Master Thesis

im Rahmen des Universitätslehrganges „Geographical Information Science & Systems“ (UNIGIS MSc) am Interfakultären Fachbereich für GeoInformatik (Z_GIS) der Paris Lodron-Universität Salzburg zum Thema

Revealing forest cover loss in Paraguay´s Atlantic Forest region
- A remote sensing and GIS based forest monitoring

vorgelegt von

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102621, UNIGIS MSc Jahrgang 2012

Zur Erlangung des Grades

„Master of Science (Geographical Information Science and Systems) – MSc (GIS)“

Gutachter:

Ao. Univ. Prof. Dr. Josef Strobl

München, 28.02.2014

Acknowledgements

This study was carried out in cooperation with the Department *Land Surface* of the German Remote Sensing Data Center (DFD) of the German Aerospace Center (DLR).

I would like to thank Dr. Claudia Künzer, Dr. Christina Eisfelder, Marco Ottinger, Juliane Huth and Alexander Mager for their support, advice and patience.

Very special thanks go to Nicole Hiekel and Mira Baur for proofreading, as well as David Wöllmer for encouraging me in moments of doubt and uncertainty.

WWF Paraguay provided valuable information on forest and biodiversity conservation in Paraguay for which I am grateful.

Erklärung

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Abstract

This study examined the spatial impact of forest loss in Paraguay´s Atlantic Forest between 2003 and 2013 with a special focus on biodiversity conservation. The subtropical Atlantic Forest is a highly diverse ecosystem in South America and one of the most endangered rain forests in the world. Due to its critical conservation status, the Atlanitc Forest was designated as a global biodiversity hotspot. The present study focuses on the Paraguayan part of the trinational Atlantic Forest. It covers an area of 86,000 km² in Eastern Paraguay. The main threats are the loss of forest cover due to other land use priorities and increasing forest fragmentation. For many years, the Atlantic Forest in Paraguay had one of the highest rates of deforestation worldwide and today only a small part is still covered with natural forest. In recent years, forest conservation has become more prominent in Paraguay´s environmental policies. Within this context, geo-spatial techniques such as remote sensing and GIS analyis were applied to reveal forest loss within the last decade, distinguish deforestation patterns, and characterize the current forest landscape within the study area. Initially, the forest cover of two points in time were derived using pixel-based classification of Landsat satellite data. Eight Landsat-7 images in 2003 and eight Landsat-8 images in 2013 were classified in order to cover the large study area. The forest cover classification reached a high level of accuracy, ranging between 83 and 95 percent. Subsequently, forest loss between 2003 and 2013 were quantified and mapped for the whole study area. In addition, four different forest loss patterns were distinguished by visual interpretation. The object-based detection of these specific deforestation areas was particularly challenging and are in need of further investigation. In order to evaluate the effectiveness of protected areas, forest loss in and outside protected areas were analyzed by GIS analysis. The forest landscape and its fragmentation level was characterized by a set of landscape metrics. In particular, the core area and proximity analysis support the identification of forest priority areas and potential biological corridors. In summary, the study revealed that deforestation and fragmentation of the Atlantic Forest area continued, but at a slower pace than in the previous decade. Different deforestation types and patterns are caused by different drivers. Protected areas are very effective in forest consevation. However, forest core areas without any protection status need further attention. Intact forest patches and their connectivity are a crucial prerequisite to biodiversity conservation in a highly fragmented forest area. Forest protection and biodiversity conservation are strongly interlinked processes. The combination of different remote sensing and GIS methods provide valuable information for a sustainable forest management in the study area. The results were presented in several maps, providing an overall picture of the developments in Paraguay and its Atlantic Forest region.

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List of Abbreviations

BAAPA	El Bosque Atlántico del Alto Paraná / The Atlantic Forest of the Upper Paraná
BAAPAP	El Bosque Atlántico del Alto Paraná en Paraguay/ The Atlantic Forest of the Upper Paraná in Paraguay
CGIAR	Consultative Group on International Agricultural Research
CI	Conservation International
CONAM	National Council of the Environment (Paraguay)
DEM	Digital Elevation Model
DFD	Deutsches Fernerkundungsdatenzentrum / German Remote Sensing Data Center
DLR	Deutsches Zentruk für Luft- und Raumfahrt / German Aerospace Center
ESA	European Space Agency
FAO	Food and Agriculture Organizationof the United Nations
FRA	Forest Resource Assessment
INFONA	Instituto Forestal Nacional / National Forestry Institute (Paraguay)
IUCN	International Union for Conservation of Nature
NASA	National Aeronautics and Space Administration
OBIA	Object-based Image Analysis
REDD	Reducing Emissions from Deforestation and Degradation
SEAM	Secretária del Ambiente / Environmental Department (Paraguay)
SINASIP	El Sistema Nacional de Áreas Protegidas / National System of Protected Areas
SRTM	Shuttle Radar Topography Mission
TNC	The Nature Conservancy
UNDP	United Nations Development Programme
UNEP	United Nations Environmental Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
WWF	World Wildlife Fund

1 Introduction

Tropical and subtropical forest ecosystems are of immense global importance. They are highly complex systems that play a significant role in regulating and stabilizing the climate, biochemical cycles, and biological diversity. These forest ecosystems contain 25 per cent of the carbon in the terrestrial biosphere, account for 33 per cent of terrestrial net primary production and can sequester large amounts of carbon (Joseph, Murthy, & Thomas 2010). Tropical and subtropical forests also help to maintain the water cycle and act as reservoirs of biodiversity. These biodiverse areas contain more than half of all plant and animal species, yet their area is only 7 per cent of total land mass (Joseph, Murthy, & Thomas 2010). However, tropical forests are threatened by different deforestation and degradation processes. Deforestation continues at an alarming rate of about 13 million ha per year worldwide. It is responsible for about 17 percent of human-produced greenhouse gas emissions (FAO, 2010a). Thus, deforestation is a global challenge that affects the whole global society. Within the United Nations Framework Convention on Climate Change (UNFCCC), the issues of deforestation and degradation are central and have been more prominently placed in an evolving post Kyoto Protocol policy process. The mechanism for Reducing Emissions from Deforestation and Degradation (REDD+) is considered a key instrument in climate change mitigation (FAO, UNDP, & UNEP, 2008). Beside carbon emissons, another main obstacle linked with deforestation and degradation processes is the loss of biodiversity. Tropical rainforest are biodiverse habitats for many rare and endemic species. Due to its important ecosystem functions, 18 of the world´s 25 biodiversity hotspots owe their status to tropical forests. The conservation of forest biological diversity was adopted as one important work program of the Convention of Biological Diversity (United Nations, 2002). Thus, biodiversity conservation and ecologically sustainable forest management are closely interlinked processes that need to be investigated in an interdisciplinary and multiscaled approach (Lindenmayer & Franklin, 2002).

Within this context, comprehensive forest and biodiversity monitoring needs to be enhanced on a national, regional and global level. To tackle this issue, comprehensive information on deforestation is needed: where is it occurring, at what rate and why? For conversion for other land use? Quantitative information on progress in maintaining and expanding forests is vital, particularly for realizing systems of payment for the environmental benefits that forests provide. Within recent years, earth observation and remote sensing tools became central in monitoring programs (FAO, 2010a; Strand et al., 2007). Satellite based remote sensing provides images of the earth of the last 30 years. Vastly improved techniques and methods allow a very detailed knowledge and perception of our planet and therefore form an important pillar of effective monitoring tools. The main advantage of remote sensing based monitoring is that satellite data cover remote areas all over the world and is acquired frequently. The top-down view of aerial and satellite data allows detailed insights in very inaccessable areas such as rainforest ecosystems and are therefore preferentially used in many regions all over the world.

The Atlantic Forest is a global ecoregion and one of the most endangered rain forests in the world. In South America, the Atlantic Forest rivals the Amazon forest as one of the Earth´s most biologically diverse ecosystem and was designated as one of the 25 global biodiversity hotspots (Myers et al. 2000; Conservation International, 2013). The Atlantic Forest is a trinational forest area that covers parts of Paraguay, Brazil and Argentina. This study focuses on the Paraguayan part of the Atlantic forest ecoregion. It is dominated by humid subtropical forest and covers an area of about 86,000 km². For many years, the Atlantic Forest in Paraguay had one of the highest rates of deforestation in Latin America and only a small part is still covered with primary forest. As in many other tropical forest systems worldwide, its stability is seriously threatened and degradation may be irreversible. Among other environmental challenges (like water pollution), deforestation is a very critical issue in that area. Following a new initiative of forest protection and conservation in 2004, the Forest Conversion Moratorium was implemented, thereby impeding any deforestation in Eastern Paraguay. Supported by the international environmental actors, such as the WWF, USAID or The Nature Conservancy, the national and municipal government facilitates the enforcement of these laws to maintain and restore critical biodiverse habitat and assist the livelihoods of the local population. According to the WWF, these measures did successfully reduce the deforestation rate in the Atlantic Forest by 90 per cent in 2009 compared to 2002.

Within this context, this study examines current state of the Atlantic Forest in Paraguay. In order to evaluate recent developments, forest cover dynamics of the last decade (2003-2013) will be studied by remote sensing and GIS analysis of Landsat data. The five guiding research questions are: 1) *Did forest cover loss occurr within the last decade? 2) And if so what did the deforestation patterns look like? 3) Are protected areas effective regarding forest conservation? 4) How can the current forest landscape be characterized? 5) And what are the important forest priority areas in order to conserve biodiversity within the study area?*

The analysis will provide information on forest cover change and spatial patterns of deforestation activities. Subsequently, the forest cover will be characterized in accordance to landscape fragmentation and connectivity of forest patches. Based on this forest characterization, important and valuable forest areas with regard to biodiversity conservation will be identified. A combination of different remote sensing and spatial analysis methods are applicable.

The study is structured as following. Chapter 2 gives an overview on the Atlantic Forest ecoregion as well as an introcution to its biodiversity status. Chapter 3 characterizes Paraguay and its Atlanitc Forest, its history of deforestation and the main pillars of Paraguays environmental governance. Chapter 4 depicts the theoretical background of the study and the data that is used. Chapter 5 describes all steps of the analysis workflow. Also, the methods used in this study are explained in detail. Chapter 6 presents the results of the study. Chapter 7 discuss the results applying the guiding research questions. An overall conclusion regarding results, methodology, and outlook on future research ideas are the closing remarks of this study and are summarized in Chapter 8.

The master thesis was prepared as a pilot study in the context of an upcoming project (*Paraguay Landuse,* PARLU) that is planned to start in 2014 and will be a collaboration of the Team *Land Surface Dynamics* at the German Remote Sensing Data Center (DFD) at the German Aerospace Center (DLR) and WWF Paraguay.

2 The Atlantic Forest Ecoregion

2.1 The trinational Atlantic Forest – a threatened Biodiversity Hotspot

Following a global strategy to conserve biodiversity, the World Wildlife Fund (WWF) authors Olson & Dinerstein (2002) defined 238 priority ecoregions for global conservation as the so called “Global 200”. These ecoregions were identified by an assessment of biodiversity indicators as species richness, endemism and its irreplaceability or distinctiveness. The Atlantic forest was designated as one of the terrestrial Global 200 ecoregions and thereof one of the 50 tropical and subtropical moist broadleaf forests (see number 48 within Figure 1). Tropical and subtropical moist forests biomes amount 35% of all terrestrial ecoregions worldwide which reflects the biological richness and complexity of tropical moist forests. Together with the Western Arc forests in the Amazon Basin and the Chocó-Darién ecoregion of northwestern South America, Sumatra and Peninsular Malaysia and northern Borneo forest ecoregion, the Atlantic Forests is one of the most diverse ecoregions. However, the designated conservation status of the Atlantic forests was assessed as critical or endangered by the International Union for Conservation of Nature (IUCN, 2013).

Due to its critical conservation status, the Atlantic Forest was designated as one of the biodiversity hotpots by Conservation International (CI) authors (see Figure 2). Dealing with the conservation of endangered areas of the globe Myers et al. (2000) defined biodiversity hotspots as regions that “must meet two strict criteria: it must contain at least 1,500 species of vascular plants (> 0.5 percent of the world's total) as endemics, and it has to have lost at least 70 percent of its original habitat.”

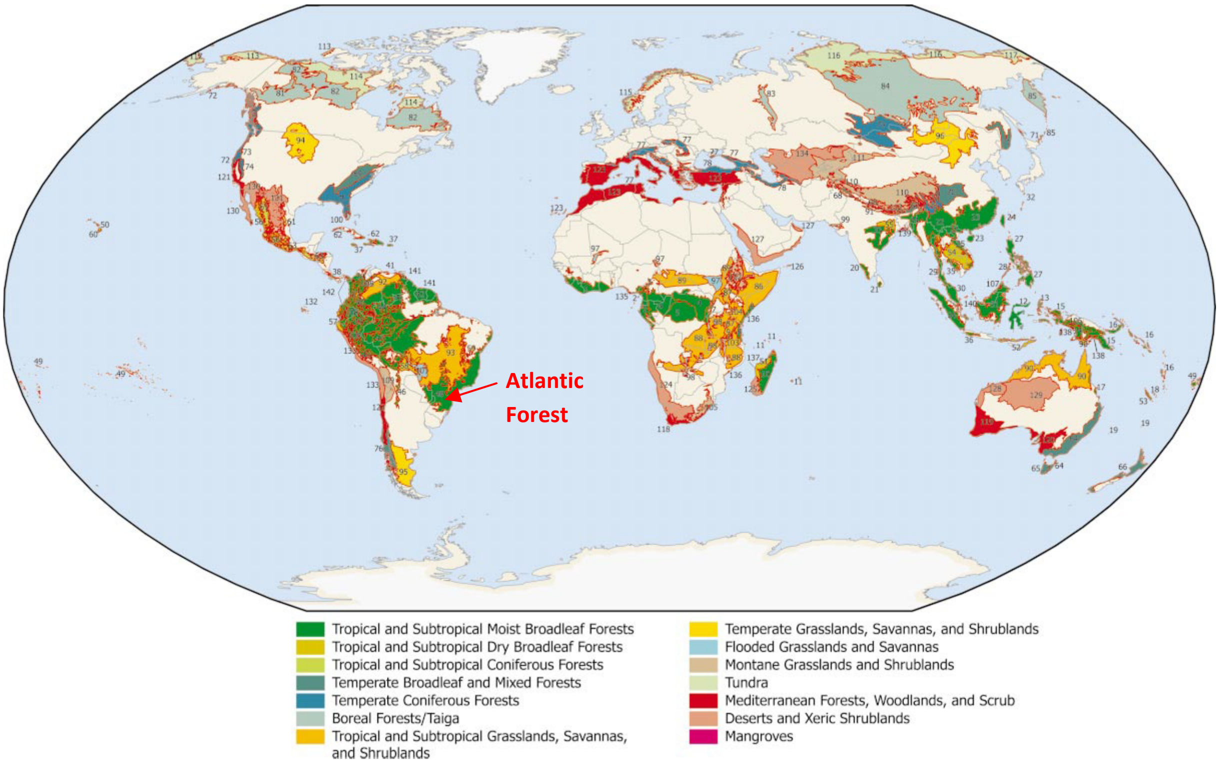


Figure 1: The terrestrial Global 200 ecoregions. The map shows terrestrial ecoregions with outstanding biodiversity features and representative value. The numbers correspond to the ecoregions published by Olson & Dinerstein (2002).

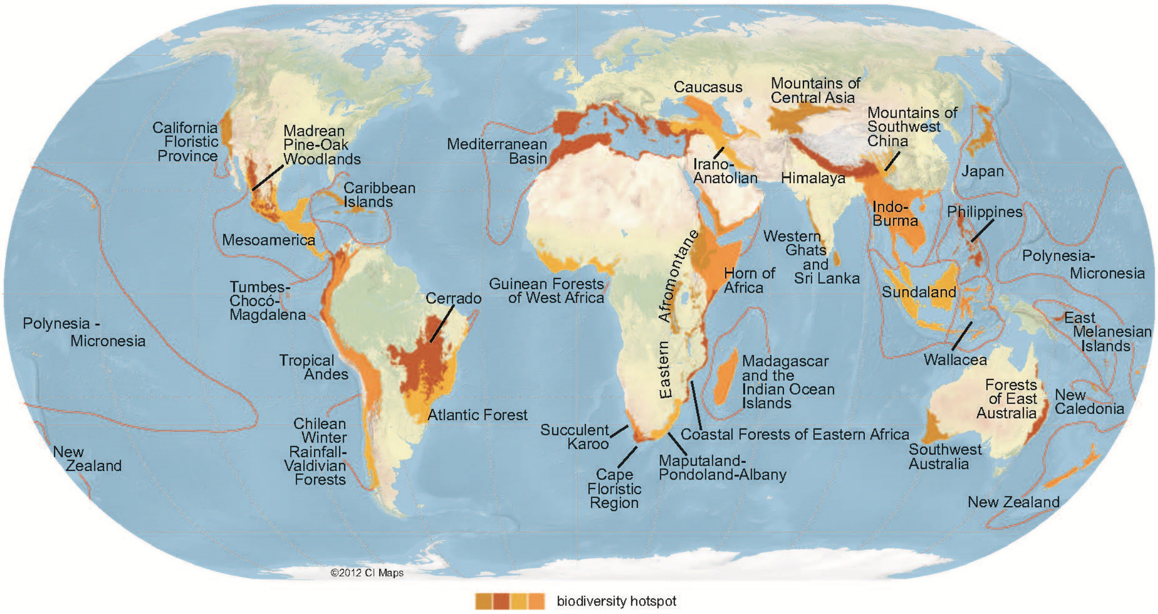
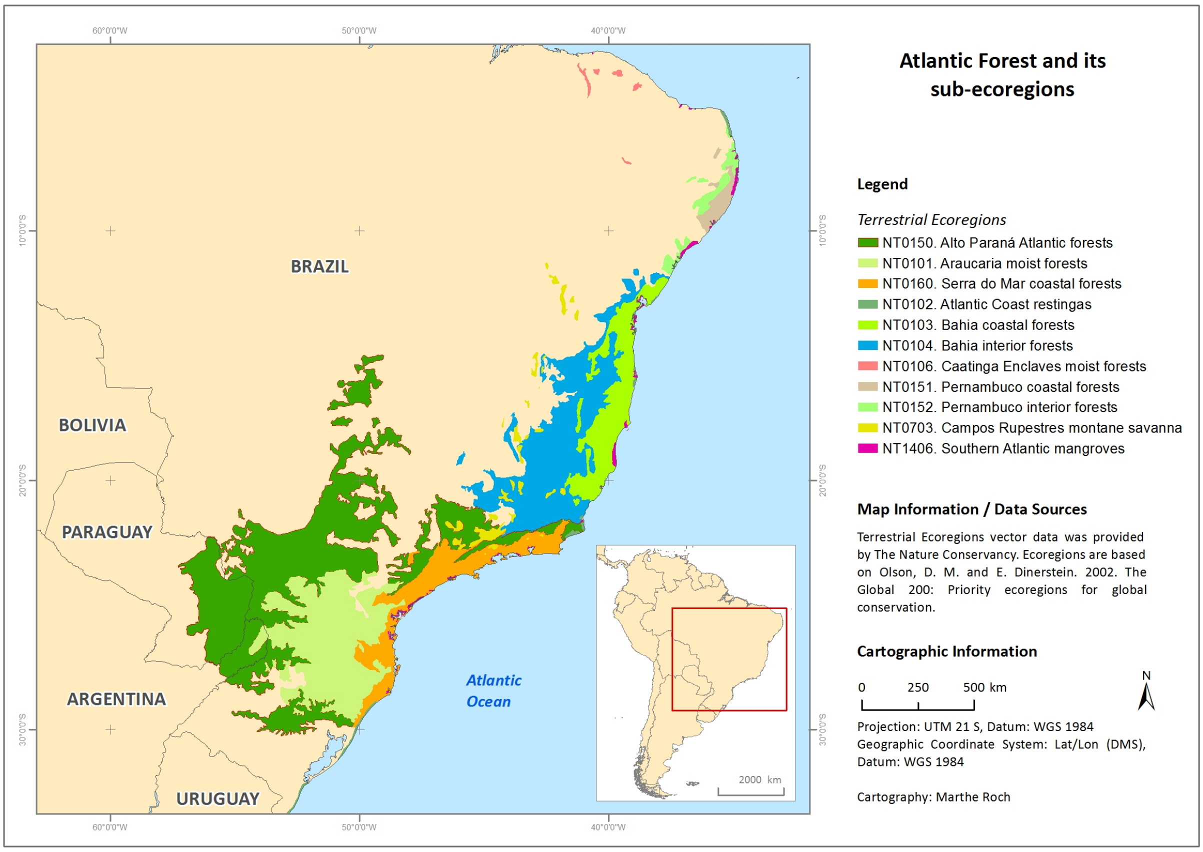


Figure 2: Biodiversity Hotspots worldwide. Source: Conservation International (2011).

The Atlantic Forest is a trinational ecoregion in South America. The main part stretches along Brazil's Atlantic coast, from the northern state of Rio Grande do Norte south to Rio Grande do Sul. Furthermore, it extends inland to Eastern Paraguay and the province of Misiones in northeastern Argentina (see Figure 3). The two main sub-ecoregions in the hotspot are the coastal Atlantic forest, a narrow strip of about 50-100 kilometers along the Brazilian coast which covers about 20 percent of the region. The second main sub-ecoregion is the interior Atlantic Forest or the so called Alto Paraná Atlantic Forest that stretches across the foothills of the Serra do Mar into southern Brazil, Paraguay and Argentina. These forests extend as far as 500-600 kilometers inland and range as high as 2,000 meters above sea level. Altitude determines at least three vegetation types in the Atlantic Forest: the lowland forest of the coastal plain, mountain forests, and the high-altitude grassland or campo rupestre (Conservation International, 2013).

Although only a small part of the original forests remains, it is still one of the most diverse ecosystems on the planet, second only to the Amazon. The Atlantic Forest has an extremely diverse and unique mix of vegetation and forest types that accommodate many different animals. The high biodiversity and endemism is caused by the long floristically isolation from other major rainforest blocks in South America by the woodland and savannas of the Cerrado ecoregion. Conservation International (2013) provides information of amount and endemism of the existing species in Atlantic forest biodiversity hotspot (see Table 1).



Terrestrial Ecoregions vector data was provided by The Nature Conservancy. Ecoregions are based on Olson, D. M. and E. Dinerstein. 2002. The Global 200: Priority ecoregions for global conservation.

Projection: UTM 21 S, Datum: WGS 1984
Geographic Coordinate System: Lat/Lon (DMS), Datum: WGS 1984

Cartography: Marthe Roch

Figure 3: The Atlantic Forest and its main sub-ecoregions.

Table 1: Diversity and endemism in the Atlantic forest ecoregion.(Source: Conservation International 2013)

	Species	Endemic Species	Percent Endemism
Plants	20,000	8,000	40.0
Mammals	264	72	27.3
Birds	934	144	15.4
Reptiles	311	94	30.2
Amphibians	456	282	61.8
Freshwater Fishes	350	133	38.0

About 20,000 plants exists in the Atlantic Forest ecoregion. Thereof 40 per cent are endemic and do not exist in any other part of the world. Endemism in trees is in particular very high. For example, Brazil-wood (*Caesalpinia echinata*) and Brazilian rosewood (*Dalbergia nigra*) have a high value in timber industry and are very rare today. Or another timber specie, the paratecoma peroba, approach extinction in that region. More than 900 different bird species are living in that area, about 15% of which are found nowhere else. There are many unusual and endangered birds including the red-billow curassow (*Crax blumenbachii*), the Brazilian merganser (*Mergus octosetaceus*) and a lots of parrots such as the red-tailed Amazon (*Amazona brasiliensis*) and the red-browed Amazon (*Amazona rhodocorytha*). More than 60 per cent of the amphibians in that area are endemic and very rare reptiles and mammals exists e.g. the lion tamarins or the jaguar (see pictures in Figure 4).

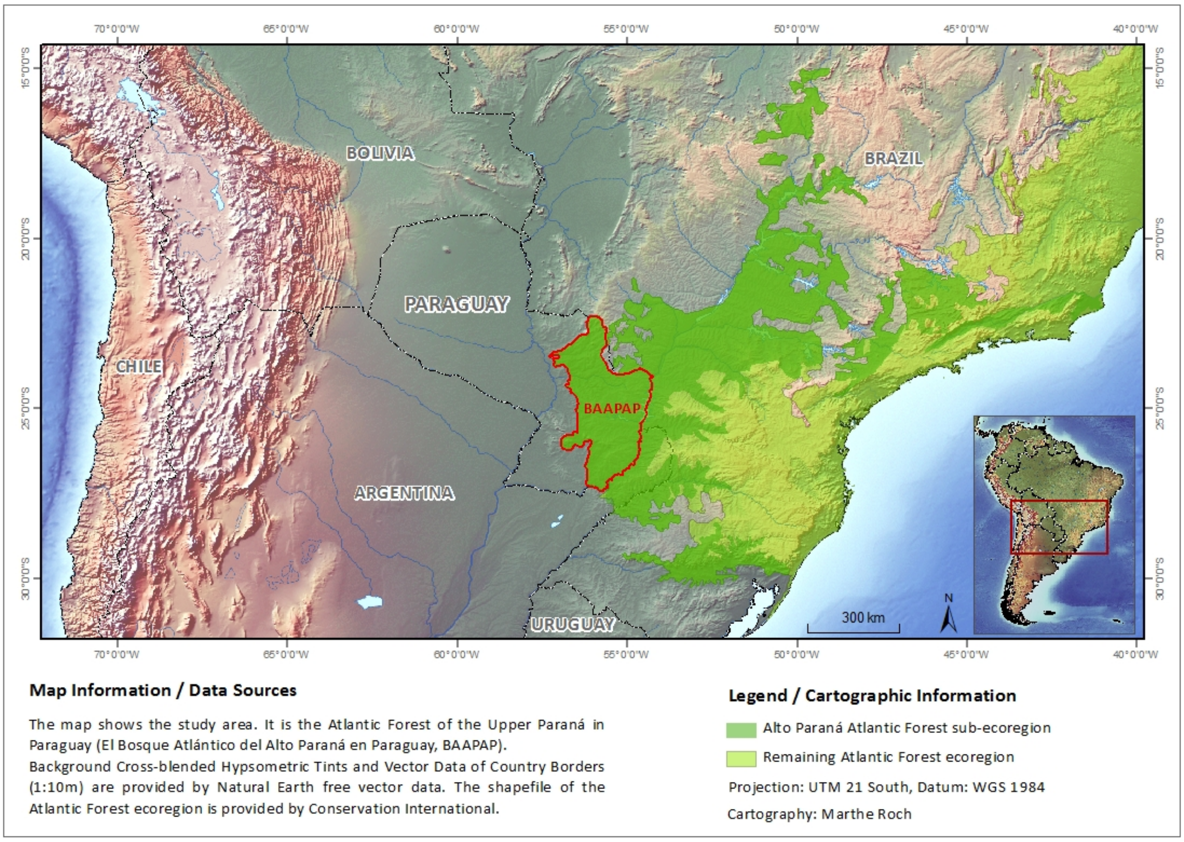
Figure 4: Rare and threatened species of the Atlantic Forest ecoregion. (Source: Conservation International 2013).

The main threats of the biodiversity hotspot are the loss of forest cover, destruction and degradation of the Atlantic forest due to other land use priorities within the previous three centuries (settlement, timber, cattle ranching and coffee plantations) and in particular within the last 50 years (increasing urbanziation, intensification and expansion of agriculture as plantations of sugar, cotton, eucalyptus and soy). Only about eight percent of the more than 1 million km² unbroken tropical and subtropical forests remain (Conservation International, 2013). The largest contiguous area of original forest (10,000 km²) is located in Misiones province in northern Argentina. The famous Iguazú falls are located in this area (see Figure 5).

Figure 5: Aerial view of the Atlantic Forest canopy. San Rafel Reserve (left) and Iguaçu Falls (right). Source: Flickr.

2.2 *Defining the Study Area: Paraguay´s Atlantic Forest Region*

The present study focuses on the Paraguayan part of the Atlantic Forest sub-ecoregion, the Atlantic Forest of the Upper Paraná or in Spanish: *El Bosque Atlántico del Alto Paraná* (BAAPA). The study area will be abbreviated as “BAAPAP” (*El Bosque Atlántico del Alto Paraná en Paraguay*) in the following.



Map Information / Data Sources

The map shows the study area. It is the Atlantic Forest of the Upper Paraná in Paraguay (El Bosque Atlántico del Alto Paraná en Paraguay, BAAPAP).
Background Cross-blended Hypsometric Tints and Vector Data of Country Borders (1:10m) are provided by Natural Earth free vector data. The shapefile of the Atlantic Forest ecoregion is provided by Conservation International.

Legend / Cartographic Information

🟩 Alto Paraná Atlantic Forest sub-ecoregion
🟩 Remaining Atlantic Forest ecoregion
Projection: UTM 21 South, Datum: WGS 1984
Cartography: Marthe Roch

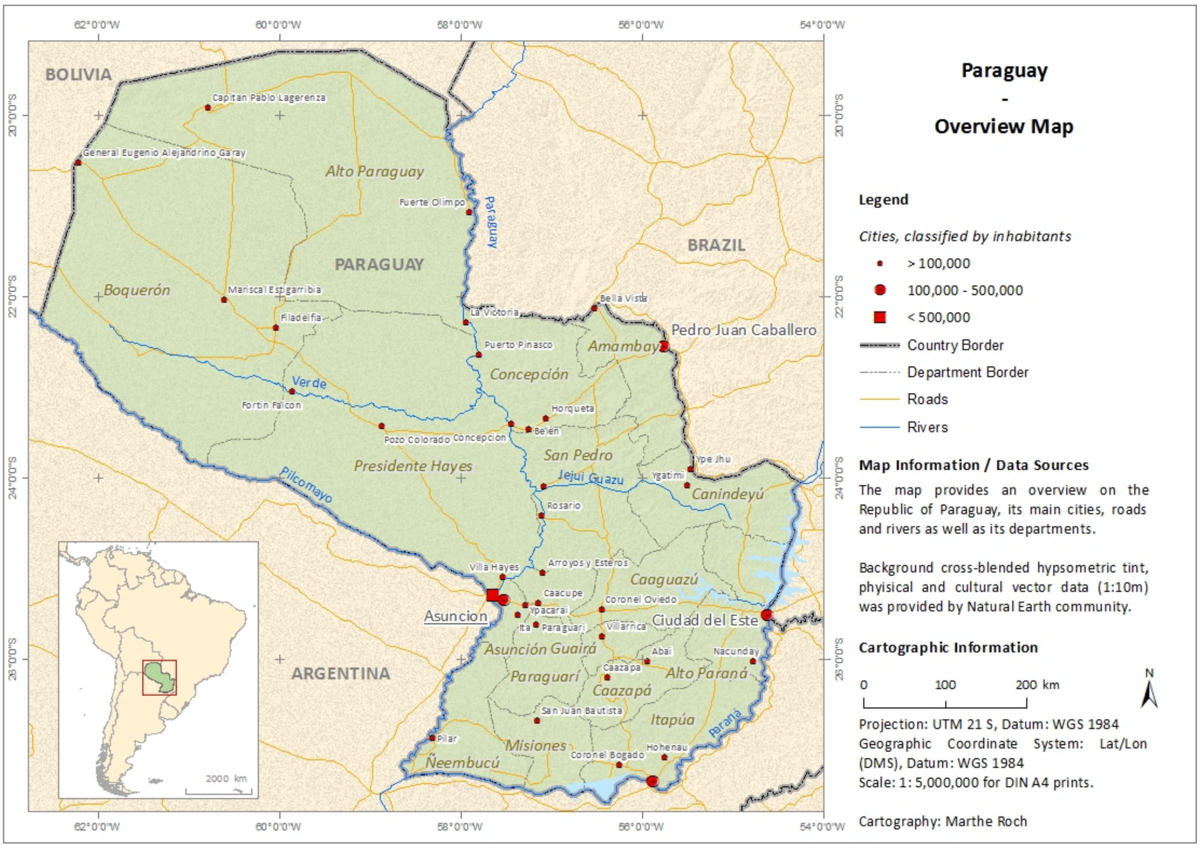
Figure 6: Overview map of the study area: the BAAPAP region.

The total area covers 86 thousand km² (8,6 million ha). Depending on applied data sources, the size of the area can slightly varying to other indications. For this study, the BAAPAP region area was technically defined by the overlapping area of the Paraguayan territory (defined by the vector layer 1:10m of the Natural Earth community) and the territory of the Atlantic Forest ecoregion (defined by the vector layer of biodiversity hotspots provided by Conservation International).

3 Paraguay and its Atlantic Forest

3.1 Geography of Paraguay

Paraguay is a landlocked South American Country, bordering Brazil, Argentina and Bolivia. Its total area is 406,752 km² (in comparison, Germany has an area of 375,121 km²), of which 397,752km² are land and 9,450 km² are water (World Factbook, 2013). The territory of Paraguay is bisected by the Paraguay River into Eastern Paraguay and Western Paraguay. The other main rivers are the Rio Paraná shaping the eastern border to Brazil and Argentina and the Rio Pilcomayo shaping the southwestern border to Argentina. Area is located inside the greatest freshwater basin of South America, the Guaraní Aquifer. The Republic of Paraguay is administratively divided into 17 departments; three very large departments are located in the western part (Boquerón, Alto Paraguay and Presidente Hayes) and 14 smaller departments in the eastern part. The capital is Asunción.



The map provides an overview on the Republic of Paraguay, its main cities, roads and rivers as well as its departments.

Background cross-blended hypsometric tint, phyisical and cultural vector data (1:10m) was provided by Natural Earth community.

Projection: UTM 21 S, Datum: WGS 1984
Geographic Coordinate System: Lat/Lon (DMS), Datum: WGS 1984
Scale: 1: 5,000,000 for DIN A4 prints.

Cartography: Marthe Roch

Figure 7: Paraguay - overview map.

3.1.1 Topography, Climate and Biodiversity

Due to its topography and climate, the eastern and western part differ a lot. Eastern Paraguay´s topography is mostly flat with four ranges of hills (the Cordilleras of Amambay, Maracayú, Ybutyruzú and Caaguazú) and highest elevation is 842m above sea level. The western part is almost an entirely plain that slopes east towards the Paraguay River with highest elevation of 380m above sea level. Eastern Paraguay is situated onm the the Brazilian Shield whereas the Andean Depression underlies western Paraguay. Most Soils in western Paraguay are mostly sandy and frequently become saline when they are cultivated or irrigated. In contrast about 65% of the soil in Eastern Paraguay is fertile and well drained and thus very suitable for agriculture and pasture.

As it is shown in the three climate charts in Figure 8, the climate varies from subtropical and humid with high rainfalls (up to 1,800mm per year) in the southeast to drier and temperate areas in the northwest (with rainfalls less than 400mm per year). The average temperature varies from 21 degrees Celsius in northeast to 25 degrees Celsius in southeast. These differences in topography, soil and climate lead to different ecoregions and vegetation zones in Paraguay. Five different ecoregions are located within Paraguay, mainly the dry Chaco in the northwest, the humid Chaco in the middle-south and the Atlantic forest of the Upper Paraná (BAAPA) in the eastern part of the Country. The Cerrado and Panatal ecoregion only reachs very small parts of Paraguayan territory close to the northern border with Brazil (see Figure 8). The study area is the part of the BAAPA area that is congruent within the Paraguayan territory. The BAAPAP region is bordered on the east by the Paraná river and the Mbaracayu and Amambay Mountains, on the north by the Apa River, and on the west by the Paraguay river. The entire region is humid (average rainfall between 1300-1800mm), midly hilly and irrigated by numerous rivers and streams that empty into the Paraguay and Paraná. It shares a large part of the Guaraní Aquifer. Three ecoregions of the BAAPAP region are the Amambay/ Monatane Forests in the north, the Upper Paraná / Paraná Forests in the east and the Central Jungle/ Central Forests in the south (Fragano & Clay, 2003).

According to FAO (2010a) Paraguay´s forest area is estimated to 175,820 km² (44 per cent of total land area). A coarse land cover map of Paraguay is shown in . It is a subset from ESA´s a Global Land Cover product and illustrates that the forest cover in western Paraguay is more prevalent than in the eastern part of the country. Whereas the western side is dominated by Chaco woodland, the eastern part is ecologically dominated by subtropical Atlantic Forest. This study focuses on the Atlantic forest region in Eastern Paraguay. Extensions of the Atlantic Forest ecoregion reach from the southeastern Atlantic coast in Brazil cover the eastern part of Paraguay. However, only a few remnants of the original forest cover remains in that area, the eastern Atlantic forest region has a much higher biodiversity than the Chaco woodland in Western Paraguay. Though, to conserve the high biodiversity in Paraguay, conservation and protection activities have to be concentrated to the eastern part of the country. The large area of Chaco woodland in western Paraguay is really important to secure Co2 emissions and needs to protect specially to its ecosystem funtion of carbon storage and in the context of the REDD+ mechnism. However, this is not the focus and further details would exceed the framework of this study.

The eastern part of Paraguay is the area once dominated with Atlantic forest - one of the world´s most diverse bio ecosystem. The Globcover product dataset based on MODIS data estimates a forest area of 24,380 km² within the BAAPAP region. Three different types exists: Closed to open broadleaved evergreen or semidecidous forest (18,057 km²), closed broadleaved deciduous forest (6,281 km²) and open broadleaved deciduous forest (41 km²) (ESA, 2011).

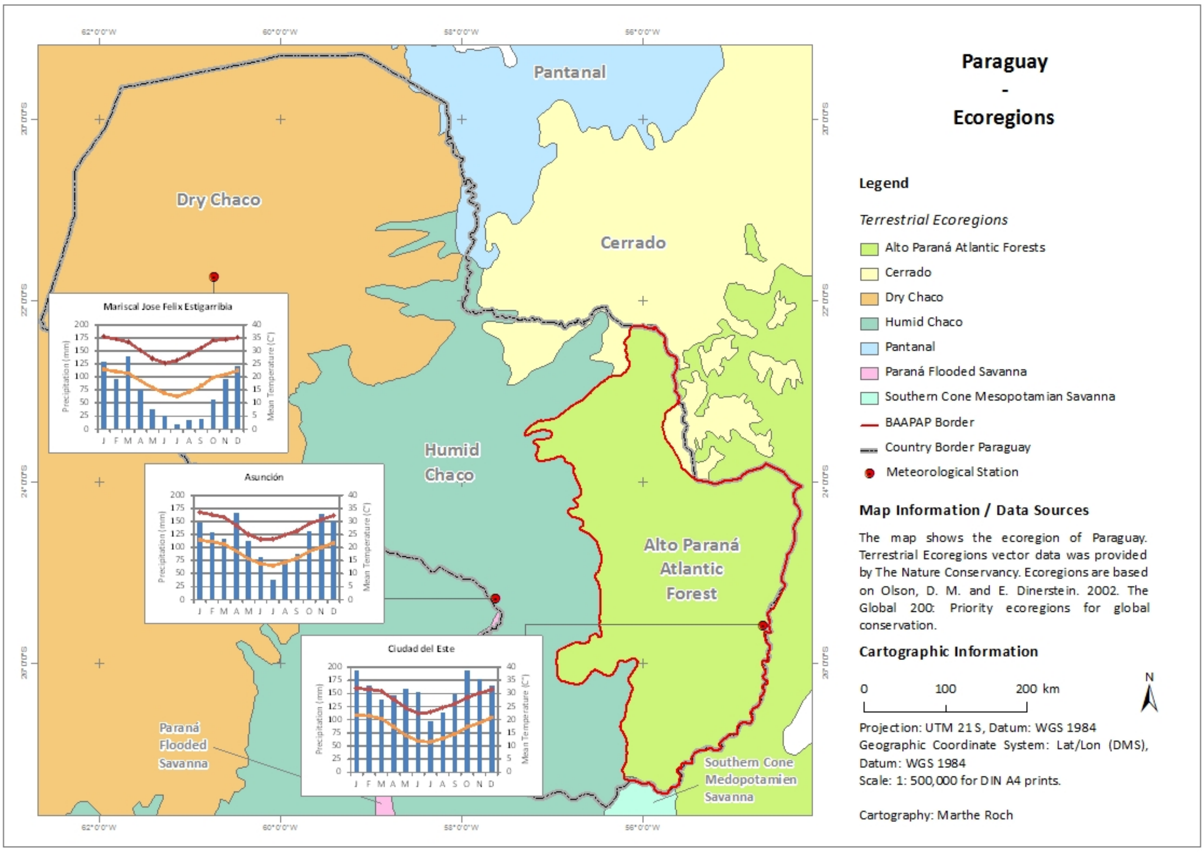


Figure 8: Paraguay - terrestrial ecoregions map.

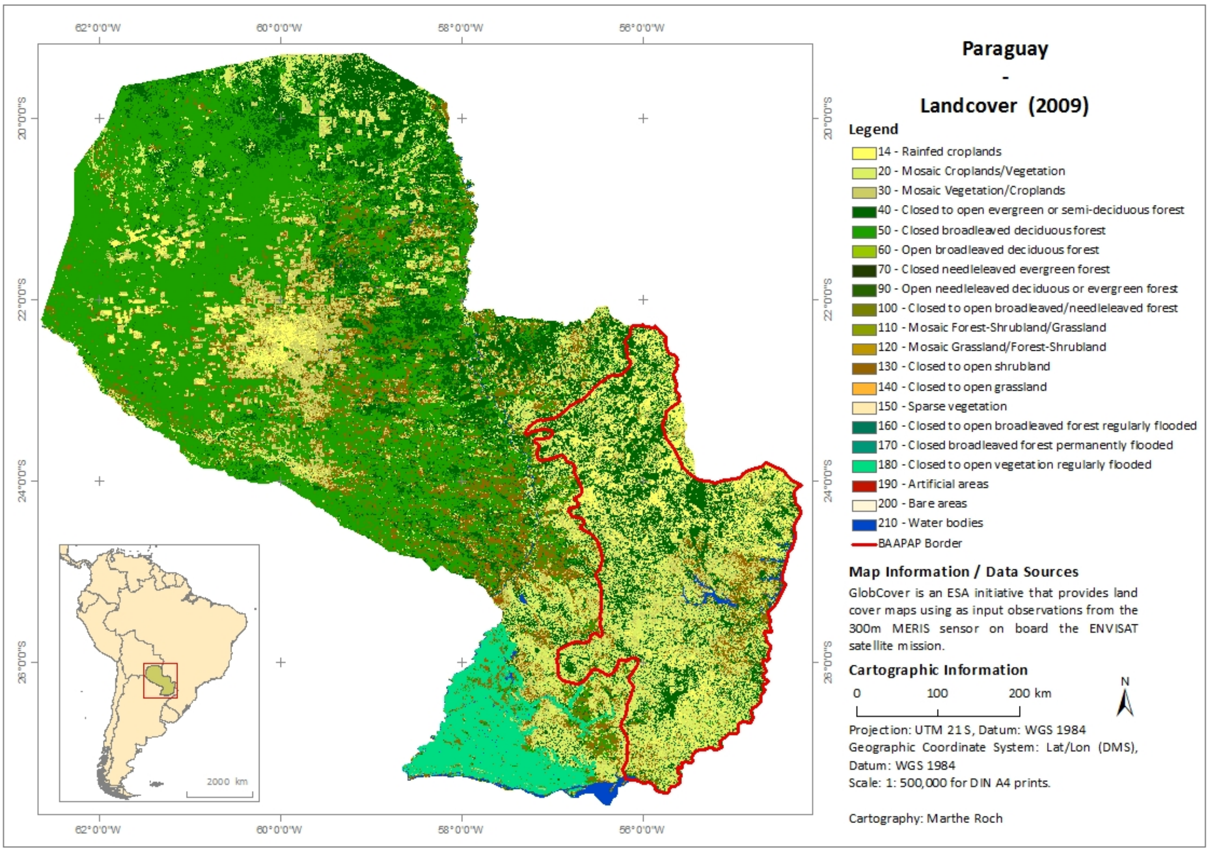


Figure 9: Paraguay - landcover map.

Although only a very small part of the original forest still remains, these small natural forest areas accommodate many endemic species that are threatened to extinction. Paraguay’s biodiversity is unique because of its strategic location, where the Atlantic forest, Cerrado, Pampa, and the Gran Chaco ecoregions merge**.** Unfortunately, scientific research so far has drawn little attention to the biodiversity in Paraguay´s Atlantic forest. The political isolation imposed by dictatorial regimes made it less inviting for researchers to visit the country. After Paraguay´s transition to democracy in 1989, more research activites took place that invstigate the biodiversity of Paraguay’s Atlantic Forest. The first main Biological Inventory Project in which young Paraguayan biologists worked with specialized U.S. Peace Corps volunteers, the WWF, U.S. Fish and Wildlife Service started in 1980 and led to the establishment of the National Museum of Natural History, the main natural scientific institute in Paraguay. With the support of The Nature Conservancy, a Conservation Data Center that promotes a systematic collection of information on biodiversity was established.

Fragano & Clay (2003) provided an overview on the biodiversity status of the BAAPAP region in Paraguay according to the little available information and always emphasizing that more research on this topic has to be conducted. However, the estimates of species diversity indicate considerable biodiversity. About 13,000 vascular plants, 100,000 species of invertebrates (including 765 butterfly species), 46 amphibians, 100 reptiles and 167 mammals. The bird conservation organization Guyra Paraguay documented about 700 avian species in the BAAPAP region (Guyra Paraguay, 2004; Fragano & Clay, 2003). Although little information on freshwater ecosystems exists, more than 300 species of fish live in the Paraná River basin, as well as large invertebrates such as river crab and mollusks. Many of these species are endemic in the Atlantic Forest region or even in Paraguay itself. Especially in the northeastern Amambay mountains, endemic plants as the mastic tree *(Schinus wein manniifolia* var. *hassleri*), six species of custard apple (*Annona*), *Callistene hassleri, Peltastes stemmadeniiflorus*, and *Rhodacalyx rotundifolius* grow. More than 5000 of the documented invertebrates are endemic, also about 85 of documented fish species. Among the 100 known reptiles four appear endemic – the lizards *Tropidurus guarani* and *Colobosaura kraepelin* and the snakes *Simophis rohdei* and *Phalotris nigrilatus*. Although Paraguay has no endemic avian species of its own, more than 80 species are endemic in the Atlantic forest. Paraguay harbors these endemic populations, such as the Amazon parrot (*Amazona vinacea*) or the helmet woodpecker (*Dryocopus galeatus*). Endemic mammals of the paraguayan Atlantic Forest are the opossum, different bats, mice and rats. In addition, also rare big cats were recorded in the BAAPAP region, e.g. the jaguar (*Panthera onca*), the puma (*Felis concolor*) and the ocelot (*Felis pardalis*). Many other species are listed as threatened or endangered on the world list of endangered species (IUCN, 2013).

Regarding cultural biodiversity, Fragano & Clay (2003) emphasize importance for wild relatives of crop plants including custard apple, guava, cassava, papaya, peanut, peppers, guayaba, pineapple, potatoes, rice and tomatos, some of them are threatened to national or global extinction. Y*varo (prunus) and* kino (Rauvolfia sellowi) trees or herbs as stevia *(stevia rebaudiana)* or *yerba mate* (*Ilex paraguariensis*) are near endemic species of Paraguay with economic importance due to their increasingly use in traditional medicine or the growing natural food market.

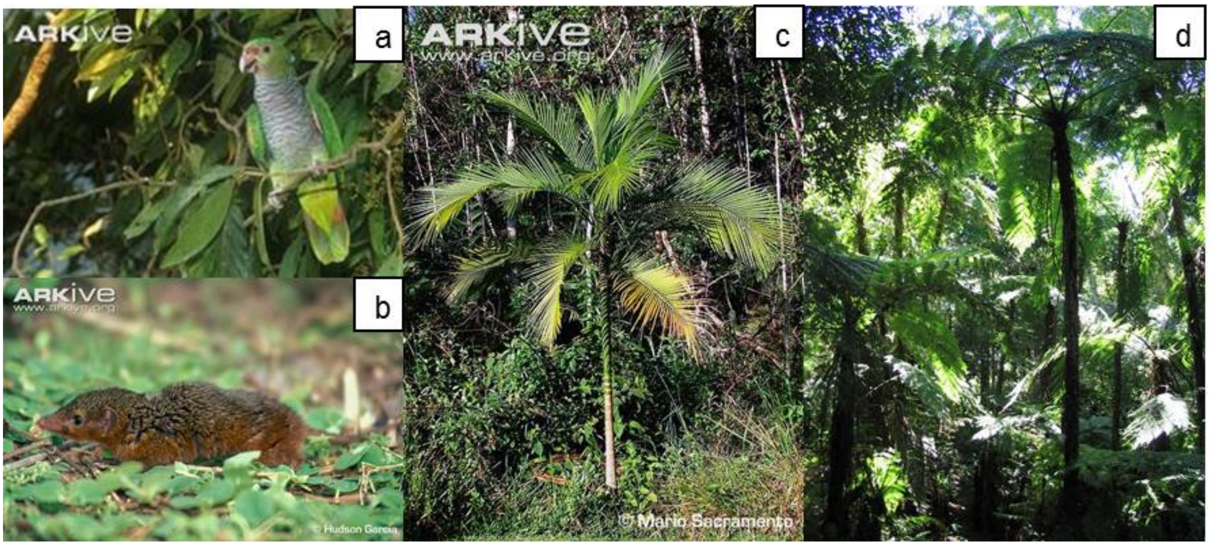
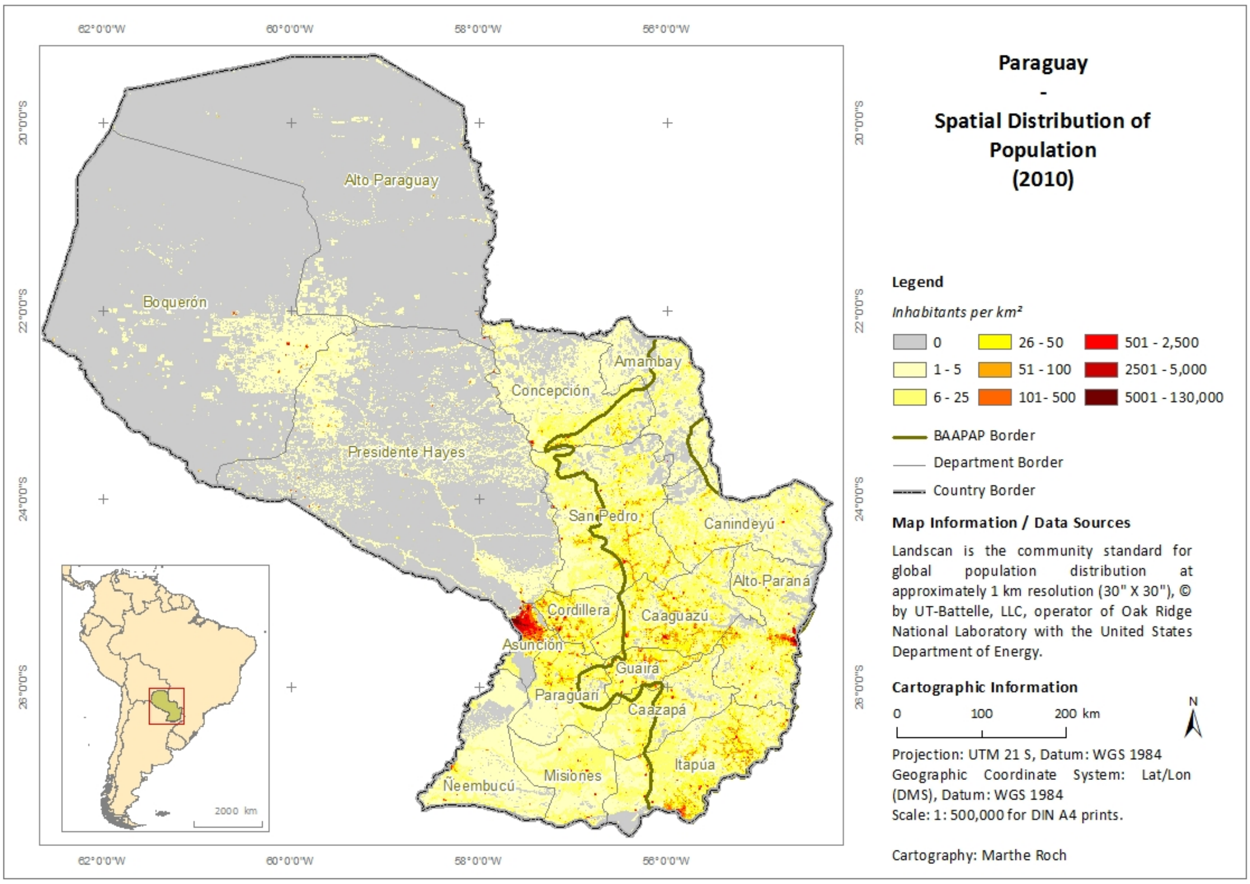


Figure 10: Diverse and endemic species of Paraguay´s Atlantic Forest. The pictures show some examples of endemic species of the BAAPAP region: a) Shrewish short-tailed opossum (*Monodelphis sorex*), b) vinaceous Amazon parrot (*Amazona vinacea*), c) Assai palm (*Euterpe edulis*), d) tree fern (*Cyathea atrovirens),* Photos a-c) © ARKIVE or photo d) © Pro Cosara.

3.1.2 Demography, Politics and Socioeconomic Development

Paraguays natual geography and biodiversity is highly influenced by human development and its impacts. To understand the drivers of the land cover change and deforestation processes a basic overview on demography, political and economic situation is depict here. The population of Paraguay count about approximately 7 million people (6,687 million in 2012, World Factbook, 2013). Population growth rate is 1.23 per cent. Due to the geographic conditions, more than 90 per cent of the population is living in the eastern part of the country. The western part of the country is sparsely populated. About 2 million inhabitants live in the capital Asunción and its surroundings. Within the BAAPAP region, the two main cities are Ciudad del Este in the east and Encarnación in the south. Smaller cities are located in the center and south of the region, whereas the north is less populated (see Figure 11 below). In general, the Landscan project estimated in 2010 present average population densities ranging between 5 to 100 inhabitants per km² outside of urban areas (Oak Ridge National Laboratory, 2013). About 60% of the Paraguayans live in urban areas (World Factbook, 2013). About 90 per cent are Roman Catholics, 6 per cent are Protestants. 95 per cent of the population are mestizo (mixed Spanish and Amerindian). The census in 2002 identified 20 groups of indigenous people with a total population of 87,009 people. The main groups are Ave Guaraní, Pai Tavytera, Mbya, Nivaclé. Enlhet and Enset Sur (Kernan et al., 2010).



Paraguay
-
Spatial Distribution of Population (2010)

Legend

Inhabitants per km²

0	26 - 50	501 - 2,500
1 - 5	51 - 100	2501 - 5,000
6 - 25	101 - 500	5001 - 130,000

BAAPAP Border
Department Border
Country Border

Map Information / Data Sources

Landscan is the community standard for global population distribution at approximately 1 km resolution (30" X 30"), © by UT-Battelle, LLC, operator of Oak Ridge National Laboratory with the United States Department of Energy.

Cartographic Information

Projection: UTM 21 S, Datum: WGS 1984
Geographic Coordinate System: Lat/Lon (DMS), Datum: WGS 1984
Scale: 1: 500,000 for DIN A4 prints.

Cartography: Marthe Roch

Figure 11: Paraguay - demography map.

The political and socioeconomic situation within Paraguay explain some important drivers of landuse changes. Paraguay, which achieved independence from Spain in 1811, is a presidential representative democratic republic by now. But democracy has no long tradition in Paraguay. *Caudillismo* and authoritarian regimes influenced politics from colonization period until today. In 1989, the last authoritarian president Alfredo Stroessner of the right-wing Colorado Party was overthrown after 35 years in power. Two main political parties exist – the rightwing conservative Colorados and the leftwing Liberals - of which the Colorados dominated most of the governments in the past. The fragility of the country's emerging democratic institutions resulted in nearly 15 years of popular uprisings, military mutinies, antigovernment demonstrations, bitter political rivalries, and continued rule by the Colorados (Freedom House 2012, BTI 2010). In 2008, the Paraguayans got their first taste of an alternation of power in six decades, when Fernando Lugo, a left-wing former priest, wrested the presidency from the conservative Colorado Party, which had been in power since 1947. Although the Lugo government achieved some improvements in social services (built health-care centers, financial incentives to the poor if they sent their children to school and vaccinated them and allocate public jobs after competitive examination for the first time), he failed to accomplish his promise of land redistribution and social justice. After a kind of impeachment by its own party members in 2012, president Lugo was displaced by the liberal Frederico Franco. The illegitimate action resulted in foreign isolation. All other leftwing – governed Latin American countries refused the new president to acknowledge as legitim and suspended Paraguay of their regional organizations such as MERCOSUR or UNASUR (Economist, 2012; Etscheid, 2012). In April 2013 a new president was elected and the short period of Liberal government in Paraguay came to an end. The current president is

Horacio Cartes, whose business empire spans banking, farming, tobacco and football. He is a “political neophyte” who had never candidated before and joined the Colorados recently in 2009. However he presented himself as the candidate of change by promising a “new direction for Paraguay” and proclaiming a break with corruption and clientelism that have characterized the Colorado party for a long time. He upgraded the country’s roads, river ports, airports and power lines, which were in a precarious state (The Economist, 2013).

It still remains to be seen if the new government will be able to change traditional rules and habits and to finance the very ambitious infrastructure investments. Furthermore, no strategy has yet been developed to manage the social challenges which the country is facing with regard to land tenure conflicts and its resulting land grabbing activities, poverty and high social inequalities. (World Factbook, 2013). Paraguay is a lower middle income country with an average of $3,290 per capita. In comparison, the Latin American and Caribbean region's GNI per capita is with $7,733 is twice as high. The Gini index, that measure the income distribution of economies, in 2010 was 52.4 and was listed within the last quarter of the global ranking). Extreme differences in wealth and property have their historical roots in the system of *latifundios*. Today, the owners of these large farms are involved in large scale agribusiness of cash crops – mainly soy, cotton or corn – as well as cattle ranching. Agricultural products and meat are exported to the international market (about 90 per cent of Paraguays exports). Other agricultural crops are rice, sugar cane, tobacco and corn. In recent years, soybean prices have soared on the world market. With its deep clay soils, rolling terrain, and moderate rainfall, Paraguay has provided ideal conditions for this crop. Today, soy accounts for 70 per cent of Paraguay’s exports and has been a key element in the country’s economic growth. The rural poor do not profit from these high revenues, and rather live from subsistence agriculture, small scale farming or migrate to the urban centres to find employment. Paraguay´s economy is dominated by the service sector (about 67 per cent GDP and 55% of labor force) whereas agricultural sector is shrinking (16% of GDP & 26.5% of labor force) and relatively small industry sector (17% of GDP and 18% of labor force). Due to its large dam constructions on the Paraná River, Paraguay is one of the world´s largest hydropower producer. The world´s 2nd largest binational Itaipú dam was opened in 1984 with a installed capacity of 14000 MW and the Yacyretá dam was opened in 1994 with an installed capcity of 3100 MW. Despite high exports, the country recently suffers power cuts. The Economist summarized the current situation as follows: *“Modern Paraguay - flat, landlocked and steamy - is a geopolitical pipsqueak. Its foreign influence is limited to two giant dams on its borders, soya bean exports that feed Chinese livestock and the free-for-all bazaar of Ciudad del Este, a border town where vendors of cut-rate electronics and clothes operate in public, and arms dealers and Hizbullah fund-raisers do so in private”* (Economist, 2012; 2013). Informal economy seems to prosper especially in the unruly region at convergence of Argentina-Brazil-Paraguay borders. It is seen as locus of money laundering, smuggling, arms and illegal narcotics trafficking, and fundraising for extremist organizations (World Factbook, 2013).

3.2 Deforestation and its Drivers

The history of the Atlantic Forest region in Paraguay is marked by extensively deforestation. As a result, a once continuous and impenetrably dense ecosystem is now a patchy series of isolated fragments, with just 13 per cent of the original forest area remaining (Hutchison & Aquino, 2011).

Causes and drivers of deforestation are very complex. In general, the suitability of red clay soils for agriculture and the high quality of the timber found in the forest are important reasons of deforestation in the BAAPAP region. Within the colonial phase until 1950, deforestation was mainly associated with selective logging and yerba mate harvesting activities. However, these selective logging did not have severe impacts. Until the 1950s almost the whole area was covered with natural forests.

After 1950, the establishments of settlements and expansion of agricultural frontier lead to the practice of clear-cutting, accelerated especially on clay soils that were considered as good for farming and cattle ranching. Instead of timber use, clearing for agricultural land purpose became more relevant. In the 1960s, the so called Green Revolution of Agriculture lead to the introduction of high-yield crop varieties, mechanized farming equipment, and chemical pesticides and fertilizers. Large agribusinesses were established which aimed at single crop production of soy or cotton to exports them to Argentina and Brazil. Deforestation due to biofuel developemnt, soy bean and palm expansion is a general challenge in South America (Gao et al., 2011; Pacheko, 2012).

Figure 12: Typical deforestation process in Paraguay. The photo compilation "From the virgin forest to soy fields" is provided by The Pro Cosara Project that is dedicated to the forest conservation of the Atlantic Forest remnants in the San Rafael National Park in Paraguay. The four pictures show a typical process of deforestation. a) The remaining vestige of Atlantic Forest in the San Rafael Reserve in South East Paraguay. b) Slashing and burning continues at a fast pace. c) Complex ecological systems with rich flora and fauna are being destroyed for the development of soy monocultures. d) Since the beginning of the soy-boom in the 70s the destruction of the virgin forest for the development of fields has continued at a particularly fast pace. (Sorce: http://procosara.org).

The subventions paid by the government for agricultural exports increased economic driven large-scale deforestation. Large scale cattle farming also enforced deforestation. Not only large-scale agribusiness had negative impacts on the Atlantic Forest and its biodiversity, but even small-scale and subsistence farming caused forest fragmentation and degradation. In response to land tenure and distribution conflicts that arose in the nineteenth century and resulting illegal squatting on private lands, intensive settlement forced by state sponsored settlement programs lead to extensive forest clearing.

Extensive deforestation started in the early 1970s. Paraguay lost nearly two thirds of its Atlantic Forest between 1973 and 2000. Huang et al. (2007) distinguished two different deforestation processes. In the 1970s and 1980s deforestation was caused mainly by settlers and since the 1990s in particular by large landowners. The latter process was more devastating. Between 1989 and 2000 Paraguay loosed nearly 40 per cent of its forest cover. The main reasons for the extensive clearing were the cultivation of cattle and soy – the backbone of Paraguay´s economy. Furthermore, large infrastructure projects were realized that resulted in forest clearing or flooding in case of dam construction (together with resettlement of many villages in that area). Whereas in 1970 still 73.4 per cent of the original forests cover remained, it has been reduced to 40.7 per cent in 1989 and furthermore to 24.9 per cent in 2000. To date, only 13 per cent (11.618 km²) of the original primary forest cover still exists (Conservation International, 2013).

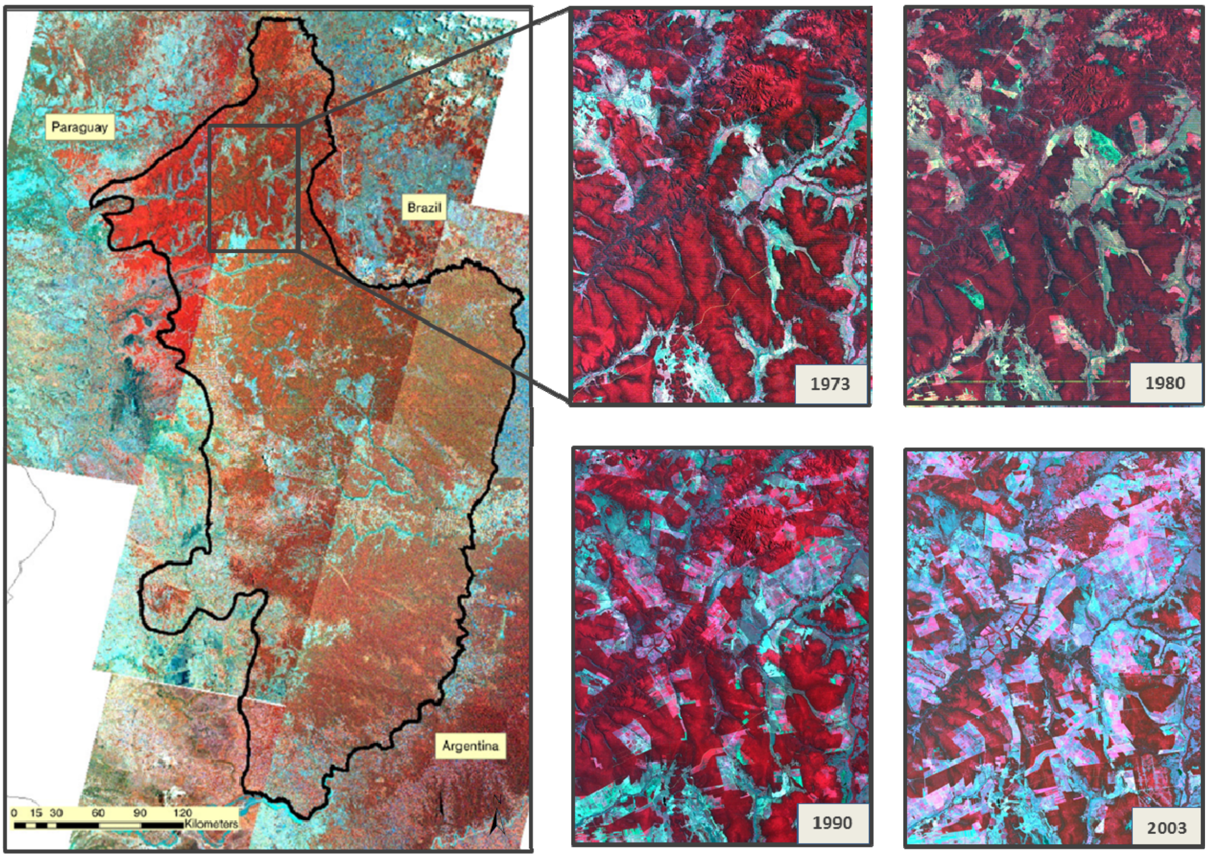


Figure 13: Deforestation in Paraguay´s Atlantic Forest 1970-2000. Left: The overview of Landsat satellite data of the whole BAAPAP region was provided by Huang et al., (2007), Right: Landsat satellite data of a subset of BAAPAP region (60x90 km) in a) 1970, b) 1980, c) 1990 and d) 2000 (© USGS).

Figure 13 shows Landsat satellite data that demonstrates an example of deforestation process from the 1973 to 2003 within the BAAPAP region. The Landsat data is displayed as false color images that use the infrared, red and green spectral bands and shows vegetation in a red tone (vegetation reflects much light in the near infrared). Forests area displayed in dark red, crop fields in pink and non vegtation land cover (such as bare soil or settlements) in blue. The large map on the right side shows the BAAPAP area in 1973. Almost the whole area is covered with forest. On the right side the deforestation process within the last 30 years is shown for one extent. Forest conversion into large crop areas started in the 1980s in the center of this area, increased in the 1990s, and in 2003 only small forest remnants of the original forest remained. Broad deforestation trends can be revealed by purely visual interpretation and comparison of satellite data. A detailed analysis of forest losses is conducted within this study for the last decade.

Since the late 1960s the deforestation rate increased steadily. Between 1970 and 2000 Paraguay's deforestation rate was higher than 2,000 km² per year and among the highest rate in the world. In 2009, deforestation rate had dropped by 90 per cent in comparison to the 2002 rate. As Figure 14 shows, deforestation rate decreased from 110,000 ha in 2002 to 20,000 ha in 2005 and to 8,000 ha in 2011.

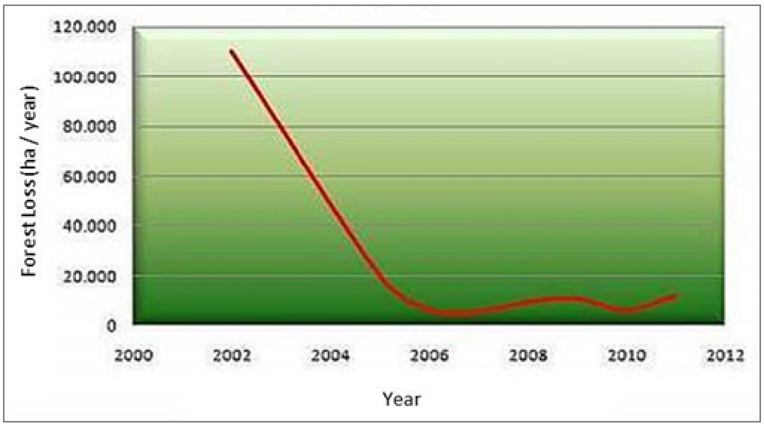


Figure 14: Deforestation rate 2000-2011. Source: (WWF Paraguay, 2012).

Two main reasons on decreasing deforestation rates can be stated. First of all, deforestation decreased due to the simple fact that only a very small area of natural forest still existed. Large scale clearing is almost impossible anymore. And secondly, within the recent years the few remaining forests in the BAAPAP region were more effectively protected by environmental and conservation policies than in the past. However, deforestation in Paraguay's western Chaco woodlands is still very high. The Chaco woodlands of Bolivia, Paraguay and Argentina are under intensive pressure from agro-industrial development. Recently, Paraguay's Chaco woodlands in the western half of the country are experiencing a rapid and extensive deforestation due to the building of cattle ranches. The result is the highest rate of deforestation in the world (Hansen et al., 2013). The shift of extensive deforestation from the east to the western part of Paraguay can be explained by the exclusive focus of Environmental Governance in Paraguay on the Eastern BAAPAP region.

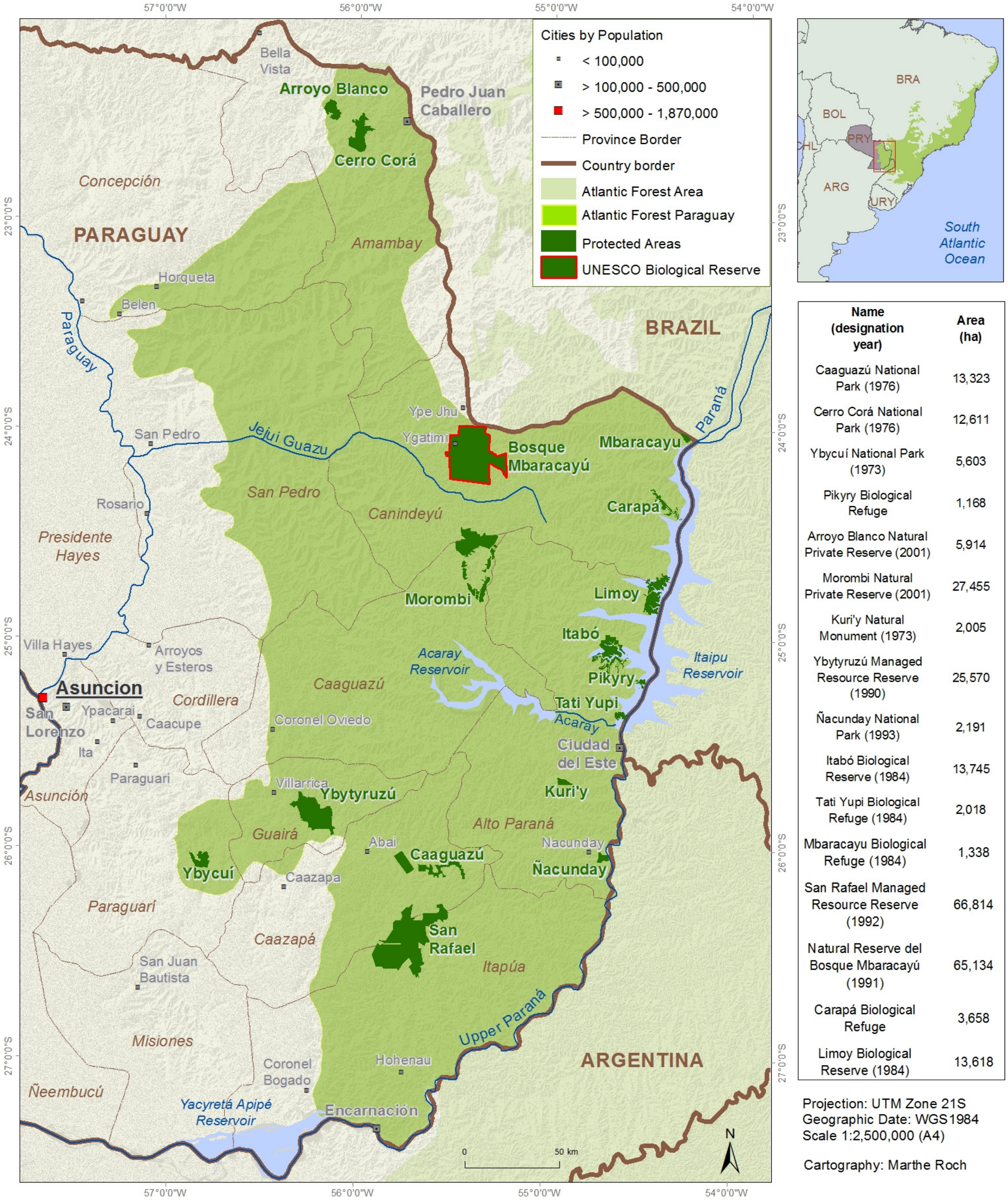
3.3 Environmental Governance

In general, environmental governance was not a priority area of Paraguayan politics for a long time and wild area protection began late in Paraguay compared to other Latin American countries (Cartes 2003). The development of protected areas began in 1945 with the Decree 9,535 which established "reserve areas" along the national highways. Since 1963, the Ministry of Defense was the first agency in charge of implementation and administration of public protected areas. In 1973, a shift in responsibility and administration of protected areas was made towards the Ministry of Agriculture and its National Forest Service and the Department of National Parks and Forest and Wildlife Management. During this time, the Government of the Republic of Paraguay designated several remaining forests as protected areas. However, implementation of the respective protection and conservation objectives was not efficient. Additionally, the approved Forestry Law (422/73) did not efficiently protect natural forest areas. The new law permits to convert 75% of forested land on any one property to crop or pasture; only 25 per cent had to remain forest land. However, if properties were subdivided, 75 per cent of the 25 per cent of each subdivision were allowed to be converted. As a result, almost all of the forest has been cleared (Government of Paraguay, 1973).

According to Cartes (2003) among other factors two main factors that caused deforestation and the loss of biodiversity in Paraguay have historical roots: the inequalities in land tenure and the perception that forests are "unproductive" land. In Paraguay, forests were seen as obstacle to agricultural production and a land of wild animals and vermin. The important ecosystem functions of forests and negative impacts of forest clearing have not been considered within land use developments. In addition, the great inequality in land tenure and the lack of public lands to be offered for settlement lead to the current land disputes. Illegal "invasions" of private lands (squatting) of natural forest areas caused widespread deforestation due to two different impacts. On the one hand, deforestation was caused by landless farmers (squatters) who took over forest areas of private lands and then very often cleared forests for illicit wood trafficking. On the other hand, private landowners wanted to avoid these illegal occupation and possible expropriation of their land and therefore cleared extensive areas that were easier to keep under control. The invasions of private forest property by the rural poor, without effective enforcement of property rights by the government were considered as a large obstacle to sustainable forest management.

3.3.1 Protection Laws and Policies

Environmental legislation started late in Paraguay and was a long time limited to the desgination of protected areas. Finally in 1986, the Paraguayan legislation officially protects forests at a first time. Decree 18.831 was enacted that made it mandatory to conserve at least 50m of forestland on both sides of rivers. Therefore, many remnant forest areas within the BAAPAP region are located along riversides. During the 1990s, Paraguay established a legal basis for protecting biodiversity and tropical forests by approving laws that concern endangered species, wildlife, environmental impact assessment, biodiversity, protected areas, climate change, natural resources, aquatic fauna, wetlands, environmental crimes, reforestation, desertification, fisheries and migratory species (overview on environmental laws and regulations see annex 6 in: Kernan et al., 2010). Among these regulations a National System of Protected Areas (SINASIP) was created that consists of 58 areas with a total area of 2.6 million ha. The largest protected areas in Paraguay are located in the western part of the country. 16 protected areas are located within the BAAPAP region and cover an area of 300 thousand ha (11.5 per cent of SINASIP area). The main protected areas within the Atlantic Forest region of Eastern Paraguay are shown in Figure 15. The main areas are located in the center of the study area, two smaller reserves are loctaed in the north and many smaller reserves in the east along the Paraná River. The table on the right side of the map provide specific information such as the official name, the designation year and size of the protected areas as it was reported by the World Database on Protected Areas (UNEP/ WCMC, 2013).



Name (designation year)	Area (ha)
Caaguazú National Park (1976)	13,323
Cerro Corá National Park (1976)	12,611
Ybycuí National Park (1973)	5,603
Pikyry Biological Refuge	1,168
Arroyo Blanco Natural Private Reserve (2001)	5,914
Morombi Natural Private Reserve (2001)	27,455
Kuri'y Natural Monument (1973)	2,005
Ybytyruzú Managed Resource Reserve (1990)	25,570
Ñacunday National Park (1993)	2,191
Itabó Biological Reserve (1984)	13,745
Tati Yupi Biological Refuge (1984)	2,018
Mbaracayu Biological Refuge (1984)	1,338
San Rafael Managed Resource Reserve (1992)	66,814
Natural Reserve del Bosque Mbaracayú (1991)	65,134
Carapá Biological Refuge	3,658
Limoy Biological Reserve (1984)	13,618

Projection: UTM Zone 21S
Geographic Date: WGS1984
Scale 1:2,500,000 (A4)

Cartography: Marthe Roch

Figure 15: Protected areas in Paraguay´s Atlantic Forest.

The SINASIP distinguish between public protected areas, private protected areas, protected areas within indigenous territory and protected areas within special territories (SEAM, 2009). The main public protected areas in BAAPAP region are the San Rafael Reserve (72,849 ha) and the Caazapá National Park (16,000 ha). In 1994, the Law on Protected Natural Areas (Law 352/94) involves also the private sector in natural resource conservation activities. Private land owners provide part of their property for conservation and sustainable use, receive tax benefits instead and are protected from expropriation of their lands. The main private protected areas in BAAPAP region are the Natural Reserve of the Mbaracayu Forest (64,405 ha core area; 280,000 ha total area under administration of the Moisés Bertoni Foundation) that was also designated as UNESCO-MAP Biosphere Reserve in 2000 (UNESCO, 2013) and the Morombi Natural Reserve (25,000 ha under administration of the Grupo Riquelme).

Limoy and Itabó Biological Reserves are protected areas under special management. That means that they are areas of special use that were established as a environmental compensation of the Itaipú dam floodding. In the 1970s and 1980s, the construction of the binational Itaipú dam – one of the largest hydroelectric dams in the world – caused resettlement and flooding on both sides of the Paraná River in Brazil and Paraguay. Beside many other socio-economic and environmental impacts a huge forest area disappeared. As a compensation measure the two Biological Reserves were established in the 1990s under the administration of the Itaipú Binational Company.

At the beginning of the 21st century environmental legislation was extended from protected areas to the whole BAAPAP area. A milestone of forest conservation policies was the approval of the Deforestation Zero Law (2524/04) in 2004. It prohibits any conversion of forest land in Eastern Paraguay to other use, unless the required permits were approved prior to the promulgation of the law (Government of Paraguay, 2004). As many studies emphasized, this law was a main reason that the deforestation rate decreased extremely within last decade (Hutchison & Aquino, 2011; Kernan et al., 2010). Shortly prior to its expiry in 2013, the Paraguayan government extended the Zero Deforestation Law until the end of 2018 (WWF, 2013). This time will be necessary to implement instruments to slow down the deforestation rate permanently.

3.3.2 Environmental Actors

Effective forest conservation needs efficient and powerful actors within the government, private sector, civil society and the public (especially in rural areas). Existing public institutions are still inefficient in implementing extisting laws in conservation actions. The Secretariat for the Environment (SEAM) is responsible for formulating and enforcing environmental and conservation regulations and for managing the SINASIP. However, it is not a member of the Cabinet and therefore it has little influence to coordinate environmental policies with other policies. Furthermore, in 2008, the Law 3464 created the National Forestry Institute (INFONA) as an autonomous institution (replacing the former National Forestry Service). Its funding is assured by the fees that have to be paid for forest clearing certificates. However, the law did not substantially change the Forestry Law 422/77 to take into account the current situation in Paraguay. Thus, Paraguay does not have an official forestry policy or comprehensive strategy that take inot account current environmental challenges as extrem deforestation and loss of biodiversity. There are various reasons for this reluctance. Overlapping environmental agencies and the lack of coherence and coordination of environmental and forest policies with other policies fields. INFONA is still highly influenced by the Ministry of Agriculture. For example, it proposes the candidates of INFONA presidents and therefore the alignment of the institution. Especially the agriculture and livestock policy of Paraguay aims at growth of production and recommends the production of "agro-energy" without considering its strong relationship with deforestation and conversion of forests to crop land and pasture. Another example of opposed policies are the Agrarian reform that has been based on the distribution of forest land to the rural landless poor without considering the fact that these people tend to degrade and clear forest to use their land for more profitable agriculture and pasture. The National Council of the Environment (CONAM) is a consultative group that has the legal responsibility of coordinating environmental policies within the Government of Paraguay. It coordinates different environmental actors as SEAM, INFONA, national ministries, department and municipal governments, and indigenous and non-governmental organization as well as the private sector. The proposal for a National Forestry Development Plan was prepared from the National Forestry working group but never approved by the government (Kernan et al., 2010). The inadequate legal and institutional framework needs to be improved to achieve a sustainable management of Natural resources. A participatory approach including local people and the involvement of the private sector are crucial elements of such a framework. Additionally the role of the municipal governments and their cooperation with SEAM and INFONA should be strengthened to enhance their presence in rural areas (Cartes, 2003; Kernan et al., 2010).

3.3.3 Conservation Initiatives

One of the priorities within curent environmental policies is the involvement of the private sector. More than 100 private landowners have indicated their interest in managing and protecting natural vegetation on their properties. However, within the Network of Private Reserves (RED) only 19 private landowners have established protected areas that are registered in SEAM, of which 8 are located in the BAAPAP region with a total of 117,012 ha (Kernan et al., 2010). To enhance private engagement in conservation activities, financial incentives for conservation, sustainable forest management and reforestation have to be provided by the government. First regulations were already elaborated. The Law 3703 on tax deduction for reforestation and forest management projects was approved, but still has to be implemented and the business sector has to become aware of its advantage (e.g. soy-agribusiness or large-scale ranching business). These incentives for reforestation projects do not directly conserve biodiversity because exotic species of trees are allow to be planted in monocultures (e.g. eucalyptus). In contrast, the Law 3.001/06 of Payment for Environmental Services is a direct financial incentive for biodiversity conservation. Landowners who conserved more forest than required by the Forestry Law 422/73 receive a certificate of environmental services from the government. These certificates can be negotiated to other landowners. Every landowner has the obligation to conserve forest land or to develop reforestation programs with native species. If a landwoner is not able to fulfill these obligation he can buy a certification of other landowners instead. (Kernan et al., 2010).

The creation of biological corridors between the main forest areas of the Atlantic Forest of the Upper Paraná is also a central conservation initiative of many environmental actors (e.g. World Bank, Itaipú Binational, WWF, USAID). The connectivity of separate and fragmented native forests is vital to the preservation of Paraguay's rich biodiversity. To contribute to the planning of such a corridor, WWF coordinated a multi-disciplinary study in the three countries entitled “A Biodiversity Vision for the Upper Paraná Atlantic Forest Ecoregion” and brought together government agencies, NGOs and research institutes to create a trinational initative was aimed at creating a green corridor to ensure conservation of biodiversity. The trinational biological corridor was planned to connect the main protected areas exceeding from the Mbaracayu Forest in Paraguay to the Parque Estadual do Turvo en Brazil to the Green Corridor of Misiones province in Argentina (Bitetti, Di, Placci, & Dietz, 2003). USAID environmental programs are also dealing with the creation of biological corridors. They do not emphasize only the importance of connectivity within the trinational BAAPA ecoregion, but also the connection between the BAAPAP area and the Chaco woodlands in western Paraguay (Kernan et al., 2010). Biological exchange between different ecoregions is also very important to conserve high levels of biodiversity. Therefore, conservation strategies and initiatives have to be thought beyond national and regional borders.

4 Theoretical Background

The conducted forest monitoring is based on two main theoretical approaches. Satellite data and remote sensing methods were used to derive forest cover and forest loss within the last decade. Chapter 4.1 depicts the main principles and techniques of remote sensing and image interpretation. Remote sensing based land cover maps are the main basis of forest loss detection and comprehensive landscape analysis. The main ideas and methods of landscape ecology, spatial pattern and fragmentation analysis are introduced within the subchapter 4.2. The following subchapter 4.3 describes the main data sources that were used within this study.

4.1 Remote Sensing

Remote sensing based Forest Monitoring has a long tradition. In the beginning, mainly aerial photos (infrared aerial photos) were used, while today satellite data is increasingly used to elaborate forest maps of huge areas (Albertz, 2009). Forestry applications analyze different topics, such as forest cover, forest type, forest damage or forest fire. Depending on these analysis objectives, appropriate data and image interpretation methods need to be chosen. This subchapter introduces basic principles and main methods of remote sensing used in this study.

4.1.1 Spectral Reflectance and Vegetation Indices

The specific reflectance of a surface material within a certain wavelength is called spectral signature (Albertz, 2009). As an example,

Figure 16 shows spectral reflectance curves for three different surface materials.

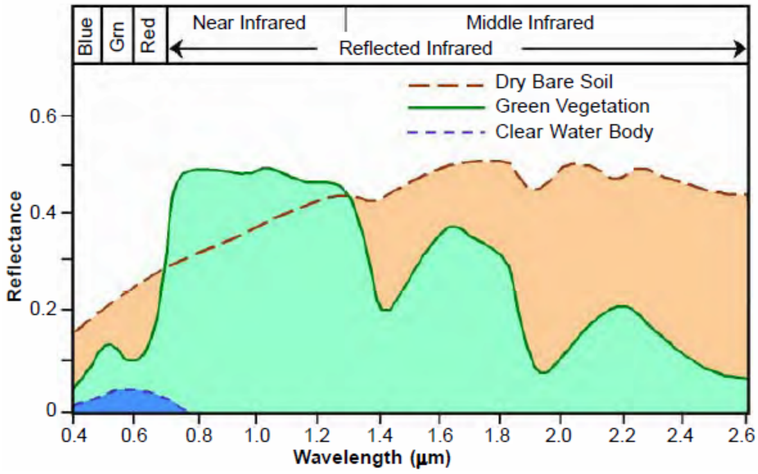


Figure 16: Typical spectral signature of healthy vegetation in comparison to other surfaces.

(Source: www.remotesensing.net)

The green curve in Fig. 12 visualizes the spectral characteristics of green vegetation. Visible light (from 0.4 µm to 0.7µm) is absorbed for use in photosynthesis (chlorophyll absorption bands). The cell structure of leaves strongly reflect radiation of near infrared wavelengths which range from 0.7 µm to 1.1 µm. Within the mid and shortwave infrared wavelengths (1.3 µm to 3µm), vegetation essentially absorbs or reflects energy, with little to no transmittance. Wavelengths in these spectral bands are referred to as water absorption bands - shown by the dips at 1.4 µm, 1.9 µm and 2.7 µm depending on how much water is present in the leaves (moisture) and the thickness of the leaves (Hildebrandt, 1996; Jones & Vaughan, 2010). Tropical Forests correspond to the typical healthy vegetation signature. Due to its reflectance characteristics, vegetation can be differentiated from other materials or land surface objects, e.g. water and dry bare soil. The differentiation between different types of vegetation is more challenging. Tropical forests correspond to deciduous trees that have higher reflectance values within the near infrared wavelength than coniferous trees due to their dense and broad leaf structures (Jones & Vaughan, 2010; Lillesand, Kiefer, & Chipman, 2008).

Tropical forests are evergreen and therefore mostly independent to phonological events. In comparison to other vegetation types, spectral reflectance is relative invariable during the seasons (Hildebrandt, 1996).

The application of various spectral vegetation indices allows for the identification and separability of different types of vegetation. Jones & Vaughan (2010) provide a comprehensive overview on existing vegetation indices and their application. Vegetation indices mostly make use of the fact that vegetation shows large differences in reflectance between near infrared and visible bands, whiles surfaces such as soil show comparatively small reflectance differences between these wavelengths. For healthy and dense vegetated pixels, an abrupt increase of spectral reflectance in wavelengths of 0.7 µm and higher can be observed. This is due to the fact that high vegetation density leads to a rise in reflection of energy in the infrared region of the spectrum.

A prominent vegetation index is the Normalized Difference Vegetation Indices (NDVI). Since Rouse et al. (1973) published their first study on vegetation monitoring, the distinction of both wavelength types (red and near infrared) are used to measure the healthiness and density of vegetation or biomass. The density of vegetation growth on earth as expressed in the NDVI can be calculated with the help of the following equation:

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

(NIR: near-infrared wavelengths, RED: red wavelengths). The resulting values of the calculated index range from -1 to 1. Vegetated pixels have positive values due to higher reflectance in near infrared and lower in visible wavelength. High NDVI values correspond to high density or greenness of vegetation. Very low values of NDVI (0.1 and below) correspond to barren areas of rock, sand, or snow. Moderate values represent shrub and grassland (0.2 to 0.3), while high values indicate temperate and tropical rainforests (0.6 to 0.8). In contrast, clouds, water, and snow have larger visible reflectance than near infrared reflectance resulting in negative NDVI values. Rock and bare soil areas have similar reflectance in the two bands and result in NDVI values near zero (Hildebrandt, 1996; Baldenhofer, 2013; Ray, 1994; Weier & Herring, 2000).

4.1.2 Image Classification and Validation

Each Image classification needs a comprehensive preprocessing in order to correct distortions of the input satellite data. Raw digital images usually contain significant geometric and radiometric distortions due to variations in the altitude, position, and velocity of the sensor platform. The earth's curvature, atmospheric refraction, relief displacement and non-linearity can contribute to distortions as well (Albertz, 2009; Lillesand et al., 2008).

There are various approaches and quantitative methods for using remote sensing data to distinguish between different types of land cover present in a single satellite image. These are broadly called classification methods. Two main approaches exist: pixel-based and object-based classification. Pixel-based image classification separates single pixels into classes according to spectral characteristics with unsupervised and supervised techniques. Unsupervised classification aims at grouping pixels with similar spectral characteristics into cluster. A variety of mathematical models have been developed to realize this, such as Maximum-Likelihood, Minimum-Distance to- Means or Parallelepiped algorithm. Unsupervised classification categorize pixels on a purely mathematical base. In contrast, supervised classification approaches use training data to define classes before the actual classification process and analyse specific spectral characteristics of the training areas. According to these spectral characteristics, pixels will then be put into the class they most closely fit according to a mathematical model or algorithm. Supervised classification is more accurate in representing real world objects, but due to the manual creation of training data it is a very time-consuming analysis process (Albertz, 2009; Lillesand et al., 2008).

Traditional image classification algorithms operate at the level of single pixels, but ignore the surrounding pixels. A relatively new object-based approach is more focused on the classification of different spatial entities than on a single pixel. It is based on the awareness that “human perception does not observe, nor do we actually think in pixels” (Blaschke & Strobl, 2002). Human beings perceive objects instead. the importance of spatial patchiness has been recognized in the research community. They emphasize the importance on spatial patterns through integrating concepts of neighborhood, distance and location (typical GIS concepts) into the pixel-based approach of remote sensing analysis. Especially the usually ignored problem in pixel-based characterization of land cover is that a substantial proportion of the signal apparently coming from the land area represented by a pixel comes from the surrounding pixels (Blaschke & Strobl, 2002, Blaschke, 2010). The most common operational method to work with relatively homogeneous areas is image segmentation which is a technique to extract image objects that are the basic analysis features for spectral classification. Lang & Blaschke (2006) argue for a paradigm shift to object based image analysis (OBIA). While acknowledging its advantages, Koch et al. (2003) also emphasize the apparent weak points of the new object-based classification method. The delineation of homogeneous objects (segmentation) may hold back some detailed information on individual pixels and their spectral similarities. Factors such as the resolution of the satellite data , the effort needed to classify vast areas and the type of product the analysis aims at need to be taken into account when deciding for or against any of the avobe mentioned methodologies.

A comprehensive assessment of accuracy enables the identification and correction of errors. Accuracy assessment analyzes whether or not and to what degree certain pixels have been classified as their corresponding objects in reality. This is achieved by comparing classification results with reference data such as in-situ data or higher resolution satellite imagery. If both types of reference data are not available, cross-checking classification results with input data is possible. The most widely accepted way of deriving the results of accuracy assessments is called error matrix. The main components of the errror matrix are the producers accuracy, the users accuracy and the overall accuracy (see Chapter 6.2). A valuable complement to compare different error matrix is the Kappa coefficient that expresses the proportionate reduction in error generated by a classification process compared with the error of a completely random classification. For example, a value of 0.82 implies that the classification process is avoiding 82 percent of the errors that a completely random classification generates (Congalton, 1991; Congalton & Green, 2008).

4.1.3 Review of Forest Monitoring Methods

Deforestation assessment and monitoring is one of the most widely used applications of remote sensing sensors. New sensors and satellites are expanding the scope of earth observation and remote sensing based assessments increased dramatically in recent years. Joseph et al. (2010) provided a comprehensive overview on remote sensing based technologies that are used for forest monitoring considering the current improvements in spatial, spectral, temporal and radiometric resolution of remote sensing data within the past few decades. They emphasized the variety of remote sensing applications, ranging from multispectral to assess vegetation at biome level and molecular assessment of individual species regarding the spatial resolution improvements. These developments also increased the ability to monitor tropical forest systems and degradation processes. At present, many global operational programs are based on it. A prominent example of these operational programs is the Global Forest Resource Assessment (FRA) conducted by the United Nations Food and Agriculture Organization (FAO). Since 2000, the FAO has been publishing national-level data on forest cover at five year intervals based on national reporting and remote sensing analysis (FAO 2010b, 2010c). However, Grainger (2008) claimed the poor reliability of deforestation estimates in global databases due to the lack of standard definitions of forests and deforestation, changes in statistical design and use of new data. Within recent years, many other operational monitoring programs of forest cover mapping and forest fire detection based on remote sensing methods have been implemented (MODIS Rapid Response System, Global Fire Maps, GLOBSCAR and GOFC-GOLD are some examples). They try to tackle the above mentioned limitations. A few tropical rainforest countries have expertise, institutions, and programs in place to monitor deforestation (e.g. Brazil with INPE and India with its Forest survey). US and European institutions are technically able to monitor deforestation across the tropics (Shimabukuro et al. 2012; Joseph et al. 2010; Achard and Hansen 2012).

Depending on the size of the study area and the specific object of analysis, different sensor data and image interpretation techniques are applied. For forest assessments on a global or continental scale, coarse resolution satellite sensor data (resolution of 250m to 1 km, usually MODIS, AVHRR or SPOT VEGETATION) is mainly used for the detection of large-scale deforestation events. For example Hansen, Stehman, & Potapov (2010) applied a globally consistent methodology to quantify gross forest cover loss (GFCL) between 2000 and 2005 and to compare the results among biomes, continents, and countries. With a specific focus on tropical forest, Defries et al. (2005) provided an overview on deforestation monitoring methods for emerging carbon markets. They emphasized the need for a multi-sensor approach that combines moderate to coarse spatial resolution data on a global scale and medium to high spatial resolution data on a regional scale in order to monitor ubiquitous small-scale tropical deforestation (<10 ha). Caused by progress in sensor technology, the spatial resolution of global forest monitoring methods improved in recent years. Townshend et al. (2012) described methods, opportunities and challenges of global monitoring of forest cover with Landsat data (30m resolution). In the past, the use of Landsat for large scale monitoring was still very time consuming due to the high amount of single images and the lack of consistent high-quality training data. Thus very recently, Hansen et al. (2013) derived global forest cover maps of 2000-2012 from Landsat 7 data. They used advanced computing systems, such as Google cloud, to efficiently process and characterize global-scale time-series and provide the resulting products via Google Earth Engine. It was considered the first map of forest change that is globally consistent and locally relevant. The global study summarized that the tropical domain experienced the greatest total forest loss and gains indicating the prevalence of deforestation dynamics. Overall, tropical forest loss is increasing by about 2,100 km² per year with Paraguay, Malaysia and Cambodia having the highest national rates of forest loss (Hansen et al., 2013).

For regional and national scale, medium resolution remote sensing instruments are more appropriate. Due to its long temporal scale (since 1972) and cost efficient (or nowadays even free) availability, Landsat imagery (spatial resolution of 30m) is widely used in the majority of conducted studies. Main study areas regarding regional tropical deforestation and degradation monitoring are the Amazon forests in Brazil (Souza, 2012; Foley et al., 2007; Wang, Qi, & Cochrane, 2005) as well as tropical forests in the Democratic Republic of Congo (Duveiller, Defourny, Desclée, & Mayaux, 2008; Laporte & Lin, 2001; Potapov et al., 2012) and Indonesia (Schoen, 2004). With a special focus on Paraguay, Huang et al. (2007, 2009) analyzed deforestation in the past decades using Landsat imagery. Results were provided by the University of Maryland and NASA's Land Use Land Cover Change Program as a 'Forest Change Product of Paraguay in 1990 to 2000' (The Global Land Cover Facility, 2006).

Appropriate methods of deforestation monitoring vary with the type of forest and disturbance. No single method is most appropriate for all situations. Unsupervised Isodata Clustering, supervised classification with training samples (Achard et al. 2012), decision tree algorithms (Potapov et al., 2012) and wall-to-wall change mapping or a combination of those methods (Huang et al., 2007, 2009) are used for large and medium scale forest monitoring. Elderly medium resolution instruments have their advantage in covering large areas and provide data, but have limitations in assessing certain parameters, species types and the functional and structural properties of plants. More recently developed very high resolution data and hyper spectral methodologies have more advantages in assessing these parameters (Kalacska & Sanchez-Azofeifa, 2008). Object-based image analysis is often used with high resolution data. For example, Eisfelder et al. (2009) show that the object-based approach is really useful to distinguish different forest types and classes. Beside very high resolution and hyper spectral data, a further trend occurs within remote-sensed based analysis in recent years. Due to their advantages of penetrating clouds and featuring high resolution, microwave and radar data are increasingly used for forest monitoring (Lucas et al. 2012; Thiel et al. 2006; 2008). For the future, a combination of multi-and hyperspectral optical data and microwave or radar data is expected to achieve new synergies and provide best results in tropical deforestation and degradation monitoring (Achard & Hansen, 2012; Belward, Achard, Hansen, & Arino, 2012).

4.2 Landscape Ecology, Spatial Pattern and Fragmentation Analysis

Landscape ecology is the study of composition, structure, function, and change in a heterogeneous land area composed of interacting ecosystems. Barnes (2000) introduced the concepts and principles of landscape ecology for managing wildlife and natural resources at a landscape level. In this context, a landscape is a heterogeneous area composed of a cluster of interacting ecosystems that are repeated in various sizes, shapes, and spatial relationships throughout a landscape. Following this approach, landscapes consist of three main components: a matrix, patches, and corridors (see Figure 17). Better understanding of these components and their relationships can improve management decisions at the landscape level.

The matrix is the dominant component in the landscape, the most extensive and connected landscape type, and it plays a dominant role in landscape functioning. The landscape matrix is a mosaic of patches. Patches are units of land or habitat that differ in vegetation and landscape from their surroundings. Remaining patches within a landscpae matrix are sometimes connected by corridors. Corridors are defined as strips of lands that differ from the matrix on either side and link patches together.

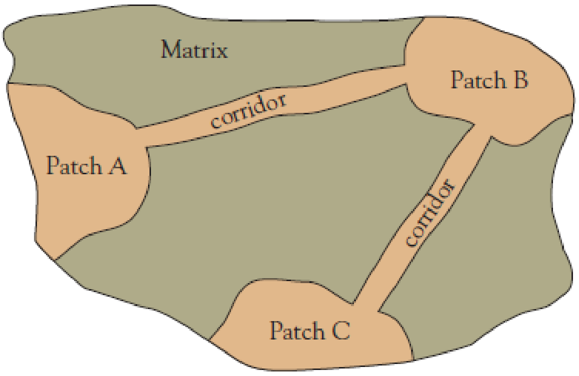


Figure 17: Main components of landscape ecology. (Source: Barnes 2000).

As landscapes are interacting dynamic ecosystems, the structure and composition of the matrix, patch and corridor relationship changes over time. This change process is defined as fragmentation. Fragmentation is a process that occurs along a continuum in which a particular area initially consists of a single habitat type which eventually decreases until only isolated patches remain. Fragmentation often results in habitat loss and discontinuity and eventually leads to the isolation of habitats.

Applying these theoretical considerations to the example of a forest matrix starts with a first step: To begin with, the entire area of a certain landscape is covered by forests (see Figure 18). In a second step of the example, farmers move in, clear the forests and cultivate small plots of land (a). Step by step, farmers expand their agricultural activities and convert more forest to agricultural lands (b). This results in a rising number of larger gaps within the forest matrix. Successively the forest matrix is changing into an agricultural matrix (c). The small remaining forests within the agricultural matrix can be assigned as remnant patches. Barnes (2000) concluded that landscape and habitat change is perpetual within dynamic, ever changing entities such as human induced ecosystems. Thus, changes have to be considered in environmental decision making such as forest and biodiversity conservation.

Changes such as a decrease in size of the patches or an increase in the proportion of edges can lead to a variety of effects. These include the local extinction of organisms, reduced dispersal and decolonization of habitat patches, invasion of exotic or nonnative species, increased nest parasitism or predation on birds, and a reduction in the diversity of forest interior wildlife species. Changes in the microclimate of a patch, caused by factors such as sunlight exposure, fluctuations in temperature or increasing exposure to wind, can also contribute to the aforementioned consequences. Thus, understanding landscape ecology is an important prerequisite for effective and sustainable decision making in the context of biodiversity conservation (Barnes, 2000).

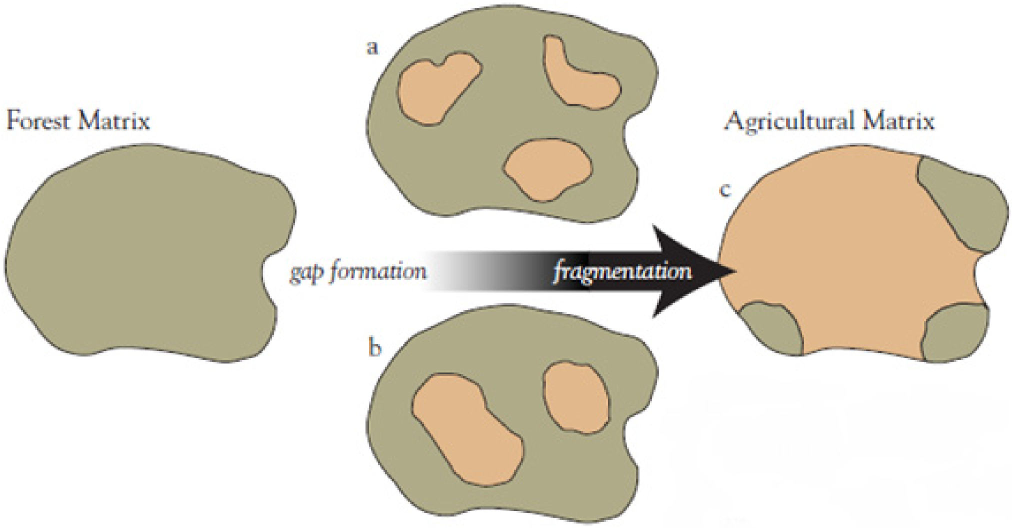


Figure 18: Habitat fragmentation process. (Source:Barnes 2000).

The value of forest patches with regard to biological consideration is also explained by Schelhas & Greenberg (1996). They emphazised the fact that fragmented forest landscapes that consist of many different forest patches are less biodiverse than large intact forest ecosystems. Forest fragmentation leads to biodiveristy loss. The higher the fragmentation of forest cover, the higher the value of each remaining forest patch. For example, forest patches in buffer zones of protected areas are critical for the provision of seasonal resources and movement corridors, stepping stones and shelters for organisms that spend most of the time in protected forests or local or long-distance migratory organisms (e.g. birds). Regarding the decreasing interior habitat, patches are often thought of as islands (Barnes, 2000; Lindenmayer & Franklin, 2002; Schelhas & Greenberg, 1996). The smaller and more isolated the island (or remaining land cover fragments), the lower the species diversity. A larger patch can normally support a larger number of species and a greater variety of habitat types. This idea is based on a key concept of an equilibrium point that exists in population between the rate that new species invade an area and the rate that previously existing species become extinct. Once this point is reached, the island´s populations of species are then kept stable at this equilibrium point.

From a perspective of habitat diversity, patch size is really important (Barnes, 2000; Lindenmayer & Franklin, 2002; Schelhas & Greenberg, 1996). Relevance and ecological value of forest patches depend among others on the size of the interior habitat of the patch. From a biological perspective it is important to keep patches in the landscape as large as possible to supply habitat to various species. Only large continous forest blocks (>100 km²) are resilient to environmental changes and able to maintain so called umbrella species and ecological processes of the natural selection such as predation or pollination (Bitetti, Di et al., 2003). For example, long term survival of large mammals such as the lowland tapir (*Tapirus terrestris*), jaguar (*Panthera onca*), or birds of prey such as the harpy eagle (*Harpia harpyja*) will need core areas greater than 100 km² (Fragano & Clay, 2003). Barnes (2000) estimated that a minimum patch size should be 10,000 acres (about 4,000ha or 40 km²) to maintain minimum viable populations for many neotropical migrants. Additionally, many species avoid the edges of forests. These edge effects reduce the relevant area of forest patches and have to be considered when most relevant forest patches are identified for conservation activities. A minimum habitat size is needed for every species. The requirement varies by species.

Not only patch size, but also the shape, configuration, and number of patches affect the amount of interior habitat. Small, single, rectangular patches provide the least amount of interior habitat, and large circular patches provide the most interior habitat. The relation between habitat patch size and edge effect becomes also prominent in landscape ecology studies. The higher the interior-to-edge ratio, the less patch border exists, which decreases the amount of interaction with the surrounding matrix. A high interior-to-edge ratio is preferred since it decreases the probability of barriers that can limit the movement of organisms. Such a ratio would also decrease the probability of habitat diversity within the patch. The latter fact would not necessarily be harmful because it constitutes natural diversity as opposed to artifical diversity. A high interior-to-edge ratio has also positive effects on the movement of species which would be able to move more freely throughout the matrix compared to movements that are enabled by corridors only. Last but no least, the ratio just described would increase the diversity of species and the the total number of animals within the patch. A low interior-to-edge ratio would lead to the exact opposite effects.

Two main negative impacts of landscape fragmentation in the context of wildilfe management and biodiversity conservation can be stated. First, a decrease in the amount of interior habitat. Second, a decrease in the connectivity between those habitat patches.

Intact forest with large core areas are the central objectives of conservation activities. Connectivity between these large forest blocks has to be created through biological corridors. Small forest fragments play important roles and need to be well maintained. They serve as so called stepping stones or ecological trampolines for biological corridors. These fragments are also useful for the conservation of catchments and soils. Additionally, the patches just described can serve as winter refugee for local or large distance migrating birds. Besides containing seeds for future reforestation, they play and important cultural and educative role (Bitetti, Di et al., 2003). Thus, connectivity between the forest habitat patches allows native biodiversity to flourish in fragmented forest habitats. Wildlife management and biodiversity conservation attempts to maintain or create corridors between the forest habitats. Corridors serve as channels for organisms to transfer or move from patch to patch. Corridor structure and function depend on a variety of different factors, including the degree of curvature, breaks, narrows, nodes, and connectivity. Corridors need to be wide enough to provide more positive benefits for wildlife. Riparian forests often provide important corridors (Schelhas & Greenberg, 1996).

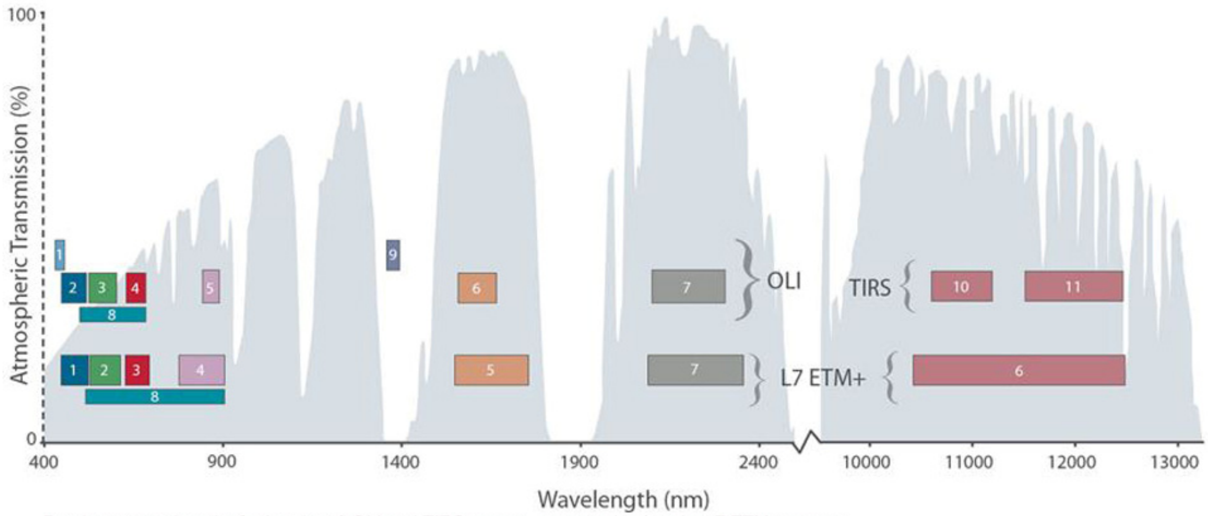
Landscape structure analysis and characterization of forest areas helps to identify forest priority areas for biodiveristy conservation. Spatial patterns and fragmentation of landscape are often studied by using image segmentation, landscape metrics and GIS analysis. For example, Meddens et al. (2008) characterized forest fragments in boreal, temperate, and tropical ecosystems by incorporating image object segmentation and different landscape metrics. They demonstrated that remotely sensed data, image segmentation, and landscape analysis tools can be used in a consistent manner to characterize and compare fragmented forest landscape and increase the capabilities for quantifying human-induced forest fragmentation. The strong relationship between landscape structure and biodiversity was studied by Walz (2011). He discussed the role of landscape metrics in investigation, evaluation and monitoring. The author presents strengths and weaknesses of different landscape strcuture studies, but finally concluded that it is an expedient approach for environemental management and planning. Landscape metrics are helpful tools to evaluate and analyze habitat and its structures from an ecological perspective. Lang & Blaschke (2007) provided an overview on existing landscape metrics and their applications on three levels: the patches itself, the class level and the landscape level. A very huge amount of landscape metrics exist and many of them are redundant. For each specific research question a relative small set of metrics is sufficient, but it is difficult to decide for a specific set of metrics. A set of landscape metrics can be chosen by a mathematic statistical or a semantic-content approach. Regression and factor analysis are examples of statistically based methods, and the semantic-content methods aims at a limitation of landscape metrics based on ecological assumptions (Lang & Blaschke, 2007). Cushman, McGarigal, & Neel (2008) emphasized the parsimony in landscape metrics and compared existing metrics according to their strength, universality, and consistency. Although they provided a set of metrics that are more universal, consistent and strengthened than others, the final choice of particular metrics is driven by the research question that is being addressed (Cushman et al., 2008).

4.3 Data used for Forest Monitoring

4.3.1 Landsat Data

Satellite images to be used for environmental monitoring are selected by appropriate characteristics such as spatial extent, spatial and spectral resolution, repeat cycle, availability and acquisition costs (Kuenzer & Fosnight, 2001). This study is based on Landsat satellite data. Landsat images provide a very good trade off of sensor parameters, availability and costs. Landsat data have been available globally since 1972 and the spatial resolution of 30m is appropriate for forest monitoring assessments since it can detect most changes in land use or land cover (Meddens et al., 2008). The spectral resolution of seven multispectral bands including visible, near infrared and thermal bands is likewise convenient to derive forest vegetation. The temporal frequency of 16 days to cover the whole earth allows a broad collection of images and compensates possible cloud cover hints.

To monitor the forest cover losses within the last decade (2003-2013), the most recent Landsat data was used. In February 2013, the launch of the Landsat 8 mission made it possible to continue former Landsat missions and to strengthen the wealth of this scientific data and its long time series. In comparison to the predecessor mission of Landsat 8 and its Enhanced Thematic Mapper (ETM+), the Landsat 8´s OLI sensor includes two additional bands. A new coastal/aerosol band (band 1) can be used for closer investigations of coastal waters and to estimate the concentration of aerosols in the atmosphere. Also new, OLI's cirrus band (band 9) provides better detection of cirrus cloud contamination in each scene. Figure 19 shows the wavelengths from both Landsat 7 (bottom row) and Landsat 8 (top row). Table 2 below lists the bandwidth and spatial resolution of each band to compare both sensors. The visible bands (Blue, green, red) as well as the near and short wave infrared bands of OLI sensor are sensitive to similar wavelengths, but have more narrow ranges than as ETM+ sensor bands. The panchromatic band width has also been narrowed. For the Landsat 8 mission, the thermal band of ETM+ sensor (resolution of 60m) has been replaced by two new thermal bands on a separate Thermal Infrared Sensor (TIRS) with a lower spatial resolution of 100m. These differences have to be considered when processing and comparing images of both sensors.



Bandpass wavelengths for Landsat 8 OLI and TIRS sensor, compared to Landsat 7 ETM+ sensor

Note: atmospheric transmission values for this graphic were calculated using MODTRAN for a summertime mid-latitude hazy atmosphere (circa 5 km visibility).

Figure 19: Landsat 8 OLI and TIRS bands compared to Landsat 7 ETM+ bands (Source: USGS, 2013a).

Table 2: Comparability of Lansat7 and Landsat8 bands

Landsat 7 (ETM+)			Landsat 8 (OLI, TIRS)		
Band Name	**Bandwidth (µm)**	**Resolution (m)**	**Band Name**	**Bandwidth (µm)**	**Resolution (m)**
-	-	-	Band 1 COASTAL	0.43-0.45	30
Band 1 BLUE	0.45-0.52	30	Band 2 BLUE	0.45-0.51	30
Band 2 GREEN	0.52-0.60	30	Band 3 GREEN	0.53-0.59	30
Band 3 RED	0.63-0.69	30	Band 4 RED	0.64-0.67	30
Band 4 NIR	0.77-0.90	30	Band 5 NIR	0.85-0.88	30
Band 5 SWIR1	1.55-1.75	30	Band 6 SWIR1	1.57-1.65	30
Band 7 SWIR2	2.09-2.35	30	Band 7 SWIR2	2.11-2.29	30
Band 8 PAN	0.52-0.90	15	Band 8 PAN	0.50-0.68	15
			Band 9 CIRRUS	1.36-1.38	30
Band 6 TIR	10.40-12.50	60 (30)	Band 10 TIRS1	10.60-11.19	100
			Band 11 TIRS2	11.50-12.51	100

Since 2008, Landsat archives (with data from 1973 onwards) are free and very easy accessible through the United States Geological Survey (USGS) and its web explorer GLOVIS or Earth Explorer. Since April 2013, the new Landsat 8 images are also freely available for download. For this study, Landsat 8 data of 2013 was compared to Landsat 7 data of 2003.

A common disadvantage of using optical image data is cloud cover, especially in tropical regions. However, for the two dates in 2003 and 2013 and the proposed study area appropriate data sets with less than 10 per cent cloud cover was available at Landsat archive. An overview of the two datasets, their location in path and row numbers and acquisition dates is given in Table 3 and mapped in Figure 20 including the BAAPAP region borderline in yellow color.

Table 3: Overview on Landsat data used in this study

WRS2		Acquisition Date	
path	row	(ETM+)	(OLI/TIRS)
224	77	2003/05/28	2013/05/31
224	78	2003/05/28	2013/07/02
224	79	2003/04/26	2013/07/02
225	76	2003/05/03	2013/05/06
225	77	2003/05/03	2013/06/07
225	78	2003/05/03	2013/05/06
225	79	2003/05/03	2013/05/06
226	76	2003/05/10	2013/04/11

Suptropical landscapes have a slight phenological variation. Thus, different acquisition dates from April to July do not hamper comparability of the images. However, the different acquisition dates bear radiometric variations due to different sensor viewing angles and variable atmospheric conditions. To overcome these variations and make the different images comparable, radiometric correction was performed (see data preprocessing in chapter 0).

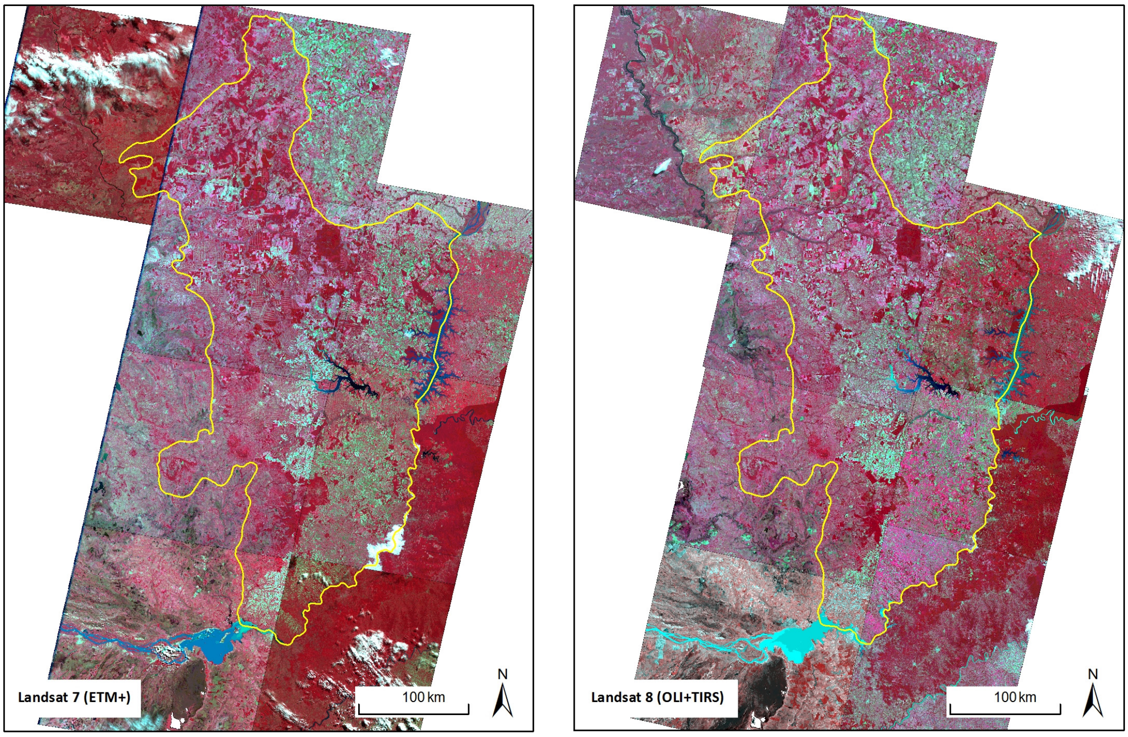


Figure 20: Overview on used Landsat data sets of 2003 (Landsat-7 ETM+) and 2013 (Landsat-8 OLI/TIRS).

4.3.2 Further Geo Data and Statistics

The main vector data sets used in this study are the “global biodiversity hotspot”- shapefile provided by Conservation International (2011) and the “global terrestrial ecoregion”- shapefile provided by The Nature Conservancy (2013). General physical and cultural vector data of Paraguay and South America (e.g. country and department borders, roads and rivers) as well as the “Cross-blended Hypsometric Tints”-raster are provided by Natural Earth (2013) community.

Further raster data used in this study was a set of TerraSAR-X data (Scansar mode, Enhanced Ellipsoid Corrected) to examine the rectification of the Landsat data. Access to this data was facilitated through the TerraSAR-X Science Coordination of the German Remote Sensing Data Center of the German Aerospace Center (DLR). An overview on Metadata of used dataset is listed in Table 4: TSX data used for geocoding of Landsat data (TerraSAR-X Science Coordination, 2013).

Table 4: TSX data used for geocoding of Landsat data

Mission/Mode	Date	Resol.	Mission/Mode	Date	Resol.
TDX1_SAR_EEC	2012-05-07	8.25m	TSX1_SAR_EEC	2008-06-17	8.25m
TDX1_SAR_EEC	2012-05-07	8.25m	TSX1_SAR_EEC	2008-05-21	8.25m
TSX1_SAR_EEC	2010-08-29	8.25m	TSX1_SAR_EEC	2008-05-21	8.25m
TSX1_SAR_EEC	2010-05-28	8.25m	TSX1_SAR_EEC	2008-05-21	8.25m
TSX1_SAR_EEC	2010-05-28	8.25m	TSX1_SAR_EEC	2008-05-10	8.25m
TSX1_SAR_EEC	2010-05-28	8.25m	TSX1_SAR_EEC	2008-04-02	8.25m
TSX1_SAR_EEC	2008-06-17	8.25m	TSX1_SAR_EEC	2008-04-02	8.25m
TSX1_SAR_EEC	2008-06-17	8.25m			

In addition, the NASA Shuttle Radar Topographic Mission (SRTM) has provided digital elevation data (DEMs) with 90m resolution for over 80 per cent of the globe. This data is currently distributed free of charge by USGS and freely available for download, e.g. at the website of the CGIAR Consortium for Spatial Information (CGIAR-CSI, 2013). A mosaic of the correponding 9 tiles was created to derive slope, aspect and hillshade files from digital elevation information of Paraguay map extent.

The population estimation of Landscan datasets from 2002 and 2010 was used for the population map and the examination of population as a driver of tropical deforestation in Paraguay. Landscan is the community standard for global population distribution at approximately 1 km resolution (30" X 30"). This data was provided by UT-Battelle, LLC, operator of Oak Ridge National Laboratory with the United States Department of Energy (Oak Ridge National Laboratory, 2013).

As reference point of the land cover composition in Paraguay, the Glob cover Product 2009 was used here. GlobCover is an ESA initiative that provide land cover maps using observations from the 300m MERIS sensor on board the ENVISAT satellite mission as input (ESA, 2011).

The main statistical data source for country information and forestry sector characterization in Paraguay was the INFONA quarterly (INFONA, 2012a, 2012b), the World Factbook (USCIA, 2013) and World Devlopment Indicators (World Bank, 2013).

5 Methods

5.1 *Analysis Workflow*

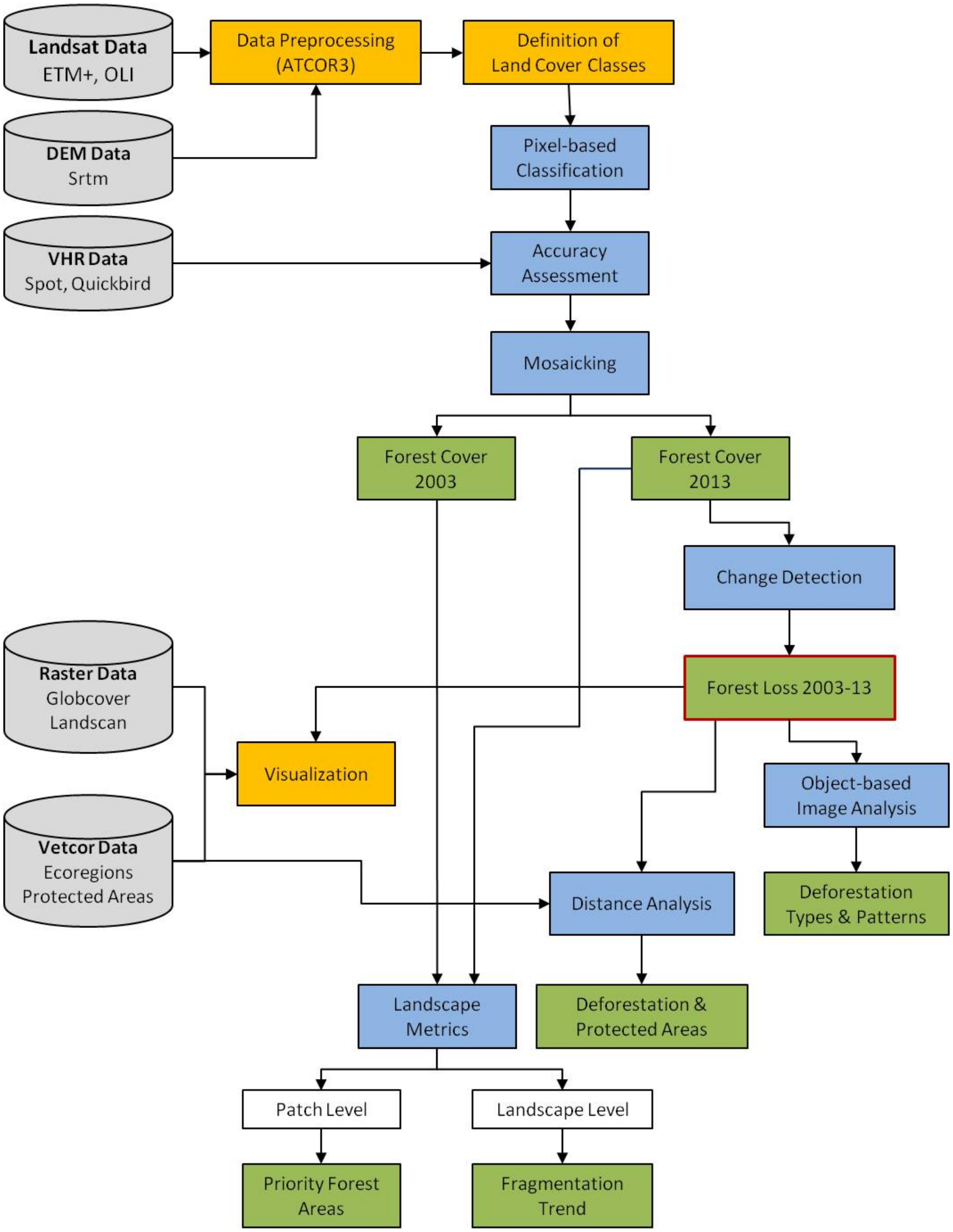


Figure 21: Workflow of remote sensing and GIS based forest monitoring.

5.2 Data Preprocessing

5.2.1 Geometric Correction

Raw digital images usually contain significant geometric distortions due to variations in the altitude, position, and velocity of the sensor platform. The earth's curvature, atmospheric refraction, relief displacement and non-linearity can contribute to distortions as well. According to Lillesand et al. (2008), geometric correction intents to compensate for those distortions. A corrected image will have the highest practical geometric accuracy and can be used as a base for mapping. The Landsat data used in this study was already geometrically corrected. According to the *Landsat Processing Details* on the USGS website (and the metadata files of each scene), the used scenes were processed to Standard Terrain Correction products (Level 1T). A systematic radiometric and geometric accuracy was provided by incorporating ground control points. Geodetic accuracy of the product depends on the accuracy of the ground control points and the resolution of the DEM used. Ground control points used for Level 1T correction come from the Global Land Survey 2000 data set (USGS, 2013b). The geometric accuracy of the Landsat scenes was examined by visual comparison with geocoded TSX Scansar data (EEC, 8.25m resolution) using the SWIPE-Mode in ERDAS imagine 2011 (see Figure 22).

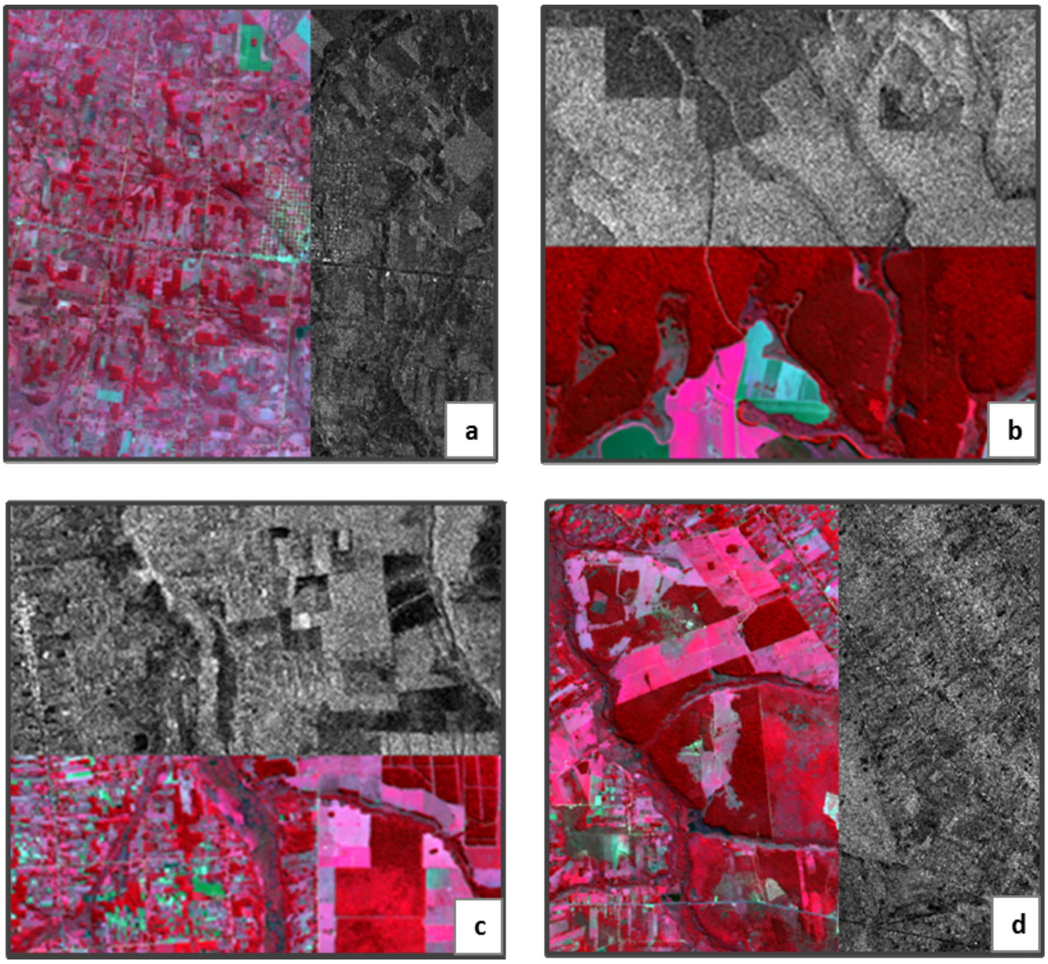


Figure 22: Examination of Landsat image rectification with TerraSAR-X data. Landsat images (colored) and geocoded TerraSAR-X data (black/white): a) and b) are subsets of Landsat 7 images and c) and d) subsets of Landsat 8 images. All subsets are scaled in 1 : 50,000.

5.2.2 Radiometric Correction

To compare multi-temporal images and images of different sensors, radiometric correction of optical satellite data is required. As a final result, the brightness values (digital numbers) recorded at the sensors and saved in raw satellite images will be converted to real and comparable reflectance values of the respective earth surface feature. According to Richter & Schläper (2013), the extraction of physical earth surface parameters such as spectral albedo, directional reflectance quantities, emissivity, and temperature is the objective of any radiometric correction of airborne and space borne imagery of optical sensors. To achieve this goal, the influence of the atmosphere, solar illumination, sensor viewing geometry, and terrain information have to be taken into account. Radiometric correction aims at three main components: the radiometric calibration of the respective sensor as well as the elimination of atmospheric and topographic effects.

As shown in Figure 23, for each spectral band of a sensor a linear equation (L= c1+c2+DN) describes the relationship between the recorded brightness or digital number (DN) and the at-sensor radiance (L). To convert the DN numbers into real surface reflectance values, first of all an accurate radiometric calibration is required. The knowledge of the radiometric calibration coefficients (c0, c1) in each spectral band is included in the corresponding metadata of each Landsat image.

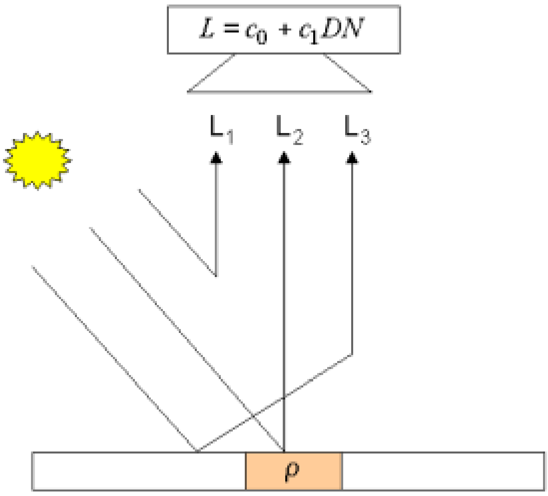


Figure 23: Solar radiation components. Schematic sketch of solar radiation components in flat terrain. L1: path radiance, L2: reflected radiance, L3: adjacency radiation (Source: Richter & Schläper, 2013).

The at-sensor radiance includes three different components. But only the reflected radiation (L2) contains information from the earth surface of the currently viewed pixel. The direct and diffuse solar radiation incident on the pixel is reflected from the surface. The task of atmospheric correction is the calculation and removal of path radiance (L1) and the reflected radiation from the neighborhood (L3). The path radiance mainly consists of photons that are scattered into the sensor's instantaneous field-of-view, without having ground contact (Raleigh scattering). The adjacent or neighborhood radiation consists of atmospheric backscattering and volume scattering. To remove or reduce the effects of these radiance components from at-sensor reflectance, an accurate estimate of the main atmospheric parameters (aerosol type, visibility or optical thickness, and water vapor) is necessary (Richter & Schläper, 2013).

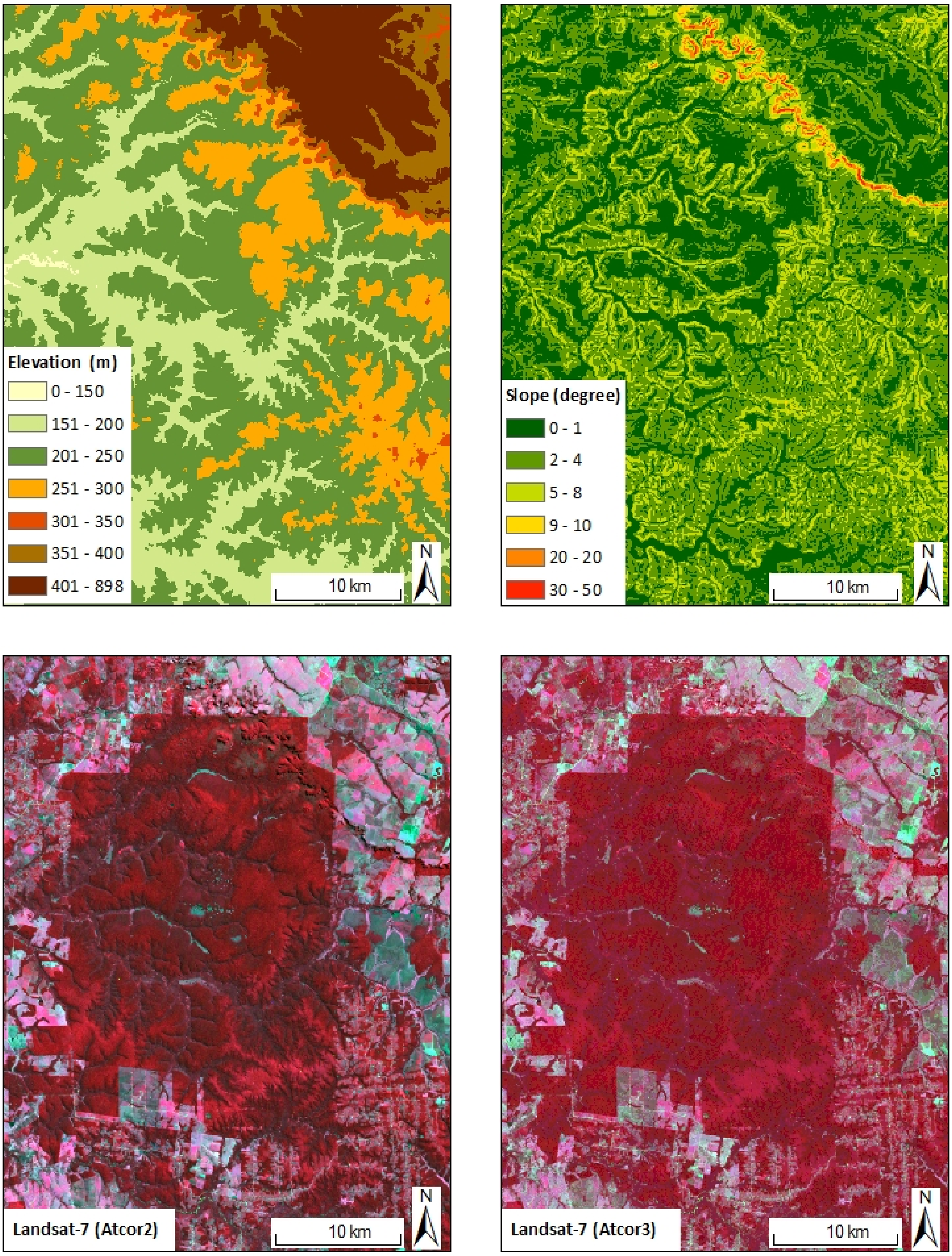


Figure 24: Comparison of ATCOR 2 and ATCOR 3 results of Landsat-7 satellite data covering the Mbaracayu Forest Area.

The terrain correction removes topographic illumination effects. Although the terrain of the study area is not very rugged, it contains a lot of river valleys and some mountainous areas. For example, the area of the Natural Reserve of the Mbaracayu Forest has a mean elevation of 100 to 300m, but one mountain range in the north (elevated up to 500m and slopes up to 20 degree) and many river valleys with slopes up to 10 degrees (see Figure 24). Comparing the results of atmospheric correction without and including terrain correction shows that even on relative flat terrain the illumination effects of the terrain was reduced (see Figure 24).

All Landsat images were atmospherically corrected including the terrain correction of rugged terrain (ATCOR 3 code). The parameters that were used for the atmospheric correction are shown in Table 5. The optical thickness or visibility was variable. For the Landsat 8 images the Cirrus removal was enabled. OLI's cirrus band (band 9) provides better detection of cirrus cloud contamination and improved the result of radiometric correction (see Figure 25).

Table 5: Overview Parameter of ATCOR3 code

Path/Row	Sensor	Date	Solar azimuth angle	Solar elevation	Solar zenith	MODTRAN atmosphere
224/77	ETM+	28.05.2003	31.52	33.98	56.02	rural tropical
224/78	ETM+	28.05.2003	37.17	32.70	57.30	rural tropical
224/79	ETM+	26.04.2003	42,76	37,72	52,28	rural tropical
225/76	ETM+	03.05.2003	42,37	39,87	50,13	rural tropical
225/77	ETM+	03.05.2003	41,81	38,65	51,35	rural tropical
225/78	ETM+	03.05.2003	41,34	37,39	52,61	rural tropical
225/79	ETM+	03.05.2003	40,88	36,15	53,85	rural tropical
226/76	ETM+	10.05.2003	40,65	38,44	51,56	rural tropical
224/77	OLI	31.05.2013	34,20	35,41	54,59	rural tropical
224/78	OLI	02.07.2013	34,68	32,45	57,55	rural tropical
224/79	OLI	02.07.2013	34,41	31,14	58,86	rural tropical
225/76	OLI	06.05.2013	38,24	41,20	48,80	rural tropical
225/77	OLI	07.06.2013	33,93	34,59	55,41	rural tropical
225/78	OLI	06.05.2013	37,28	38,65	51,35	rural tropical
225/79	OLI	06.05.2013	36,87	37,37	52,63	rural tropical
226/76	OLI	16.07.2013	37,03	36,19	53,81	rural tropical

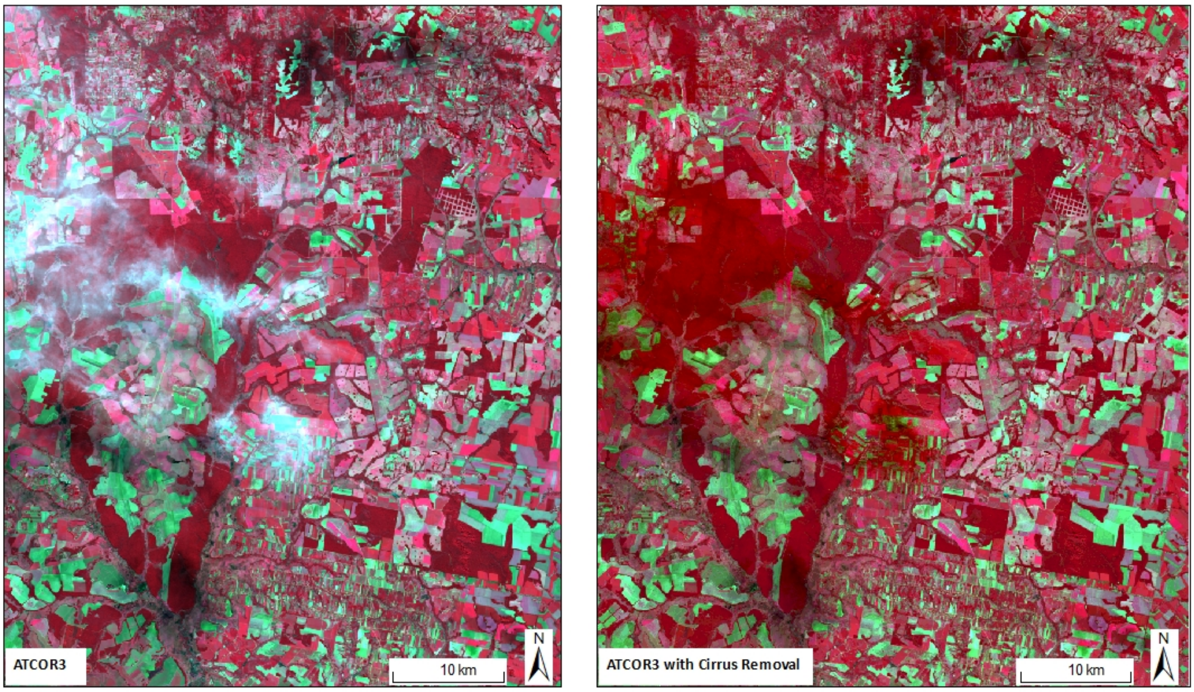


Figure 25: ATCOR3-Result for Landsat 8 image (before and after Cirrus Removal).

5.3 Forest/Non-Forest Classification

5.3.1 Training Samples and Spectral Analysis

The main purpose of the image classification is to reveal and to quantify the forest cover within the study area for two different dates. A threshold approach was conducted to map the forest/non forest classes. To determine the classification thresholds, an extensive training set of forest and main non forest classes was manually created by visual interpretation.

First of all, an initial classification scheme was defined to structure the content of an image (see Figure 26). The interpretation schemerepresents land cover classes that are represented in the Landsat images. The key works hierarchically beginning with large and easy to describe classes such as vegetation or non vegetation classes. These major classes are divided into sub-classes which are usually smaller in size. This way the image is structured spatially and semantically.

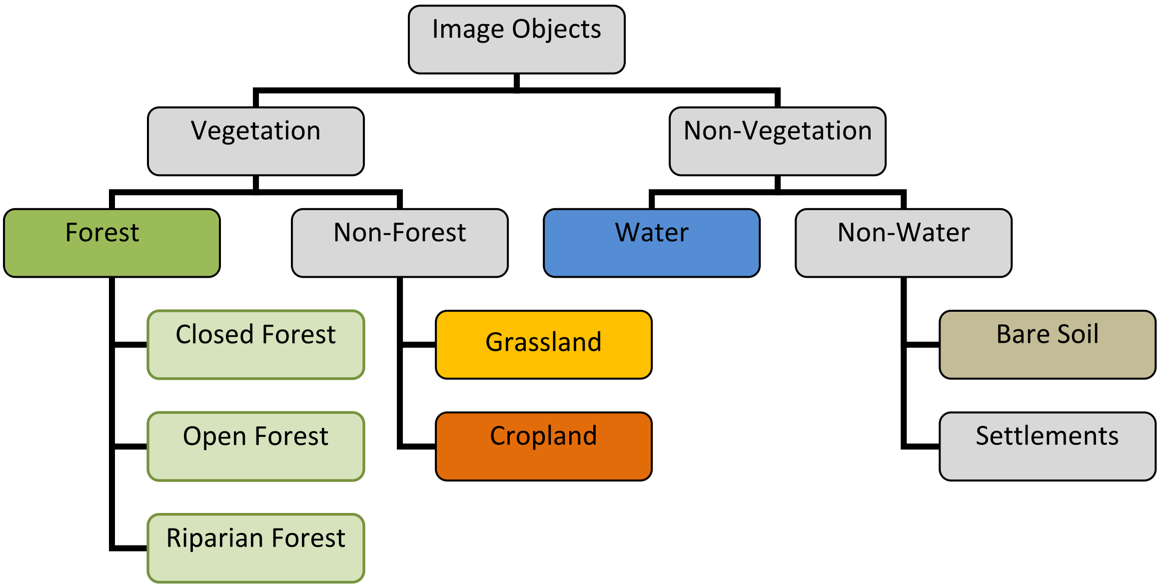


Figure 26: Image interpretation scheme.

In a first step, the observed features were separated into vegetation and non-vegetation classes. Within the vegetation class, forest features were distinguished from non-forest classes such as cropland or grassland. Within the forest class, different types were observed: very dense and close forests, sparse and open forests and riparian forests along riversides. Within the non-vegetation features, water could be distinguished from non-water features such as bare soil, settlements or infrastructure. Thus, the main classes used for training samples were pre-defined as forest (including the sub-classes **c**lose and dense forest, open and sparse forest and riparian forest along riverside), cropland (representing green fields), grassland, water and bare soil (including fallow land and settlements).

Following the interpretation key, up to 40 training samples were selected for each main class. The *region growing tool* In ERDAS Imagine 2011 was used to define the size of each training sample using Spectral Euclidean Distance values between 5 to 10 and 1000 pixels as maximum area constraint. The Euclidean Spectral distance is distance in n-dimensional spectral space. It is a number that allows to compare the similarity of two measurement vectors (ERDAS, 2010). Training samples were set using a band combination of 4-3-2 (NIR-RED-GREEN).

Figure 27: Examples of training data set.

Visual interpretation allows a relative easy differentiation between forest features and other non-vegetation objects (as bare soil, settlements and infrastructure) by comparing the different colors. Using the band combination 4-3-2 (Green-Red-NIR), vegetation appears in red colors, non-vegetation pixels appear in light blue, grey and brown colors (see water and bare soil samples in Figure 27). The differentiation between forests and other vegetation features such as dense grassland or very green fields of cropland is more difficult.

Pixel-based image classification is based on spectral characteristics of each land cover feature type. In order to find confusing and overlapping classes, appropriate band combination and thresholds to separate forest from non-forest objects, a spectral image analysis was realized. Based on manually created training data sets, signature separability was calculated for any combination of available bands. Signature separability is a statistical measure of distance between two signatures. For the euclidean distance evaluation, the spectral distance between the mean vectors of each pair of signatures is computed. If the spectral distance between two samples is not significant for any pair of bands, then they may not be distinct enough to produce a successful classification (ERDAS, 2010). As a result of separability analysis, a combination of Landsat spectral bands and NDVI was seen as an appropriate technique to separate between averages of main classes. The reported results of separability between main classes are listed in Table 6. The best average separability using 8 Layers (ETM+ bands 1-7 + NDVI) is 44.74 and the best minimum separability is 14.66. Separability between forest and other non-vegetation classes (water and bare soil) are very high (more than 60). Signature separability with other vegetation classes like grassland and cropland is much lower, thus spectral signatures are relatively similar to forests.

Table 6: Results of separability report

Signature		Water	Bare Soil	Cropland	Grassland	Forest
		1	2	3	4	5
Water	1	0	46,88	68,93	55,06	66,67
Bare Soil	2	46,88	0	55,94	46,54	61,95
Cropland	3	68,93	55,94	0	14,75	14,66
Grassland	4	55,06	46,54	14,75	0	15,99
Forest	5	66,67	61,95	14,66	15,99	0

5.3.2 Threshold Classification Approach

The objective of image classification is the assignment of pixels to real-world object classes. For the forest cover classification, only the forest class was separated from all other non-forest classes. A simple threshold approach was used for the forest / non forest classification. Thus, threshold classification leads to the elimination of disturbing competitive objects (Hildebrandt, 1996). After signature analysis of the collected training samples for each band, minimum and maximum thresholds were defined in order to separate the forest class from other main classes. Figure 28 present mean signatures of main classes and the defined thresholds for forest classification.

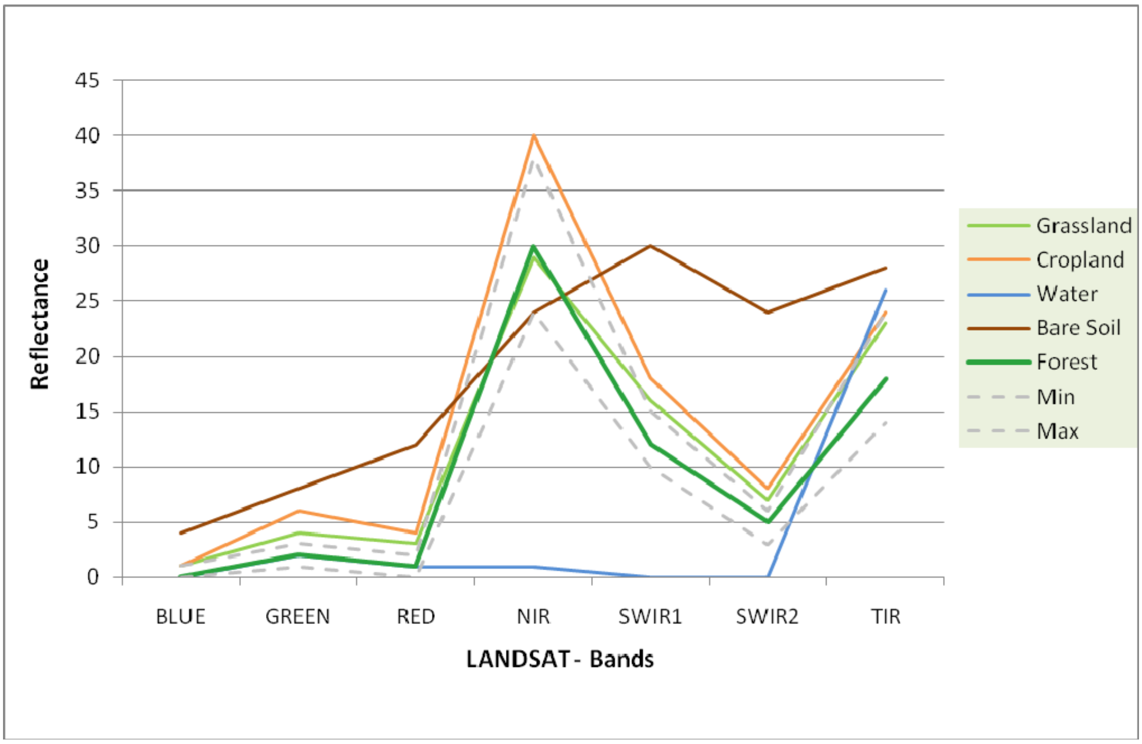


Figure 28: Mean signatures of training samples per class (including minimum/maximum thresholds of forest class).

Table 7 lists the minimum and maximum thresholds used for forest classification. For two of all Landsat 7 (ETM+) images (path 226 row 76, path 224 row 79), the maximum threshold of TIR band was raised to 28 or 32. For the Landsat 8 images, the thermal band was excluded since ATCOR 3 was not able to realize radiometric correction for the two new TIRS bands at this stage of analysis. In near future, ATCOR 3 code will be able to perform TIRS band correction. The thermal band will then be included into threshold classification of Landsat 8 images. However, it has to be considered that the resolution of Landsat 8 TIRS bands is 100m and therefore lower than the 60m of Landsat 7 images (resampled to 30m in both cases).

Table 7: Minimum and maximum thresholds of reflectance (Layer 1-7) or NDVI values

Layer	Min	Max	Wavelength ETM+
Layer 1 (Blue)	0	1	0.45-0.52
Layer 2 (Green)	1	3	0.52-0.6
Layer 3 (Red)	0	2	0.63-0.69
Layer 4 (NIR)	24	38	0.77-0.9
Layer 5 (SWIR1)	10	16	1.55-1.75
Layer 6 (SWIR2)	3	6	2.09-2.35
Layer 7 (Thermal)	14	24	10.4-12.5
Layer 8 (NDVI)	0.8	1	(NIR-RED)/ (NIR+RED)

In addition to the seven spectral bands of Landsat images, the NDVI was added for image classification. The NDVI can reveal the spatial pattern of green vegetation (see chapter 4.1.1). The NDVI values for the subtropical rainforest in Paraguay are very high with values greater than 0.8. The minimum NDVI of 0.8 ensures that only high green canopies are analyzed (see threshold of Layer 8 in Table 7). However, in some areas and phonological stages, green fields of cropland have also very high NDVI values. Thus, the NDVI on its own cannot be used to separate forests and other green vegetation, but utilizing it helps to separate water, bare soil, grassland and sparse green vegetation fields from forests.

5.3.3 Accuracy Assessment

The need for accuracy assessments to evaluate the quality of a classification was already explained in chapter 4.1.2. Since ground truth and reference data sets were unavailable, each classification was compared to the satellite image it was based on. An equalized random sampling approach was chosen to perform the accuracy assessment for the forest land cover classifications described above. Congalton & Green (2008) suggest a minimum of 75 to 100 samples for each map class for maps larger than 1 million acres in size. Since one Landsat image accounts of about 34,225 km² (8,457,181 acres), 200 sample points were randomly selected, resulting in 100 random points for each of the two classes (forest, non forest). The accuracy results are presented in chapter 6.2.

In general, classification results should be verified with reliable reference data. Ideally, this consists of spatially well-distributed data collected on the ground. However, due to financial and time limitations, it was not possible to realize a field trip or to find reliable in situ data. Another possibility to verify classification results are very high resolution satellite data. However, for this pilot study it was not possible to receive very high resolution data, but it is planned to order Quickbird or SPOT data in the following project phase. In some cases, a manually collected training data set of very high resolution data provided by Google Earth is a very helpful alternative to cost intensive ordering of high resolution data (especially for very large study areas). However, due to the fact that very recent data was analyzed in this study it was not possible to find sufficient datasets for the study area. Without up-to date and well distributed reference datasets (especially for the 2013 Landsat 8 composite) reliable verification of the classification results and forest loss detection with ground truth data or very high resolution data is still needed.

5.4 Forest Loss Detection and Mapping

After the validation of forest classification of the sixteen Landsat images, forest cover quantification and mapping for the whole BAAPAP region was conducted. Afterwards, changes between both forest coverages were detected in order to quantify and map the forest loss that occurred between 2003 and 2013.

To get these main study results, certain processing steps had to be realized:

- *Mosaicking* of eight classification results for each date. The feather option was chosen as overlap function.
- A *subset* of the study area (with BAAPAP region polygon layer) was created for each mosaic composite.
- A *convolution filter* (3x3 median) was applied to reduce pixel speckling.
- The *image difference* of both forest cover maps was calculated to get the forest loss results between 2003 and 2013.
- The *raster layer was converted to polygon layer* (disabling simplifying polygon functions) and the area of all polygons was calculated in hectare. According to the FAO definition, forest is land spanning more than 0.5 ha (FAO, 2010b). Therefore, areas smaller than 0.5 ha were removed from the result.
- *Statistics* were calculated for each dataset to to sum up the area of all remaining polygons.
- To differentiate between the departments, an *intersection* of the department polygon layer and the forest polygon layer was created and then statistics were calculated for each department.

The resulting maps and statistics are presented in chapter 6.2.

5.5 Deforestation Pattern and Forest Fragmentation Analysis

Within this study, three different methods were examined to analyze the spatial distribution and characteristics of forest loss and forest fragmentation within the BAAPAP region. The three approaches are explained in the following.

5.5.1 Object-based Image Analysis (Segmentation)

The intention of this study was to examine if the specific deforestation patterns, that were observed in the BAAPAP region, can be detect (semi) automatically with an object-based image analysis approach. The expected result would be a map that illustrate the forest losses in the BAAPAP region and distinguish between different deforestation patterns.

The objective was to find a process chain that detect the forest loss areas into the four main deforestation patterns. The specific deforestation patterns were supposed to recognize by their special geometries. Thus, the four main patterns of forest loss differ in shape and geometry and their spatial relation with the original forest layer.

The idea of this approach was, to conduct a segmentation of the forest loss layer and forest cover layer in 2003 that were derived by the pixel-based classifcation or change detection within this study. The segmentation aims at distinguishing between feature objects based on their geometric attributes. In particular, the parameter scale, shape and compactness were used to refine the segmented objectes. After the segmentation process, conditions were developed that specify each pattern type.

- *Compact clearing*: Forest loss objects that are larger than 100 ha with high values of compactness and rectangular borders.
- *Fishbone Clearing*: Long and drawn out objects of forest cover that are surrounded by likewise long drawn out objects of forest loss objects. In case the forest loss are highly frazzled, a smoothing tool may be applied to simplify the geometries.
- *Circle Clearing*: Forest Loss Objects with shapes similar to circles.
- *Spreckle/Spotted Clearing*: Forest loss objects that are smaller than 10 ha with high values of compactness and are located within a larger forest cover area (and have similar objects within its neighborhood).

These considerations were planned to assign into class definitions. These class assignments were then applied to the forest loss layer of the whole BAAPAP region. Some first tests of segmentation and class defintion were conducted using the Trimble eCognitions Developer software product.

However, at this stage of the study, the OBIA results are not satisfying. This had two main reasons. The detection of the specific patterns was very difficult due to the fact that the forest loss areas and the forest cover in 2003 was already highly fragmented. The specific gemetries that were identified as circles or fishbones by visual interpretation were not that ideal shapes that they were able to detect and to distinguish from other forms that are similar. The combination of shape defintion of forest loss areas and the spatial relationship to the original forest patches was expected to facilitate the seperation process. However, in many cases the original forest pacthes were also highly fragmented that the class defintions did not work out for all areas. However, the object based approach offer much more complex tools and algorithms that were not tested within this study. More comprehensive knowledge and skills are needed to follow this approach. Due to time constraints and in favor of other priorites of this pilot study, the OBIA approach was not intensified.

5.5.2 Distance Analysis (Multiple Ring Buffering)

To analyse the forest losses inside and outside protected areas, it was used the Multiple Buffer Ring tool in ArcGIS 10.1. This tool creates multiple buffers at specified distances around the input features. The Forest Loss rates were generated as a percentage of the forest cover in 2003.

Firstly, forest loss inside protected areas was examined by the following steps:

- *Create Layer* of Protected Areas greater than 100 km² → 8 Polygons remained
- Intersect Forest 2003 Layer with 8 Protected Areas Layer → *Recalculation of* Forest 2003 Area
- Intersect Forest Loss Layer with 8 Protected Areas Layer → *Recalculation of* Forest Loss Area
- Calculate Statistics for each Protected Areas → Sum of Forest Loss areas within Protected Areas in km² and as a percentage of respective 2003 forest area

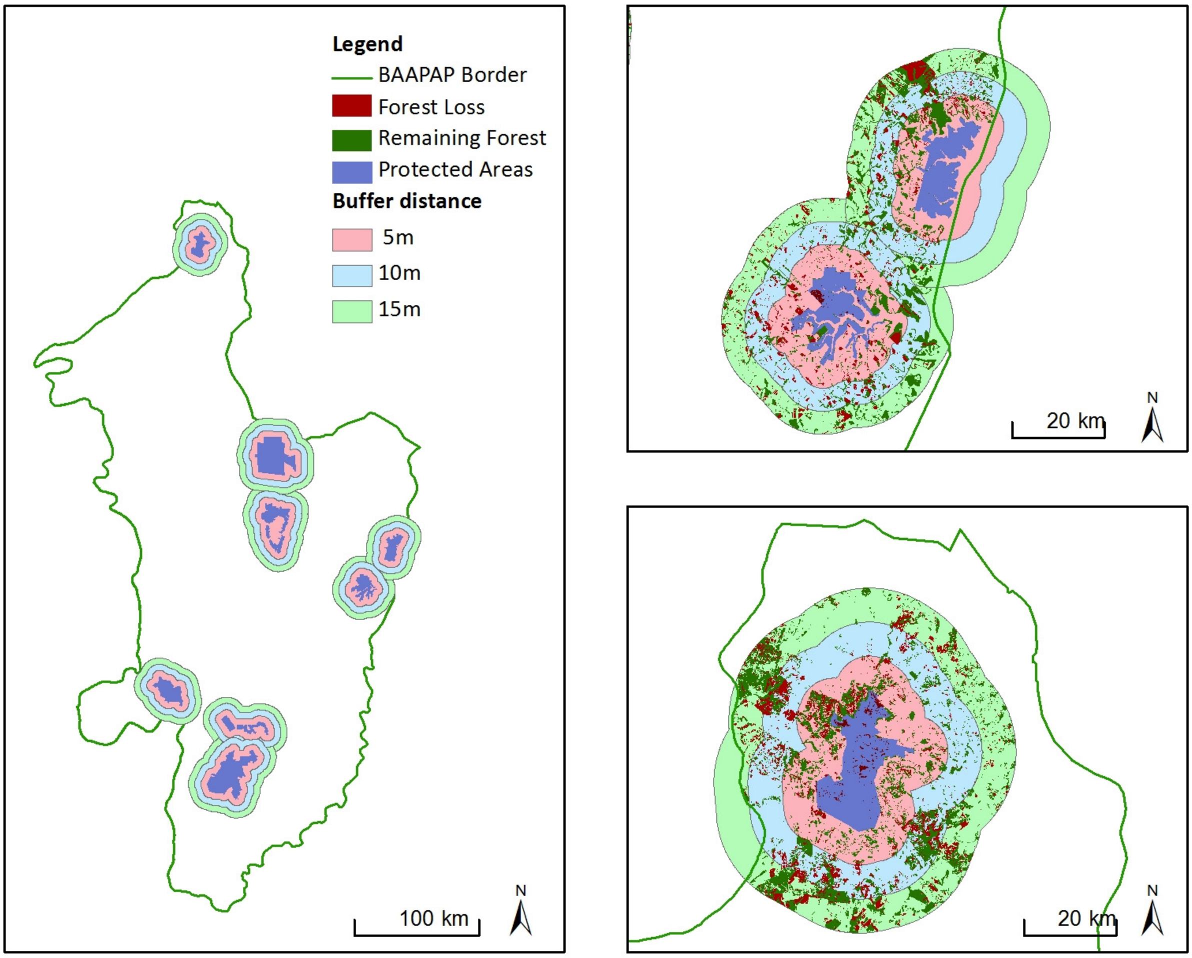


Figure 29: Multi buffer ring selection of forest loss outside protected areas.

Secondly, forest loss outside ptotected areas was examined by the following steps:

- *Create MultiBuffer* around 8 Protected Areas (5,10,15 km, “none dissolve” and “outside polygons only”)
- *Intersect* with Forest Loss Layer → Recalculate of Forest Loss Areas per Protected Area Name and Buffer Distance (5,10,15)
- *Select* Polygons and *Calculate* Statistics for each Protected area and Buffer Distance (5, 10, 15) → Sum Area Forest Loss per Bufferzone and Protected Area in km² and as a percentage of respective 2003 forest area

Some of the Areas are located near the BAAPAP region border (e.g. Limoy and Itabó Reserve). In these cases, only forest and forest loss within BAAPAP border is considered even if the buffer area lies across the BAAPAP border (see Figure 29).

5.5.3 Landscape Metrics

The quantitative Landscape Ecology assumes that the concrete form and spatial composition of landscape elements is relevant for many ecological processes. The structure of the landscape or one landscape class as forest habitats can be described and compared by different landscpae metrics. A huge amount of Landscape metrics exists to characterize landscpae structures (Lang & Blaschke, 2007; Mcgarigal & Marks, 1994). The challenge is to identify the appropriate and relevant set of metrics. Some universal metrics exist that are useful to apply in many cases and different study areas, but the final set of metrics depends on the respective research question.

Within this study, the decision which metrics were involved were taken on a semantic-content approach. It is based on ecological assumptions and a research focus on fragmentation and biodiversity value of the Atlantic forest in Paraguay. The aim of this analysis is to characterize the forest landscape in the BAAPAP region with a special focus in fragmentation processes and the identification of priority forest areas with high value regarding biodiversity conservation.

In this context, the following topics were chosen: *core areas, fragmentation, neighborhood and subdivision*. The applied metrics and the description of their implication are listed in Table 8.

Table 8: Applied landscape metrics

	Metrics	Description	Unit/ Range
Core Areas	Total Core Area	The sum of n core areas.	m^2/ km^2
	Core Area Index	Relationship between the resulting core area size and the size of the total area.	0-100 %
	Cority	The difference of the amount of original patches and resulting patches without a core area is divided by the amount of resulted core areas.	0-1
Fragmentation	Shape Index	Mean deviation of the patch from an ideal form of a circle.	1-∞
	Perimeter Area Ratio	Mean area of patches in relation to its perimeter.	0-1
	Mean Fractal Dimension	Mean curvilinearity of patch edges.	1-2
Neighborhood	Nearest Neighbor Distance	The shortest distance between patches of the same type within the landscape.	m/km
	Proximity Index	Embedding of patches within the mosaic of the same class.	0-∞
Subdivision	Subdivision Index	Probability that two random pixels are located within the same patch.	0-1
	Effective Mesh Size	Weighted average size of patches after subdivision.	m^2/km^2
	Splitting Index	Amount of equal size patches that result by subdivision.	m^2/km^2

The majority of landscape metrics is based on area and perimeter of the patches within the landscape mosaic. Area and perimeter are standard metrics of GIS software and the most prominent and basic indicator to quantify landscape classes.

Core Area: A very important mesure to identify the most valuable forest patches is core area analysis. It is based on the ecological knowledge that many animal species avoid habitat border areas and prefer to stay in the interior area of forest habitats. To identify and quantify the interior areas within the forest patches core areas were calculated. In this study, the edge distance was set up to 50m, 100m and 500m. These distances were applied as a negative buffer to the border of each forest patch. As a result whether one, more or no core area remain depending on form of the patches and its relationship of area size and edge distance. If the patch size is very small no core area result or if it was a long stretched polygon eventually two or smaller core areas result. The core area index (CAI) describes the relationship between the resulting core area size and the original size of the forest area. In addition, the cority figures consider the number forest patches without core areas and is calculated by the amount of original patches minus the amount of resulting patches without a core area divided by the amount of resulted core areas.

Fragmentation: Another standard function to measure patch size is the perimeter of one forest patch. The perimeter of one patch is equal to its total edge. The Total Edge (TE) is the total length of all edges within one class or within the whole landscape. A prominent indicator to quantify forest fragmentation is the Edge Density (ED). In general, a high edge density implies structure diversity. The Mean Patch Edge (MPE) is the mean length of edges. Shape and form of patches are more important indicators to describe the fragmentation degree of landscape and patches itself. For example, the Mean Perimeter Area Ratio (MPAR) is a common indicator to evaluate relationship between edge length and area of the patches. The lower the values the higher is the fragmentation of the patch or the less compact is a patch. The mean fractal dimension (MFRACT) describe the curvilinearity of patch edges.

Neighborhood: Nearest Neighbor Distance (NNDIST) calculates the shortest distance of a forest patch to its nearest forest patch. The mean Nearest Neighbor Index (MNN) is the average of the shortest distance between patches of the same type within the landscape. These Calculations failed due to extrem long processing time and system crashs.

However, in the context with focus on biodiversity and relevant patches to define potential biological corridors between highly valuable forest, the concept of proximity is more suitable than the nearest neighbor distance of each patch. The concept of proximity consider not only the distance to the nearest neighbor, it also considers the size and amount of near located patches within a certain search distance (proximity buffer, PB).

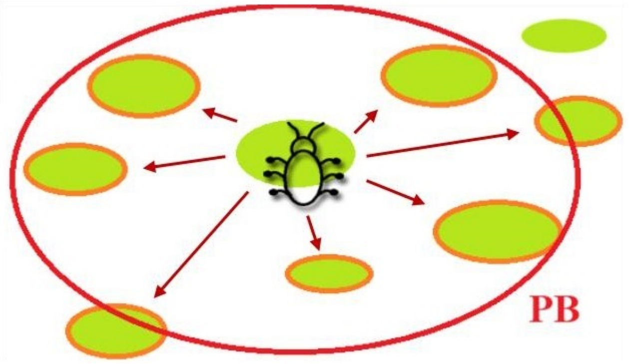


Figure 30: FRAGSTAT proximity concept. (Source: Lang & Tiede 2002).

The *Proximity index* was developed by Gustafson and Parker (1992) and considers the size and proximity of all patches whose edges are within a specified search radius of the focal patch. The proximity describes the relative incorporation of one single patch within the mosaic of the same class patches.

Subdivision: The Landscape subdivison Index is based on a coherence level and describe the propability that two random pixels are not located within the same patch. The Splitting Index (SPLIT) describe the amount of equal size areas that remains after division. The effective mesh size (MESH) These general figures provide an informative basis of more detailed subdivision analysis by different factors.

Two Extensions of ESRIs ArcGIS 10.1 software were used to calculate landscape metrics: the Patch Analyst (Grid) and the V-LATE Beta 2.0 extension. The Patch Analyst extension was developed at the Centre for Northern Forest Ecosystem Research (Canada) and facilitates the spatial analysis of landscape patches, and modeling of attributes associated with patches. It is used for spatial pattern analysis, often in support of habitat modeling, biodiversity conservation and forest management (Rempel, Kaukinen, & Carr, 2012). The advantage of the Patch Analyst is that a broad set of landscape metrics are implemented and both data types raster and vector data can be analyzed.

The V-LATE Extension was developed by Lang & Tiede (2002). It allows to analyze vector data sets and has a reduced set of availbale landscape metrics. However, the most important metrics used here are available. The interface was really intuitive and easy to understand and calculation time was less than in Patch Analyst (Grid) extension.

As a result of testing and comparing both extensions, all figures mentioned in the following are calculated with V-LATE Beta 2.0. Both extensions, the Patch Analyst and V-LATE are based on FRAGSTAT software. Among Landscape Ecologists FRAGSTAT is the standard spatial pattern analysis program for quantifying landscape structure (Mcgarigal & Marks, 1994).

FRAGSTAT calculates metrics at three main levels: Landscape, level, patches. The landscape level includes all of the patches within a defined landscape, the class level mainly involves differences between classes and the patch level metrics calculate for each individual patch within each class (in this case just the forest class).

As forest development and changes is the research object and forest mask layer is the data input, analysis level was applied on a the landscape and patch-level:

- On a *landscape level*, the forest cover of 2003 and 2013 were analyzed to give an overview on main trends of forest fragementation within the last decade.
- On a *patch level*, the forest patches of 2013 were analyzed to provide a detailed insight on structure and characteristics of the current forest landscape.

The *class level* was not considered within this study due to the fact that only a forest mask layer was used as input data. In case a detailed land cover layer exist, the analysis of the class level will provide additional information on structure and composition of differnet land cover classes within the whole landscape.

The calculation of some metrics is really complex and needs a long time. Calculations at the landscape level was done overnight and patch amount of analyzed forest area was reduced to patches greater than 10ha to reduce the processing time.

A detailed presentation of the results of the landscape metrics analyis on both levels is are presented in chapter 6.4. The evaluation of these results is discussed in chapter 7.5.

6 Results

This chapter presents the results of this study in detail.

6.1 Mapping

The results and background information of the study were visualized in different maps. These maps are shown in the chapters in reduced size to fit into the manuscript and give an idea of the content. Additionally, all maps can be found in the original A4 format in the Annex.

In general, the BAAPAP region is defined as the part of the Atlantic Forest ecoregion that is located in the Republic of Paraguay. Main rivers and water bodies were included in specific maps as background information for better orientation, but not a comprehensive insight in watershed of that area. The main source of the data that were vizualized in the maps are explained in the maps itselfs and in the chapter of data sources used in this study (see chapter 4.3).

6.2 Forest Classification Accuracy

All study results are based on two remote sensing based forest classifcations that were conducted to reveal the forest cover in the BAAPAP region in 2003 and 2013. The two results of forest cover classification and their accuracy are presented in the following.

6.2.1 Forest Classification: 2003

The starting point of the analysis was the forest cover classification of eight neighboring Landsat 7 (ETM+) images of 2003 covering the total study area. After a comprehensive preprocessing of the data, a simple threshold classifcation approach was used to derive the forest areas within each Landsat image. The quality of the forest classifcations was examined by accuracy assessments.

The results of the accuracy report for each image classification are listed in Table 9. The pixel-based forest classifcation shows high levels of overall accuracies for all images with total accuracy values ranging from 81 to 95 per cent. The same applies for Kappa. The Kappa coefficients of all classifications in this study are ranging between 0.66 and 0.93. These coefficients imply that the classification process is avoiding errors that a completely random classification generates by 66 to 93 per cent. The Landsat image of path 225 and row 76 has the highest total accuracy. The high accuracy resulted from very high matching of classified and reference points. As the table shows, 99 of the 100 randomly selected forest reference pixels are classified correctly as forest pixels and only one pixel was misclassified as non forest pixel. Thus, the users accuracy is 99 per cent for the forest class. The Non forest class shows also high results of users accuracy with 92 per cent. 91 of the 100 forest reference pixels were correctly classified as forest. The producers accuracy is slightly lower for the forest class than for the non-forest class. Within this dataset of 2003, the lowest accuracy was reported for the Landsat image of path 224 and row 79. The reason for that low accuracy is that not enough areas were classifed as non-forest areas due to high spectral similarities of dense vegetated crop fields and forest areas.

Table 9: Results of accuracy assessment for each Landsat 7 (ETM+) images of 2003

Landsat Image		2003 (path 226, row 76)		2003 (path 225, row 76)		2003 (path 225, row 77)	
Error Matrix		Reference Data		Reference Data		Reference Data	
		Forest	Non-Forest	Forest	Non-Forest	Forest	Non-Forest
Classified Data	Forest	96	4	99	1	93	7
	Non-Forest	14	86	9	91	10	90
Accuracy Totals							
Reference Totals (RT)	200	110	90	108	92	103	97
Classified Totals (CT)	200	100	100	100	100	100	100
Number correct (Errors)		96(4)	86(14)	99(1)	91(9)	93(7)	90(10)
Producers Accuracy	% of RT	87.27	95.56	91.67	98.91	90.29	92.78
Users Accuracy	% of CT	96.00	86.00	99.00	91.00	93.00	90.00
Total Classification Accuracy (%)		91.00		95.00		91.5	
Kappa Statistics							
Conditional Kappa		0.91	0.75	0.98	0.83	0.86	0.81
Overall Kappa Statistics		0.82		0.90		0.83	

Landsat Image		2003 (path 225, row 78)		2003 (path 225, row 79)		2003 (path 224, row 79)	
Error Matrix		Reference Data		Reference Data		Reference Data	
		Forest	Non-Forest	Forest	Non-Forest	Forest	Non-Forest
Classified Data	Forest	94	6	83	17	94	6
	Non-Forest	8	92	5	95	32	68
Accuracy Totals							
Reference Totals (RT)	200	102	98	88	112	126	74
Classified Totals (CT)	200	100	100	100	100	100	100
Number correct (Errors)		94(6)	92(8)	83(17)	95(5)	94(6)	68(32)
Producers Accuracy	% of RT	92.16	93.88	94.32	84.82	74.60	91.89
Users Accuracy	% of CT	94.00	92.00	83.00	95.00	94.00	68.00
Total Classification Accuracy (%)		93.00		89.00		81.00	
Kappa Statistics							
Conditional Kappa		0.88	0.84	0.70	0.89	0.84	0.49
Overall Kappa Statistics		0.86		0.78		0.62	

Landsat Image		Mosaic 2003 (path 224, row 77+78)	
Error Matrix		Reference Data	
		Forest	Non-Forest
Classified Data	Forest	139	16
	Non-Forest	10	134
Accuracy Totals			
Reference Totals (RT)	300	155	144
Classified Totals (CT)	300	150	150
Number correct (Errors)		139 (10)	134(16)
Producers Accuracy	% of RT	89.68	93.06
Users Accuracy	% of CT	92.67	89.33
Total Classification Accuracy (%)		91.00	
Kappa Statistics			
Conditional Kappa		0.85	0.79
Overall Kappa Statistics		0.82	

In general, the majority of misclassifed pixels were usually caused by two main errors. On the one hand, the over-correction or remaining shadows of terrain pixels leads to misclassification of forest pixels to the non-forest class. On the other hand, very dense and green fields (e.g. maize or soy) are in some cases classified as forests due to its very similar spectral characteristics (see Figure 31).

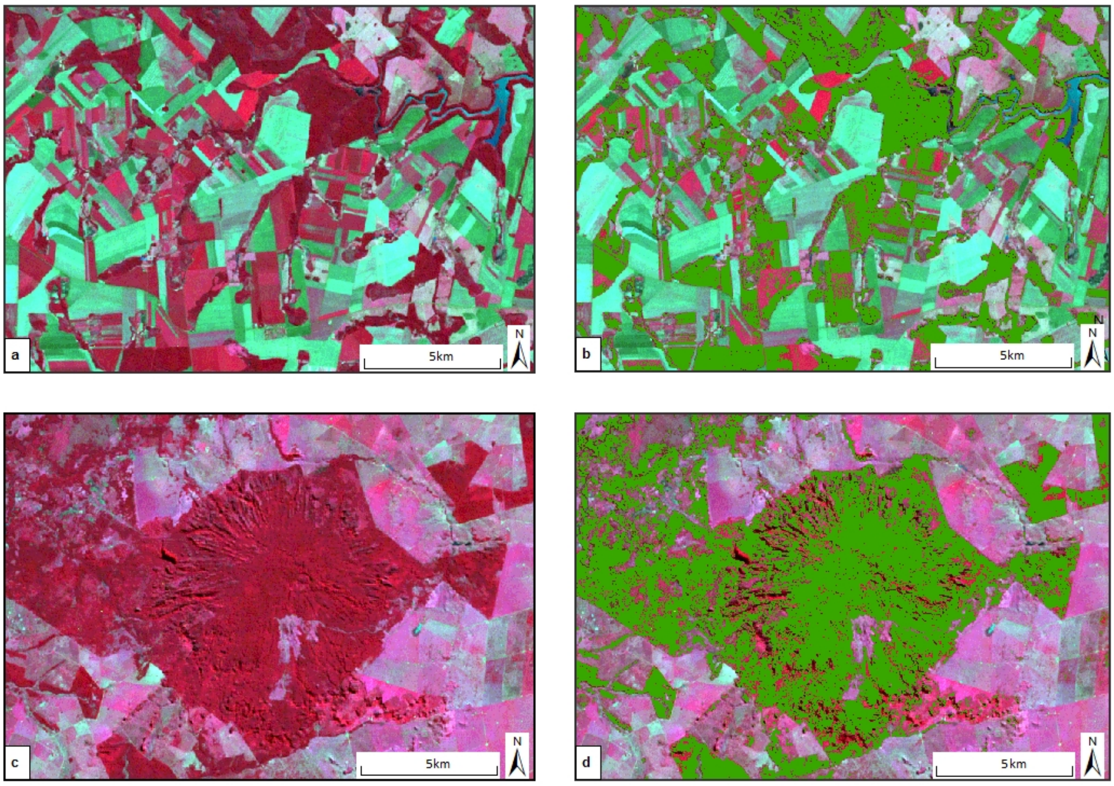


Figure 31: Misclassification examples. The figure shows some subsets of the study area (left side) and the overlay of the forest classification (right side): Very green fields of cropland (a) were confused as forests (b) and ruggy areas (c) were confused as non forest areas (d).

6.2.2 Forest Classification: 2013

In a next step of analysis, forest cover of 2013 data was derived by conducting the same classification procedure for the Landsat 8 (OLI-TIRS) data. The final result of this process is the forest cover map of the whole BAAPAP region that is presented In Table 10. .

The total accuracy for the 2013 dataset are also very high with values ranging from 83 to 94 per cent (see Table 10). The classification of the Landsat image with the path 224 and row 77 has the lowest accuracy. It is also located in the east of the BAAPAP region where spectral similarities of dense crop fields and forest areas lead to misclassifications as it was described above for the Landsat 7 image classification (see Figure 31 a,b).

Following the reasonable accuracy assessment, the eight classifcation results were then mosaicked to one image composite and a subset of the BAAPAP region was created to provide the forest mask of the study area.

Table 10: Results of accuracy assessment for each Landsat 8 (OLI) images of 2013

Landsat Image		**2013 (path 226, row 76)**		**2013 (path 225, row 76)**		**2013 (path 225, row 77)**	
Error Matrix		Reference Data		Reference Data		Reference Data	
		Forest	NonForest	Forest	NonForest	Forest	NonForest
Classified Data	Forest	98	2	94	6	97	3
	NonForest	10	90	8	92	9	91
Accuracy Totals							
Reference Totals (RT)	200	108	92	102	98	106	94
Classified Totals (CT)	200	100	100	100	100	100	100
Number correct (Errors)		98(2)	90(10)	94(6)	92(8)	97(3)	91(9)
Producers Accuracy	% of RT	90.74	97.83	92.16	93.88	91.51	96.81
Users Accuracy	% of CT	98.00	80.00	94.00	92.00	97.00	91.00
Total Classification Accuracy (%)		**94.00**		**93.00**		**94.00**	
Kappa Statistics							
Conditional Kappa		0.9565	0.8148	0.8776	0.8431	0.9362	0.8302
Overall Kappa Statistics		**0.88**		**0.86**		**0.88**	

Landsat Image		**2013 (path 225,row 78)**		**2013 (path 225, row 79)**		**2013 (path 224,row 77)**	
Error Matrix		Reference Data		Reference Data		Reference Data	
		Forest	NonForest	Forest	NonForest	Forest	NonForest
Classified Data	Forest	96	4	85	15	73	27
	NonForest	15	85	6	94	7	93
Accuracy Totals							
Reference Totals (RT)	200	111	89	91	109	80	120
Classified Totals (CT)	200	100	100	100	100	100	100
Number correct (Errors)		96(4)	85(15)	85(15)	94(6)	73(27)	93(7)
Producers Accuracy	% of RT	86.49	95.51	93.41	86.24	91.25	77.50
Users Accuracy	% of CT	96.00	85.00	85.00	94.00	73.00	93.00
Total Classification Accuracy (%)		**90.50**		**89.50**		**83.00**	
Kappa Statistics							
Conditional Kappa		0.9101	0.7297	0.7248	0.8681	0.6600	0.8250
Overall Kappa Statistics		**0.81**		**0.79**		**0.77**	

Landsat Image		**2013 (path 224, row 78)**		**2013 (path 224, row 79)**	
Error Matrix		Reference Data		Reference Data	
		Forest	NonForest	Forest	NonForest
Classified Data	Forest	91	9	98	2
	NonForest	7	93	13	87
Accuracy Totals					
Reference Totals (RT)	200	98	102		
Classified Totals (CT)	200	100	100	100	100
Number correct (Errors)		91(9)	93(7)	98(2)	87(13)
Producers Accuracy	% of RT	92.86	91.18	97.75	97.75
Users Accuracy	% of CT	91.00	93.00	98	87.00
Total Classification Accuracy (%)		**92.00**		**92.50**	
Kappa Statistics					
Conditional Kappa		0.8235	0.8571	0.9551	0.7658
Overall Kappa Statistics		**0.84**		**0.85**	

6.3 *Forest Loss Monitoring*

6.3.1 Forest Cover 2003 and 2013

The main results of the forest classification procedure are the two forest cover maps of the whole BAAPAP region in 2003 and 2013 that are presented in Figure 32 and Figure 33 and the quantification of the forest cover itself on both dates.

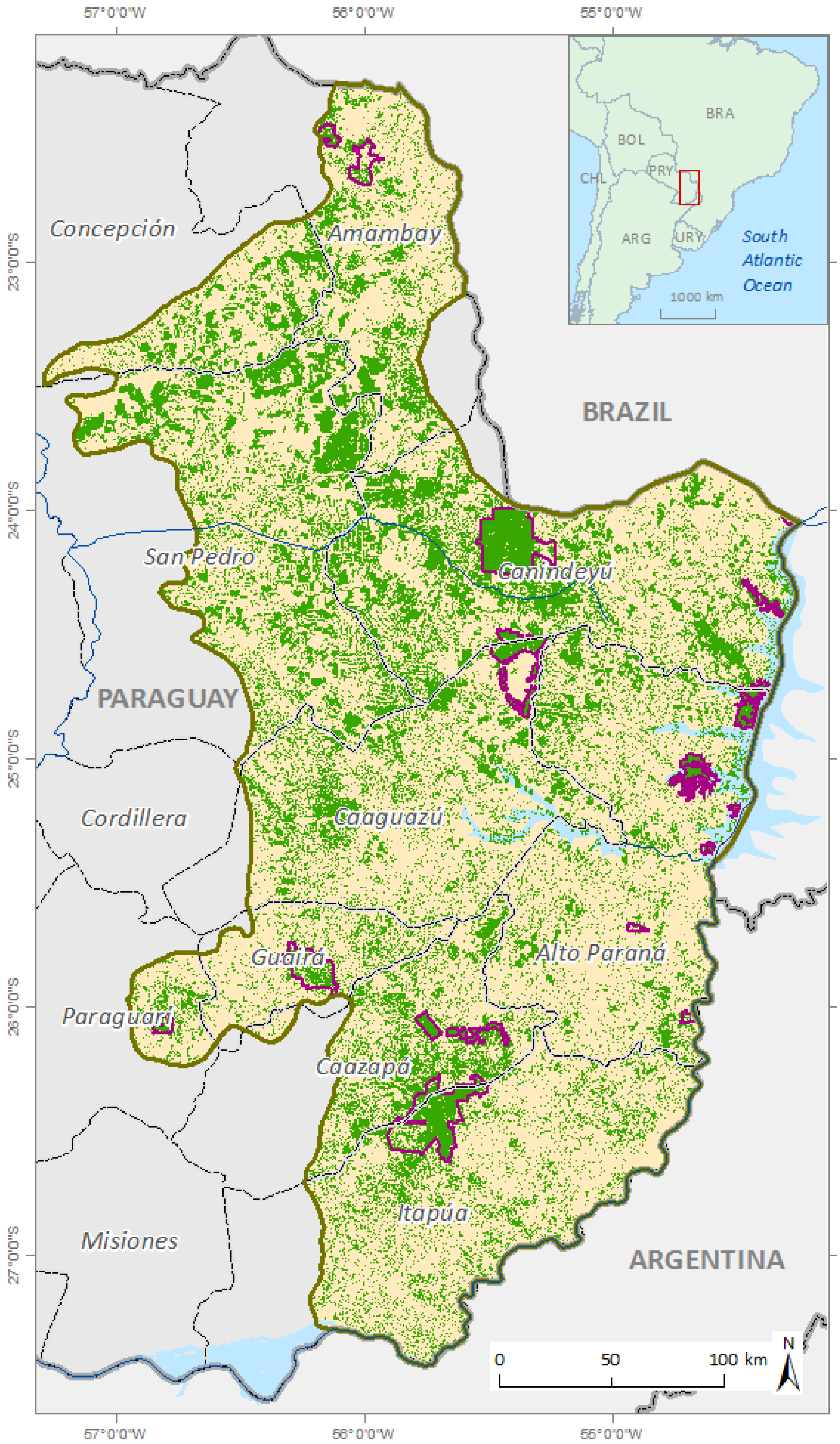
In 2003, about 38 per cent of the ecoregion area was covered by forests. It is an area of about 33,000 km². The majority of the total forest cover was concentrated in the northwest of the BAAPAP territory, the forest cover is highly fragmented and only very few continuous forest blocks still exist. The largest continuous forest areas are situated in the protected areas. However, also larger continuous forests without any protection status exist, in particular in the northwest of the study area (see Figure 32). In 2013, forest covers about 27,000 km² or 31 per cent of the BAAPAP region. Not only changed the size of the forest area, but also its spatial distribution. The concentration of larger forest areas in the northwestern part of the BAAPAP territory dissolved into a higher fragmentation across the whole study area. Many large continuous forest areas outside protected areas were diminished (see Figure 32 and Figure 33).

Table 11 distinguishes the results of the forest cover classification of the year 2003 and 2013 by departments. In 2003, the departments of Canindeyú and San Pedro exhibit the largest forest areas with more than 5,000 km² each. Almost 20 per cent of the total forest cover in BAAPAP region a) is located in these two departments. Similar high proportions of forest cover in relation to the department size of BAAPAP area b) exhibit the departments Amambay, Caazapá, and Concepción with up to the half of the territory covered with forests. Except in the protected areas, forest coverage in the eastern part of the BAAPAP region is low. Only one third or less of the area is covered by forests in the two departments that border of the Paraná River (Alto Paraná and Itapúa).

Table 11: Forest cover in Paraguay´s Atlantic Forest in 2003 and 2013

	BAAPAP Area		Forest Cover in 2003			Forest Cover in 2013		
Department	**km²**	**%**	**km²**	**% a)**	**% b)**	**km²**	**% a)**	**% b)**
Alto Paraná	14,060	16.3	3,635	11.0	25.9	3,392	12.5	24.1
Amambay	7,356	8.5	3,219	9.7	43.8	2,461	9.1	33.5
Caaguazú	11,345	13.2	3,615	10.9	31.9	3,097	11.4	27.3
Caazapá	5,458	6.3	2,773	8.4	50.8	2,450	9.1	44.9
Canindeyú	14,404	16.7	6,444	19.5	44.7	5,690	21.0	39.5
Concepción	3,797	4.4	1,888	5.7	49.7	1,459	5.4	38.4
Guairá	3,423	4.0	1,064	3.2	31.1	985	3.6	28.8
Itapú c)	12,122	14.1	3,755	11.4	31.0	2,968	11.0	24.9
Paraguarí	1,378	1.6	365	1.1	26.5	380	1.4	27.6
San Pedro	12,731	14.8	6,281	19.0	49.3	4,115	15.2	32.3
BAAPAP	**86,073**	**100.0**	**33,039**	**100.0**	**38.5**	**26,996**	**100.0**	**31.4**

share of BAAPAP forest in respective year, b) share of respective total BAAPAP area, c) area of 339.9 km² on eastern border was excluded due to cloud coverage



Paraguay´s Atlantic Forest region

(BAAPAP)

Legend

Forest Cover 2003

🟩 Remaining Forest
🟨 Non Forest
▭ Protected Areas
— BAAPAP Border
--- Country Border
---- Department Border

Cartographic Information

Local Projection: UTM 21S, Datum WGS 1984
Geographic Coordinate System: Lat/Lon (DMS)

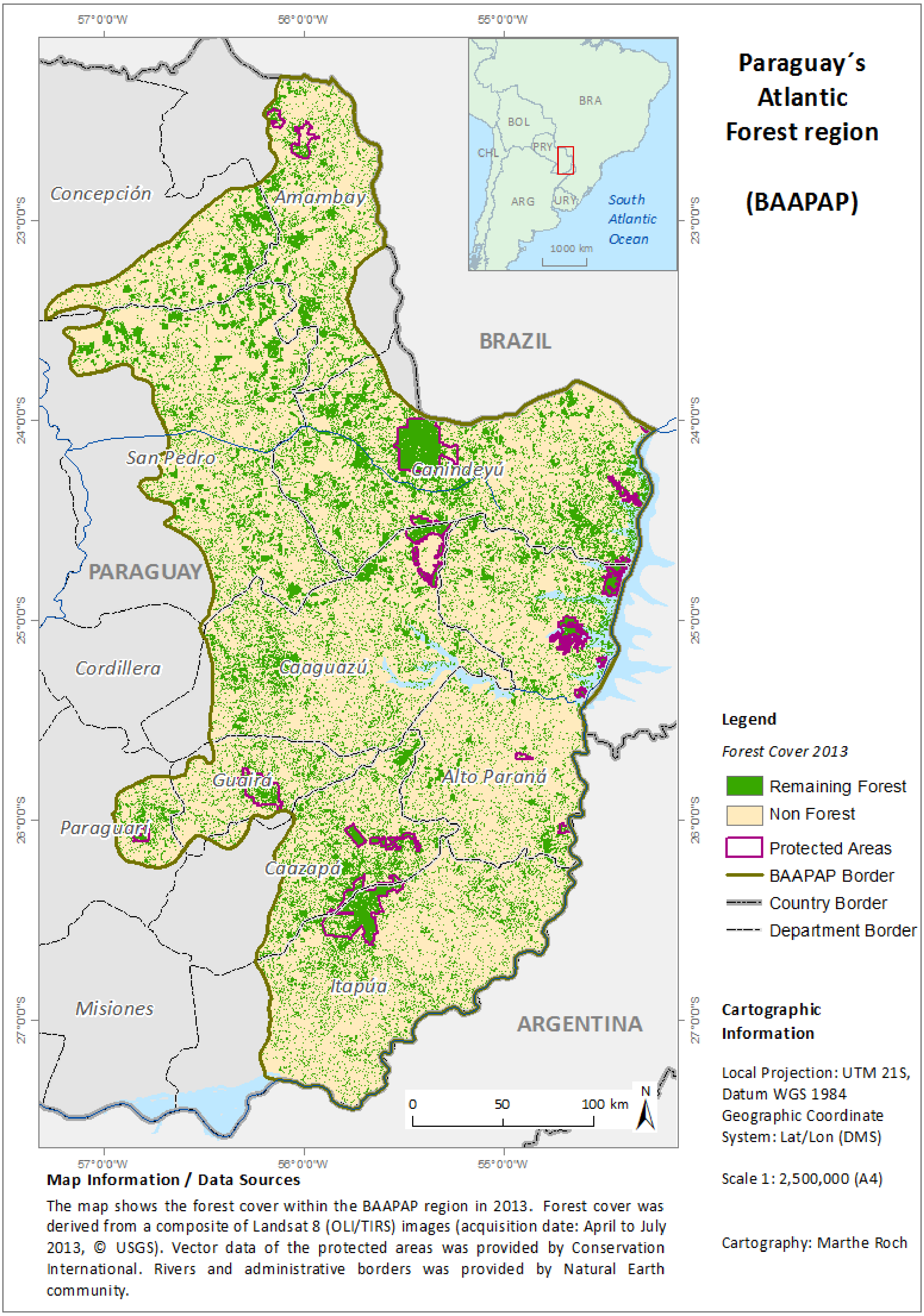
Scale 1: 2,500,000 (A4)

Cartography: Marthe Roch

Map Information / Data Sources

The map shows the forest cover within the BAAPAP region in 2003. Forest cover was derived from a composite of Landsat 7 (ETM+) images, © USGS). Vector data of the protected areas was provided by Conservation International. Rivers and administrative borders was provided by Natural Earth community.

Figure 32: Forest cover within the BAAPAP region in 2003.



Map Information / Data Sources

The map shows the forest cover within the BAAPAP region in 2013. Forest cover was derived from a composite of Landsat 8 (OLI/TIRS) images (acquisition date: April to July 2013, © USGS). Vector data of the protected areas was provided by Conservation International. Rivers and administrative borders was provided by Natural Earth community.

Figure 33: Forest cover within the BAAPAP region in 2013.

In the southeastern part of the Caaguazú department forest cover is also very low. Due to its small share of BAAPAP territory, the lowest total amounts of forest cover are represented by the department of Paraguarí. In general, forest cover in the northwestern part of Caaguazú and Canindeyú department up to the north of the BAAPAP region is significant higher ranging between 40 and 50 per cent.

Figure 34 and Figure 35 visualize the total amount of forest cover in 2003 and 2013 distributed by departments. The highest amount of forest cover is still presented by the Canindeyú and the San Pedro departments. However, Canindeyú is the only department where forest covers more than 5000 km². The departments of Paraguarí and Guairá represent less than 1000 km² of forest in 2013. A detailed analysis of forest cover change within the last decade is presented in the following chapter.

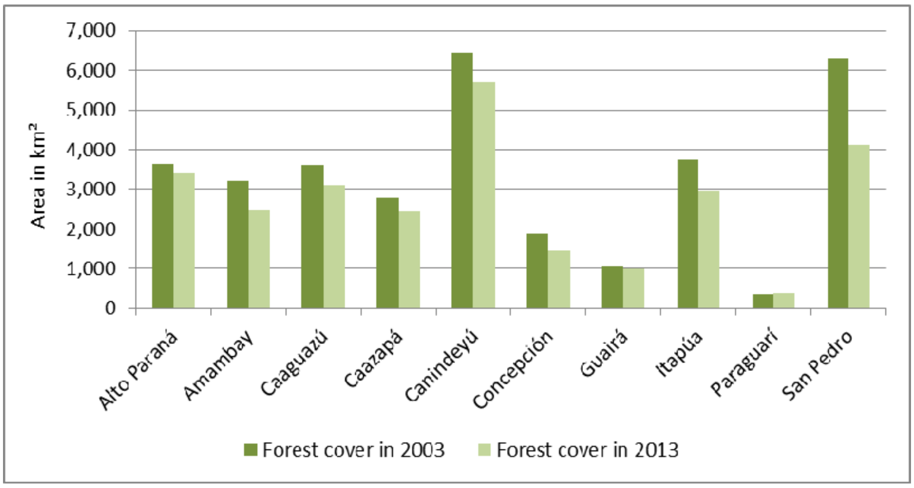


Figure 34: Forest cover 2003 and 2013 in the BAAPAP region, sorted by departments

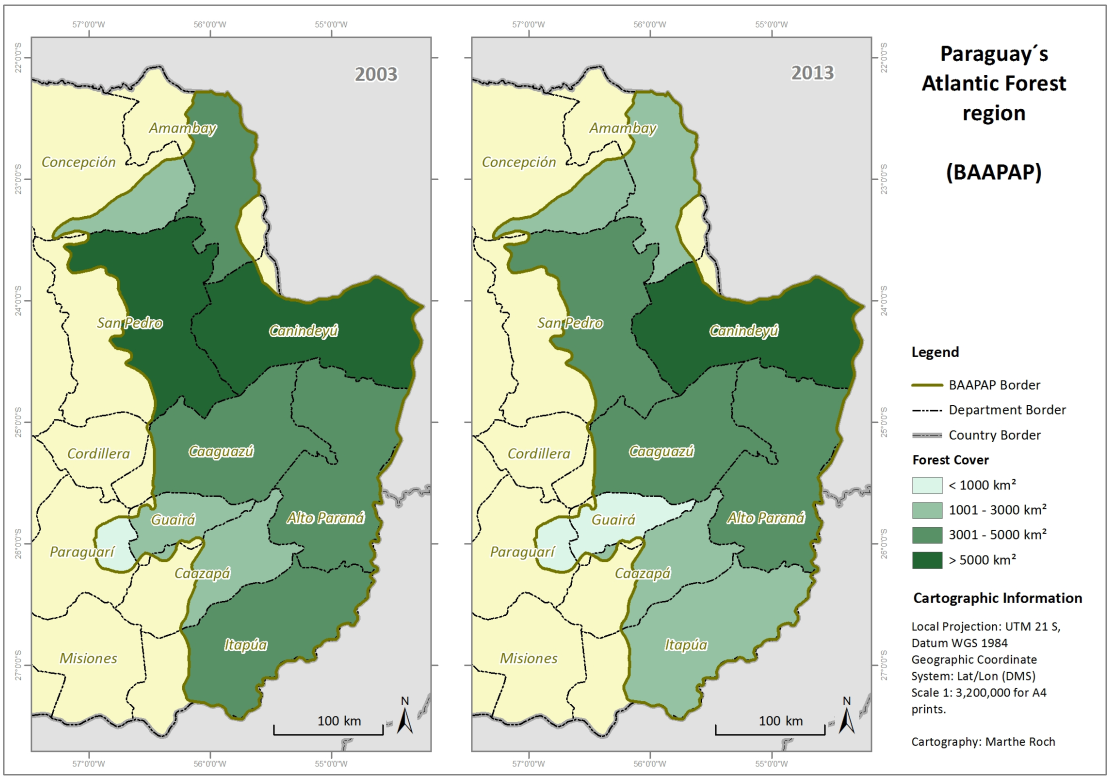


Figure 35: Total forest cover by department in 2003 and 2013

6.3.2 Forest Loss from 2003 to 2013

In order to derive information on the forest changes that ocurred within the last decade, the forest cover of 2003 was compared with this of 2013. The main result is presented in

Figure 36. In the BAAPAP region from 2003 onwards, about 6,000 km² forest cover was lost accounting for 7 per cent of the whole BAAPAP area. The total forest area in 2003 covered 33,000 km². In 2013, only 27,000 km² or one third of the BAAPAP area is still covered with forest.

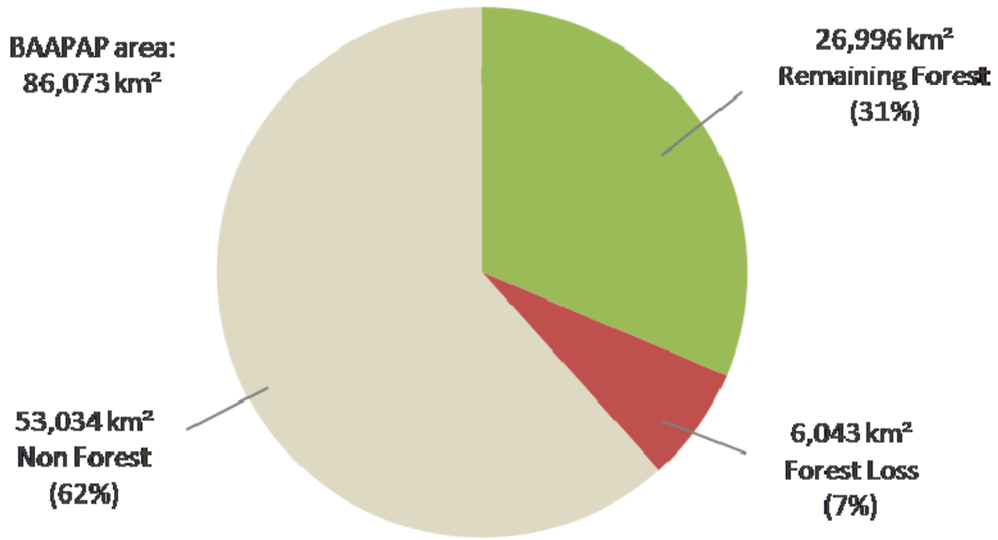


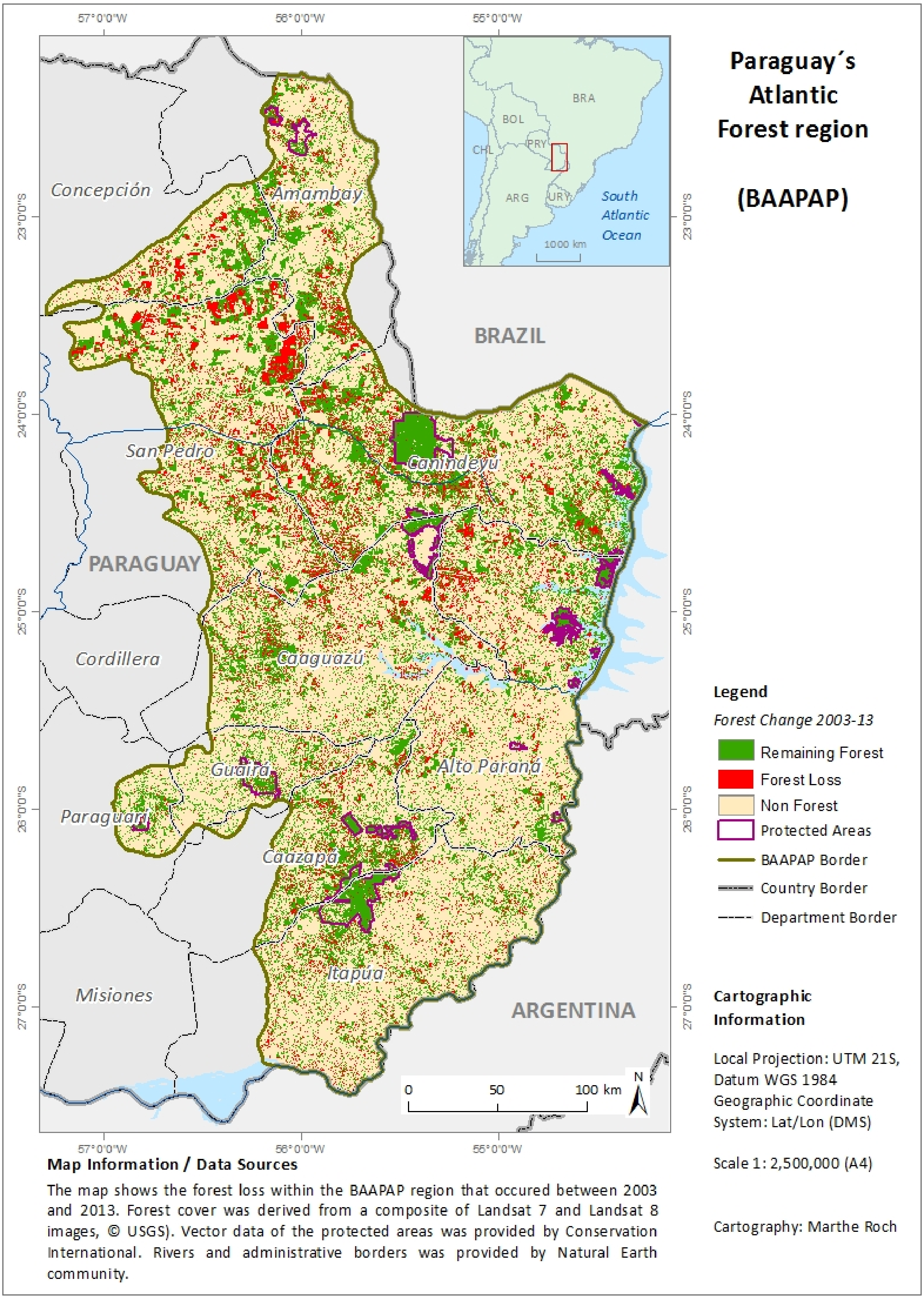
Figure 36: Forest cover change in the BAAPAP region (2003-2013)

About 18 per cent of the total forest that existed in 2003 was lost within the last decade. The average annual deforestation rate is 604.3 km² per year (at average 1.8 per cent of the forest area in 2003 where cleared annually). The spatial distribution of forest loss within the BAAPAP area is presented in Figure 37. A detailed insight into forest loss rates by department is presented by Table 12 that lists the total amount of forest loss and the average annual deforestation rates by departments.

Table 12: Atlantic Forest Losses in Paraguay (2003-2013) . sorted by departments

	BAAPAP Area	Forest 2003	Forest 2013	Forest Loss 2003 to 2013		Annual Deforestation Rate 2003-2013	
Department	**km²**	**km²**	**km²**	**km²**	**% [a)]**	**Km²/year**	**%**
Alto Paraná	14,060	3,635	3,392	243	4.0	24.3	0.7
Amambay	7,356	3,219	2,461	758	12.5	75.8	2.4
Caaguazú	11,345	3,615	3,097	518	8.6	51.8	1.4
Caazapá	5,458	2,773	2,450	323	5.3	32.3	1.2
Canindeyú	14,404	6,444	5,690	755	12.5	75.5	1.2
Concepción	3,797	1,888	1,459	430	7.1	43.0	2.3
Guairá	3,423	1,064	985	79	1.3	7.9	0.7
Itapú [b)]	12,122	3,755	2,968	787	13.0	78.7	2.1
Paraguarí	1,378	365	380	-15	-0.2	-1.5	-0.4
San Pedro	12,731	6,281	4,115	2,166	35.8	216.6	3.4
BAAPAP	**86,073**	**33,039**	**26,996**	**6,043**		**604.3**	**1.8**

[a)] share of forest loss within the whole BAAPAP area, [b)] area of 339.9 km² on eastern border was excluded due to clouds



Map Information / Data Sources

The map shows the forest loss within the BAAPAP region that occured between 2003 and 2013. Forest cover was derived from a composite of Landsat 7 and Landsat 8 images, © USGS). Vector data of the protected areas was provided by Conservation International. Rivers and administrative borders was provided by Natural Earth community.

Cartographic Information

Local Projection: UTM 21S, Datum WGS 1984
Geographic Coordinate System: Lat/Lon (DMS)

Scale 1: 2,500,000 (A4)

Cartography: Marthe Roch

Figure 37: BAAPAP region - forest cover change 2003-2013.

Figure 38 and Figure 39 illustrate the department's forest loss rates that were presented in Table 12. The map distinguishes the forest loss rates by departments. High forest loss rates are visualized in dark red, lower forest loss rates in bright green or yellow.

By far the highest forest loss within the last decade occurred in the department of San Pedro. This means more than 2,000 km² were deforested in that area. The forest loss of San Pedro province represent more than one third of the total forest loss that ocurred within the BAAPA area since 2003. San Pedro department has by far the highest average annual deforestation rate of 3.4 per cent. The deforestation rate of San Pedro is almost twice as highas the average annual deforestation rate of the whole area. At average more than 200 km² forest were cleared annually.

The forest loss of San Pedro department covers almost the same area that was cleared within the three department that follow in the ranking of highest forest losses. The two departments in the north of the BAAPAP area, Canindeyú and Amambay, lost about about 750 km² of forest cover each within the last decade. It has to be considered that Amambay´s forest cover in 2003 was not even the half of that in Canindeyú department. But it has the same amount of forest loss. 23.5 per cent of the forest cover was cleared in Amambay. In relation to its original forest cover area, the deforestation rate in Amambay is much higher than that of Canandeyú. In the larger department of Canindeyú, 12 per cent of the original forest cover in 2003 was deforested. Similar high percentage of forest loss related to its forest area in 2003 has the small part of the Concepción department in the northwest of the BAAPAP region. Within that area more than 20 per cent of the forest area (430 km² of 1888 km²) were deforested within the last ten years.

Located in the southeast of BAAPAP region, the Itapú department also lost a large area of about 750 km² of its remaining forest. Besides San Pedro, also the Canindeyú, the Amambay, and the Itapú department have high annual deforestation rates of more than 75 km² per year (more than 2 per cent of the forest cover in 2003 was cleared every year).

The average annual deforestation rates of the other departments are lower than the average for the whole BAAPAP region. The central departments have similar deforestation rates. Caaguazú lost 14.3 of its forest (758 km²) and Caazapá 11.7 per cent (323 km²). The eastern province Alto Paraná lost 243 km² representing a loss of 6 per cent of the existing forest in 2003. The departments with only a small share of BAAPAP territory have lower deforestation rates. Guairá lost less than 100 km² also seven per cent of its 2003 forest.

The Paraguarí department shows almost a slight increase of total forest cover. However, this forest increase of 15 km² can be neglected in further analysis due to its very small size and especially due to high distributed in many small spots, but not a continuous area. A small area of new forest was detected which probably presents one of the new tree plantations, e.g.eucalyptus tree plantations that were created during the last decades within the BAAPAP region due to favorable climatic conditions (see discussion in chapter 7).

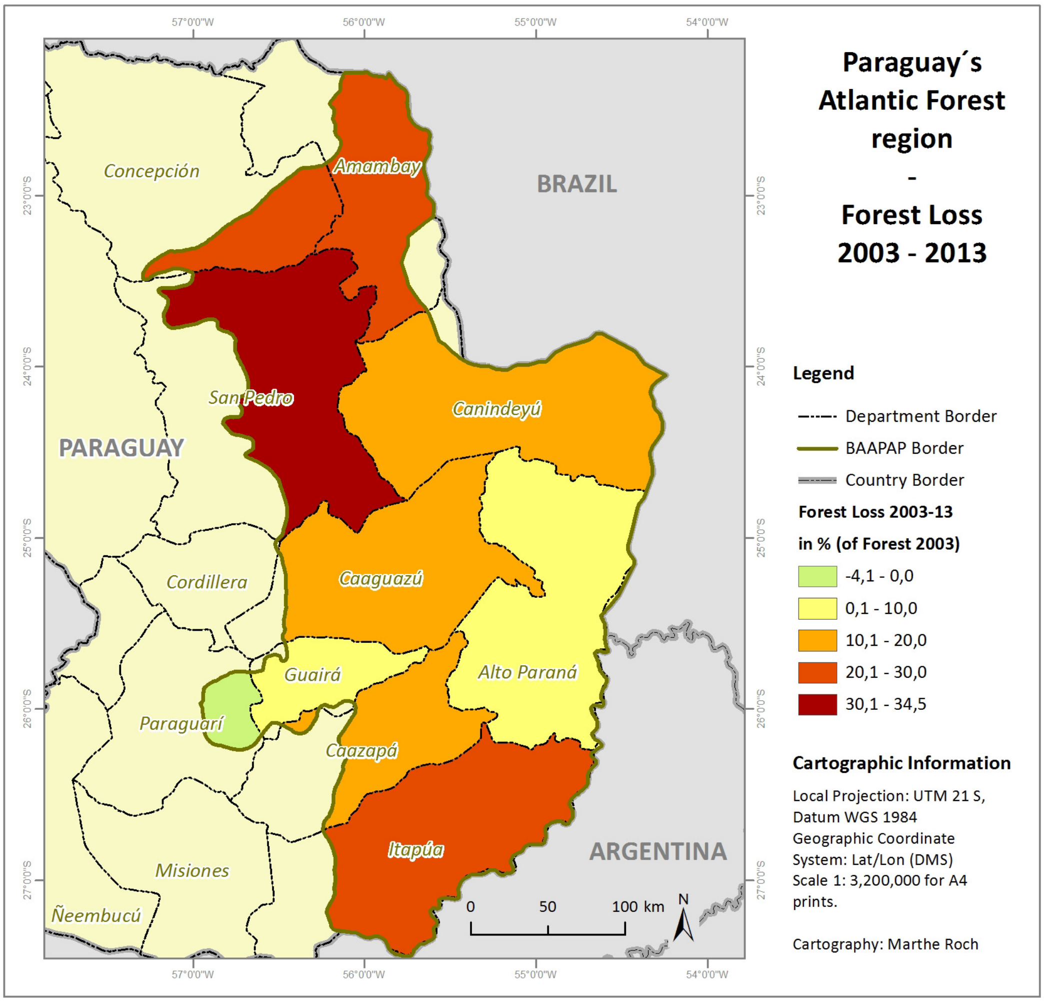


Figure 38: Map of forest loss rates 2003-2013 by department

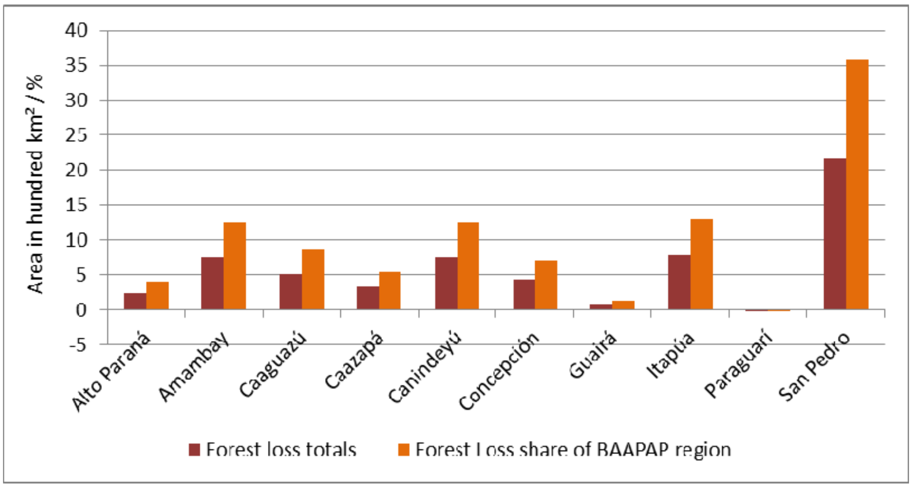


Figure 39: Forest losses of BAAPAP region departments between 2003 and 2013

6.3.3 Deforestation Patterns

Different types of deforestation occurred in the BAAPAP region. In general, the forest cover losses can be distinguished between small and large scale clearing (see examples in Figure 40). Defries et al.

(2005) defined large-scale clearing as deforested areas greater than 100 ha. The deforested land is mainly used for mechanized agriculture and agribusiness. Large-scale clearing of forest areas larger than 100 ha caused the half of all forest losses within the BAAPAP area (3000 km²). In contrast, small scale clearing means areas smaller than 10ha that are used for subsistence or small holder agriculture and shifting cultivation and in some cases selective logging. Small-scale deforestation caused 2000 km² of all forest losses (thereof forest loss areas that are smaller than 0.5ha caused 130 km²). Forest loss areas that are whether large nor small scale clearing and have size of 10 to 100 ha caused about 1000 km² of all forest losses within the BAAPAP region (see Table 13).

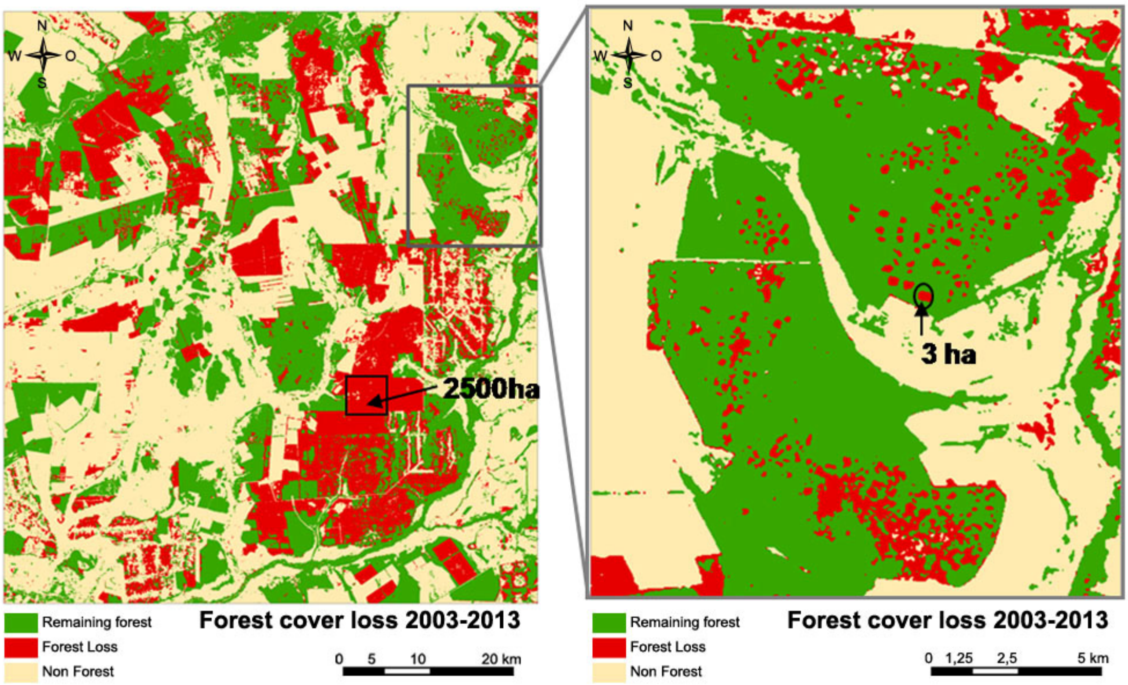


Figure 40: Large-scale vs small-scale deforestation

Depending on the shape and form of the deforested areas, four main deforestation patterns were observed in the BAAPAP region (examples see in Figure 41):

- *Compact clearing (a)*: Large areas greater than 100 ha with often rectangular borders.
- *Fishbone clearing (b)*: Along small dead end streets that were built within forest areas as lanes or forest aisles deforestation on both side of the streets increased successively. From a top view the forested areas have a shape of fishbone.
- *Circle clearing (c)*: Single points within larger forest areas were linked with small streets and each point is surrounded by a circle of streets. Starting from this circle forest is cleared successively into all directions. Form a top view the forest loss areas have shape of circles.
- *Freckle or spotted clearing (d)*: Within large forest areas only very small spots are cleared, but many of them appear in short distances. Over time many small spots area lancing the forest area as if the forest break out a rush. Step by step the small spots multiply very fast, thus larger clearing areas were created and the forest disappears successively.

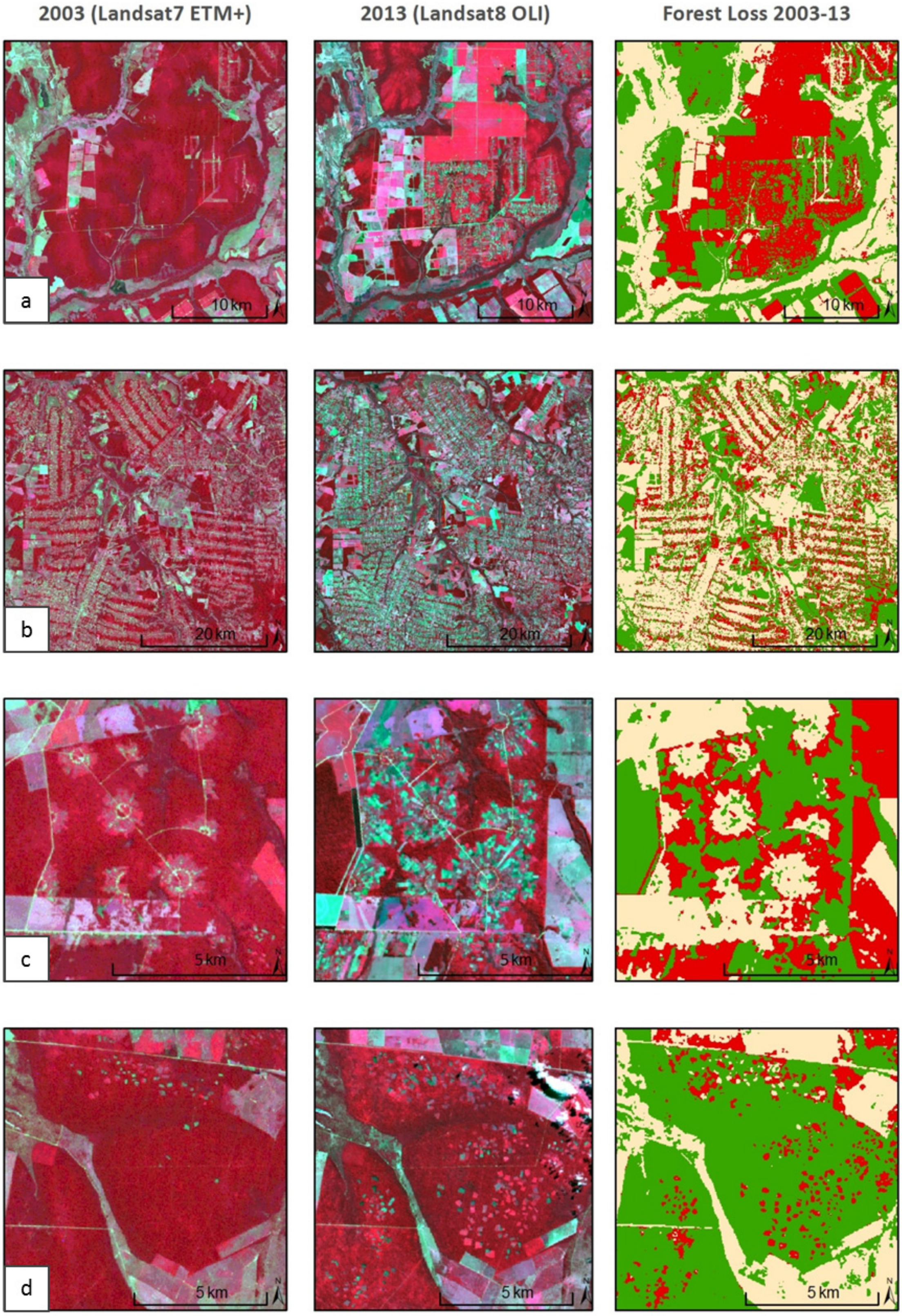


Figure 41: Deforestation pattern examples. Within the BAAAPAP region, different deforestation patterns exist: Large-scale clearing of compact areas (a), in fishbone clearing (b) or circle clearing (c). And small scale clearing of little fields, here called freckle or spotted clearing (d). Each example is presented by three images: A subset of the Landsat image in 2003 (left), the Landsat 8 image in 2013 (center) and the derived forest loss map (left) for the same subset.

Table 13: Forest loss by deforestation types and patterns

Deforestation type	Size of Forest Loss Area	Share of BAAPAP Forest Loss (Area)	Possible Deforestation Pattern
Large Scale	> 100 ha	49.7 % (3002.8 km²)	Compact and Fishbone Clearing
Medium Scale	10 ha to 100 ha	18.4 % (1111.1 km²)	Fishbone or Circle Clearing
Small Scale	< 10 ha	31.9 % (1929.1 km²)	Spotted or spreckle Clearing

Table 13 shows that about 50 per cent of all forest loss that occurred in the BAAPAP region is caused by large scale deforestation and about 30 per cent is caused by small scale deforestation. Medium scale deforestation caused about 20 per cent of all forest losses. The observed deforestation patterns correspond in most cases with one of the specific deforestation types. Large scale deforestation is often realized in compact or fishbone clearing patterns. Forest losses, that are caused by fishbone or circle clearing patterns, are mainly medium sized areas. Due to its small size, small scale deforestation areas have in most cases the form of little spots. However, the deforestation pattern of spotted or spreckle clearing describes the specific case if these little deforested spots are still surounded by forest areas. The freckle/spotted clearing areas in most cases have a size of less than 5 ha and within the sourrinding forest area are many of these little clearing spots (see Figure 42).

Figure 42: Example of small-scale freckle / spotted clearing in BAAPAP region. (Source: Google Earth).

The quantification of the forest losses caused by the specific deforestation patterns was hard to realize due to the high fragmentation status of the forest area. The identification of the specific shapes and forms of the forest loss areas was not possible to detect and categorize within this study. However, a more intensive object-based image analysis will achieve useful results, but would have exceeded the scope of this study.

6.3.4 Deforestation and Protected Areas

The protection status of forests within the eight largest protected areas (>100 km²) and its surroundings was examined within this study. Table 14 and Table 15 summarize the results of the distance analysis that used a multiple buffer ring approach. The forest loss inside the protected areas and its surroundings within a 5 km, 10 km and 15 km buffer was calculated and compared to the forest cover that existed in the respective area in 2003. For each protected area forest cover in 2003 and 2013 is presented as total amounts. Forest losses inside and outside protected areas are differentiated in total amounts (total forest loss) and as a share of the forest cover in 2003 (relative forest loss).

Table 14: Forest loss (2003-2013) inside protected areas

Protected area a)		**Forest cover**		**Forest loss inside**		**Ownership**
		2003	**2013**			
Name	**km²**	**km²**	**km²**	**km²**	**%**	
Caazapá b)	133.2	601.8	597.6	3.5	2.8	Public
Cerro Corá	126.1	124.0	120.5	7.4	13.6	Public
Itabó	137.5	54.5	47.1	0.2	0.2	Special
Limoy	136.2	119.8	119.6	0.1	0.0	Special
Mbaracayú	651.3	130.4	130.4	4.3	0.7	Private
Morombi	274.6	237.1	228.2	8.9	3.8	Private
San Rafael	668.1	527.1	507.0	20.1	3.8	Public
Ybytyruzú	255.7	137.4	123.1	14.3	10.4	Public
Total	**2,382.7**	**1,932.1**	**1,873.4**	**64.32**	**3.3**	

Table 15: Forest loss (2003-2013) outside protected areas

Protected area a)	**Forest loss outside protected areas**					
	5km buffer		**10km buffer**		**15km buffer**	
Name	**km²**	**%**	**km²**	**%**	**km²**	**%**
Caazapá b)	60.0	24.1	121.9	24.4	202.2	25.2
Cerro Corá	28.1	30.1	70.1	34.8	115.7	32.8
Itabó	32.7	40.7	66.7	36.1	99.4	32.2
Limoy	14.9	18.9	35.8	22.6	74.7	26.4
Mbaracayú	92.7	29.7	191.1	30.1	310.1	31.8
Morombi	67.3	28.8	157.9	32.6	302.3	34.4
San Rafael	80.4	20.6	162.6	22.1	268.5	24.2
Ybytyruzú	14.9	13.1	25.6	12.7	48.2	14.4
Total	**391.0**	**25.2**	**831.8**	**26.8**	**1,421.1**	**28.2**

a) The eight protected areas that are larger than 100 km² were selected here, b) former name: Caaguazú National Park.

The analysis reveal two findings. At first, deforestation within protected areas is lower than the averages of the BAAPAP region. The total forest loss of all protected areas is about 60 km². It is a decrease of 3.3 percent of the former forest cover within these areas. In comparison to the forest loss of 18 per cent within the whole BAAPAP region, the forest loss inside the protected areas is relative low. Secondly, outside of the protected areas forest loss increased drastically. Within the 5 km buffer zone, about 25 per cent of the forests that existed in that area disappeared. Within the 10 km buffer zone, 27 per cent and within the 15 km buffer zone, 28 per cent of the forests were lost. Deforestation abruptly increases behind the borders of the protected areas and hardly vary between area with higher distance from the protected areas.

Nevertheless, beside these main trends, the picture of each protected area is different. To illustrate these differences, the eight protected areas were surrounded by buffer rings of 5 km, 10 km and 15 km. Then, the forest losses inside the protected areas and within each buffer zone was generated. In addition to the numbers shown Table 14 and Table 15, the forest losses of each protected area and its surroundings can be described as follows.

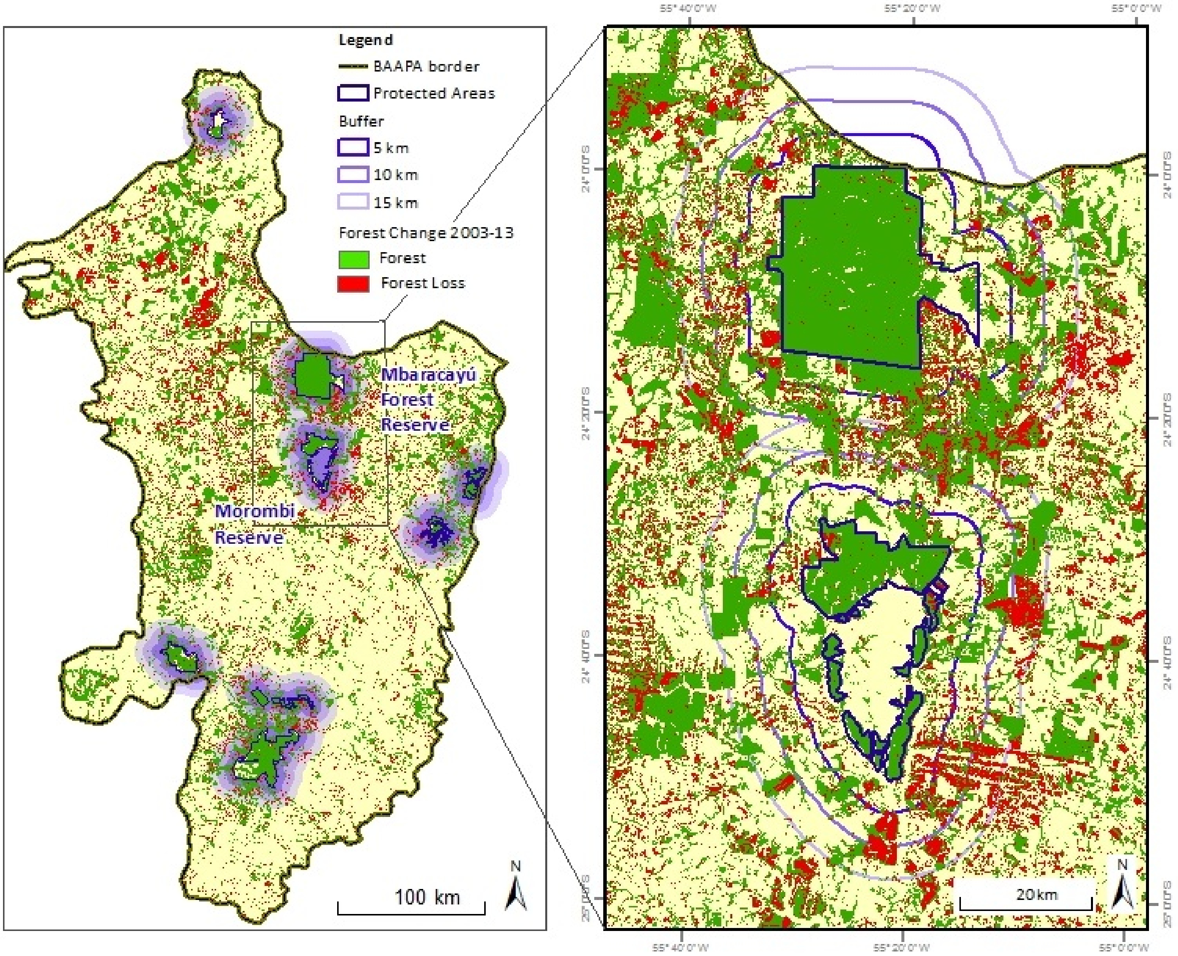


Figure 43: Forest loss inside and outside private protected areas.

The Mbaracayú Forest Reserve is one of the largest and prominent protected areas in Paraguay (see Figure 43 above). Since 1991, it is a natural private reserve administrated by the nongovernmental Moisés Bertoni Foundation. In 2000, it was designated as a core area of the UNESCO MAB Biosphere Reserve. The core area is about 650 km², surrounded by a buffer zone and transitional area. In total, the designated area covers 2800 km² (UNESCO, 2013). Within the Mbaracayú Forest Reserve almost no forest loss ocurred during the last decade (4 km² or 1 per cent of the forest area). However, in its surroundings, forest loss increased up to 30 per cent. Already in the 5 km buffer zone 100 km² forest were cleared, in the 10 km buffer zone 200 km² and in the 15 km buffer zone 300 km². Forests were cleared in all directions around its core area border, especially in the southeast. The Mbaracayú Forest emphazise the general trend that protection inside the protected area and core area of the UNESCO MAB Biosphere Reserve is effective, but outside deforestation continued at a high level. The buffer ring areas are mainly congruent with the internationally designated area of the Biosphere Reserve. However, only core area of this Reserve is effectively protected. Another important protected area is located In the south of the Mbaracayú Forest. The Morombi Natural Private Reserve is a private initiative of the Riquelme Group. It covers about 270 km², seperated in different smaller parts forming a round geometry similar to a triangle with the top oriented to the south (see Figure **43** below). The forest losses inside and outside the Morombi Reserve show similar extreme changes like the Mbaracayú Forest Reserve. In the northeastern and western part of the Morombi Reserve, about 9 km² forests were cleared inside the protected area (about 4 per cent of all forests within the Reserve). Due to the fact that any forest clearing is prohibited, a forest loss area of 9 km² is relative high within a protected area zone. In its surroundings, forest loss increased abruptly up to 30 per cent in the 5 km buffer ring and increased more up to 34 per cent in the 15 km buffer ring. Due to the fact that the Morombi Reserve consists of many different parts, the protected area itself is not that large, but the buffer ring zones around the whole area are similar in size like the buffer zones fo the Mbaracayú Forest Reserve. Thus, the deforested area of about 300 km² within the 15 km buffer zones is as high as that of the broader surroundings of its neighbor protected area in the north. The two largest private reserves of the BAAPA emphasize the main trend that forest loss within the protected areas are low, but In the nortwest of the Morombi Reserve a larger forest area was deforested. In both Reserves deforestation increased drastically behind the protection borders.

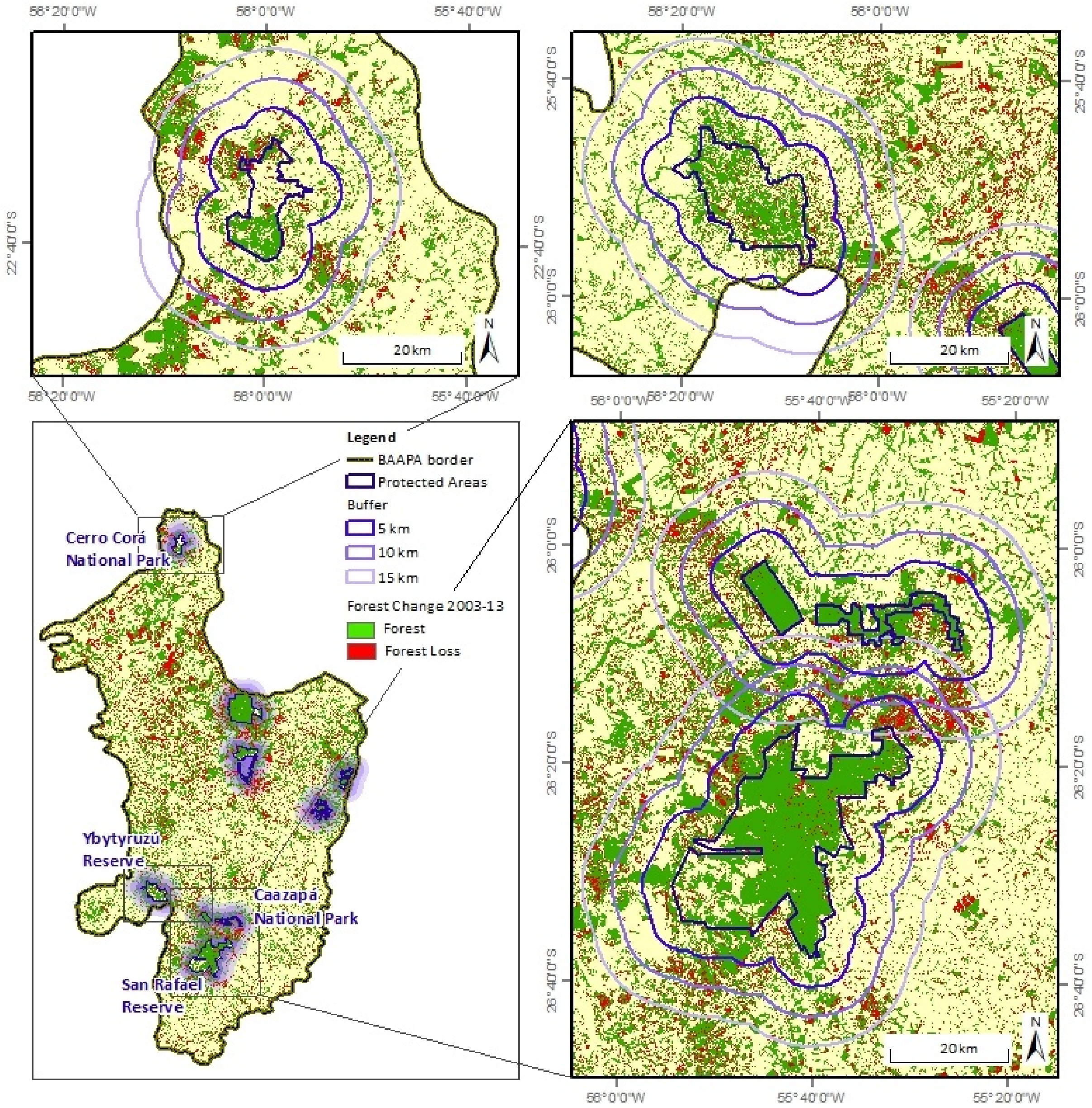


Figure 44: Forest loss inside and outside public protected areas

A similar picture depicts the largest public protected area in the BAAPAP region, the San Rafael Managed Resource Reserve. It is the largest contiguous native Upper Paraná Atlantic Forest in

Paraguay with a very high biodiversity. More than 410 different bird species have been recorded in that area. The largest protected area of Paraguay is located in the south of the BAAPAP region and covers an area of 670 km² (c below). It is administerated by the public authorities of the Paraguayan government, especially the Environmental Secretary (SEAM, 2009). Forest losses within the protected area are relative high with about 20 km² (about 4 per cent of the reserve area) within the last decade. Many little deforested areas were revealed in different locations within the reserve. In the northeast, forest loss reached into the protected area. Deforestation in the surroundings of the San Rafael Reserve also continued at a high level. About 270 km² of forests were cleared within the 15 km buffer ring zone. Main forest losses occurred in the northeast and west of the protected area. These are the areas where larger forest areas still remained in 2003.

In the east of the San Rafael Reserve almost no forest remained and cannot be cleared yet. Its neighboring protected area in the north, the Caazapá National Park (former Caaguazú National Park) covers an area of 130 km². Together with the San Rafael National Park it is a site of international importance for the conservation of birds. The two areas are located very close to each other and managed by public authorities. In 2003, the two protected areas were still linked through a larger forest coverage in between the two areas. Deforestation within the surroundings of both protected areas lead to the destruction of this connection that has an important function as biodiversity corridor between both natural reserves. Although the forest loss within the Caazapá National Park is moderate with about 4 km² (3 per cent of reserve forests), many forest areas around the borders of the protected area were cleared within the last decade (200 km² within the 15 km buffer). It is remarkable that forest losses around the Caazapá National Park are concentrated in the southern corridor with the San Rafael National Park and in the western corridor that is the connection with the Ybytyruzu Managed Resource Reserve (see also Figure 44a). Both examples of neighboring protected areas, the Mbaracayú Forest and Morombi Reserve in the north as well as the San Rafael and Caazapá National Park in the south of the BAAPAP region, show that protection of forest is effective within the protected areas, but has no positive impacts on its surroundings. In particular, the overlapping buffer zones or conntection corridors betweeen neighborhood reserves are very important areas with regard to biodiversity conservation as these areas function as biological corridors for many threatened and endemic species. The role of biodiversity corridors will be discussed in detail later in this chapter.

The Ybytyruzu Managed Resource Reserve is an exception. The forest losses within the protected areas are higher than in its surroundings. Within the reserve area that covers about 255 km² more then 14 km² forest were cleared within the last decade (about 10 per cent of the reserve forest). Deforestation within the buffer ring zones outside the protected area, deforestation rates are moderate and partly lower than inside the protection area. Forest loss is concentrated on the eastern corridor that link the Ybytyruzu Reserve with the Caazapá National Park. Another public protected area is located in the north of the BAAPA region close to the border of Brazil. The Cerro Cora National Park is one of the smaller protected areas that cover a hilly area of about 130 km² (see Figure 44). It is not only a natural reserve, but also a historical and cultural monument (the last battle of the Triple Alliance War took place here in 1870 and ancient rock paintings were found within the caves and hills of that area). Only the southern part of the reserve was still covered with forest in 2003. This part was as far as possible protected from deforestation in the last decade. However, directly in the northwest of the protected area border a larger remnant forest block was highly deforested as well as other larger forest areas in the 10 and 15km buffer zone and beyond.

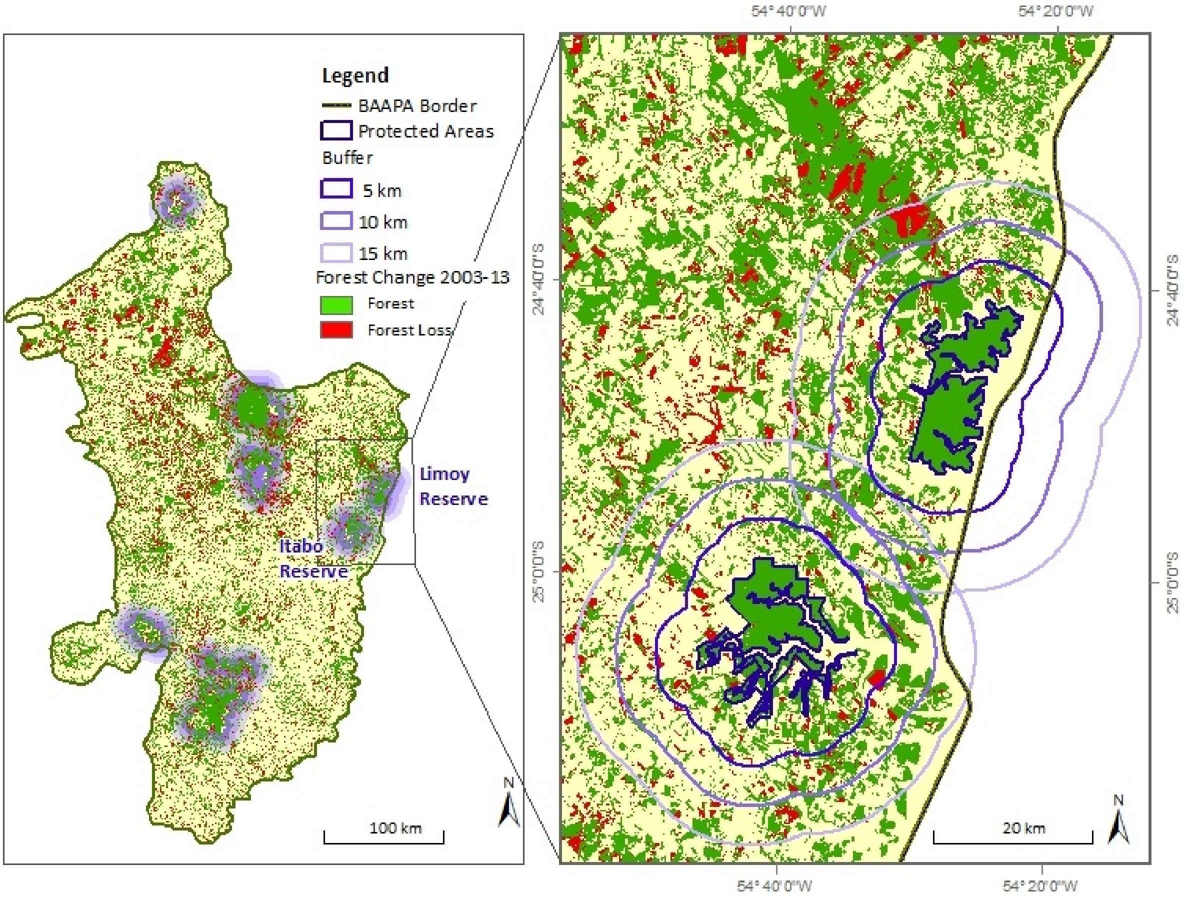


Figure 45: Forest loss inside and outside the private protected areas along riversides

The two protected areas that are located in the east of the BAAPAP region can be interpretated from a different point of view due to its borders with the larger Paraná River and its extensions (see Figure 45). Along the riverside, larger forest areas remained. The protection status of the Limoy Biological Reserve is very positive. No forest loss was observed within the protected area. Almost the whole reserve area of 130 km² is still covered with dense natural forest and is one of the few remaining continuous forest blocks within the BAAPAP area that are larger than 100 km². Within its direct surroundings of the 5 km buffer deforestation is still moderate, but in the north of the 10 km and 15 km buffer ring zone deforestation increased drastically. Many parts of a larger forest area with a geometry similar to a trinangle and no protection status was cleared there. This example demonstrates among others that the conservation of larger forest areas need effective protection. In the south of Limoy another forest area along the riverside was designated as the Itabó Biological Reserve. It is also a larger continuous forest area of about 130 km² and depicts a similar picture as its neighbor protected area in the north. Inside the protected area almost no forest loss occurred. However, deforestation of about 100 km² occurred in the surroundings, especially in the southeast of the protected area. The largest remaining forests in that area were concentrated along the riverside in the east of the Itabó Reserve. The Limoy and Itabó Biological Reserves show the lowest deforestation rates within the examined protected areas.

6.4 Forest Fragmentation and Priority Forest Patches

The current forest cover of the BAAPAP region is highly fragmented and consists of more than thousands different forest patches. With a special focus on biodiversity conservation, landscape metrics were used within this study to characterize forest fragmentation and identify forest core areas and potential biodiversity corridors that connect these core areas. In a first step, changes in forest structure between 2003 and 2013 were analyzed on a landscape level. In a second step, the status of the 2013 forest mosaic was characterized in detail on a patch level. In a third step, priority forest patches and potential connecting corridors were identified based on the landscape metric results that were presented before.

6.4.1 Trends from 2003 to 2013 (Landscape Level)

Landscape metrics does not provide evidence by itself. The informative value is given by the comparison of different areas, dates or layers. Within this study, landscape metrics of the remaining forest patches in 2003 and 2013 that are larger than 10ha were compared to get information on changes of composition and structure within that period. The results are shown in Table 16

Table 16: Landscape metrics applied for forest patches in 2003 and 2013

		2003	Unit	2013	Unit
Area	Total Area (TA)	23,313.0	km²	19,091.0	km²
	Number of Patches (NP)	16,343	-	17,786	-
	Medium Patch Size (MPS)	1.43	km²	1.07	km²
	Patch Size Standard Deviation (PSSD)	18.83	km²	12.41	km²
Core Area	Total Core Area (TCA)	11,228.2	km²	7,596.1	km²
	Core Area Buffer Distance (CAB)	100	m	100	m
	Core Area Index (CAI)	48.2	-	39.8	-
	Cority	0.324	-	0.316	-
Edge	Total Edge (TE)	180,401.8	km	179,127.1	km
	Edge Density (TD)	77.4	m/ha	93.8	m/ha
	Mean Patch Edge (MPE)	11.04	m	10.07	km
Fragmentation	Mean Shape Index (MSI)	2.734	-	2.804	-
	Mean Perimeter-Area Ratio (MPAR)	0.017	-	0.018	-
	Mean Fractal Dimension (MFRACT)	1.344	-	1.350	-
Neighborhood	Mean Proximity Index (PROX)	11,377.31		8,268.04	
	Proximity Buffer Distance (PB)	100	m	100	m
Subdivision	Subdivision	99.2	%	98.9	%
	Split	132.0	-	93.2	-
	Mesh	250.1	km²	144.7	km²

The results provide a first insight on changing trends within the forest landscape that occurred within the last decade. First of all, several metrics emphazise increasing fragmentation of the forest mosaic within the BAAPAP area. For example, the total forest area (TA) reduced from 23,000 km² in 2003 to 19,000 km² in 2013. As a consequence, the number of single patches (NP) increased and the mean patch size (MPS) declined. These standard parameters already show that forest area has decreased from larger patches into more smaller patches.

The comparison of the forest core area in 2003 and 2013 specify the general result of the total forest area with a focus on ecological higher valuable interior forest areas. For example, forest area that provide interior habitats for species that avoid the edges of forest patches with a distance of 100m were reduced from 11,300 km² in 2003 to 7,500 km² in 2013. A decrease of the total core area (TCA) 3,632.1 km² is reported (Edge Effect is 100m). The core area index (CAI) reveal that about 50 per cent of the forest area in BAAPAP region was counted as forest core area in in 2003. In 2013, only 40 per cent of the decreased forest area was counted as forest core areas. In addition, the cority figures consider the number forest patches without core areas. Cority is also reduced from 0.324 in 2003 to 0.316 in 2013. The core area metrics reveal that forest cover loss of already fragmented areas causes a even higher loss of core areas that are more valuable habitats for many speices that avoid forest edges.

In addition to the size of forest and its core areas, the edge length of forest patches plays also a crucial role in landscape structure analysis. For example, a prominent indicator to quantify forest fragmentation is the Edge Density (ED). In general, a high edge density implies structure diversity. Edge density of the forest class was reduced from 94 to 77 within the last decade. The Mean Patch Edge (MPE) is the mean length of edges and was reduced from 11.04 to 10.07 km between 2003 and 2013 due to shrinking forest patch size. Declining edge density in combination with a decrease of mean patch edge also show increasing fragmentation. However, it is remarkable that the metrics that describe shape and fragmental dimension of the forest pacthes does not show significant trends on a landscape level. The indices MSI, MPAR and MFRACT stagnate on the same level as in 2003. Thus, the aggregated indices that describe shape and forms of forest patches did not change much for the whole forest landscape within the last decade.

Landscape metrics that regards the neighborhood and subdivison also emphazise the increasing fragmentation process. The proximity index (PROX) measures the embeddness of the forest patches within the forest mosaic. The higher the embeddness, the lower the fragmentation. In 2003, the mean average proximity of all forest patches within the BAAPAP area was about 11,000 and decreased to 8,000 in 2013. Thus, the decrease of embedness implies a higher fragmentation of the forest mosaic. At a first glance, the subdivision seems to stagnate on a very high level of 99 per cent withi the last decade. However, the additional subdivison indices illustrate an increasing subdivsion into less equal size forest areas that remains after subdivision. The number of patches (SPLIT) decline from 132 to 93 reflecting the effective mesh size (MESH) of these areas that declined from 250 to 145 km². In summary, the comparison of aggregated metrics on a landscape metrics emphasize the increasing fragmentation process within the last decade.

6.4.2 Status in 2013 (Patch Level)

In general, the aggregated results for the whole forest landscape emphasize the trends of decreasing forest area and increasing forest fragmentation within two different dates. To get a detailed insight on spatial differences within the current forest area, the structure and compostion of the forest mosaic was studied on a patch level. The basis of this analyis was the forest cover within the BAAPAP region of the year 2013. The results are presented in the following subchapters.

6.4.2.1 *Core Area*

The results of the core area analysis of the forest patches in 2013 is presented in Table 17. Only forest patches larger than 10ha were involved in the analysis. Three different edge effects (50m, 100m and 500m) were applied in order to provide an insight on the impacts of different edge effects on the remaining forest core areas. For each effect a different amount of forest core areas remain (100 km^2, 40 km^2 and 10 km^2).

Table 17: Core areas of BAAPAP forest in 2013

Size of Edge Effect (m)	Total Core Area km^2	Core Area Index	Forest Core Areas > 100 km^2	Forest Core Area > 40 km^2	Forest Core Area > 10 km^2
0	19,090.9	100.0	18 (5264.9km^2)	38 (6426.5km^2)	202 (9514.5km^2)
50	11,617.2	60.9	5 (1639,9km^2)	28 (3108.0km^2)	139 (5127.4km^2)
100	7,596.1	39.8	3 (1098.2km^2)	19 (1925.1km^2)	101 (3393.2km^2)
500	1,076.3	5.6	1 (222.2km^2)	1 (222.2km^2)	13 (440.7km^2)

The results illustrate the relationship of edge effect size on core areas. The higher the size of edge effect the more the total core area of the forest decreases. For example, an edge effect of 100m reduce the forest patch area of 19,100 km^2 to a forest core area of 7,600 km^2. About 40 per cent of the forest cover is identified as core area (see Core Area Index). The amount of forest core areas that are larger than 10 km^2 or 40 km^2 reduced from 200 to 100 and that are larger than 40km^2 from 40 to 20. Only three forest core areas larger than 100 km^2 remain. The decrease of forest core area exacerbates for the result of the core analysis with an edge effect of 500m. Only 13 core areas greater than 10 km^2 remain whole BAPAAP region and only one forest core area that is larger than 40 km^2.

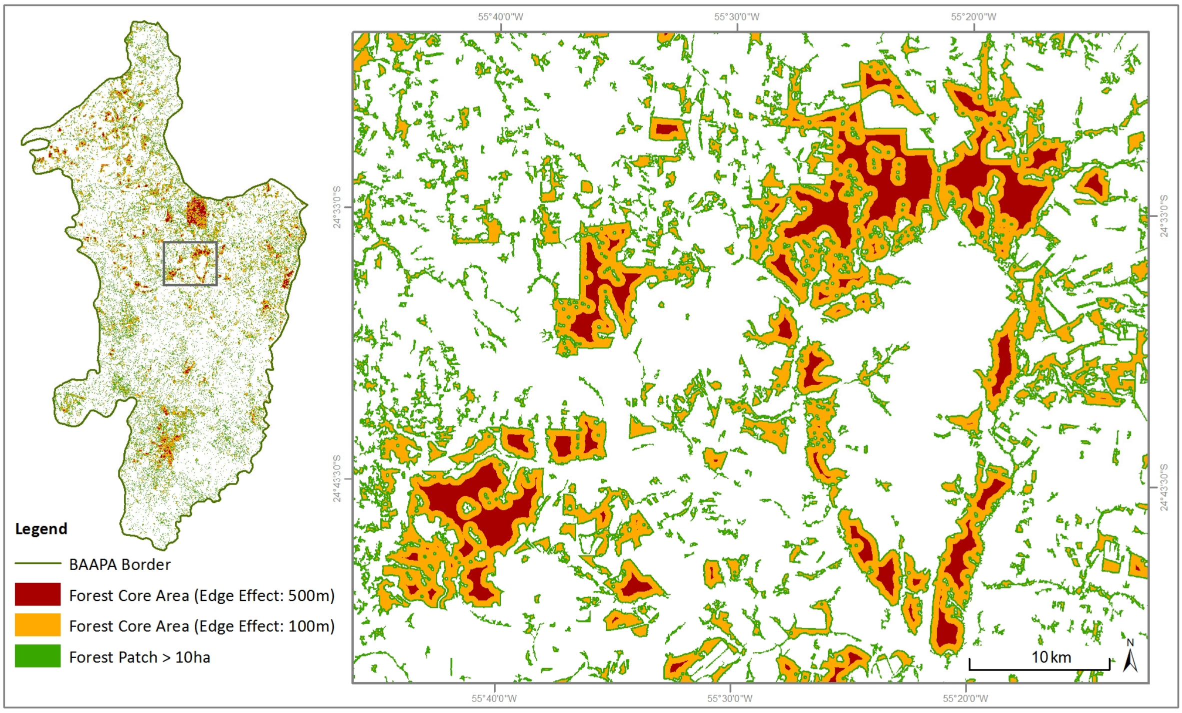


Figure 46: Forest core area Analysis with different edge effects (100m and 500m) in 2013.

Figure 46 shows an example of the Morombi Reserve area within the BAAPAP region and the different remaining core areas if an edge effect of 100m or 500m were applied. Which edge effect fits better depends on the focus of the animal species the habitat core areas are searched for.

6.4.2.2 Shape and Fragmentation

As it was shown in chapter Trends from 2003 to 2013 (Landscape Level), the values of shape related metrics did not vary much within the last decade. In a next step, these indices were examined on a patch level in order to find differences of shape and fragementation level between the forest patches itself. Therefore, the forest patches were visualized by the values of the indices and the results were visually compared to each other. The result is shown in Figure 47.

It shows examples of the BAAPAP region for the three different shape related metrics. Each map shows forest patches of the same area, but classified by values of the three different metrics. The Mean Perimeter Area Ratio (MPAR) is describe relationship between edge length and area of the patches. The lower the values the higher is the fragmentation of the patch or the less compact is a patch. The Mean Shape Index (MSI) also indicates the level of fragmentation of forest patches by calculating the patch deviation from an ideal form of a circle. And the Mean Fractal Dimension (MFRACT) describe the curvilinearity of patch edges. Within these maps, the identification of highly fragmented patches or compact ones is possible. Very high fragmented and complex shape of forest patches are highlighted in red and the compact patches are highlighted in green and yellow.

At a first glance, no clear differences are obvious between the three indicators. However, some observations are irritating on a more detailed comparison of higher and lower valued patches. For example, at a first glance the area of the Mbaracayu Forest (the large block on the upper right side of the shown extent) seems to have a very compact form. However, in all three maps it is one of the forest patches with the highest fragmentation value. The high fragmentation level of this area is caused by many little branches that are interlinked with the large compact ones. In addition, the entire area has many little gaps which increase the total edge length. The influence of these highly fragmented little branches and gaps is higher on the total patch shape than the outstanding compact shape of the natural reserve itself.

As a result, it seems that the fragmentation level increases by larger patch size. Large patches have more little branches and higher edge lengths. In contrast, smaller patches are generally compacter than larger ones. To avoid these misinterpretations it would be useful to first classify forest patches by size and then classify them by shape metrics seperately.

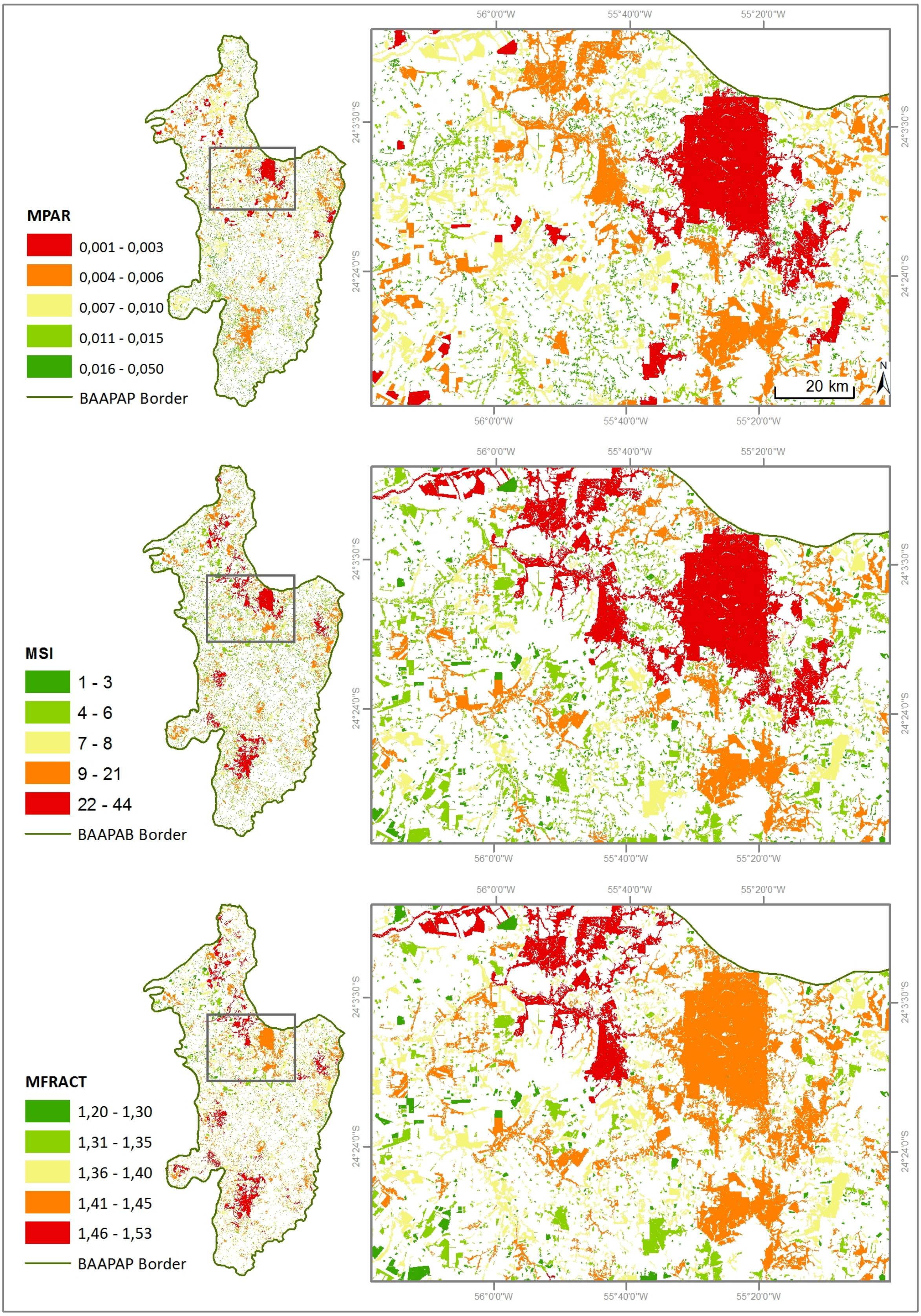


Figure 47: Form and Shape related landscape metrics of forest patches in 2013.

6.4.2.3 Neighborhood and Proximity

The neighborhood analysis on the patch level allows a differentiation of forest patches regarding its embeddness within the entire fragmented forest area. The proximity index calculates the average distance-area relationship of forest patches within a specified neighborhood. This information is in particular helpful to identify potential biodiversity corridors between forest core areas that allow a movement and distribution of various different species (see chapter 6.4.3).

Forest proximity increases the nearer and larger neighborhood patches of the same class are within the same search distance. The search distance has to be defined and depends on the search and move around distance of certain species. The result of applying the proximity index to forest landscape in the BAAPAP region is illustrated in Figure 48. On the right side the figure shows the forest cover in 2013 and on the left side the same forest patches are shown classified by values pf proximity. In this case the proximity index was calculated for all forest patches greater than 10 ha and a proximity buffer with an search radius of 500 m. The forest proximity map shows the gradient of patches that are better (dark blue patches) embedded or worse (yellow and green patches). The blue patches with a high proximity values are appropriate to build the basis of biological corridors within different greater forest blocks. By visual interpretation of the forest patches with higher proximity values, main areas that are suitable to create biological corridors become obvious.

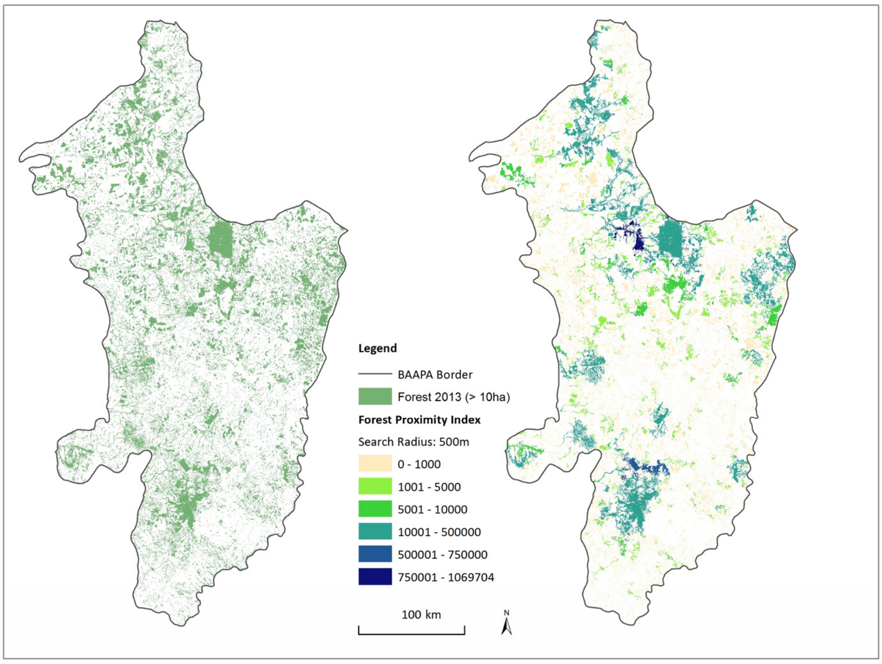


Figure 48: Comparison of simple forest cover and forest cover by proximity.

However, the interpretation of forest proximity is critical on two main factors. Firstly, the proximity index values have a continous range and thresholds defining classes of lower and higher proximity have to be defined. These different classes of proximity values allow a differentiation of forest patches that are more or less appropriate for corridor creation. For example,

Figure 49 illustrates variations of the forest patch map by changing class defintion of the calculated forest patches from natural breaks to manual classes. Natural breaks is based on natural groupings inherent in the data. Class breaks are identified that best group similar values and that maximize the differences between classes. The features are divided into classes whose boundaries are set where there are relatively big differences in the data values. Manual class definition was based on testing experience with the aim to find thresholds allow recognition of potential corridors. The exact definition on class thresholds should be based on ecological assumptions of landscape ecology experts.

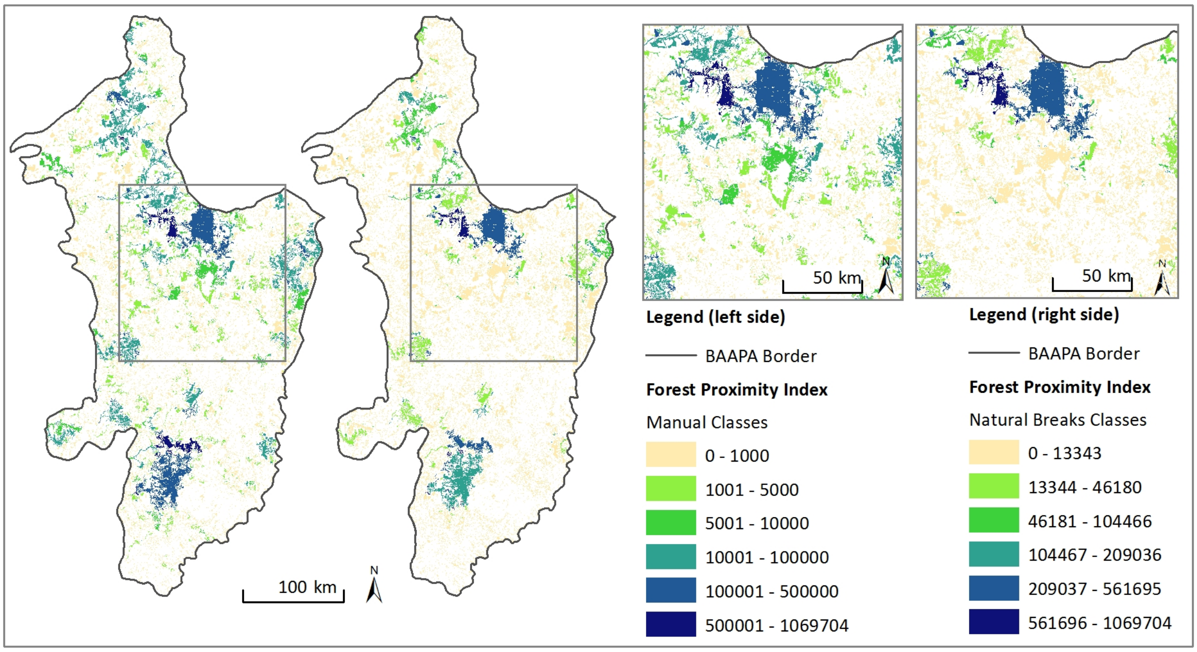


Figure 49: Proximity index of Forest patches classified by manual (left) or natural break classes (right).

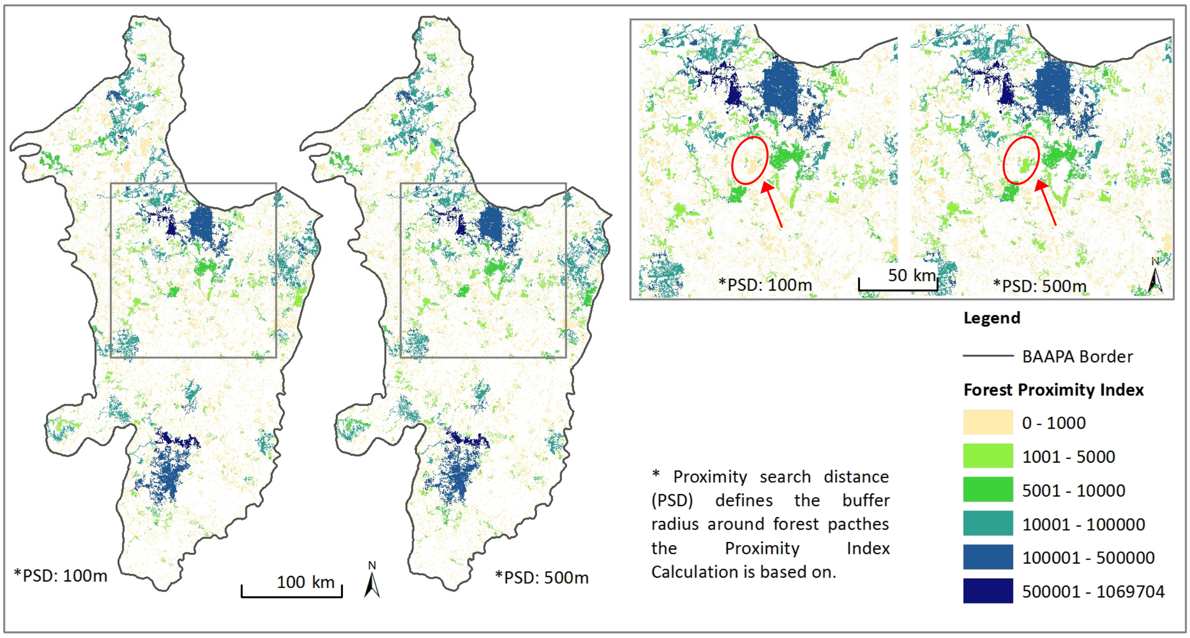


Figure 50: Comparison of proximity index with search radius of 100m (left) and 500m (right).

Secondly, the proximity search radius has also to be set up. It defines the buffer around each forest patch that was considered for neighbor patch identification. The relevant search radius is different for various species. For example, birds can more easily move from one forest patch to another than very small invertebrates.

Figure 50 shows variations of the forest patch map by changing the search radius from 100m to 500m. The main picture of the map does not change much, but as the higher resolution extent shows some patches with a search distance of 500 m got lower proximity values meaning that they are too isolated to still fit in the same class than it was with a serach radius of 100 m. If the potential corridors is planned for species that need at shorter distance to its next neighbors some ways were blocks (see red maks as an example). These areas that differ by changing search distance have to be examined especially if they are appropriate or not to create potential biological corridors.

6.4.2.4 Subdivision

The intention of this study was to provide information on the subdivison status of the current forest landscape in the BAAPAP area. Landscapes are subdivided by different factors. For example, transport lines or populated areas are human induced subdivisions of natural landscapes. The subdivision of the whole area or density of road network is calculated by the total length of roads divided by the total area of the BAAPAP region.

These analyses were planned but not realized due to the lack of comprehensive vector data that present dense and detailed road network. Natural Earth provide free vector data of roads, but it contains only the main highways in Paraguay. The most detailed road dataset was provided by Open Street Map Society. But even these road network dataset does not fulfill the criteria of these approach. If appropriate vector data (that contains all the small paths and lanes) is available in future a subdivision analysis of the from an ecological perspective higher valued forest class is woth to conduct to provide a more specific picture role the roadwork. The subdivision of the forest area by roads is divided by the length of roads that border on forest patches by the area size of all forest patches. The role of the road network as subdivision factor is described by the relationship of road network density and edge density of all forest patches. Subdivison analysis of forest area by populated areas and river network would also worth to examine if appropriate vector data is available.

6.4.3 Forest Core Areas and Corridors

In summary, the majority of the examined metrics emphasize the increasing fragmentation of the forest matrix between 2003 and 2013. Especially the core area and proximity anaylsis show significant results that were useful to add on the conducted forest monitoring of the BAAPAP region.The core area analysis identifies the most valuable forest patches that funcion as interior habitats for diverse species. The proximity analysis identifies forest patches that are better embedded in the fragmented forest mosaic than others. The combination of both analysis are valuable information to identify the priority conservation areas and potential biological corridors between these areas.

In the following it is shown to what extent the proximity index provide information on potential biological corridors within the BAAPAP region. Afterwards this information will be combined with the core area analysis results to give an example on the current situation of connectivity between the most valuable forest area within the study area.

First of all, the proximity index differentiate between forest pacthes that are better embedded in the forest mosaic and those that are lower embedded. The forest patches that are better embedded are more suitable to create biological corridors than forest patches that have less or only small forest patches within their neighborhood.Thus, as it was shown above, the forest proximity allows the identification of potential corridors within the BAAPAP area. At the same time, it also allows the identification of forest gaps within existing connections between important forest areas. In this study, forest gaps are identified if the distance between the forest pacthes with at least low proximity values are larger than 2 km.

Figure 51 and Figure 52 illustrate the forest proximity in the north and south of the BAAPAP region and the identified potential corridors and gaps of the current forest mosaic in 2013.The forest patches in the northern part of the BAAAP region consists of three larger connected forest blocks. The highest connectivity exists between forest patches in the central north (see Figure 51b). The Marabacayú Forest is well connected with its surrounding forest patches such as the forest core area of the Morombi Reserve in the south and larger forest pacthes in the in the west. In particular, a network of long stripes of riverside forests link the Mbaracayú Forest Block with larger forest patches leading to the north (see Figure 51a). However, one larger gap prevents the connectivity of the Marabacayú Forest Block with the larger forest block in the north of the BAAPAP region. It is only a small gap of 3 km to the next forest patch that separate both interconnected forest areas. Farer in the north two smaller forest areas are not connected as well as the forest patch in the northwest of the BAAPAP region. The forest patches in the east part of the BAAPAP region along the riverside of the Upper Paraná (or Itaipú dam) are connected by themselves, but not with the forest blocks in the central BAAPAP region (see Figure 51b). One central gap exist that separates the eastern block of forest patches with the central block of the Mbaracayú Forest as main core area. Between the southern and the northern interconnected forest blocks only one main corridor in the western arc of the BAAPAP region exists that has only some smaller gaps (see Figure 52d). This long striped corridor shapes an arc from the core area of the Morombi Reserve in the central north to the main forest areas in the south, the San Rafael and Caazapaá Reserves. No connections exist between the main southern forest blocks and smaller forest areas in the southeastern border with Argentina and in the western corner of the BAAPAP region (see Figure 52c).

In next step, this information on potential corridors and gaps was combined with the information on highly valuable forest core areas that exist in 2013. As a final result of this study, potential biological corridors are identified to interlink large forest core areas (and protected areas) within the BAAPAP region as well as the larger gaps that still prevent connectivity. The forest areas that are not interlinked with potential corridors are identified as forest islands. Figure 53 shows one example of potential corridors that interlink forest priority areas within BAAPAP region based on several assumptions on core area size, edge effect and proximity search radius that were taken within this study.In this special case, connectivity without any gap does only exist between the Mbaracayú Forest and the Morombi Reserve in the central north of the study area as well as between the Caazapá and San Rafael Reserve in the south of the BAAPAP region. A potential corridor between the protected areas in the north and south as well as between the north and east exist, but they are both interrupted by several minor gaps. Highly isolated as forest islands are the Itabó Biological Reserve in the northeast, the Aroyo Blanco and Cerrro Corá National Park in the north as well as several smaller protected areas and other forest core areas without any protection status.

Impacts on varying the parameters of the special analysis are discussed in chapter 7.5.

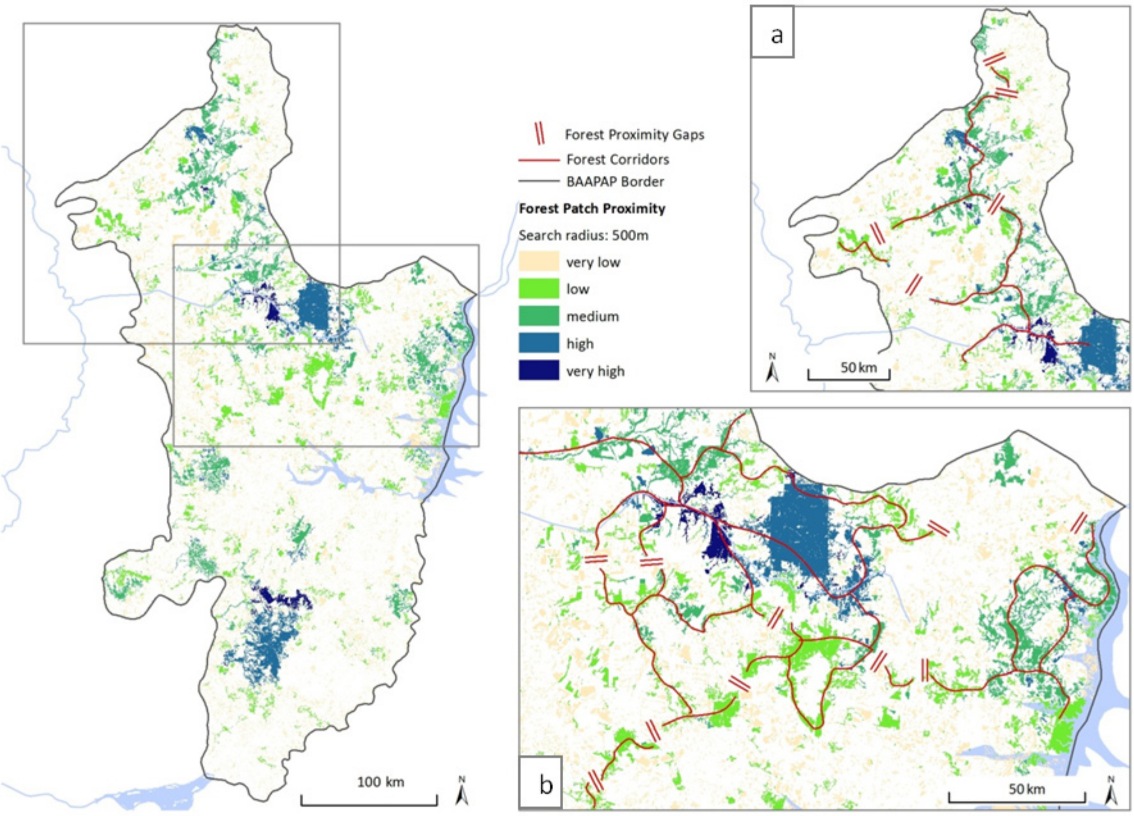


Figure 51: Forest proximity, existing corridors and gaps in the northern BAAPAP region.

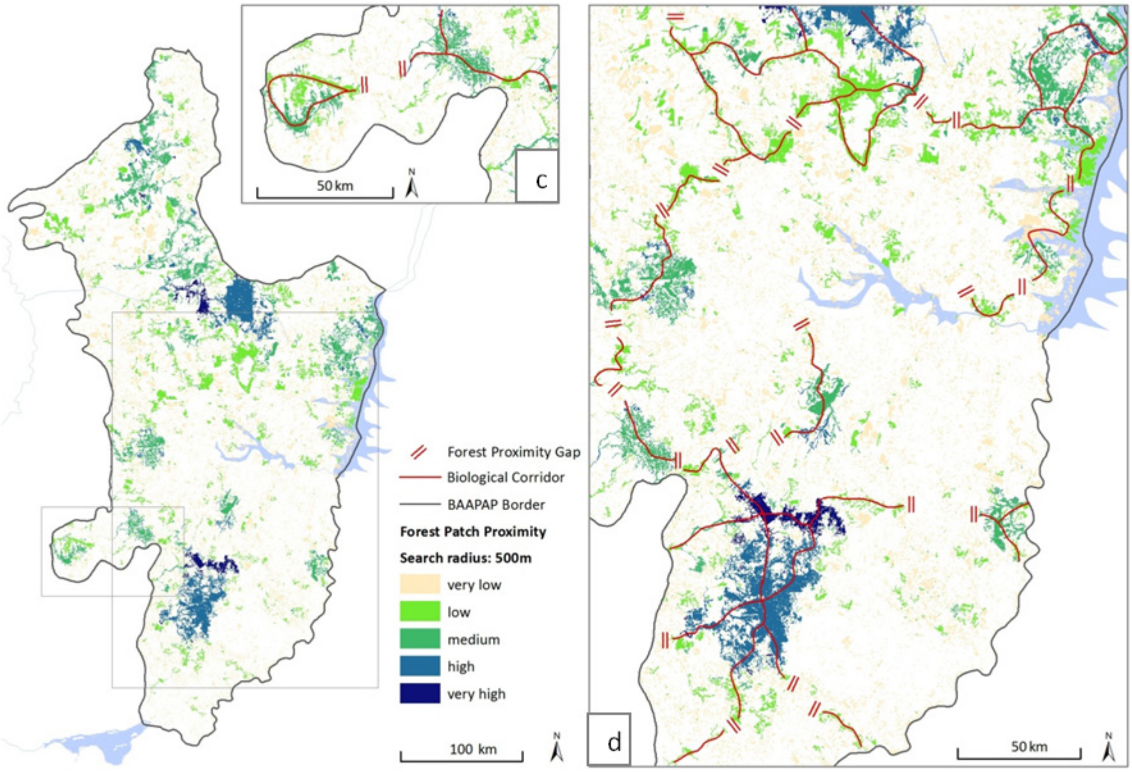
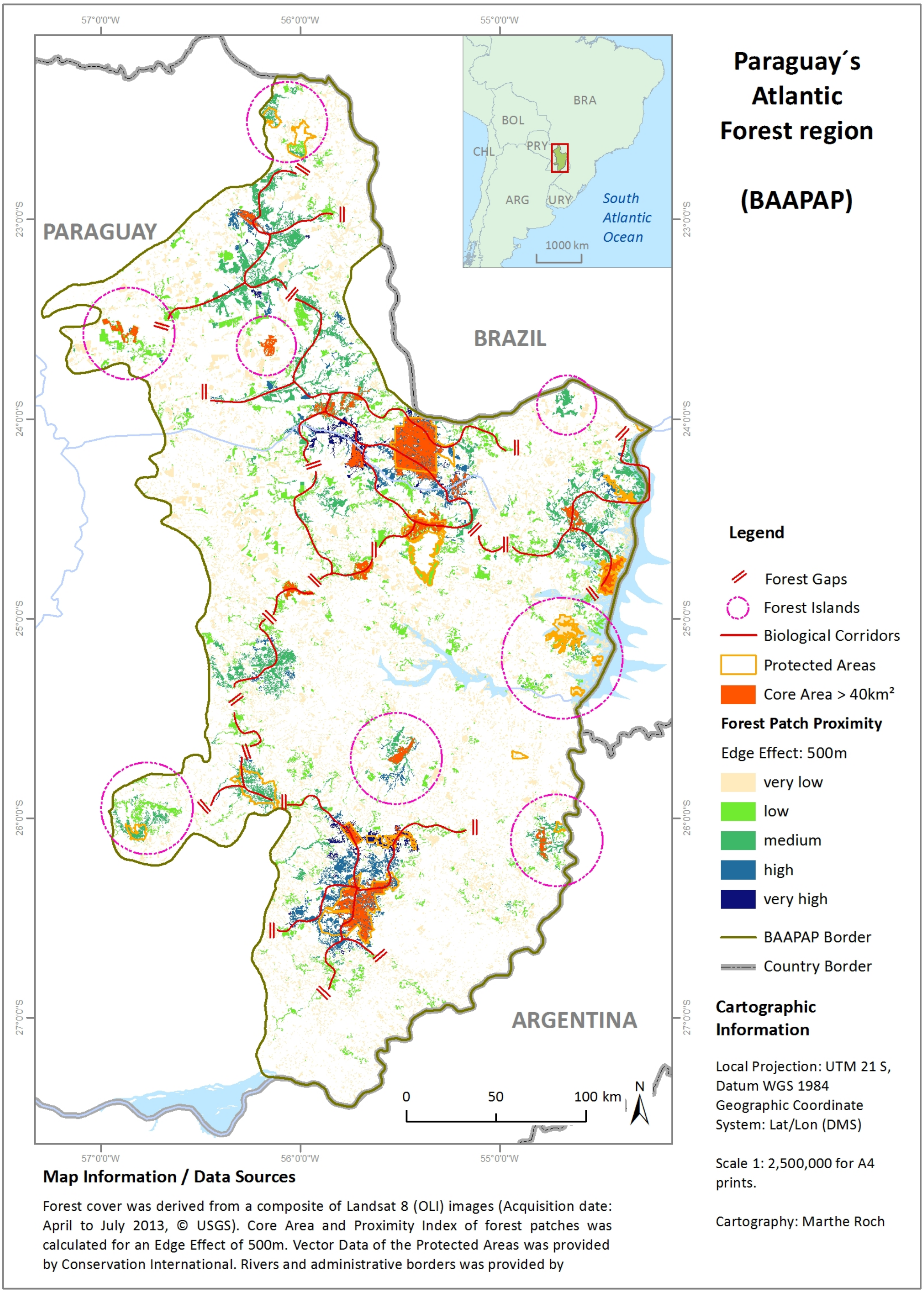


Figure 52: Forest proximity, existing corridors and gaps in southern BAAPAP region.



Cartographic Information

Local Projection: UTM 21 S, Datum WGS 1984
Geographic Coordinate System: Lat/Lon (DMS)

Scale 1: 2,500,000 for A4 prints.

Cartography: Marthe Roch

Map Information / Data Sources

Forest cover was derived from a composite of Landsat 8 (OLI) images (Acquisition date: April to July 2013, © USGS). Core Area and Proximity Index of forest patches was calculated for an Edge Effect of 500m. Vector Data of the Protected Areas was provided by Conservation International. Rivers and administrative borders was provided by

Figure 53: Potential Biological Corridors and Forest Core Areas within the BAAPAP region.

7 Discussion

At the beginning of this study, five guiding research questions were defined: 1) *Did forest cover loss occurr within the last decade? 2) And if so what did the deforestation patterns look like? 3) Are protected areas effective regarding forest conservation? 4) How can the current forest landscape be characterized? 5) And what are the important forest priority areas in order to conserve biodiversity within the study area?* In the following the results of this study are placed in a broader context. Advantages and limitations of the methods that were used will be also discussed in this chapter. Each subchapter deals with one of the above mentioned research question.

7.1 Forest Cover and Forest Loss

The main research question of this study was to find out if Paraguay lost more of its valuable Atlantic forest within the last decade. The forest classification of the Landsat data and subsequent change detection analyses revealed a forest loss of about 6,000 km² from 2003 to 2013 in the study area. About 20 per cent of the forest were deforested during this time period. Thus, deforestation continued with an average annual rate of 600 km² per year.
In comparison to the decade before, deforestation slowed down. Studies from Huang et al.(2007) and Alstatt (2006) reported much higher deforestation rates of the 1990s ranging between 1100 km² and 1350 km² per year. According to their results about 40 per cent of the forest were lost within that decade (Huang et al. 2007, 2009; Altstatt et al., 2006). However, it has to be considered that the deforestation rates depend on the amount of forest that existed in the reference year.
Additionally, the revealed forest loss has to be seen in the context of the ambitous goal of the the Zero Deforestation Law that officially impede any deforestation within the BAAPAP region. In this context, deforestation remains on a high level. It can be reasoned that forest conservation and reforestation policies does not have obvious impacts on the BAAPAP area. It is also remarkable that forest loss and deforestation rates vary among spatial location and departments. The highest forest losses are concentrated within the northwest of the BAAPAP area. In particular, the department of San Pedro lost more than 2000 km² of its forest during the last decade due to a high level of large-scale deforestation.

The small forest gains that were revealed by the analysis are caused by reforested areas. However, these reforested areas differ in spectral characteristics as well as in texture and altitude from the original forest cover. The differences are obvious even by pure visual interpretation of the Landsat image. Figure 54 shows two examples. The ordinary structure of these areas supposes that these areas are forest plantations, most probably eucalyptus plantations. According to the literature and official statements of the government, Paraguay had an eucalyptus boom during recent years. In 2011, about 530 km² were covered with tree plantations. About 80 per cent of all forestry plantations in Paraguay were estimated as fast wood forestry of exotic eucalyptus species. The majority of plantations are located in the east of the country, mostly in the BAAPAP area. The highest rates of eucalyptus plantations were reported in Caazapá, San Pedro, and Alto Paraná, with more than 100 km² of agroforestry plantations for each department (INFONA, 2011). The ambitious reforestation program is controversial. Eucalyptus is a very fast growing species and a very important resource for the agroforestry sector. The wood is mostly used as charcoal production paper and is a very important resource for local pulp production. However, negative social and ecological impacts of the increasing eucalyptus plantation industry are controversially discussed under the headline of "The Eucalypt Dilemma" (Nutto, 2007). In contrast to the positive economic effects, intensive cultivation of monoculture agroforestry (e.g. eucalyptus plantations) cause some disadvantages and risks for the environment (soil extraction, decreasing groundwater level, and erosion in sloped areas). The cultivation of monoculture forestry does not provide the conditions of biodiverse ecosystems as natural forest.

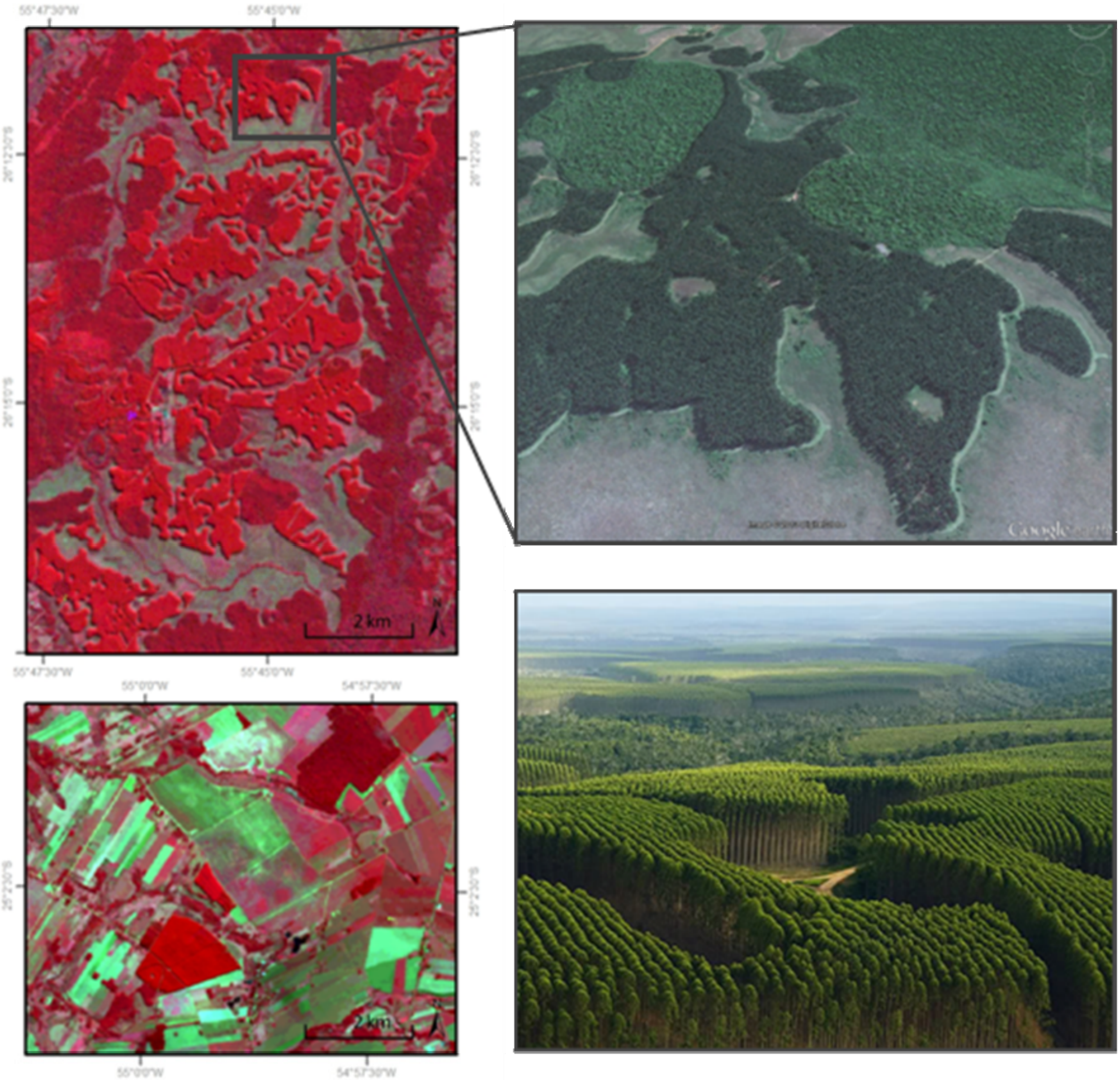


Figure 54: Examples of eucalyptus plantation forestry in BAAPAP region. A subset of Landsat 8 image presents a eucalyptus plantation area in Caazapá (a) and in Alto Paraná (b) department. The dark red areas represent original forest, the brighter red and more prominent areas in the center of the subset are forest plantations of eucalyptus trees. The difference of both forest types is presented by a very high resolution image provided by Google Earth (c). A general overview picture of eucalyptus plantations shows the high altitude and thin stands of eucalyptus trees provided by forest policy research (d).

The results of this study has to be seen in the context of the methodology that was used to derive the forest cover from the Landsat images. Discrepancies in forest loss in comparison to other studies may have different causes. First of all, the resulting figures mainly depend on the definition of forest that is based on the analysis. In this study forest was defined according to the FAO defintion with areas greater than 0.5 ha. It is a very broad definition including very small areas of tree cover. In many other studies forest were defined by tree covered areas greater than 10 ha or more. Therefore, the above presented results in forest cover tends to be higher than in studies with a stricter defintion on forests. Another reason for variation in forest loss are different study areas, scales and dates of analysis. For example, Alstatt et al. (2006) revealed forest cover losses in a study area of Eastern Paraguay. Their study area is based on the geographical border of the Paraguay river that bistects the country. Their study area did not only include the Atlantic Forest ecoregion (as it is in this study), but also parts of Humid Chaco and Cerrado ecoregions. Furthermore, they derived forest cover by satellite images acquired in 2001. Probably, the forest loss should be lower than these for the smaller study area assumed here, but this is not the case. They reported forest loss for 2001 for all Eastern Paraguay where an area of 31,463 km² was classified as forest. In this study 33,039 km² were classified as forest in 2003 for a smaller area. These variations result from different forest definitions.

Figure 55: Difference between primary and secondary forests in BAAPAP region (Source: The Nature Conservancy).

However, the main reason for variations in forest loss seems to be the differentiation of forest types (e.g. primary, secondary, or riparian forest). Most of the studies represent only areas of dense primary forest and therefore result in smaller forest coverage. For example, Conservation International (2013) only considers primary forest exclusively and therefore states that only 13 per cent (11.618 km²) of the original forest cover still exists. Primary forest has much higher tree and plant diversity than secondary forest leading to different animals species living in these habitats (see Figure 55). Although differences in texture and composition of forest canopies can be detected in arial photos, it was not possible to differentiate these two forest types by spectral analysis of Landsat data with a resolution of 30m. Using very high resolution or hyperspectral data and verified ground truth data can help to separate both classes.

7.2 Deforestation Patterns and its Drivers

In general, deforestation of large, medium, and small areas were differentiated within this study. Large-scale clearing of forest areas larger than 100 ha caused the half of all forest losses within the BAAPAP area. In contrast, small-scale clearing is mostly motivated by subsistence or small holder agriculture and shifting cultivation and selective logging in some cases. Small-scale deforestation caused one third of all forest loss within the BAAPAP region. The four different types of deforestation that occurred in the BAAPAP region have different causes. They were differentiated between large-scale clearing of (mostly compact) forest areas, two patterns of medium-size deforestation (fishbone and circle) and one specific type of small-scale deforestation (spotted or spreckling clearing). As it was mentioned in the second chapter economic interests, high social inequalities and land tenure conflicts have been identified as the main driver of deforestation in Paraguay within the recent years. Thus, large-scale clear cutting was realized in many areas with a economic driven purpose or due to the fear of land exproriation asa result of illegal squatting activities.

Table 18: Main Dirvers of Deforestation

Deforestation type	Possible Deforestation Pattern	Main Drivers of Deforestation
Large Scale	Compact and Fishbone Clearing	Agribusiness (cash crop farming, cattle ranching), land control (fear of expropriation due to illegal squatting)
Medium Scale	Fishbone or Circle Clearing	Medium/Small-scale farming, urban growth, settlements, clear-cut logging
Small Scale	Spotted or spreckle Clearing	Illegal squatting, subsistence farming, shifting cultivation, selective logging

Different deforestation types and patterns have different drivers. For example, large scale clearing of (mostly compact) forest areas large-scale clear cutting was realized in many areas with a economic-driven purpose. The conversion of large continous forest areas in agricultural land that is mostly motivated by agribusiness (e.g. soy production or cattle ranching). Especially the conversion of forest into agricultural land needs large and compact forms to apply mechanized cash crop production. Therefore, the compact pattern can be reasoned by agribusiness activities of large landowners.

Forest losses that are caused by fishbone or circle clearing patterns are mainly medium sized areas. These patterns illustrate an ongoing slow deforestation process that is in most cases motivated by settlement and medium-scale farming activities. The fishbone clearing occurred along small lanes that were built across larger forest areas. On both sides of these lanes arise little houses and gardens. Gradual irregular extension of agricultural lands or settlemeents behind the houses caused a fishbone pattern. The forest areas were slowly eroded by these medium-scale clearing processes. Similar drivers cause the circle clearing forest losses. The difference ist that the eroding deforetsation is originated by a traffic circle. The settlements around this circle extent their land use activities by clearing forests in all directions of the circle.

Drivers of small-scale deforestation are hard to conceive. Small forest losses can have various reasons. Beside human induced impacts also natural processes may cause small forest losses. Also misclassification errors may contribute to these type of deforestation. However, one specific pattern of small-scale deforestation was outstanding within the BAAPAP area. In many continous forest areas various little spots of forest losses appear that leave a spreckled cloud of spots within the forest. Some of the observed spotted or spreckle clearing patterns within the BAAPAP area seem to be squatting fields. For example, the small *freckle/ spotted clearing* areas fit in this scheme. As it was reported in literature, these clearings by squatters occurred in a small-scale. The freckle/spotted clearing areas are mostly less than 5 ha. It seems to make sense that a group of landless farmers occupy small fields within a large forest area. Each famer (and its family) clears an area of a size which is adequate for subsistence farming. Not far away, the next squatter clears its small-scale farming area and so on. With time, more and more spots were cleared and some of these spots increase and merge to greater deforested areas (see example d in Figure **41**). Illegal squatting of land and land tenure conflicts are one of the main drivers of deforestation in Paraguay. In some cases illegal occupied land was expropriated from large landowners and given to lendless farmers. In order to avoid these illegal squatting activities and the fear of land expropriation as a result of these activities many large land owners cleared large forest areas to achieve better control on their huge land.

Thus, economic interests, high social inequalities, and land tenure conflicts also have been identified as the main driver of deforestation in Paraguay within the recent years.

Distinguishing and recognizing different deforestation patterns is really helpful for forest monitoring and a crucial prerequisite for implementing and placing effective conservation activities and instruments. It makes a difference if the environmental actors reveal large-scale clearing or smallscale illegal activities. For large-scale clearing it has to be examined if the respective land owner has a permission to clear these forests and what might be appropriate sanction instruments for those who clear ithout permission. In cases of compact clearing it is relative easy to name originators of clearing and take their responsibility into account. For small-scale clearing (like spreckling or spotting) the appropriate instruments to prevent deforestation differ a lot from preventing large scale clearing. Small-scale clearing activities are often hard to detect and dificult to confirm its originator due to moving squatters or shifting cultivation farmers and illegal loggers. Frequent revealing of these clearing activities would enhance the opportunity to implement ad hoc measures to prevent further deforestation. Mapping different deforestation patterns based on object-based image analysis would provide a helpful overview on location of different deforestation patterns. The initiated OBIA approach to detect different deforestation patterns should be pursued and intensified within further studies.

7.3 Effectiveness of Protected Areas

A crucial instrument of forest protection and biological conservation is the designation of larger forest blocks as protected areas. The analysis results of forest loss inside and outside protected areas illustrates the effectiveness of forest conservation.

The analysis of eight protected areas within the BAAPAP region reveal two main trends. Firstly, deforestation inside the protected areas was low between 2003 and 2013. The average deforestation rate within the examined protected areas was about 3 per cent of the forests that existed in 2003. However, forest loss increased drastically behind the borders of the protected areas. Deforestation rates of the 5 km to 15km buffer zones range from 13 up to 35 per cent. Huang et al. (2007, 2009) described a similar trend of forest losses within the protected areas for the 1990s. However, the deforestation rates within the surrounding buffer zones of protected areas have been recorded much higher than in the current decade with rates ranging between 35 up to 55 per cent. Thus, the main trend of forest loss within the BAAPAP area between 2003 and 2013 were also asserted for the surrounding buffer zones of protected areas. In comparison to the decade before, deforestation were slowed down but remains on a high level. Although environmental policies impede any deforestation in the study area, forest conservation of areas without official protection status is not effective within the last decade.

Huang et al. (2007) stated a difference of effectiveness within public and private protected areas regarding their effectiveness in forest conservation in Paraguay within the 1990s. This trend is partly confirmed by the results of this study between 2003 and 2013. The lowest deforestation rates have the two Biological Reserves that are managed by the binational Itaipú Company and the Mbaracayú Forest Natural Reserve that is managed by the privateMioses Bertoni Foundation. Within these protected areas, less than one per cent of the existing forest was cleared within the last decade. In contrast, deforestation within some of the protected areas that are managed by the government are much higher than that of the private reserves. In particular, the Cerro Corá National Park in the north and Ybytyruzú Reserve in the western corner of the BAAPAP region have forest loss rates of more than 10 per cent. For these five examples, the trend that forest conservation within public protected areas is less effective than in private ones, can be confirmed. The results of the other four protected areas does not confirm a better effectiveness private protected areas in comparison to private ones.

The distance analysis that was used to examine the forest losses inside and outside protected areas is limitated to the fact that only forest losses within the BAAPAP area was considered. The buffer zones around some protected areas reach also forest losses that were located outside the study area. These forest losses were not included within the analysis. Especially, the protected areas in the north and east of the study area may have higher forest losses if deforestation outside the study area is included. Within further studies the impact of this methodological limitation has to be examined.

In general, the study results illustrate that forest conservation within protected areas has positive impacts. Nevertheless, the high rates of forest loss in the areas surrounding the protected areas left the protected areas isolated as ecological islands within a highly fragmented forest landscape.

7.4 Forest Fragmentation

The analysis of forest fragmentation in the BAAPAP area was conducted by applying different landscape metrics on four main topics: 1) core areas, 2) shape and fragmentation, 3) neighborhood and proximity as well as 4) subdivision. The landscape metrics were applied on two different levels.

In a first step, the forest covers of the BAAPAP region in 2003 and 2013 were analyzed on a landscape level. As a result, the comparison of the aggregated values of both dates reveals that the forest fragmentation increased during the last decade. The forest loss is accompanied with a reduction in forest patch size and an increase in spatial spreading of forest patches within the study area. The analysis of the landscape level allows comparing landscape characteristics between different dates and other study areas. General trends can be described using these results, such as: the total forest core area declined, the subdivision increased or shape and fragmentation did not vary much between 2003 and 2013. Nevertheless, the aggregated values of all forest patches within the landscape do not allow a spatial differentiation within the landscape.

To reveal spatial differences in fragmentation process within the study area, the forest landscape of 2013 was characterized by applying landscape metrics on a patch level. For example, forest core areas were identified and the forest patches it selves were evaluated regarding their shapes and proximity to other forest patches in its surroundings. This patch level analysis allows valuable information on forest landscape characteristics within the BAAPAP region. However, the analysis does not consider the forest cover outside the study area. Patches that are located in the border zones of the study areas are likely distorted due to the fact that not all forest patches in the neighborhood are considered or forest patches were intersected by the border of the study area. The border zones of the study area have to be examined a broader context within future studies.

A further remark regarding the methodology of landscape metrics is the third level of analysis. Beside the patch and landscape level, also a class level of landscape analysis exists. The class level was not considered within this study due to the lack of input data. In case, a detailed land cover classification exist, differences of characteristics and relationships between different land cover classes are also possible to analyze in future.

In summary, landscape metrics allow deeper insight in landscape characteristics such as forest fragmentation. The analysis on a landscape level is a helpful to describe general trends of longer time series and to compare different study areas. The patch level analysis allows a spatial differentiation and identification of extreme cases and focus areas within the study area. Therefore, the analysis results were used to identify priority areas of forest and biodiversity conservation within the BAAPAP region.

7.5 Forest Protection and Biodiversity Conservation

Intact forests with large core areas are the central objectives of biodiversity conservation activities. Many threatened species needs a certain size of forest habitat to survive. Within the highly fragmented forest matrix that still exist in the BAAPAP region is very important to identify these large and compact forest core areas. In particular, the results of the core area analysis reveal that many of the larger areas are highly fragmented and does not serve as intact forst core area habitats. The results strongly depend on the assumed edge effect. The size of this edge effect has to be based on ecological assumptions, for example habitat criteria that threaten species need to survive. Within this study, different edge effects were applied to illustrate the impacts and demonstrate the key parameter that have to be defined before applying the analysis. Large edge effects reduce the remaining core area of forets patches. The results are very valuable. For example, if a size effect of 50 m is assumed, less than 60 per cent of the total forest cover was identified as total core area. Within the entire BAAPAP region, less than 5 continuous forest core areas exist that are larger than 100 km² and less than 30 forest core areas that reach a size of 40 km². Most of these largest forest blocks are already designated as protected areas, but not all. Core area analysis also identify highly valuable forest core areas that are not officially protected. A stricter protection of these non offically protected forest core areas is crucial to conserve biodiversity within the BAAPAP region.

Furthermore, connectivity between these large forest blocks is also a crucial prerequisite of biological conservation. Biological corridors provide the opportunity for many species to move from one forest area to another. Within this study, forest patch proximity was used to identify biological corridors or forest patches that are appropriate to be a basis of such a corridor. It was shown, that connectivity is often interrupted by larger gaps between neighbouring forest patches and that in same cases only one specific area can be served as a biological corridor. For example, between the largest forest core areas in the north and the south in the BAAPAP region exist only the western arc corridor. This important biological corridor is already interrupted on many places. The connection between the eastern forest of the Paraná riverside and the main forest in the center of the BAAPAP region is also reduced to one potential corridor and this corridor is already interrupted by smaller gaps. Thus, the few remaining potential corridors are threatened to dissapear forced by continuing deforestation within the BAAPAP region.

The forest proximity provides important information for the identification of potential biological corridors. Some patches are better embedded than others and therefore are better appropriate to be a basis of biological corridors than other forest patches. As it was explained above, the limitations of bordering areas that was explained above has to be considered using this methods. In addition, The relationship of proximity, size, and compactness of forest patches have to be evaluated for the ecological objective the biological corridors are planned for. The proximity or embedness of forest patches may be one important criteria, but not the only one. For example, subdivision factors of forest landscapes, such as roads and settlements have to be include in this analysis. Furthermore, the extension of the landscape analysis to include other landcover classes may improve the results. For example, an forest patch that has many neighboring patches of natural grassland is more valuable than forest pacthes that is located in the neighborhood settlement or productive agriculture.

The provided approach used corea area and proximity metrics to identify priority areas of forest and biodiversity area as a first step. This can be enhanced by more factors and special focus on the impact of study area borders in future.

8 Conclusion and Outlook

The conducted forest monitoring with special regard to biodiversity conservation aims to support sustainable environmental plannning and conservation activities in Paraguay´s Atlantic Forest region. Comprehensive information about the trends and patterns of deforestation as well the characterization of the current state of the Atlantic Forest is a crucial prerequisite of developing and implementing effective conservation strategies.

The results of this study contribute valuable information on deforestation trends within the last decade and the current state of the Atlantic Forest in Paraguay. The study reveals that deforestation and fragmentation of the Atlantic Forest still continued between 2003 and 2013, but at a slower pace than in the decades before. Forest losses of the Atlanitc Forest in Paraguay have been quantified and localized within the study area. In addition, specific deforestation types and patterns were distinguished and discussed regarding their potential drivers. The effectiveness of protected areas in forest conservation was examined. Furthermore, the forest landscapes of 2003 and 2013 were characterized according to their level of fragmentation. Subsequently, the priortiy forest patches with special regard to biodiversity conservation were identified.The results show that continuing deforestation increases forest fragmentation and challenges biodiveristy conservation within that area. Within a highly fragmented Atlantic Forest only very few intact forest core areas remain and connectivity between these areas is limited or in some cases even blocked. To reconnect these areas, reforestation of the identified gaps within the potential corridors would be necessary to maintain the high levels of biodiversity that still exist in that region.

Summarizing the result of this study, forest conservation, reforestation and the creation of biological corridors are current challenges of sustainable management in Paraguay´s Atlantic forest. The conducted forest monitoring provide valuable information that may support environmental planning and conservation activities. At the same time, the study results also examine how effective the current policies are. For example, the revealed forest loss illustrate that the Zero Deforestation Law (which officially impedes deforestation since 2004 within the study area) obviously lacks effective implementation. The highest forest loss occured in the northwest of the study area and in particular in the department of San Pedro. The question rises whether the deforestation of high amounts of valuable forests were permitted, whether the environmental actors neglected their responsiblity, or whether other developments are the cause of high forest losses.

The results of this study also illustrate effective forest protection strategies. The designation of forests as protected areas is a very effective instrument. Very low forest loss occured within the examined protected areas. However, directly behind the borders of the protected reserves deforestation increased drastically. Thus, it might be argued that more protected areas are needed or, even better, forest conservation outside protected areas have to be improved. Frequently conducted forest loss monitoring allow neccesarry information of early intervention in illegal deforestation activites. The detection of specific deforestation patterns would provide important information to possible drivers of the respective clearing activity. Based on that information, the selection of appropriate instruments that are needed to prevent further clearing within that specific area may be eased.

The study also attempts to illustrate that forest protection and biodiversity conservation are strongly interlinked processes and should evaluated together. In this context, the ambitious reforestation programme of the Paraguayan Government requires some critical remarks. The reforestation programme aims at the introduction of monoculture plantation forestry. The government subsidizes smallholders in Eastern Paraguay that reforest their land with fast growing eucalyptus trees. From an economic point of view it is a kind act and also increases the area that is covered with forests. However, the cultivation of monoculture forestry does not provide the same conditions of biodiverse ecosystems as natural forests. Instead of subsidizing munoculture forrestry, financial incentives for reforestation of diverse and native trees is needed.

Another example of interlinking forest protection and biodiversity conservation, is the identification of forest prioraty areas. The few remaining larger forest core areas need special protection due to their high value regarding biodiversity conservation. In addition, the creation of biological corridors that reconnect these important habitats is also very crucial. Many international environmental actors, such as the World Bank, WWF, USAID and even the private Itaipú Binational company emphazise the importance of these biological corridors as a last way out to prevent the extinction of many rare and threatened species that still exist in Paraguay´s Atlantic Forest region.

In conclusion, the study results may support environmental management and help to evaluate the effectiveness of current conservation strategies within Paraguay´s Atlantic Forest region.

However, the presented study also has its limitations. Three main limitations concern the conceptual approach of this study. First of all, the defintion of the study area as the Paraguayan parth of the Atlantic Forest does not consider the forest cover and losses within the neighbouring countries and regions. The Atlantic Forest ecoregion is a trinational forest. Paraguays forest is only one part of it. National conservation activities are very important, but have to be seen in the context of the whole region. Conservation strategies have to be evaluated beyond national borders. Embedding the Paraguayan part in the whole trinational Atlanntic Forest ecoregion is a crucial prerequisite of sustainability and effective conservation. Especially the green corridor of Argentinas Misiones Province and the Iguazú National Park are the largest remaining forest areas and are bordering directly on the Paraguayan part on the other side of the Rio Paraná. All presented results have to be seen in a broader context of the whole ecoregion. For example, forest loss that occurred outside te BAAPAP region, but inside the surrounding buffer zones of the protected areas have to be included in the analysis. Furthermore, the identification of core area and biological corridors needs to be extended to the remaining forest within the neighboring countries in Brazil and Argentina. The connection between the large Iguazú Natural Reserve and the huge remaining forest in the Misiones Province of northern Argentina change the perspective of the priorities in biological corridor creation. Analysis beyond national and regional borders is a crucial precondition of sustainable forest monitoring and biodiveristy conservation.

Secondly, the focus on the link of forest protection and biodiversity conservation may be a further limitation due to its transferability and validity. The specific focus neglects other important land use changes and environmental challenges within and the study area and Paraguay in general. Separate analysis of the impacts of other land cover changes within that area have to be considered in a comprehensive environmental planning. It should also be considered that biodiversity conservation is not always the focus and priority in Paraguay´s environmental policies. For example, in the western part of the country forest protection is strongly interlinked with carbon storage. Deforestation in western Paraguay increased drastically within the last years and became the priorities and budgets of environmental governance at a national and international level. REDD+ plays a crucial role in the western Chaco woodlands. Thus, national forest monitoring in Paraguay should be involve all ecosystem services of forests.

Thirdly, the presented analysis focuses only on the land cover class of forest within the study area. The impacts of other landcover classes within that area were excluded. The exclusion of other land cover classes is acceptable in order to start the analysis with a focus on forest development and deforestation trends. However, the evaluation of forest patches as biodiverse ecosystem habitats also strongly depends on the neighboring land cover classes and their land use activities. For example, smaller forest patches that are located on natural grassland are probably more valuable than larger forest pacthes within settlements or highly productive agricultural areas. Thus, the inclusion of other landcover classes and its impacts on landscape ecology will improve the quality of analysis results.

Considering these three conceptual limitations, the methodology used in this study was appropriately conducted as initial pilot study to gather basic information on forest development and deforestation within the Atlantic Forest of Paraguay. First of all, remote sensing based analysis is a useful method to support forest monitoring. The main advantage is that satellite data cover large areas and aquire records of the same spatial extent at frequent intervals. Once an earth observation system is established, the cost of data acquisition remain low. The free and open access to the Landsat archive (that provide time series starting in the 1970s) increased the use of remote sensing within enviromental monitoring on a regional and global scale. The spatial and spectral resolution of Landsat data was appropriate for deriving forest cover maps and differentiating between specific deforestation patterns within a large study area of 85,000 km². However, a detailed analysis of forest types and disturbances would require very high resolution or hyperspectral data that allow an intensive specification of land surface objects, but cover only very small areas. Thus, for the purpose of this study, the use of Landsat data was a very good trade off. The use of new Landsat 8 data was an advantage and disadvantage at the same time. The benefit is the high actuality of the information that is derived from this very current satellite data. Some minor hints of spectral analysis were caused by differences within the band range and resolution of Landsat 8 and Landsat 7 sensors. (e.g. the thermal channel within Landsat 8 was changed to two bands on TIRS sensor with higher spectral resolution but lower spatial resolution and Red and NIR narrower wavelength spectrum caused differnecesd in single band reflectance and values of derived vegetation indices as the NDVI). A major challenge was that not all of the utilized preprocessing tools were configured to the characteristics of this new of Landsat data.

Comprehensive data preprocessing is the main prerequisite for deriving remotes sensing based products of high quality. The geometric and radiometric callibration of the satellite data reduce distortions due to variations in the altitude, position, and velocity of the sensor platform as well as the earth's curvature, atmospheric refraction, relief displacement and non-linearity. Although it is a very time consuming procedure, it is worth the time spent on it. For example, within this study almost all monitoring results were based in the forest classification of the sixteen Landsat images. To conduct the same classification method on all images, the comparability of reflectance values between the images have to be as accurate as possible. For large area and multitemporal analyis it is really worth the time it takes for comprehensive data preprocessing. Thus, the resulting reflectance values are the basis information for allfurther analyses. In general, the ATCOR 3 code is a very useful tool to do data preprocessing including sensor calibration, atmospheric and terrain correction. During the last months the code was adapted to the requirements of the new Landsat data 8 sensors. In future, the preprocessing of all OLI and TIRS bands will be easier to conduct as it was in the stage of this study. The results of the terrain correction can be improved by the use of higher resolution DEM. The 90m resolution of the srtm data had its limitations in correction of detailedn relief shadowing. Within the near future, global datasets such as the TandemX-DEM with a higher resolution of 12m will be further improve these results. In general, data preprocessing is a very important step of remote sensing analysis for ensuring spatial and temporal comparability of satellite data and providing high quality data products.

As a classifcation method, a simple pixel-based threshold approach was used for forest mask derivation. The very large study area required the classifcation of sixteen Landsat images. The thematic information which was proposed to derive was a differentiation between foret and non forest areas. The validation of the conducted threshold forest classifcation are acceptable with total accuracies ranging between 83 to 95 per cent. The high accuracies illustrate that the method was appropriate for the purpose of this study. For a more detailed land cover classification, a supervised or decision tree approach will probably provide similar or even better results. However, supervised image classifcation is based on manually created training data for each image. This process is very time consuming. Thus, the choice to conduct a simple trehsold approach was a pragmatic one. However, many other image classifcation methods exist that could be applied as well. For example, object based image analysis would also be an option. The advantage of the OBIA approach is that the image classification is based on objects instead of pure pixels. Therefore, object geometry attributes such as shape and compactness can be included in class assignments in addition to spectral characteristics. Due to time constraints, the potential of object based image analysis was not exhausted within this study. In particular, the detection of different deforestation patterns is expected to realized using this approach. However, OBIA software tools are very complex and analyis is very time consuming for beginners. Thus, study should be intensified within the future, but limited to a smaller extent in the beginning (not the whole study area of the BAAPAP region).

To conclude, the applied remote sensing methods were appropriate for the purpose of this study, but can be extended and intensified to conduct more detailed analysis. In further studies the invorperation of other sensors and systems would enhance the information value. High resolution and hyperspectral data may provide information on detailed vegetation and tree type mapping, in particular, the differentiation between primary and secondary forest. In addition, passive sensor systems such as radar and lidar data can be used to detect different types of forest destruction. The validation and the quality of the forest classifcation can also be improved by utilization of very high resolution data (as Quickbird or Wordview) or high qualitative in-situ data that will be available in the context of the upcoming PARLU-project.

The involvement of detailed and high quality in-situ data would also increase the application of further GIS analysis, such as the distance that was employed to evaluate the effectiveness of protected areas on forest conservation. In particular, the use of high resolution vector data of the road network in Paraguay that include vers small lanes and alleys would provide important information on subdivison factors of the forest landscape. Further subdivison fatcors are rivers and water bodies. Rivers and water bodies are biological barriers and corridors at the same time. Many forests along riversides exist and are valuable habitats for many species. Comprehensive river network data or watershed data are also worth examining according to the introduced distance analysis approach.

The use of landscape metrics provides valuable information on fragmentation processes and forest priority areas. The results of the core area and proximity analysis on a patch level, support the identification of highly valuable forest patches and potential connections between these priority areas. This kind of information is very useful for environmental planning and conservation activities. In future studies, the landscape characterization can be enhanced by the involvement of further landcover classes and information about land use trends within the study area. The application of landscape metrics on a class level would enhance the quality of the results. For example, a differentiation of forest patches which are located within natural grassland areas, in neighboring settlements, or in high productive agricultural fields would enhance the quality of the results. One of the competetive advantages of remote sensing methods is the derivation of detailed land cover classifications and multitemporal land use anaylsis for large areas.

The main benefit of this study is the combination of different methods and its synergies. Every method has its competetive advantage. For example, the quantification of the forest cover and forest loss is the first step in characterizing forest change within the BAAPAP region. Pixel-based image classification provides basic information on forest cover and forest losses within the whole area. Based on this information, specific deforestation patterns be detected by object based information of geometry, shape, and texture of the segmented objects. The results of the remote sensing based analysis were further studied in detail by different GIS based analyis. The classical distance analysis provides information about the relationship of forest loss and specific areas, e.g. protected areas. Landscape metrics were used to derive forest cover information in order to characterize the forest landscape and identify forest priority areas. The study illustrates an integrated approach that interlinks remote sensing and spatial analysis with a focus on forest loss and biodiversity conservation. In general, remote sensing methods extract information about land surface dynamics of large areas. In addition, spatial analysis methods characterize and structure this information and link it to ecological and socio-economic findings by the spatial information.

To overcome the ongoing conflict between economic development and sustainable resource management, as well as support the maintenance of local ecology and biodiversity, comprehensive knowledge, information, and monitoring of socio-ecological dynamics within this area is needed. Therefore, forest monitoring needs to link interdisciplinary knowledge on forest dynamics and its ecological funcions, as well as socio-economic and cultural drivers of deforestation and biodiveristy loss. Conservation of forests, biodiversity, and sustainable use of natural resources require a coherent, effective set of supportive policies, strategies, laws and regulations. However, environmental policies and conservation activites in Paraguay are still challenged by inefficient governance, inconsistencies of strategies, and the lack of coherence between ministries. The multiple functions and values of forests are increasingly recognized as key in resolving global issues such as climate change, green energy, poverty, environmental degradation, biodiversity loss, and raw material supply. However, the main challenge is ‘bridging the communication gap’ between different sectors, e.g. financial and economic vs. environmental (Boscolo, Dijk, & Savenije, 2010). A remote sensing based monitoring product like the forest cover change detection for the last decade that include detailed information on deforestation patterns, forest fragmentation and conservation priority areas is one important contribution to an integrated ecologically sustainable forest management for relevant decision makers.

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10 Annex

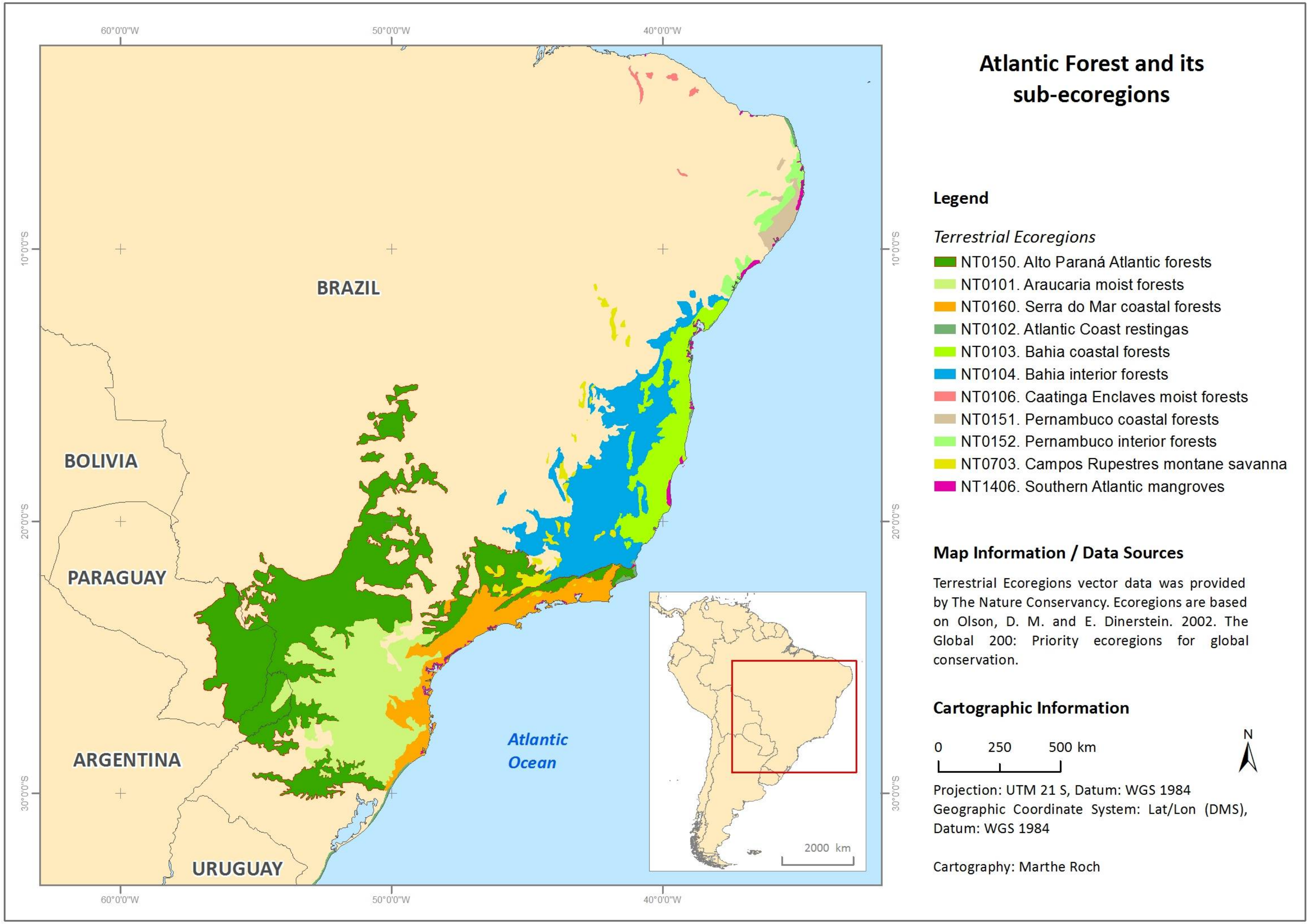
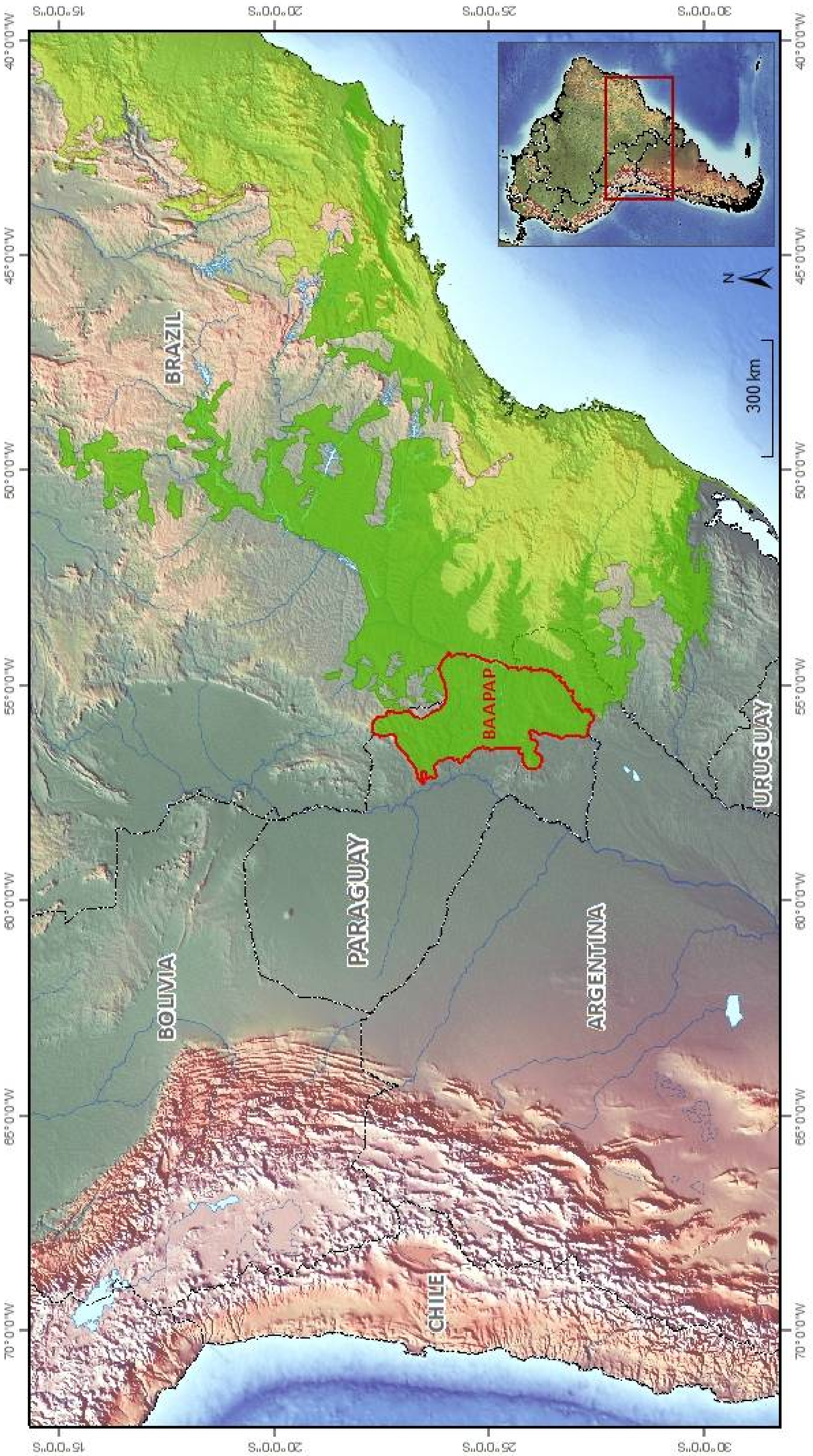


Figure 56: Map of the Atlantic Forest and its main sub-ecoregions.



Legend / Cartographic Information

🟩 Alto Paraná Atlantic Forest sub-ecoregion

🟩 Remaining Atlantic Forest ecoregion

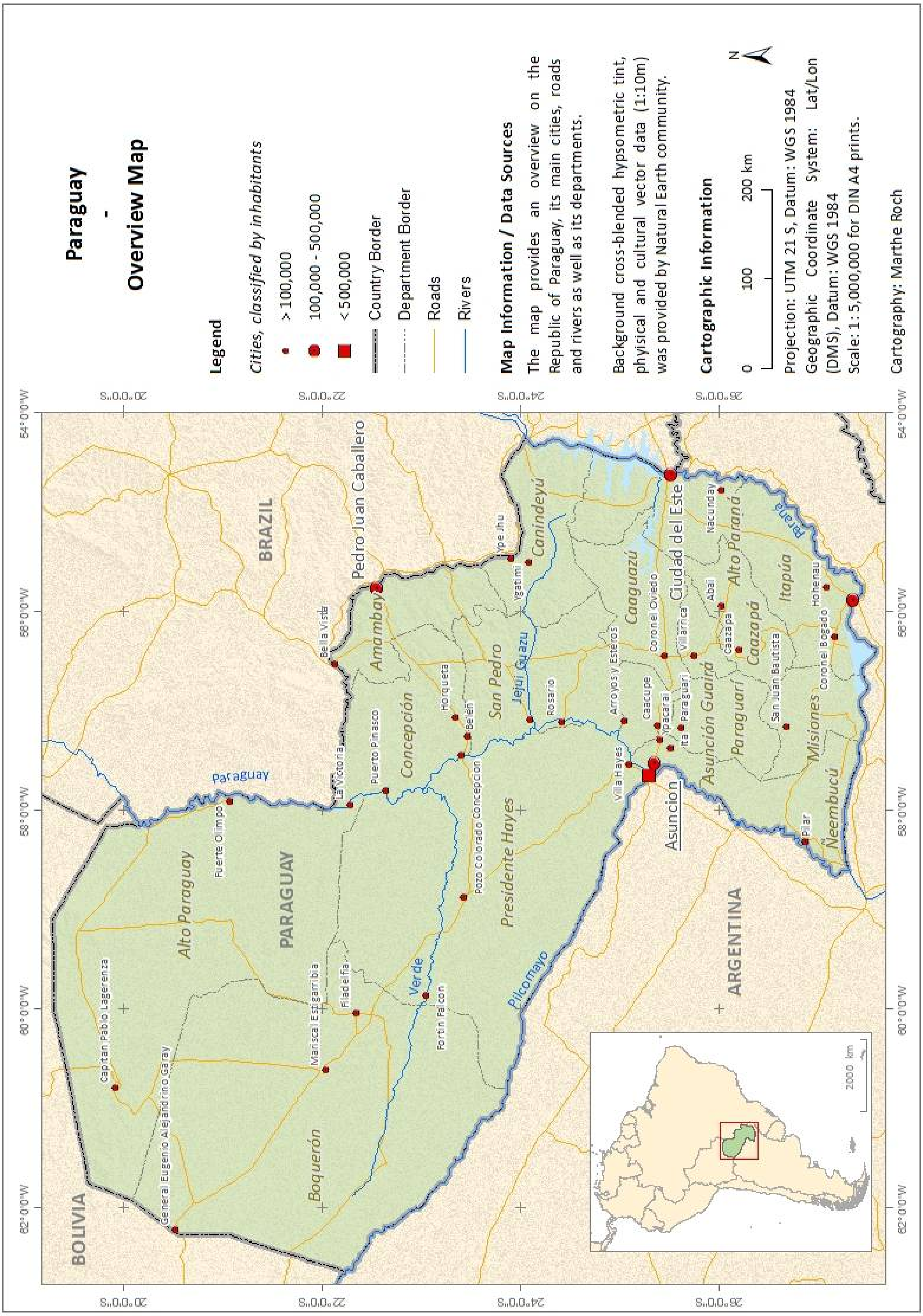
Projection: UTM 21 South, Datum: WGS 1984

Cartography: Marthe Roch

Map Information / Data Sources

The map shows the study area. It is the Atlantic Forest of the Upper Paraná in Paraguay (El Bosque Atlántico del Alto Paraná en Paraguay, BAAPAP). Background Cross-blended Hypsometric Tints and Vector Data of Country Borders (1:10m) are provided by Natural Earth free vector data. The shapefile of the Atlantic Forest ecoregion is provided by Conservation International.

Figure 57: Map of the BAAPAP region (study area).



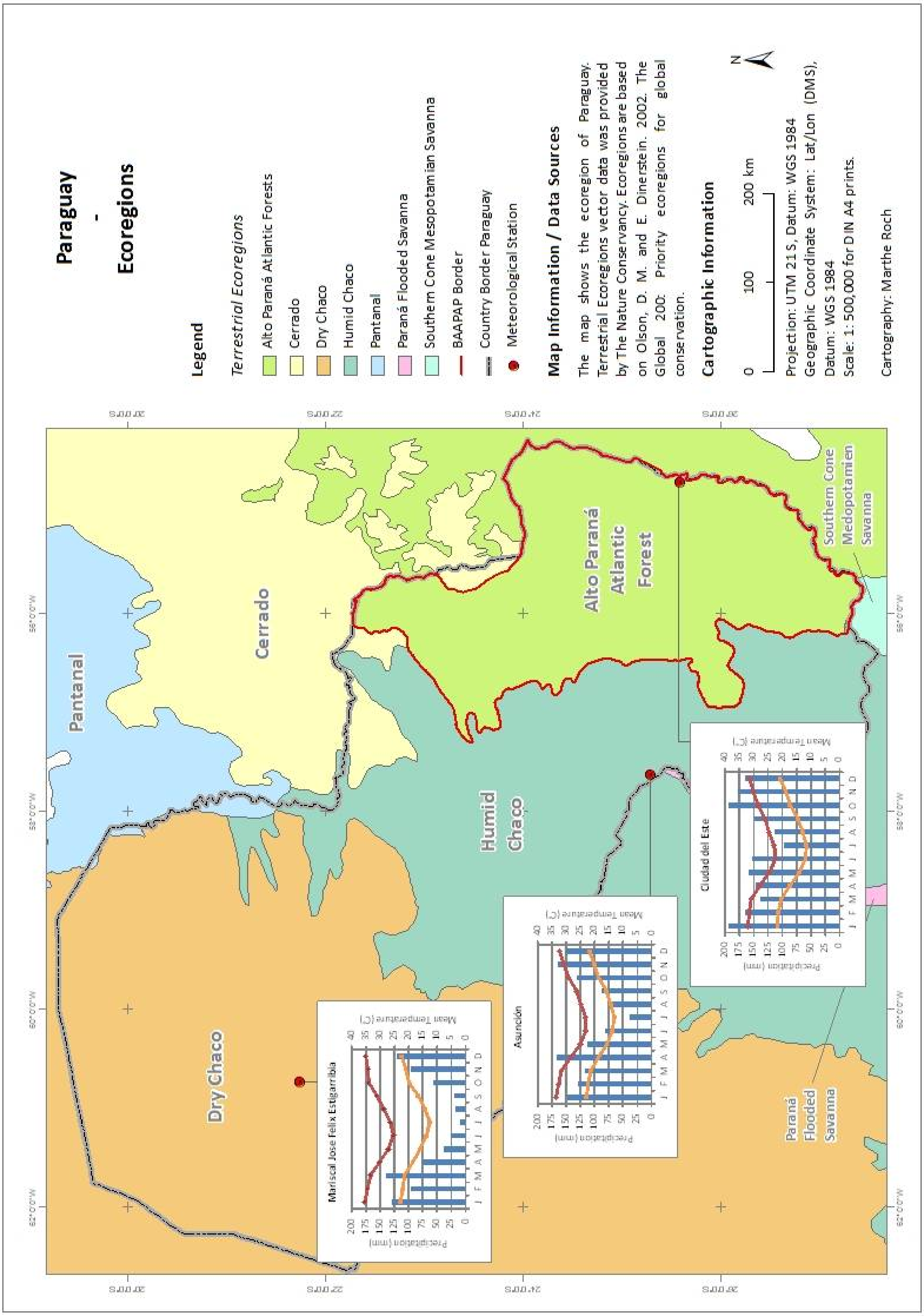
The map provides an overview on the Republic of Paraguay, its main cities, roads and rivers as well as its departments.

Background cross-blended hypsometric tint, phyisical and cultural vector data (1:10m) was provided by Natural Earth community.

Projection: UTM 21 S, Datum: WGS 1984
Geographic Coordinate System: Lat/Lon (DMS), Datum: WGS 1984
Scale: 1:5,000,000 for DIN A4 prints.

Cartography: Marthe Roch

Figure 58: Map of the Republic of Paraguay.



Map Information / Data Sources

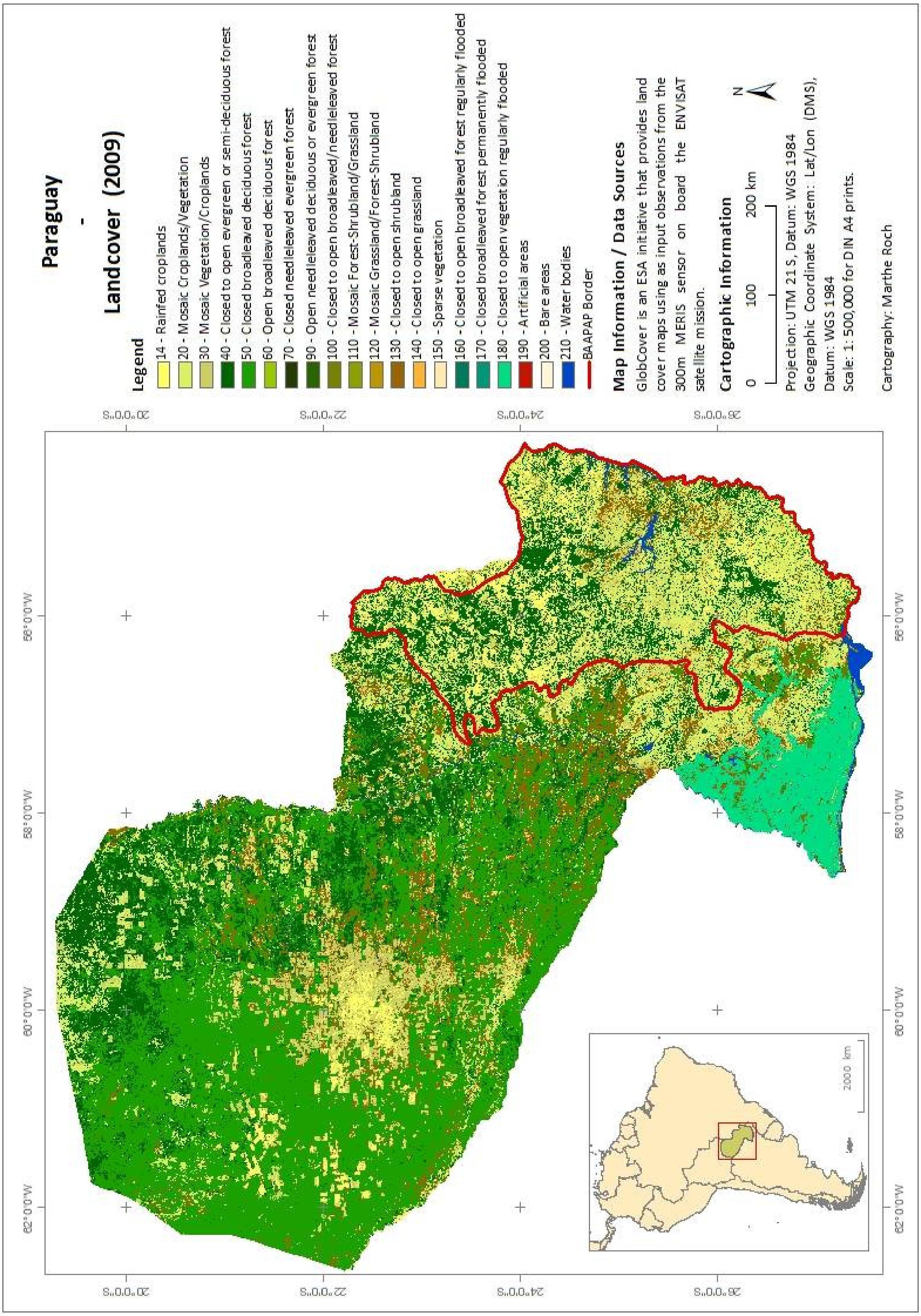
The map shows the ecoregion of Paraguay. Terrestrial Ecoregions vector data was provided by The Nature Conservancy. Ecoregions are based on Olson, D. M. and E. Dinerstein. 2002. The Global 200: Priority ecoregions for global conservation.

Cartographic Information

Projection: UTM 21 S, Datum: WGS 1984
Geographic Coordinate System: Lat/Lon (DMS),
Datum: WGS 1984
Scale: 1: 500,000 for DIN A4 prints.

Cartography: Marthe Roch

Figure 59: Map of ecoregions and climate zones in Paraguay.

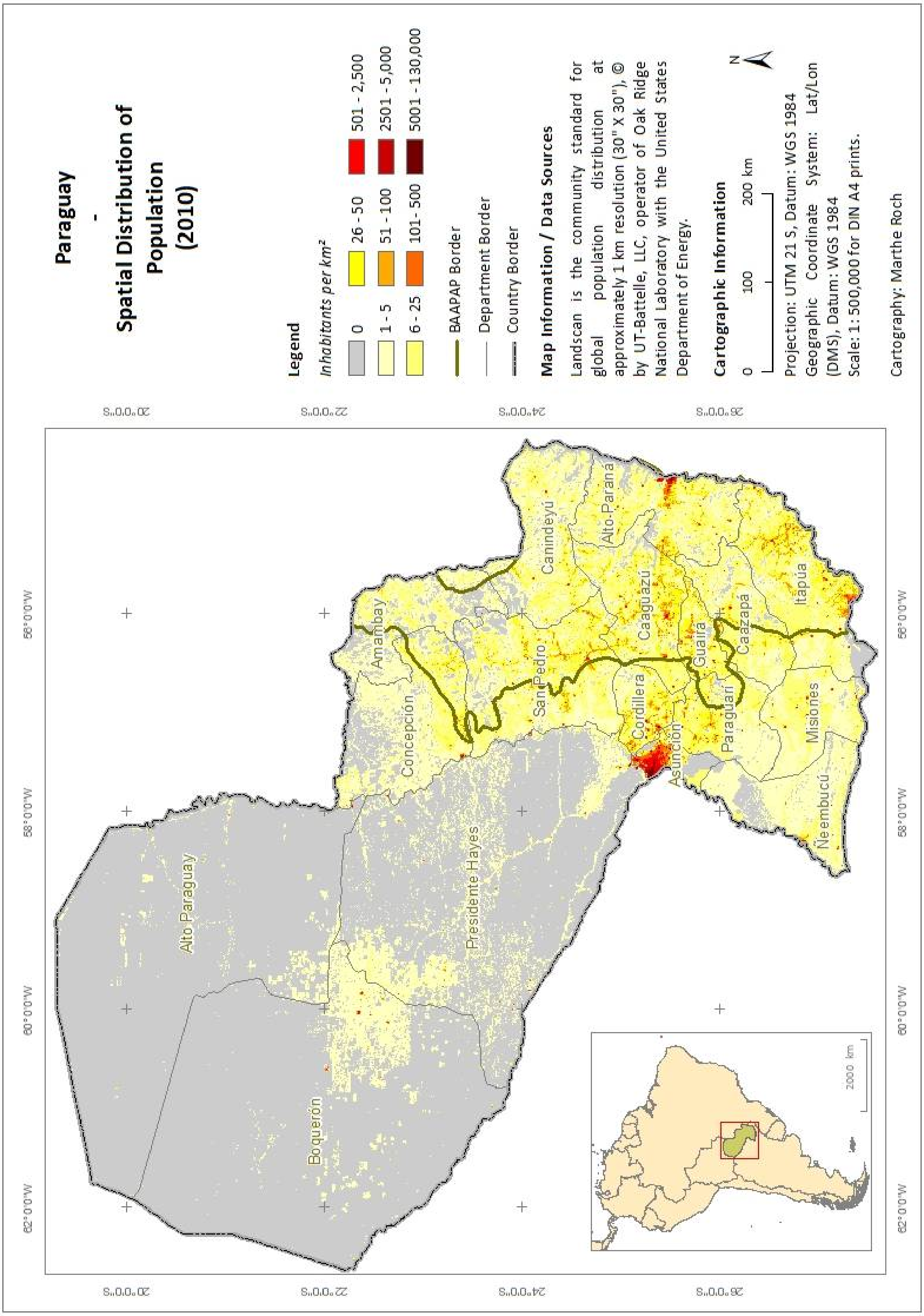


GlobCover is an ESA initiative that provides land cover maps using as input observations from the 300m MERIS sensor on board the ENVISAT satellite mission.

Projection: UTM 21 S, Datum: WGS 1984
Geographic Coordinate System: Lat/Lon (DMS), Datum: WGS 1984
Scale: 1: 500,000 for DIN A4 prints.

Cartography: Marthe Roch

Figure 60: Map of landcover in Paraguay.



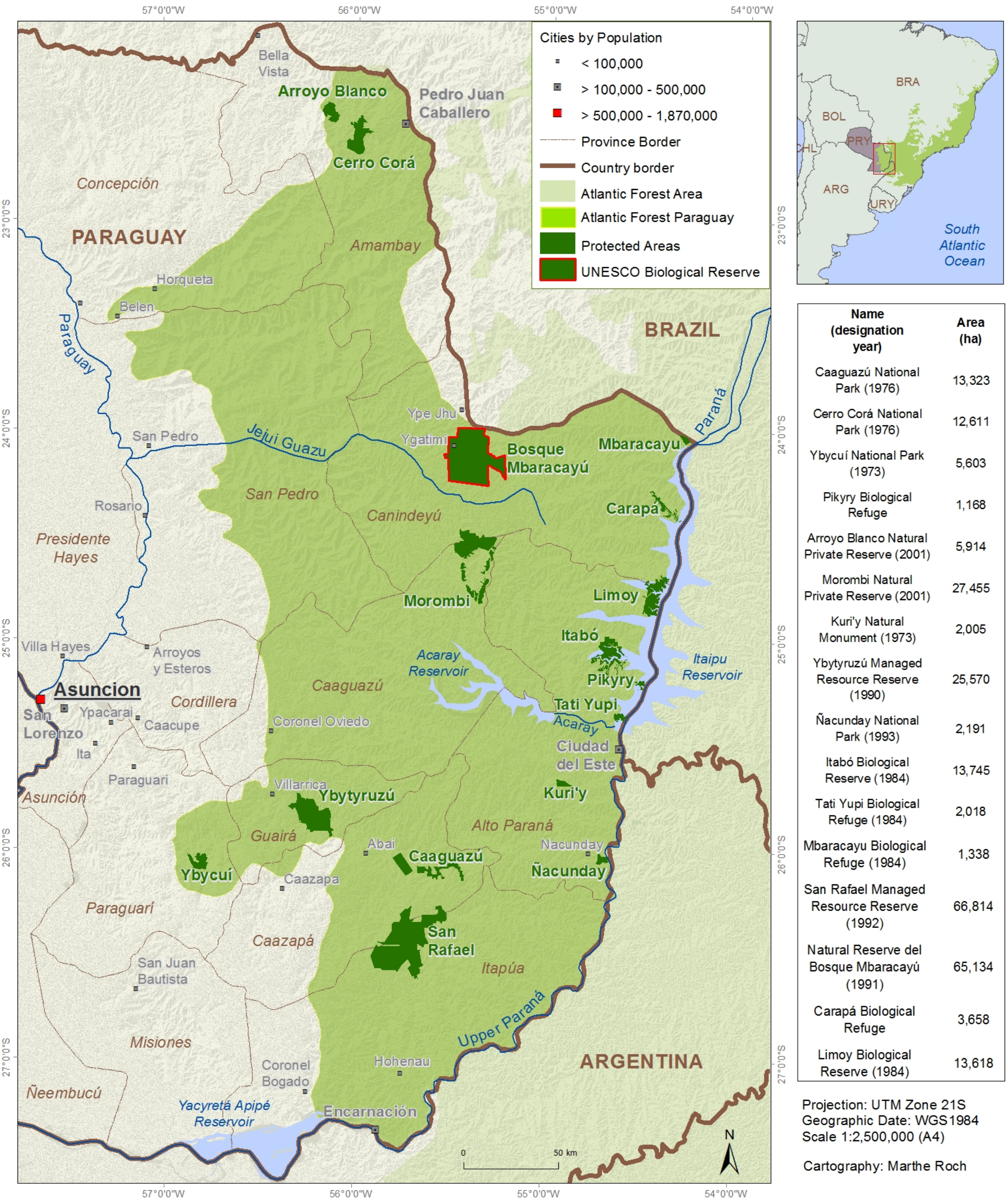
Map Information / Data Sources

Landscan is the community standard for global population distribution at approximately 1 km resolution (30" X 30"), © by UT-Battelle, LLC, operator of Oak Ridge National Laboratory with the United States Department of Energy.

Projection: UTM 21 S, Datum: WGS 1984
Geographic Coordinate System: Lat/Lon (DMS), Datum: WGS 1984
Scale: 1: 500,000 for DIN A4 prints.

Cartography: Marthe Roch

Figure 61: Map of demography in Paraguay



Name (designation year)	Area (ha)
Caaguazú National Park (1976)	13,323
Cerro Corá National Park (1976)	12,611
Ybycuí National Park (1973)	5,603
Pikyry Biological Refuge	1,168
Arroyo Blanco Natural Private Reserve (2001)	5,914
Morombi Natural Private Reserve (2001)	27,455
Kuri'y Natural Monument (1973)	2,005
Ybytyruzú Managed Resource Reserve (1990)	25,570
Ñacunday National Park (1993)	2,191
Itabó Biological Reserve (1984)	13,745
Tati Yupi Biological Refuge (1984)	2,018
Mbaracayu Biological Refuge (1984)	1,338
San Rafael Managed Resource Reserve (1992)	66,814
Natural Reserve del Bosque Mbaracayú (1991)	65,134
Carapá Biological Refuge	3,658
Limoy Biological Reserve (1984)	13,618

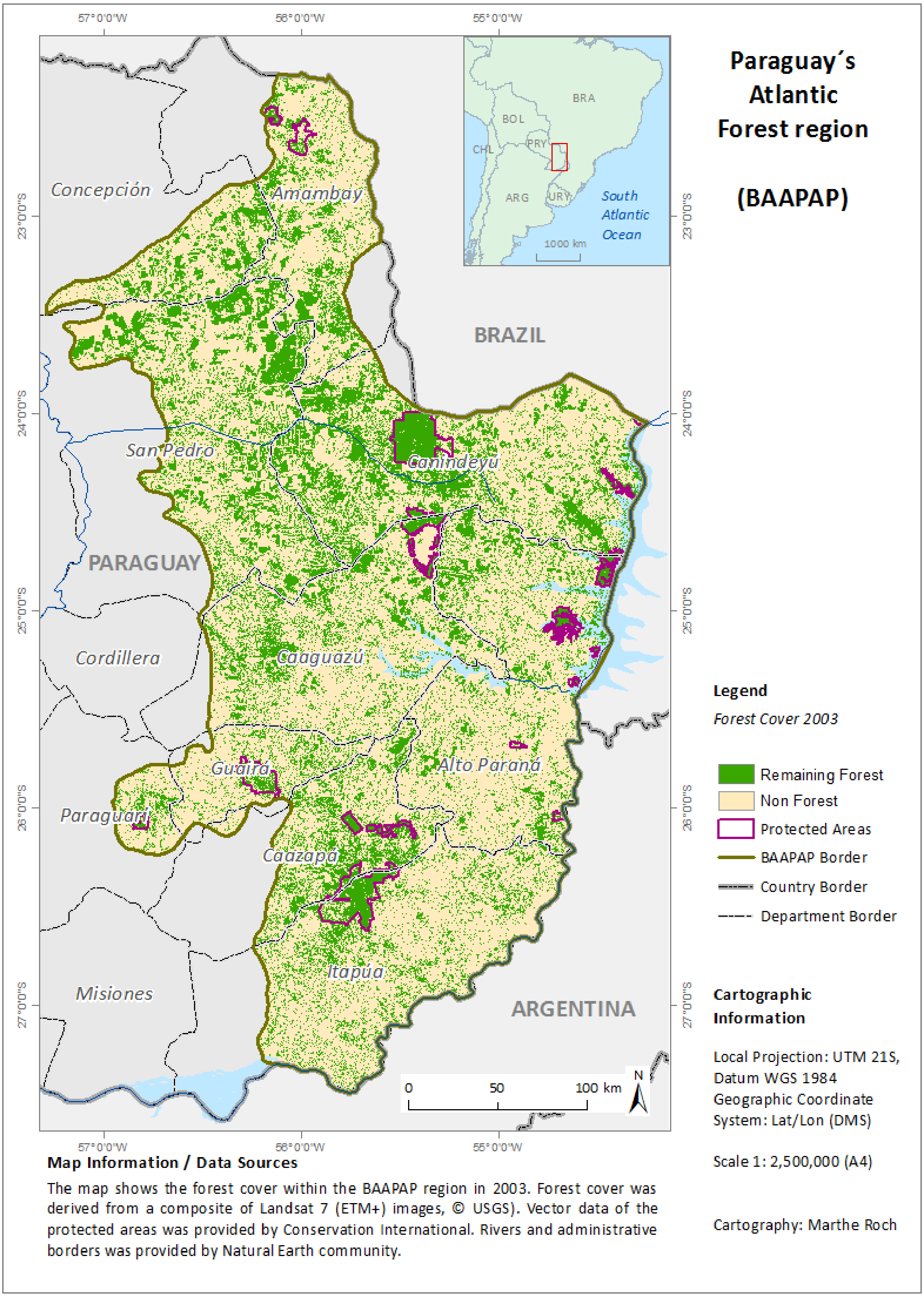
Projection: UTM Zone 21S
Geographic Date: WGS1984
Scale 1:2,500,000 (A4)

Cartography: Marthe Roch

The Atlantic Forest is one of the earth's most endangered and biologically richest ecological systems. Originally, the Atlantic Forest covered eastern Paraguay, northeastern Argentina and the area along the Atlantic coast from south to northeastern Brazil. Of the almost 2 million km², which it once covered, today, it is only approximately 7% of its original size because of massive clearing. The forest is now sparse and mainly consists of scattered forest islands. These forests form important ecological niches for birds, mammals, reptiles, butterflies and plants.Approximately 8,500 of these animal and plant species are endemic, i.e. they are native to the ecological conditions of the Atlantic Forest and only exist in this region. Extinction threatens many of the animal and plant species. The paraguayan part of this ecoregion is called "Atlantic Forest of the Upper Paraná" and covers an area of 85,833 km². Sixteen Protected Areas were designed to conserve forest and biodiversity.

Data Sources:
- World Database on Protected Areas, WCMC/UNEP2013;
- Natural Earth Vector Graphics;
- CGIAR SRTM data.

Figure 62: Map of protected areas in Paraguay´s Atlantic Forest region.



Paraguay´s Atlantic Forest region

(BAAPAP)

Legend

Forest Cover 2003

- 🟩 Remaining Forest
- ▭ Non Forest
- ▭ Protected Areas
- — BAAPAP Border
- --- Country Border
- ---- Department Border

Cartographic Information

Local Projection: UTM 21S, Datum WGS 1984
Geographic Coordinate System: Lat/Lon (DMS)

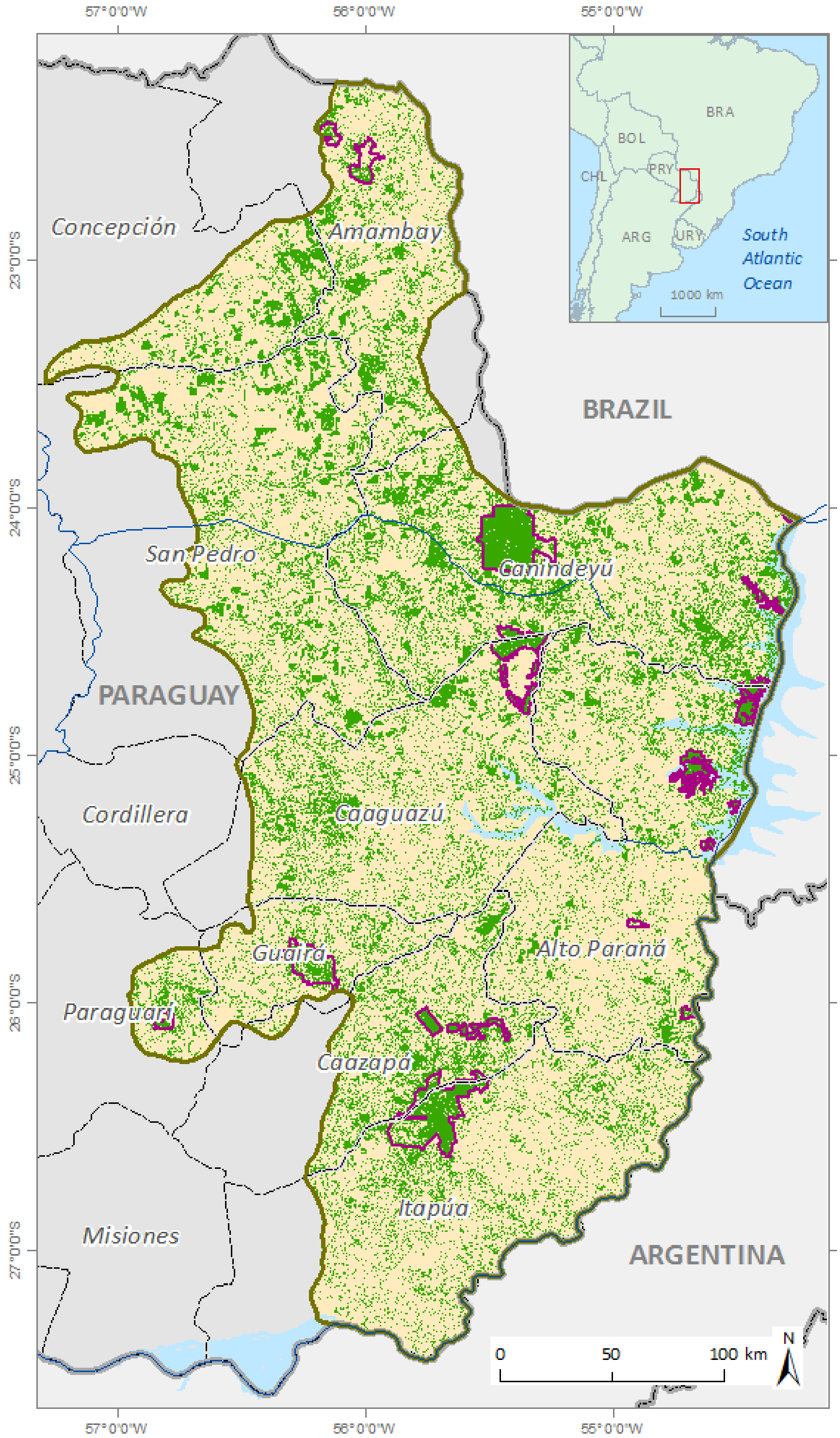
Scale 1: 2,500,000 (A4)

Cartography: Marthe Roch

Map Information / Data Sources

The map shows the forest cover within the BAAPAP region in 2003. Forest cover was derived from a composite of Landsat 7 (ETM+) images, © USGS). Vector data of the protected areas was provided by Conservation International. Rivers and administrative borders was provided by Natural Earth community.

Figure 63: Map of forest cover 2003 in Paraguay´s Atlantic Forest region.



Paraguay´s Atlantic Forest region

(BAAPAP)

Legend

Forest Cover 2013

🟩 Remaining Forest
▭ Non Forest
▭ Protected Areas
— BAAPAP Border
-·-·- Country Border
- - - Department Border

Cartographic Information

Local Projection: UTM 21S, Datum WGS 1984
Geographic Coordinate System: Lat/Lon (DMS)

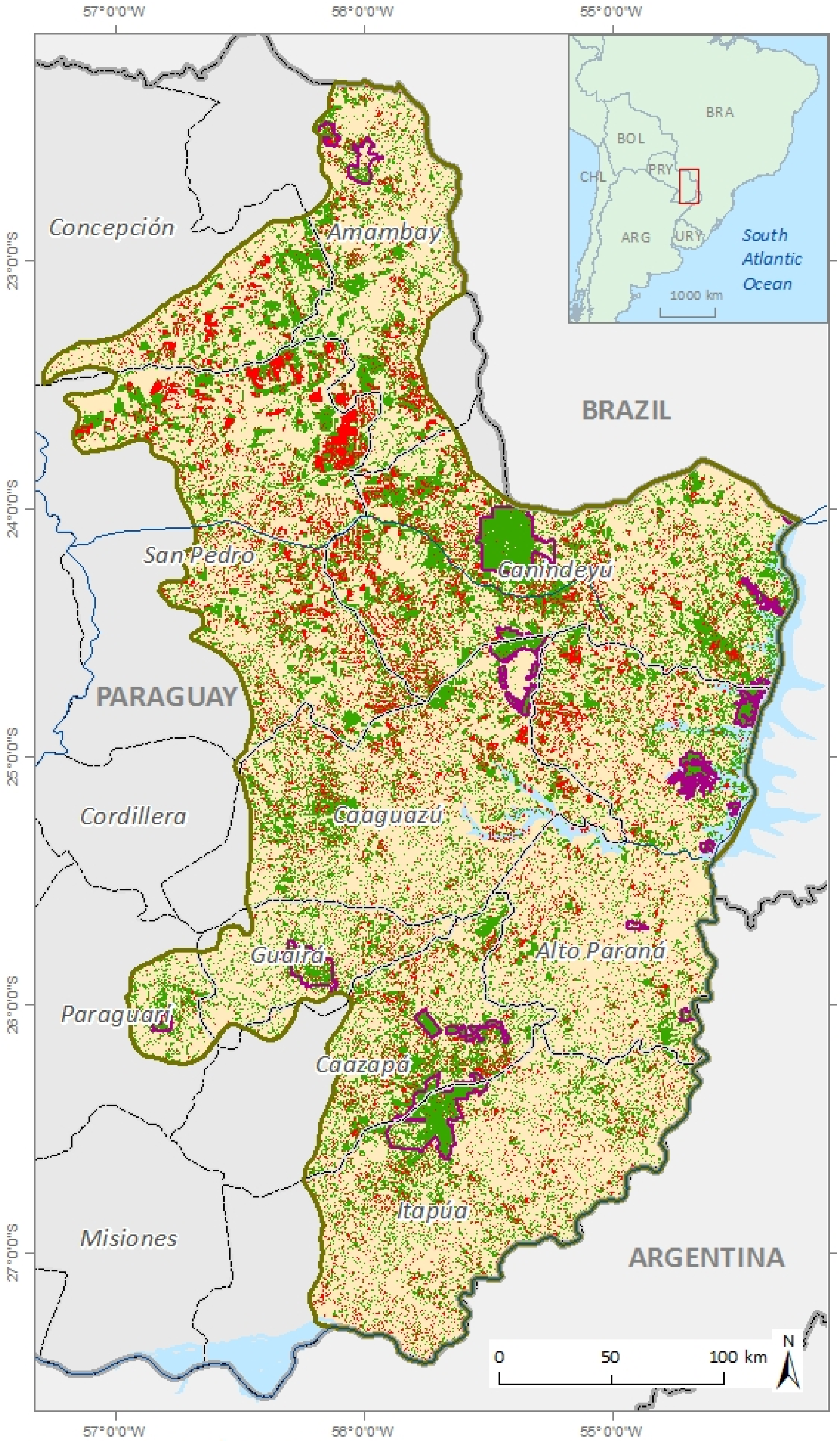
Scale 1: 2,500,000 (A4)

Cartography: Marthe Roch

Map Information / Data Sources

The map shows the forest cover within the BAAPAP region in 2013. Forest cover was derived from a composite of Landsat 8 (OLI/TIRS) images (acquisition date: April to July 2013, © USGS). Vector data of the protected areas was provided by Conservation International. Rivers and administrative borders was provided by Natural Earth community.

Figure 64: Map of forest cover 2013 in Paraguay´s Atlantic Forest region.



Paraguay´s Atlantic Forest region

(BAAPAP)

Legend

Forest Change 2003-13

🟩 Remaining Forest
🟥 Forest Loss
▭ Non Forest
▭ Protected Areas
— BAAPAP Border
— Country Border
--- Department Border

Cartographic Information

Local Projection: UTM 21S, Datum WGS 1984
Geographic Coordinate System: Lat/Lon (DMS)

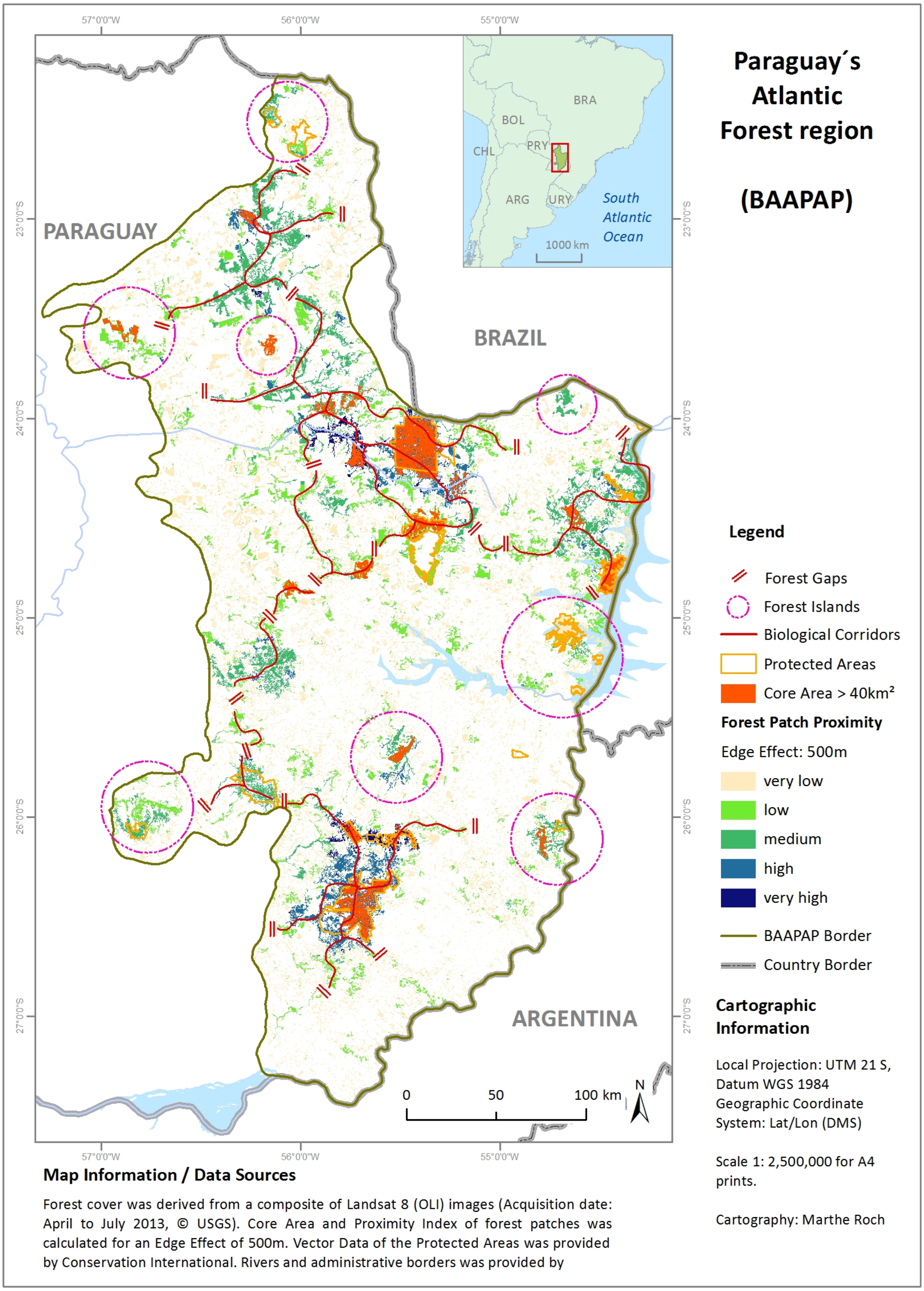
Scale 1: 2,500,000 (A4)

Cartography: Marthe Roch

Map Information / Data Sources

The map shows the forest loss within the BAAPAP region that occured between 2003 and 2013. Forest cover was derived from a composite of Landsat 7 and Landsat 8 images, © USGS). Vector data of the protected areas was provided by Conservation International. Rivers and administrative borders was provided by Natural Earth community.

Figure 65: Map of forest loss between 2003 and 2013 in Paraguay´s Atlantic Forest region.



Paraguay´s Atlantic Forest region

(BAAPAP)

Cartographic Information

Local Projection: UTM 21 S, Datum WGS 1984 Geographic Coordinate System: Lat/Lon (DMS)

Scale 1: 2,500,000 for A4 prints.

Cartography: Marthe Roch

Map Information / Data Sources

Forest cover was derived from a composite of Landsat 8 (OLI) images (Acquisition date: April to July 2013, © USGS). Core Area and Proximity Index of forest patches was calculated for an Edge Effect of 500m. Vector Data of the Protected Areas was provided by Conservation International. Rivers and administrative borders was provided by

Figure 66: Map of forest core areas and biological corridors in Paraguay´s Atlantic Forest region.