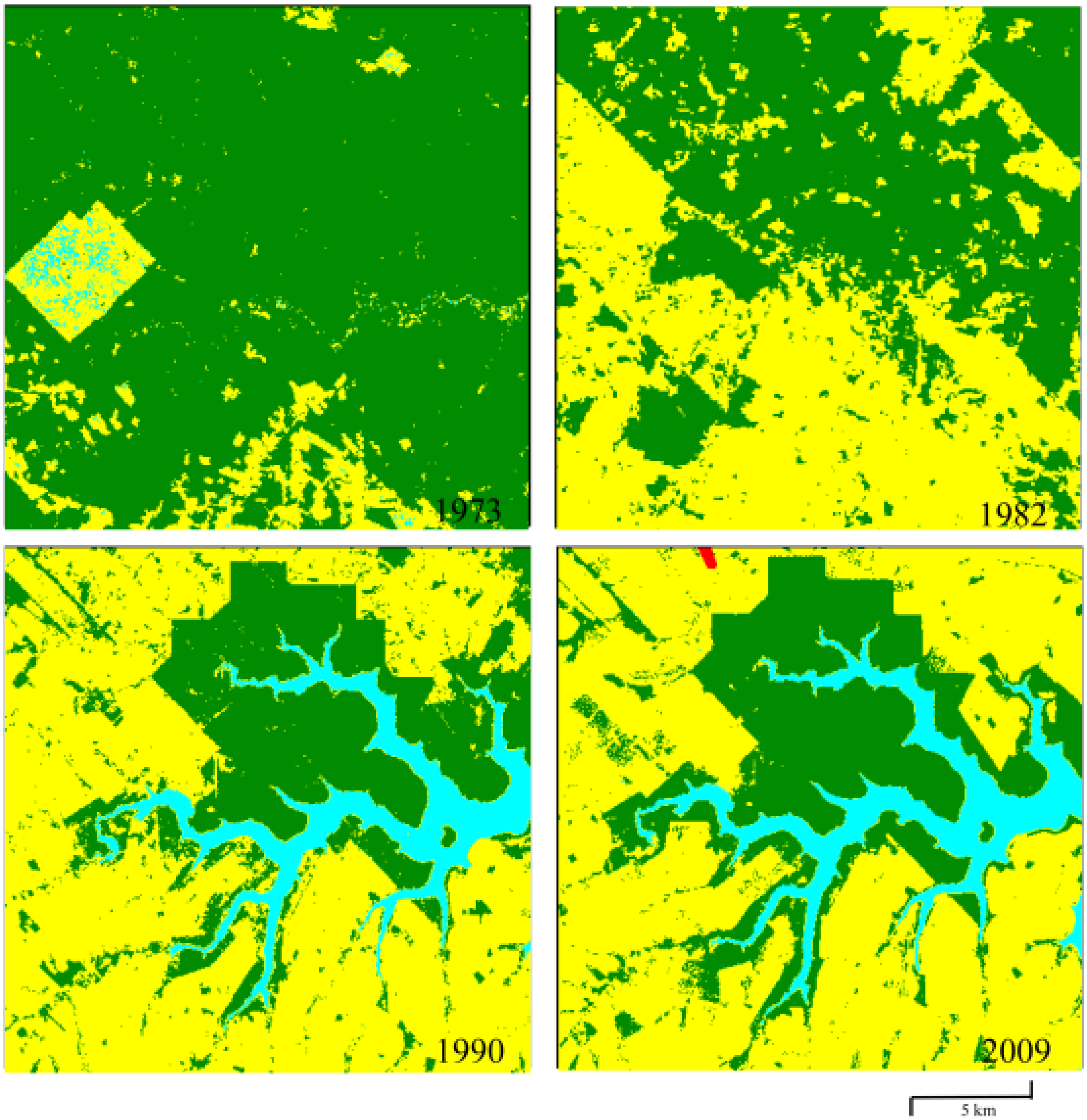

Figure 6.13: Area 4.

The final area in Figure 6.13 shows the region between the districts of Mbaracayu and Hernandarias. In the southeast of this area, there is a highway that crosses the region, passing through the middle of the Itabo Reserve. This reserve was also created by the Itaipú project after the formation of the reservoir.

The greatest modifications in area 4 occurred in the initial period (1973-1982), when in the southwest region of the area there was a tendency toward deforestation due to logging and agricultural expansion. In the 1982 map, it can be observed that the deforestation begins in the center of the region to be flooded that same year.

In the period 1990-2009, the maps show that there were no large modifications in the forest areas. Reductions of fragmented areas in the north and increases in the riparian zone can be observed.

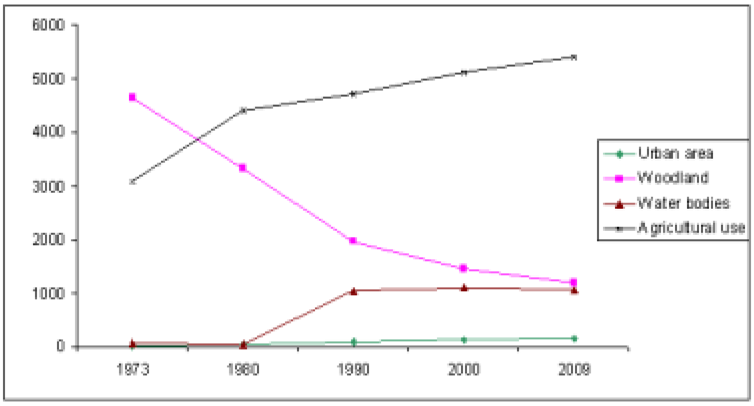

Figure 6.14: Graph of the evolution of the classes from 1973 until 2009.

The graph in Figure 6.14 shows the relationship between the classes from 1973-2009. The graph indicates a continuous tendency toward losses in forest area, which becomes less acute in the 1990s and tends toward stability at a low level of cover.

Were the curves can be connected, the variation in flooded area observed in the 1980s coincides with the tendency toward a smaller increase in agricultural expansion. That leads us to believe that it was not so much the formation of the reservoir that caused the loss of vegetation cover in the region, but the migratory movement driving the expansion of the agricultural sector, which was based on the availability of migrant credit. Another conclusion is that the process would have occurred even without Brazilian migration, because the Paraguayan agricultural expansion policy encouraged production for the international market and attracted investors to the region.

The difference that Itaipú made was in the speed of those transformations. The hydroelectric plant accelerated a process that was already underway in a less acute manner. Nevertheless, it must be mentioned that the forest areas dedicated to preservation still do not correspond, either qualitatively or quantitatively, to the portions of terrain directly affected by the construction of the dam and formation of the reservoir. It can be said that even with quite superficial data, such as the series of classifications made from the original forest, Paraguay's large forested area would have suffered less fragmentation. Forest fragmentation, a well-known phenomenon in Brazil because of Atlantic Forest devastation, causes not only isolation and habitat reduction, but increases microhabitat border. Its results for both flora and fauna species include either extinction due to insufficient food and environmental conditions or a decline in numbers, which leads to deficits in genetic variability.

The first official environmental measures began in 1977 with the formation of the Committee for Forest Inventory, which was associated with the Forest Institute of the Federal University of Paraná, Brazil. The purpose of the committee was to identify the structure of the forest vegetation that had been affected by the Itaipú project.

In view the recommendations of this committee and the environmental impact study that had been carried out, Itaipú decided to create refuges and biological reserves whose purpose was to attenuate the alterations in the atmosphere caused by the formation of the reservoir.

The Itaipú agreement established that any administrative actions or programs had to be applied bilaterally. Thus Itaipú included two administrative branches, one Brazilian and the other Paraguayan. Subsequently, the following six refuges and biological reserve areas, totaling 364 km^2, were created in Paraguay and Brazil: Santa Helena (14.8km^2), Itabó (152.1km^2), Limoy (148.3 km^2), Bela Vista (19.2km^2), Tati Yupi (22.5km^2), Yui Rupá (7.5 km^2), Maracaju(1.4 km^2). The reserves were created as part of Project Gralha-Azul (Azure Jay), which also planned the reforestation of the reservoir borders.

According to Itaipú, the project was scheduled to begin in 1979, three years before the formation of the reservoir. Judging from the woodland region extant in 1973, the forest area occupied by the reservoir was about 488 km^2. Adding the 315 km^2 of total biological reserves in the region to the rivers bordering Permanent Protection Zone forest (PPZ), there would be a superior range of area. But since the protected area does not compensate for the continuous areas of forest there was a deficit of 173 km^2 in the study region.

6.2 Environmental questions

In 1975, as part of the Itaipú agreement between the governments of Brazil and Paraguay, a commission was created to draw up a basic plan for environmental conservation. This was to include not only surveys and inventories of fauna and flora, but also to perform sedimentological and hydro-biological measurements and to register archaeological sites(IPARDES,1980).

According to recommendations and environmental impact studies made by Itaipú managers, 1,050 km^2 were affected by the Itaipú project and should be protected by the creation of forest preservation areas, refuges, and biological reserves. According to Itaipú(2009) the reforestation program began in 1979, three years before the reservoir filled the area upstream of the dam.

The study area contains three of the six refuges and biological reserves, as well as part of Iguaçu National Park. These reserves include Santa Helena (14.8 km^2) in Brazil and Itabó (152.1 km^2 in Mbaravayu) and Limoy (148.3 km^2 in San Alberto) in Paraguay. The other three reserves are Bela Vista (19.2 km^2) in Brazil and Tati Yupi (22.5 km^2) and Yui Rupá (7.5 km^2)in Paraguay, which are both North of the study area. The reserves were part of the *Gralha Azul* project(Itaipú,2009), which was a reforestation plan for the reservoir's riparian forest. The projected riparian forest was to be formed by the natural regeneration of forest vegetation. A forest zone of this kind can drastically reduce shore and slope erosion around reservoirs as well as prevent direct contamination of the lake by agricultural pesticides, etc. Such a zone can also create a protective biotope for fauna and flora while acting at the same time as a windbreak. Nevertheless, the thematic map series (section 6.2) revealed that the riparian forest suffered more losses than gains in the recent years.

One of the biggest problems for the Itaipú reservoir is the influx of dissolved matter. The amount of soil erosion that occurs in an area depends on three main factors: the soil type, the speed at which water and wind travel across it, and vegetation. Obviously, there are substantial differences in erosion resistance in various soil types. The Caiua sandstone region in northwestern Paraná is especially susceptible to erosion, consisting of 50 – 70% sand and only 12 –25% clay, as well as a low concentration of organic material. This contrasts with the soils formed from the basic igneous rock (dark red latosols), which have a high clay content (66 – 81%) (IPARDES,1980) and are relatively resistant to erosion and to transport in dissolved form. However, cultivation methods can increase susceptibility to erosion.

Areas subject to large-scale mechanical cultivation several times a year are particularly susceptible. Since there is usually only a short gap between the soybean harvest and the sowing of wheat in April, the erosion damage caused by soil preparation for wheat sowing is not as great as that in October. Following the wheat harvest the soil is subjected to intensive preparation for soybean or maize planting. Consequently, October is the month in which about 25% of the damage occurs. The greatest risk exists during the phase when the soil has been ploughed and prepared for sowing but does not yet have any plant cover. In this situation, even a relatively slight slope can have damaging results.

The growing of crops parallel to slopes and the creation of contour terraces have succeeded in reducing the effects of erosion by nearly 50% on slopes of less than 3%, but such measures are insufficient for steeper slopes (Norton et al.,2001). For this reason the direct sowing method, developed in recent years and obviates the need for deep plowing, is a particularly important factor in reducing soil loss by erosion. The farmers have also come to understand the importance of a winter crop to provide cover for the soil.

Another aspect of great importance is water quality, which is influenced, or can be influenced, by a large number of factors. One problem that many dam projects, especially in tropical regions, have either completely ignored or failed to take adequate account of, is the clearance of forest vegetation from the future bed of the reservoir before it is submerged.

When a district with dense forest cover is submerged, considerable quantities of organic substances are degraded in the reservoir, leading to an oxygen deficiency and the formation of hydrogen sulfide, methane and ammonia. The anaerobic degradation of the biomass, with the accompanying release of toxic gases, can result in nuisances ranging from bad odors to symptoms of poisoning in local residents. The toxic effects may also present a serious threat to the fish population and thus have direct economic consequences. In a few cases (e.g. Curua-Una in Amazonia/Brazil), corrosion damage to turbines has even been found. Aggravating this was another major problem verified by Itaipú: control of golden mussels (*Limnoperna fortunei*) larvae in the power plant's reservoir. This mollusk is responsible for obstructing pipes in hydroelectric power plant equipment as well as causing environmental imbalance. This is probably a result of *eutrophication* due to Paraguay’s failure to clear the land to be flooded, as demonstrated in section 6.1.

	Brazil	Paraná	Region
Population in 1960	70,992,343	4,296,375	33,919
Population in 1970	70,992,343	6,997,682	171,975
Population in 1980	111,622,144	7,723,197	234,779
Population in 1990	146,825,475	8,448,713	258,226
Population in 2000	169,799,170	9,563,458	338,629
Population in 2009	183,987,291	10,284,503	414,434

Table 6.7: Evolution of the Paraná population. [Source:(IPARDES, 2007)]

Since the 1980s, Brazilian environmental policy has begun to change. In 1981 Law 6.938 was passed to set up the National Environment Policy, which established the first legal device for Environment Impact Assessment (EIA). However, the norms for this evaluation were only drawn up for The National Environment Council (CONAMA) in 1986. Since then, environmental cost has acquired more importance in all Brazilian engineering projects.

	Foz do Iguaçu	Itaipulandia	Missal	St. Helena	St. Terezinha	São Miguel
Population in 1960	33,919					
Population in 1970	136,321		19,835		15,819	
Population in 1980	179,597		20,935		34,247	
Population in 1990	190,123		10,372	18,861	14,149	24,721
Population in 2000	258,543	6,836	9,959	20,491	18,368	24,432
Population in 2009	325,137	9,349	10,760	22,198	20,539	26,451
Founded in	03.03.1917	01.01.1993	30.12.1981	26.05.1967	01.02.1983	28.11.1961

Table 6.8: Population increase of Brazilian side of study region [Source:(IPARDES, 2007)]

Another important advance in Brazilian environment policy in the 1980s was resolution 9 of CONAMA, which established a public audience for the EIA process. Either the affected population or the public prosecutor can ask for a public audience if there are questions about an EIA process, a factor that brings more transparency to the process. Until this time there were many cases of corruption in EIA evaluations. Paraguayan environmental policy changed only ten years later with the new democratic period. The Itaipú project is older than these policies, but in the Itaipú agreement many similar proposals can be seen. Studying the Itaipú region presents a way of learning about the long-term development of such large projects as well as understanding regional processes, which interfere in environmental change. Environmental strategies are only effectively designed when they pay attention to such local processes.

6.3 Socio-economic questions

The interaction between humans and the environment is important factor for understanding the implications of physical alterations. To analyze this, some comparisons between Brazil and Paraguay are necessary. As presented in Chapter 3 there are many political and economical issues, mainly linked to Brazil's and Paraguay's size, that restrict a comparison of their development. Nevertheless they both have problems and applied development models that are common in South America, e.g., the clearance method used in the region.

The use of shift-share analysis (SSA) was proposed to describe the interaction among national and local development influences. The method consists of separating growth into three factors and measuring the contribution of each. Although it does not provide basic answers to changes in composition, the technique provides a useful framework for explaining the causes and effects of change.

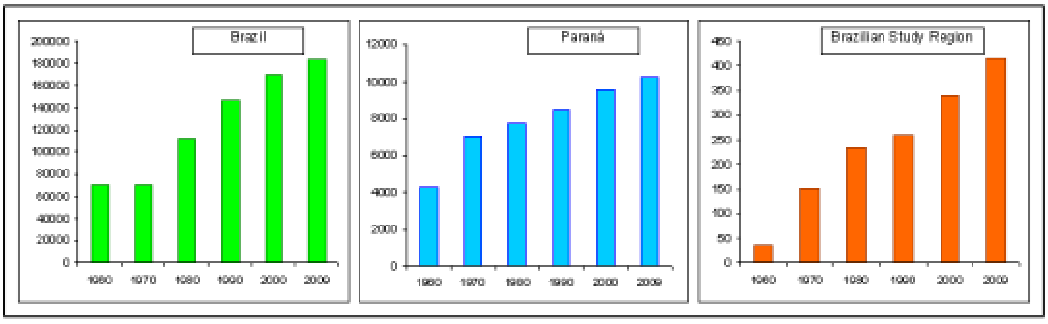

Figure 6.15: Demographic evolution in Brazil (thousand people) [Source:(IPARDES, 2007)]

The growth effects are: national share, structural share and competitive effect. The national share measures overall national growth, in this case agricultural variables such as soybean production, tractors sold and land work.

	structural share		competitive effect	
Domicilio	Urban	Rural	Urban	Rural
Municipios				
Foz do Iguaçu	+66%	-68%	+75%	-33%
São M. Iguaçu	+44%	-44%	-25%	-25%
Santa Helena	+40%	-45%	-15%	+10%
Missal[2]	+48%	-43%	+38%	+9%
Sta. Terezinha[3]	+35%	-31%	+14%	+7%

Table 6.9: Shift Share terms applied to demographic evolution [Based on:(IPARDES, 2007)]

The regional share was inferred from differences between the agricultural structure of a specific area and the agricultural structure of the nation. The competitive effect results from the position of an area in relationship to the immediate neighboring regions. The method used to calculate the three terms was detailed in chapter 5.

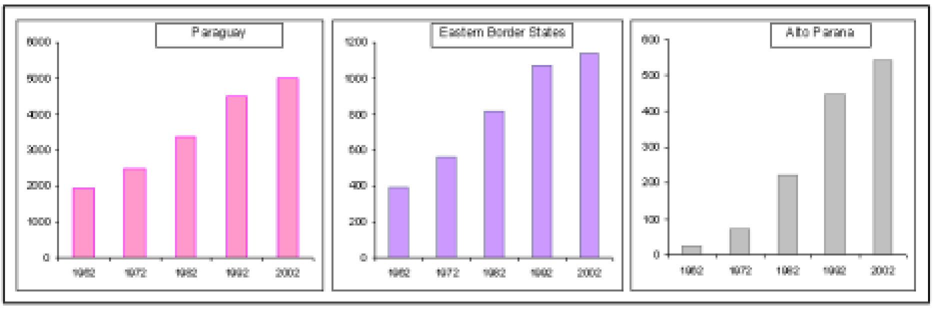

Figure 6.16: Demographic evolution in Paraguay (thousand people) [Source: (DGEEC, 2008)]

First, population development will be studied. In Brazil, the introduction of machinery and exportable cultures are associated with the beginning of the industrialization process in the 1980s. This forced the demographic structure towards fast urbanization. The demographic evolution in Table 6.8 indicates a 30% growth in Brazilian population between 1970-80 and 1990-2000, while in the study region such growth (32%) occurred only from 1970-1980. In Paraná a regular population growth of about 10% occurred in each of these decades.

The population growth from 1970-80 indicates a regional change that stimulated migration to the state. This migration could be associated with the work on Itaipú (1975-1982).

Figure 6.16 is a graphic of the data from Tables 6.8 and 6.7. There is a correlation between the national and the regional tendency, but the period from the 60s to the 80s has a lower correlation than that of the 80s to 2009. This means that from the 60s to the 80s growth took place that was independent from regional structure changes. The relationship between these increases can be reported in Shift Share terms.

Table 6.9 applies Shift Share Analysis (1980-2000) to the urban and rural population in the municipalities studied in Brazil. Because structural change has a greater weight, the regional structure has more influence than the state situation. The result shows that Foz do Iguaçu is the municipality with the largest increase in structural change in those 20 years. This municipality's centralized model of development associated with other characteristic factors led to a high competitive effect and structural share in urban population change (+66%, +75%).

The surrounding rural population decreased faster than in other municipalities. There was more structural change –68% than competitive effect –33%. The decrease in land work and reduction of land area due to the creation of the Itaipú reservoir explains the unusual rural population reduction in Foz do Iguaçu.

The Paraguayan population grew substantially from 1960s until 1990s, about +30%, as can be seen in the national share in Table 6.10 For this reason the Alto Paraná Department experienced a huge growth in tax revenue during the period in which Itaipú was built (1975-1982).

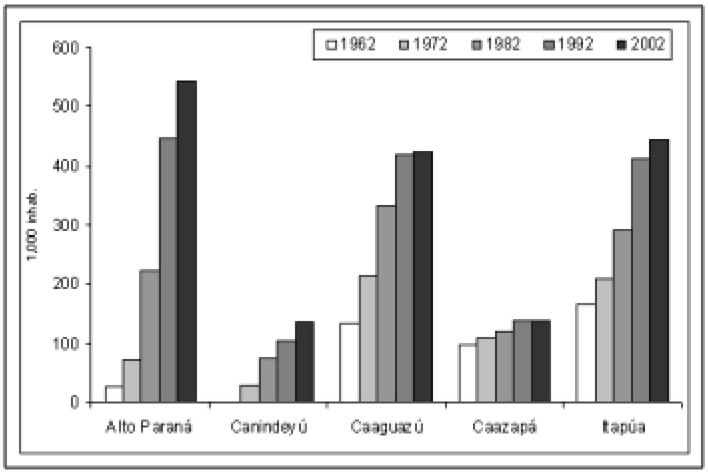

Figure 6.17: Population increase in Alto Parana - Paraguay (thousand people) [Source: (DGEEC, 2008)]

The Alto Paraná population growth rates were comparable in the 1960s and 1970s, differing from those of the national population. There has been a strong growth trend since the 70s that is not comparable with that of its neighbor (figure 6.16).

	1962-1972	1972-1982	1982-1992	1992-2002
Alto Parana	187%	210%	102%	21%
national share	29%	36%	35%	11%
structural share	117%	127%	36%	5%
competitive effect	41%	46%	31%	6%

Table 6.10: Demographic evolution in Alto Parana-Paraguay [Based on: (DGEEC, 2008)]

The structural change in the Alto Paraná Department was the main factor for this growth. The expansion of the agricultural frontier attracted not only Paraguayans but Brazilians, who saw the opportunity of an open market. The low Paraguayan import and export tax rate was also an important component of these migration movements. Finally, the Brazilian farms were producing soybean in Paraguay for export to Brazil.

Agricultural land use Paraná (km^2)					
	1970	1975	1980	1985	1995
Farming	140,026	148,369	155,038	159,137	152,217
Arable land	47,186	56,275	60,850	60,626	51,005
Pasture	45,097	49,828	55,202	59,996	66,773
Forest	25,706	23,633	25,986	28,335	27,947
Fallow land	22,037	18,632	12,999	10,181	6.491
Agricultural land use region (km^2)					
	1970	1975	1980	1985	1995
Farming	621	1,617	2,360	1,764	1,870
Arable land	133	659	1,218	1,130	1,130
Pasture	52	248	948	437	566
Forest	342	495	159	166	107
Fallow land	88	151	35	31	8

Table 6.11: Development of land use in Paraná and the study region [Source:(IPARDES, 2007)]

The immigration of Brazilian farmers produced a rapid increase in agricultural production in the Alto Paraná department. According to Nickson (1981), three kinds of crops (soybean, mint and upland rice), none of which is native to Paraguay, were introduced by Brazilian farmers, and these are now the major crops grown in the region. Their combined value reached over US$ 33 million in 1976/77.

Soybean production now dominates the agricultural economy of Alto Paraná. The area planted in soybean increased from only 54 km^2 in 1972 to over 7,500 km^2 in 2006. There was a hundredfold increase in soybean exports from Paraguay between 1972 and 2006. Paraguay is now the fifth largest exporter of soybean in the world because of this rapid increase in production in recent years.

Generally speaking, the farming area in the state of Paraná has varied little since 1970. Table6.11 demonstrates an increase in area until 1985 followed by a decrease until 1995. The same thing occurred with arable land and forest. Only pastures, both artificial and natural, have progressively increased since 1970. This is a consequence of how the region was developed, i.e., clear-cutting (deforestation) followed by use as pasture.

The influence of Itaipú on farming development is reflected in land pricing and the reduction of arable land on the Brazilian side. The agricultural structure shifted towards medium and large farms at a time when pressure for land in the neighboring region should have reduced the farming area. This only occurred because the Brazilian farmers found land for agricultural expansion in Paraguay. Brazilian migration to the Paraguayan border region disseminated soybean agriculture in that country.

The construction of Itaipú played a secondary role on the Paraguayan side. The process of deforestation depended on agricultural expansion, which was a political decision made in the 1960s. However, the Brazilian migration was influenced by Itaipú resettlement as well as by a reduction in arable land in the Brazilian border region in the 60s.

The population increase caused the creation of new municipalities in both countries, although they were not restricted to the area around Itaipú. A graph showing these new districts and municipalities is in Figures 6.18 and 6.19.

In the extreme west of the state of Paraná, more than half of the municipalities were founded in the 80s and 90s. Such was also the case in the Department of Alto Paraná in Paraguay. As late as the 80s, 9 of the 19 districts were created.

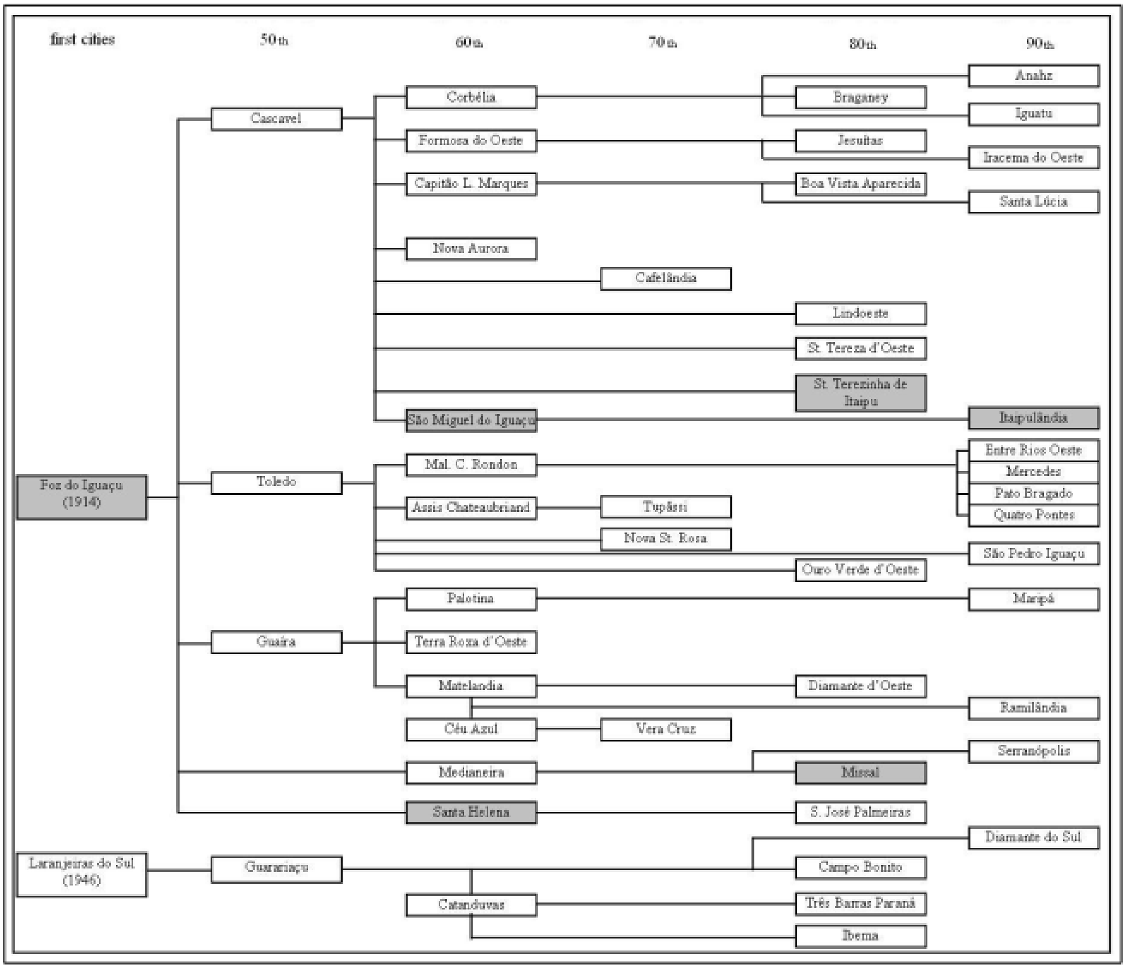

Figure 6.18: Municipalities foundation in the west Paraná - Brazil [Source:(IPARDES, 2007)]

	1970	1975	1980	1985	1995
Farms	554,488	478,453	454,103	466,397	369,875
Owner condition					
Owner	312,762	305,734	305,765	303,082	282,175
Tenants	68,741	48,466	43,340	48,431	26,945
Semi-tenants	122,937	79,869	63,044	69,077	28,117
Squatter	50,048	44,384	41,954	45,807	32,638
Land work					
Total land workers	1,981,471	2,079,174	1,807,826	1,855,063	1,287,632
Tractors	18,619	52,498	81,727	101,346	130,828

Table 6.12: Development of the Paraná agricultural sector [Source:(IPARDES, 2007)]

In these administrative areas, re-dividing can be seen as a political implication of the construction of Itaipú in association with extensive agricultural expansion in the region. Principally in Brazil, financial compensation for the use of hydro resources stimulated administrative reorganization because the compensation was proportionally shared with the municipalities. From 1985 until 2008 more than US$ 3.60 and US$ 3.31 billion were paid to Brazil and Paraguay, respectively, as financial compensation. In Brazil this financial resource is shared among municipalities, state and federal organizations (45% to municipalities and 45% and 10% to state and federal organizations, respectively).

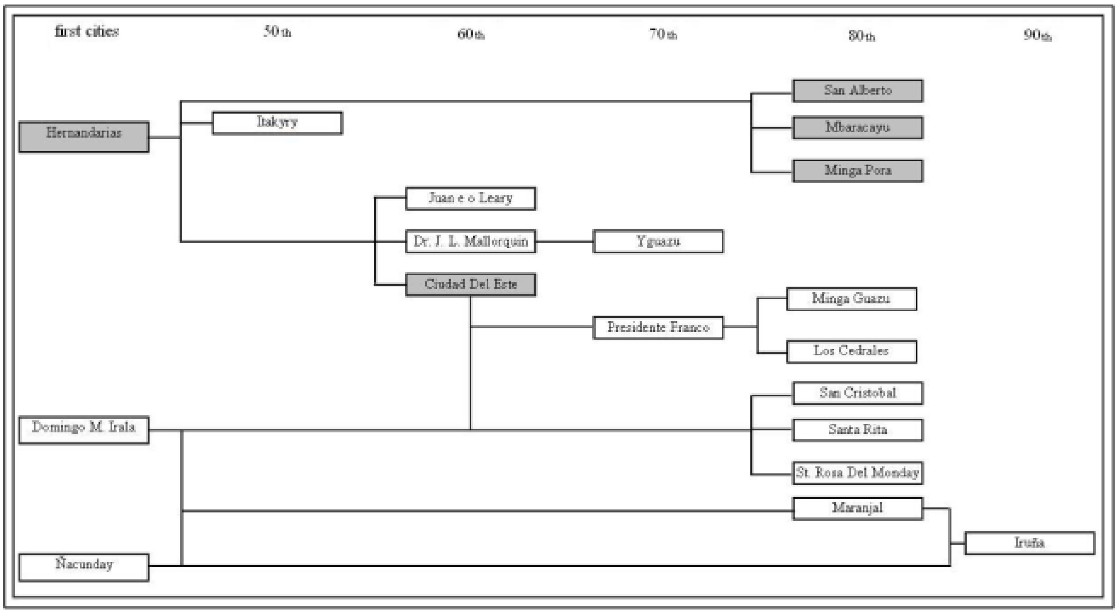

Figure 6.19: Districts divisions in Alto Parana - Paraguay [Source: (DGEEC, 2008)]

The compensation alone does not explain the administrative divisions in the 80s because in Paraguay, for instance, is the money is completely transferred to the national treasury. Therefore, it is necessary to associate the economic effect of new agricultural areas as another factor in the establishment of new municipalities in the 80s.

Other observed trends in the region are related to the ownership situation. There was a drastic reduction in farms of less than 10 hectares in the entire far west of Paraná, where they decreased from 50,267 in 1975, to 23,631 in 1990. On the other hand, large farms (between 100 and 1,000 hectares) increased from 1,742 to 2,295 in the same period.

Table 12 shows that all types of land ownership decreased in Paraná along with the number of agricultural workers and an increase of tractors from 18.619 to 130.828.

An important question for Brazil and Paraguay is land reform in the region. The failure of the IBR program in Paraguay in the 60s and the pressure to export products (such as soybean and coffee) in Brazil, propelled the landless movement in both countries.

In 1981, Brazilian landless rural workers, criticizing the lack of official titles and the Itaipú resettlement, organized the"*Movimento dos Trabalhadores Rurais Sem Terra do Oeste do Paraná*" (MASTRO), i.e., The Western Paraná Landless Rural Workers' Movement. The aim of this initiative was to fight for land reform in the region. It put forward proposals for settlements as well as credit programs for agrarian reform and small landowners in the state. Two programs were established in the following years: the *Programa Especial de Crédito para a Reforma Agraria* (Procera) - the Special Credit Program for Agrarian Reform and the *Empresa de Assistência Técnica e Extensão Rura* (Emater) - the Company for Technical Assistance and Rural Extension.

According to Brenneisen (2005), four years later (1984) MASTRO remained to help the MST foundation (Landless Rural Workers' Movement), which was already established nationwide. According to Meszaros (2007), Brazil's MST is currently the largest social movement in Latin America, with an estimated 1.5 million members in 23 of the 27 states. The agricultural trend in both Paraguay and in Brazil has contributed to agrarian inequality, concentrating the land in the hands of a few owners . These facts show the amplitude of some regional changes in the national structure.

The Itaipú region presents a good opportunity for studying the interaction between regional and national development, tracing a view of development management that is present not only in Brazil and Paraguay but also in many other South American regions. Such views change only when resources, such arable land, are about to run out and problems become unavoidable, as presented in Section 6.4.

6.4 Scenario Analyses

Naturally, unanticipated effects could be expected in any alteration of land use. As a result, the success of local decision making is largely determined by factors that are difficult to control or forecast. Thus, it is not enough to merely study contrasting long-term scenarios that generate a whole range of plausible, but different futures although they can help land managers rethink the robustness of existing strategies and discuss potential options for change.

Such scenarios are developed through a qualitative study, in which the important parameters are listed. This listing, however, follows a quantitative analysis that models the probabilities of change and pressure. For the study region, the most important change agents regarding woodland cover were:

a) the agricultural market;
b) the Itaipú reservoir and administration;
c) Demographic pressure;
d) Environment policy in Brazil and Paraguay.

The market maintains the conventional correlation of human concentration and level of consumption. But on a regional level, the world market controls demand and consequently the investment, particularly the production on large local farms, which leads to the degradation of natural resources and environmental impact. The management of Itaipú has tried to preserve the reservoir's shores through its environmental programs, although the reservoir itself has tended to weaken the environment. Although such a policy links both market and environmental interest, only its real enforcement can guarantee effective results.

Quantitative study produces an extrapolation model based on classes, which describes how development occurs. The results were plotted in the thematic map. The thematic maps done using the vulnerability observed in the development study for regional evaluation. The funded vulnerability shows the importance of the study, which takes into consideration several patterns of land use development. The division of gains or losses occurs randomly per class in the buffer zones. Three scenarios about the next 20 years were selected: the first makes assumption based on the last 30 years of regional development and predicts land use for the next 10 years; the second predicts the results of forest corridor and riparian zone reforestation; the final scenario envisions how the region might have developed without the construction of Itaipú.

The scenarios representations in thematic maps form were constructed by temporal series results. The results were used for generate forecasts of class areas. The scenario map was made with the repetition of identified patterns by comparing bi-temporal thematic maps. The regions with greater variability in the series results were replaced by other classes until the estimated regression values were reached.

In the first scenario (Figure 6.20), it is expected that 2009 ratios will be maintained for the next 10 years. This means that the remaining forest will be restricted to the parks and the highly fragmented Riparian forest in Brazil and Paraguay. On both the Brazilian and Paraguayan sides of this region, urban concentration will remain in the south and the population will grow at a lower rate than in the 2000s. This will lead to increases in employment and the commercial sector. The primary sector, however, will be saturated by soybean production, which implies considerable risks to the region.

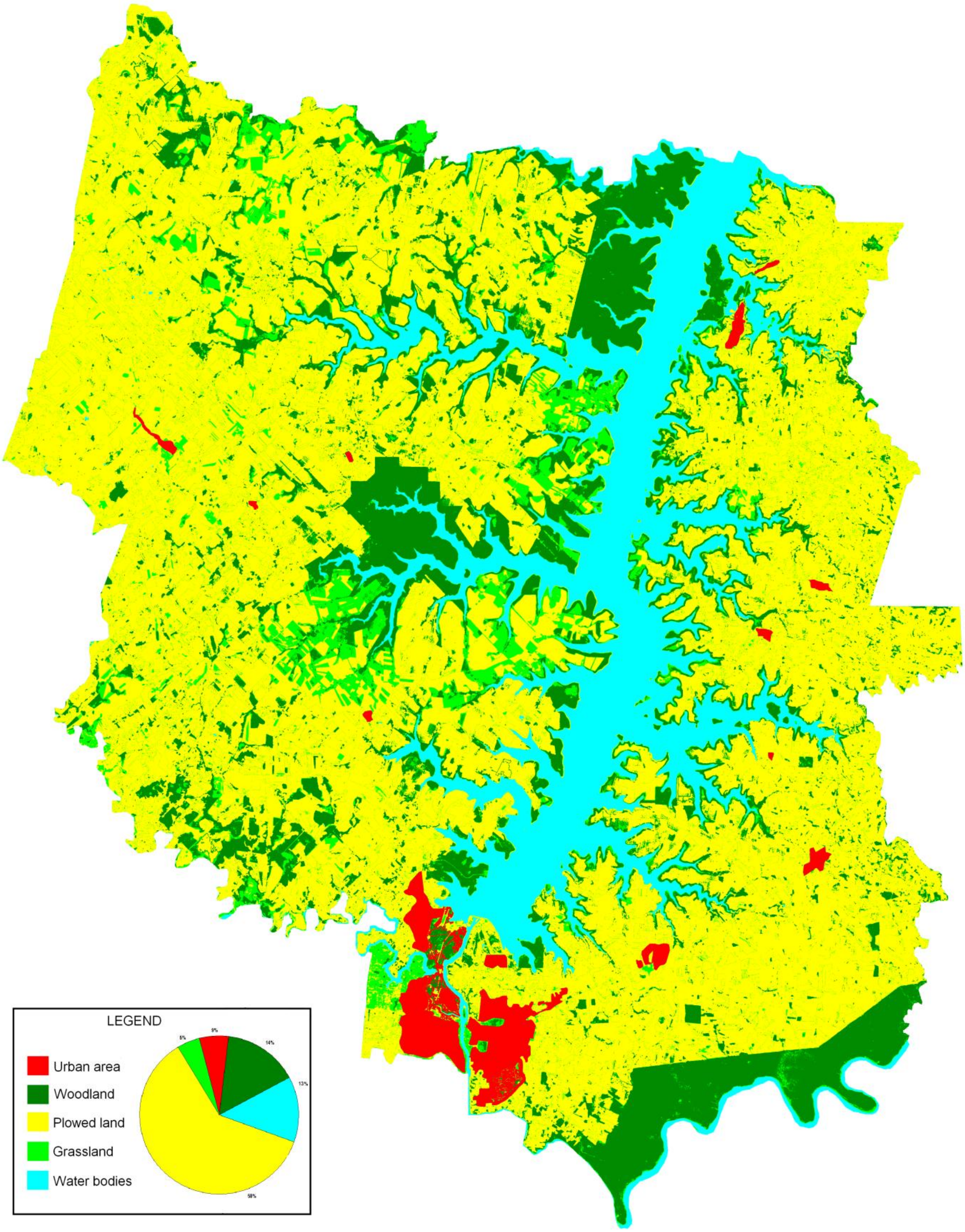

Figure 6.20: Scenario 01 - 2020. This map delineates the first based in a regression of 30 years data set.

Dependency on a single product, especially a world market product, has many disadvantages for the regional economy. An unexpected crop failure is the major risk; such a failure could come from natural climate fluctuations (drought, flooding), other natural catastrophes, continued soil degradation, pests or world price fluctuations. Moreover, soybean contributes to a higher erosion rate because it exposes the ploughed soil for a longer period of the than other local cultures practiced in this region.

Conversely, the second scenario assumes a more optimistic point of view. It considers the potential success of environmental protection programs and policies in Brazil and Paraguay. It is based on the recent evolution of management measures in both countries such as transparency in the Environmental Impact Assessment (EIA), which was described in section 6.2. The implementation of international treaties is also considered in this scenario. Since its inception in 1968 the CIC[24] has created many goals for developing the river basin. The objective of this treaty is further regional integration and development in Brazil, Paraguay and Argentina. Environmental conservation and the rational use of resources are some of the CIC's other goals. Although the most important treaties that have been signed have only dealt with hydraulic resource exploration, the harmonization of environmental policies through Mercosul[25] is currently being discussed in this council.

In this second scenario (Figure 6.21), the predicted growth in woodland area of only 10% over the next 10 years is also complex. The map in Figure 6.20 illustrates the main problems. The most important zone for conservation- the south- is also the most urbanized. Green corridors should link the areas in the riparian zone, the parks and the natural refuges. Some corridors cross the urban zone of Santa Terezinha de Itaipú, São Miguel do Iguacú, or Hernandarias, as well as the main regional roads. This means that some projects must be undertaken in all administrative spheres. A disadvantage in South America is the restricted consumer market in comparison to the European or American consumer markets. The environmental protection sector cannot use consumer activism such as boycotts, certified products, consumer organizations, etc. to pressure corporations to protect the environment. The final remark regarding this scenario is the fragility of environmental norms in South America. For example, Paraguay currently has a considerable body of related legislation but implementation and control is practically nonexistent.

[24] *Comitê Intergovernamental Coordenador da Bacia do Prata:* Inter-governmental Commission for management of the Prata River basin, which also encompasses the Paraná River basin.
[25] Mercosul or Mercosur is a Regional Trade Agreement (RTA) among Argentina, Brazil, Paraguay and Uruguay founded in 1991. Bolivia, Chile, Colombia, Ecuador and Peru currently have associate member status.

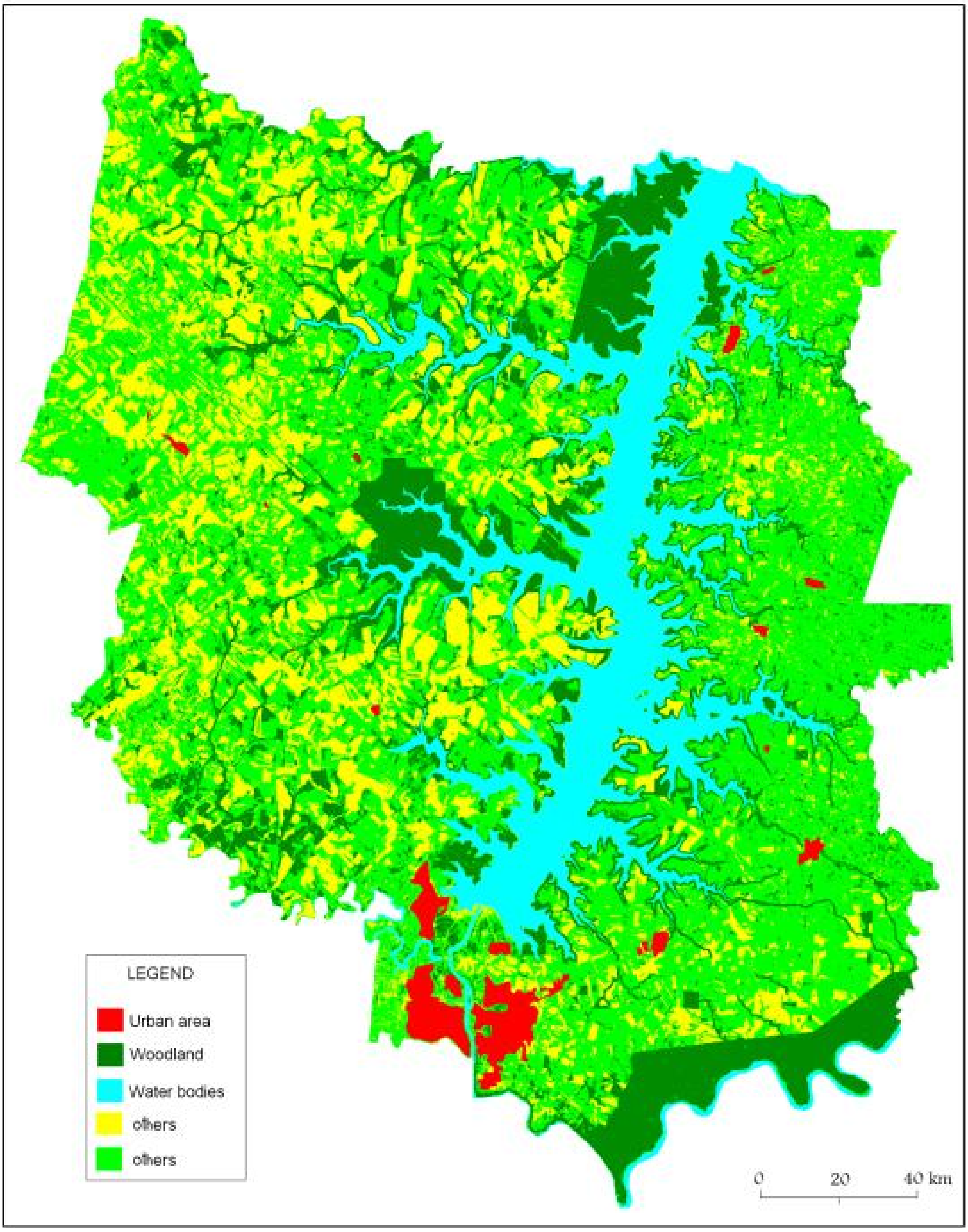

Figure 6.21: Scenario 02 - 2020. This map delineates the second scenario which considers the success of environment protection programs and policies in Brazil and Paraguay.

This final scenario (see Figure 6.22) demonstrates how the reservoir has affected the region. In the section above, the impact of the power plant on the region was estimated. The result was that it accelerated a preexisting process of Brazilian migration. The deforestation was due to agricultural expansion, which was independent of the construction of Itaipú. Based on such factors, what the region could have been like in 2009 without the construction of Itaipú can be seen in Figure 6.22. This map shows continued deforestation in Paraguay as well as urban development due to the important route connecting Foz do Iguaçu and Ciudad del Este.

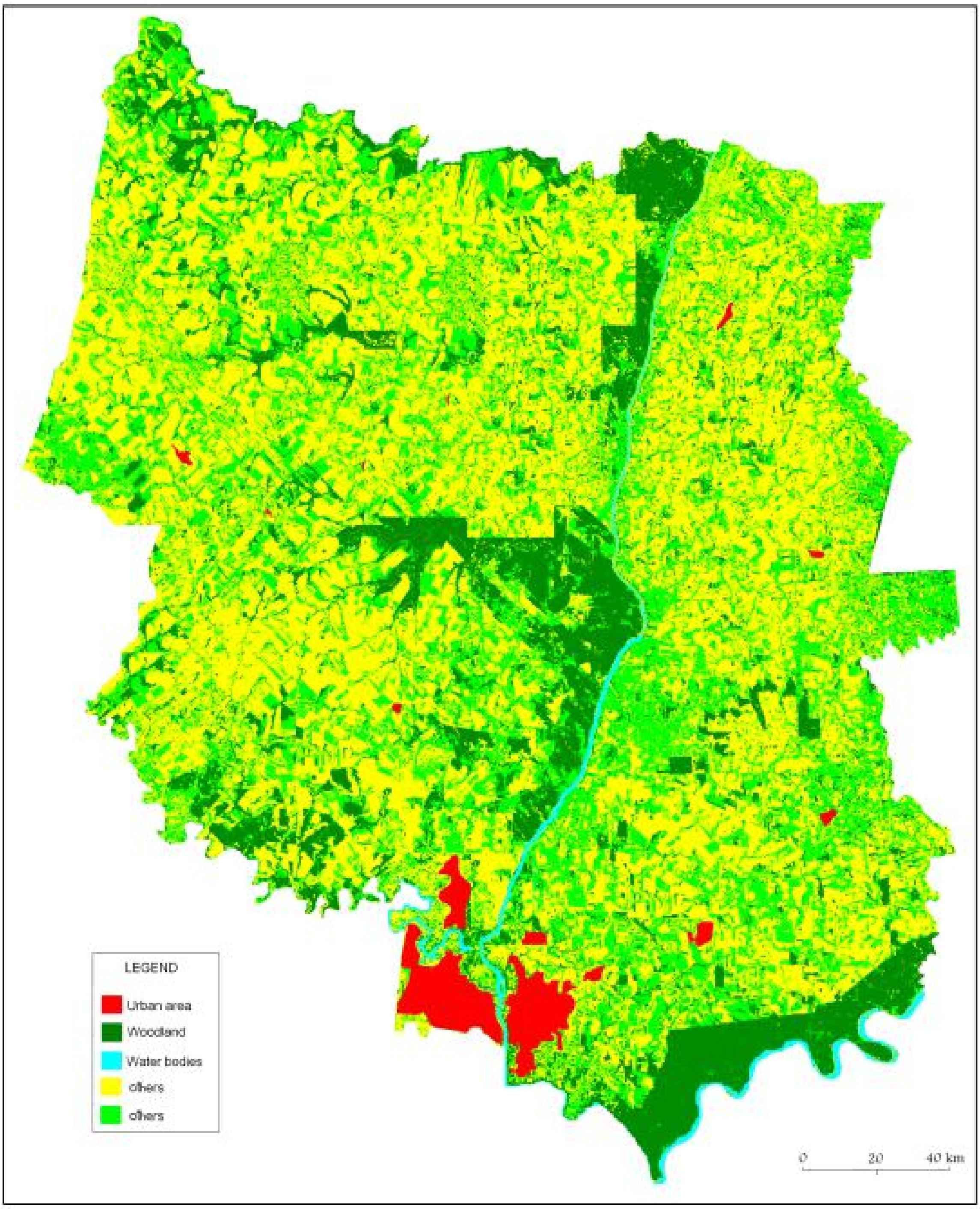

Figure 6.22: Scenario 3 - 2009. The third scenario supposes the region development from 1970 until 2009 without Hydroelectric power plant construction.

The initial Maps from 1973 and 1975 show that agricultural expansion occurred without regard for forest conservation. It began along the main roads, which mean that only opportunity and capital were necessary. Soybean is responsible for most of the deforestation in the study region because the international price grew with the its increasing use in many industrial products such as food, biofuel, oils, soap, cosmetics, resins, plastics, inks, crayons, solvents, and clothing.

This indicates that the construction of Itaipú played a relatively small role in the international process of deforestation in the region. The forest was destined for destruction as a consequence of negligent agricultural management and the rising profits from soy production.

The scenarios were the result of a linear regression applied to partial data aggregation. They were produced to demonstrate possible consequences of the observed tendencies of the most important regional agents in territorial redistribution.

Chapter 7

7. Conclusions and Recommendations

The development of a research methodology that uses remote sensing data to quantify the changes observed in soil coverage due to the construction of a large hydroelectric plant should first analyze the limitations of the technique. It is only possible to map the features and phenomena that can be spatially characterized by their image properties. To verify the validity of the method, the spectral responses linked to variation in forest cover in the image were evaluated. The methodology was designed to show the evolution of deforestation in the study region. In a bi-temporal analysis, it is difficult to define which factors and processes are involved in the observed changes. However, in a multiple observation analysis, the speed of changes can be specified and we were able to verify that the speed of the changes in this region was correlated with the construction of Itaipú, which is an important finding of this study. The changes, nevertheless, were more closely related to the migration of Brazilians to the border region of Paraguay than to the formation of the reservoir.

The central objective of this study was to analyze the development of a region that was physically and economically modified by the installation of a large engineering project. Such anthropogenic changes produce, as can be imagined, both short and long-term effects. The short-term effects can include changes resulting from the formation of the reservoir and the labor used in the construction of the dam. The long-term effects are mostly related to the rural real estate market and the environmental projects developed by the company. The point is to define which effects are due to the changes and which are associated with other local processes. In general, such questions can only be discussed in a theoretical manner, since they depend on the systematic monitoring of the region for a long period prior to the installation of a power plant. The case studied here is no different; the available information is very limited for an analysis of a broader scope. But that is always an inherent problem when studying historical facts.

The chief aspects that define the influence of Itaipú and its reservoir on the region are poor planning regarding reservoir-area occupant resettlement concomitant with the appreciation of the properties in the reservoir area. Since the Brazilian side had been developed with the necessary agricultural infrastructure for grain production, its value was much higher than the lands still covered by native vegetation in Paraguay. The flooding of cultivatable areas by the reservoir further propelled the migration of Brazilian farmers into Paraguay.

As the scenario evolved, forests were increasingly restricted to park areas (The National Park of Iguaçu, Biological Reserves and Refuges) due to progressive fragmentation. From the images it is possible to identify the forest regions that were not properly removed before the formation of the reservoir, which are in Paraguay north of Hernandarias. There has been a substantial recovery in riparian forest since the 90s, although it still remains fragmented; as can be seen in the 2009 map (figure 6.7 and in area 3, chapter 6.12), as well as in the field observations carried out in 2008. This contradicts Itaipú's official reports that 100% of the region's riparian forest is restored and protected.

Regarding the results of the thematic mapping, compatibility was determined by re-sampling the thematic maps for smaller-scale comparison, i.e., generalizing the thematic matrix maps by analyzing the majority and the minority classes elements on an identical scale to the initial image of comparison. For instance, the scale always mentioned the thematic maps of 1980 derived from the MSS when making a comparison with a thematic map in 2000 derived from the ETM.

However, the analyzed region contains several specific characteristics that influenced many of the hypotheses generated during the study. The region is in a border zone between two countries with different politics and structures, each presenting a series of unique problems in the development of the region. During the bibliographical research, it was verified that a series of socio-economical processes directly influenced the physical appearance of the area in question, including the change in production from coffee to soybean and Brazilian migration to the Paraguayan border region. These migrants are called *Brasiguaios* in reference to their bi-national character, which can be seen in their family and commercial ties with Brazil. For this reason, we attempted to identify the human aspects related to the involved processes.

Further commentary can be made about the political aspects of the processes. For future regional initiatives, the political changes involved should be examined. Currently, there is pressure from both Brazil and Paraguay to revise the Itaipú contract. The contract, which was signed during the dictatorial period in both countries, allows a series of advantages for Brazil. An analysis of those advantages without the necessary historical context would be quite tedious, because the Brazilian and the Paraguayan governments have been disputing the issue for over 20 years now. Political advantages were considered during the original negotiations that are no longer taken into account when analyzing the international contract.

In Brazil and in Paraguay, most studies of this kind are bi-temporal and can distort the facts because they do not evaluate the dynamic phenomena occurring in the studied region. Our research was limited to the free data available in both countries, which shows a viable alternative for this type of study. The use of the Chinese-Brazilian satellite data, besides revealing the detailed problems in Chapter 2, facilitated the medium-scale study of the region.

The study also observed that the infrastructure of data in Brazil and Paraguay is still in its initial phase. There is not as yet a clear organization of the various sources of spatial information like that which can be found in Europe, for example. There are movements in Brazil leading in this direction, but they are still cautious.

This study was important for its impartial depiction of the impact of Itaipú's construction on the forests of the Brazil-Paraguay border. It was also important to employ mappings and data available to any South American researcher for studying changes in soil coverage and use.

The thematic uncertainty was evaluated by analyzing the results of the "layer of belief" histograms, which showed the distribution of function through the contingency relationship of the pixels toward one or another class in the charts. These histograms are used to evaluate the uncertain on mistakes matrix considered.

The conclusions of the scenario analysis can be used as an example for other studies. The use of seasonal images for mapping and monitoring is recommended for several types of regional agriculture. Cross-referencing census information with that of agricultural and environmental institutions is also recommended to define the ecological fragility of the region.

The agricultural census in Brazil and Paraguay could use research linked to spatial distribution of the information for the following contrast with the responses and the employed models for the monitoring of harvests. The use of additional active sensors for the evaluations proved to be useful. There was a certain incompatibility between our results and those of the census due to different class definitions by the sensing equipment and different census statistics. The farming census is estimated by interviews with farmers, which makes its consistency suspect. In Brazil these data are currently crossed-referenced with models that follow the official harvest figures. Auxiliary data from the thematic mapping could improve the quality of such validation models.

In the present case, the employed methodology reached the expected result. It facilitated the study by either proving or ruling out related hypotheses, thus guiding the flow of the argument.

Future efforts must concentrate on the analysis of a larger number of classes and try to determine the rate of expansion of extensively-planted crops such as wheat and soy. Thus, the initial set of data is decisive for obtaining relevant results because the determination of classes related to the studied problems depends on it.

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