Changes in Land Use and Ecosystem Services in Paraguay

Alicia PAVETTI[1] and Osamu SAITO[2]

[1]Master Student, Graduate School of Engineering, Kyoto University
(Kyoto daigaku-katsura, Nishikyo-ku, Kyoto 615-8530, Japan)
E-mail: pavetti.alicia.78n@st.kyoto-u.ac.jp
[2]Member of JSCE, Academic Programme Officer, United Nations University

In the recent decades, Paraguay has experienced major changes in land use. In 1945 the Atlantic forest in the Eastern Region had around 88,000 km^2, of which only 13% remains as of today. As a result, dense and continuous forests had been reduced to a series of small isolated fragments with the expansion of agricultural frontier. This article aims to review land cover changes in Paraguay and its major impacts on ecosystem services. The methodology consists of an extensive review and analysis of related literature in both English and Spanish and data provided by Paraguayan institutions. The analysis was made on the basis of the Millennium Assessment conceptual framework, which states that people and ecosystems interact dynamically. The main findings show that increasing food supply was produced at the expense of the conversion of forests into agricultural land. In particular, soybean crop area was expanded by 6,240 km^2 (113% of the original) between 1990 and 2000, and by 2009 reached a total increase of 20,170 km^2. This conversion from forest to soybean farmland mainly took place in the easternmost departments of the Eastern region, and has affected various ecosystem services such as decreased in the number of natural yerba mate plantations, changes in precipitation patterns and increase in runoff levels, resulting in increases in river flows in the area. Flow data at three points in two tributaries of the Parana River showed increases of 65%, 67% and 121% respectively in the period 1975 - 2007. The increase in runoff favors soil loss and erosion of riverine coasts benefiting sediment transport in the Parana River and its affluent, increasing sedimentation levels in Itaipu Dam's reservoir.

Key Words: *land use change, deforestation, ecosystem services, ecosystem assessment, soybean.*

1. INTRODUCTION

Paraguay is a landlocked country located in the center of South America; it has an area of 406,752 km^2. Ecologically, it is considered a country with unique features due to its strategic location at the confluence of five ecoregions: the Atlantic Forest, the Chaco, the Chaco Woodland, the Pantanal and Cerrado. Geographically, the country is divided by the Paraguay River in two different regions: the western region covering 61 percent of the territory (about 246,925 km^2) and the eastern region comprising 39 percent (159,827 km^2). At the east of the river there are the remnants of the humid Interior Atlantic Forest, in the west part a vast floodplain that supports the Woodland Chaco is developed, and the Chaco is located between these two ecoregions.

The Interior Atlantic Forest is known for its high biodiversity and high levels of endemism. Originally, it covered a large portion of the eastern region, including all the departments of Alto Paraná, Canindeyú, Itapúa and Caaguazú, much of the departments of Amambay, San Pedro and Caazapá, and parts of Conception and Paraguarí (Cartes 2003[1)]). Most of this forest, an area once estimated at 88,050 km^2 (Cartes 2003[1)]), is believed to have remained intact until the mid-twentieth century (FAO 1945[2)]; Fragano and Clay 2003[3)]). However, in recent decades, Paraguay has undergone massive changes in vegetation cover, registering high rates of deforestation which have been reported by international agencies like the Food and Agriculture Organization (FAO), the World Wildlife Fund (WWF) (FAO, 2003[4)]; Dros 2004[5)]), and the United States Agency for International Development (USAID) (Catterson and Fragano[6)]). These changes in land use have taken place mainly in eastern Paraguay, where massive losses of forest resources have been recorded from the 70's as a result of rapid

agricultural expansion have led to massive and uncontrolled forest clearing.

While there are several reports on deforestation in Paraguay, Catterson and Fragano (2004)[6] and Gonzalez (2004)[7] stated that the existence of inconsistent and contradictory data sets from different studies prevented a collaborative framework for natural resource management. In this sense, the study by Huang et al. (2007)[8] involved a major contribution to the field, as it carried out a comprehensive assessment of the change of Paraguay's forest cover providing reliable quantitative data through the analysis of Landsat images. However, as it was reported by Richards (2011)[9] that very little work had been conducted to understand the drivers of the surface cover change process, and influences on the services provided by ecosystems.

This article thus aims to provide an overview of the changes in land cover in the Eastern region of Paraguay and its major impacts on ecosystem services. The related literature and various data from several governmental institutions were collected in order to analyze the information under the Millennium Ecosystem Assessment framework.

2. METHOD AND MATERIALS

Land cover and land cover changes are analyzed by an environmental history approach which takes into account the major drivers that influenced the land cover changes process experienced by Paraguay in the last decades. Major causes of land use changes include migration, agricultural development, demographic changes and the role of policies and regulations. In particular, this paper focuses on the loss of forest cover in the easternmost area of the country.

Secondly, through the analysis of quantitative data extracted from various reports and studies as well as those provided by the various governmental institutions, major ecosystem services (benefits provided from ecosystems to human well-being) and their changes are assessed on the basis of the conceptual framework of the Millennium Ecosystem Assessment.

This conceptual framework places the human well-being as the center of the assessment and assumes a dynamic interaction between people and ecosystems, with the changes in the human condition serving as both direct and indirect drivers of ecosystem changes and these changes in ecosystems cause changes in human well-being. At the same time, many other factors that are independent of the environment change the human condition, and many natural forces influence ecosystems. This approach focuses mainly on the linkages between ecosystem services and human well-being. It also deals with a wide range of ecosystems, from those relatively undisturbed, such as natural forests, to landscapes with mixed patterns of human use and ecosystems intensively managed and modified by humans, as agricultural land and urban areas. (Millennium Ecosystem Assessment 2005[10].

Our analysis uses three types of quantitative data: (a) estimates of forest cover loss between 1945 and 2010, (b) patterns and trends of agricultural production, (c) estimates and trends of population.

3. LAND USE CHANGES IN PARAGUAY

The richness and distinctiveness of Paraguay's biodiversity was recognized as early as in the late 19th century, when the country was described by Levi (1984)[11] as a paradise of life, while Morong (1889)[12] stated that few countries with the size of Paraguay could have such a diverse and prolific flora.

Even though there are a number of studies and reports available which provide summary data on forest cover in Paraguay, most of these tend to emphasize the status of the forest in the Eastern side of the country (Huespe Fatecha et al. 1994[13]; Cartes 2003[1]; Fragano and Clay 2003[3]; Gonzales 2004[7]; Huang et al. 2007[8]; Richards 2011[9]). These data sets present inconsistencies in some cases and impeded collaborative framework for natural resources management due to the lack of standardization of the results (Bozzano and Weik 2002[14]; Gonzales 2004[7], Catterson and Fragano 2004[6]; Huang et al. 2009[15])

3.1 National scale changes

Much of Paraguay's Atlantic forest remained "intact" before 1940, with the main form of deforestation being selective logging (Cartes, 2003[1]). Since then, however, forest clearance became the major form of deforestation. Massive loss of Paraguay's forest resources has been reported since 1970s, especially in eastern Paraguay (FAO, 1993[16], 2001[17]; Sanjurjo & Gauto, 1996[18]).

According to the forest cover change map developed by Huang et al. (2009)[15], Paraguay had 202,202 km^2 of forest in the 1990s. By the 2000s, the extent of the forest decreased to 176,741 km^2. The departments in eastern Paraguay with high growth of soy crop between 1984 and 2001 including Caaguazu, Canindeyu, Caazapa and Alto Parana, generally experienced higher rate of changes than those in other regions. The

Paraguayan Atlantic Fores Ecoregion (PAFE) region used to have extensive forest cover up to the early 1970s, with over 70% . Within less than 30 years from the early 1970, the forest cover in the PAFE region was reduced to 40,7% by 1989 and to less than 25% by 2000 (**Table 1**). The average deforestation rate in this region was 1,749.97 km^2/year between 1873 and 1989 and 1,228.21 km^2/year between 1989 and 2000.

Of the forest areas cleared between 1989 and 2000, nearly 80% was converted to large tracts of agricultural fields by private land owners and 20% to small farmland patches by settles. Because the size of the areas cleared by settlers is usually very different from that of the large private land owners, two types of deforestation processes can be distinguished by the Landsat images. According to a systematic analysis by Huang et al. (2007)[8], the ratio of areas cleared by the large land owners and the settlers was 6:4 between 1970s and 1990s, and 8:2 between 1990s and 2000s, which suggests that large land owners were responsible for the majority of forest loss.

Table 1. Estimation of forest cover in Paraguay's Eastern Region by different studies.

Year	Forest Cover (km^2)	Source
1945	88,050.00	Gonzales 2004
1965-1968	70,420.00	Gonzales 2004
1973	62,758.50	Huang et al. 2007
1975-1976	54,920.00	Gonzales 2004
1984-1985	53,000.00	IICA
1986	52,617.00	WWF
1989	44,640.60	Huang et al. 2007, 2009
1991	24,030.00	Gonzales 2004, IICA
1997	28,377.20	Gonzales 2004, IICA
1999	39,742.70	Gonzales 2004
2000	29,716.10	Huang et al. 2007, 2009
2002	34,751.00	Gonzales 2004
2008	22,639.20	WWF

Table 2. Departments with highest percent of forest loss. (Huang et al. 2009)

Department	Forest in 1990s (km^2)	Forest in 2000s (km2)	Percent change (%)
Caaguazu	3812.78	2261.59	40.68
Caazapa	3216.8	1933.11	39.91
Canindeyu	8262.97	4903.05	40.66
Itapua	4192.13	2577.98	54.51
Alto Parana	5043.96	2599.79	48.46

Given the expansion of cotton and soy, and to an extent cattle ranching during this period, it seems that each of these land uses played a direct or indirect role in this land cover change process between 1960 and 2000 (Richards 2011[9]). The rapid agricultural expansion of both cotton and soy in the 1970s and 1980s occurred in conjunction with the nation's highest rates of deforestation, which reached between 2,100 and 2,880 km^2 per year during that period (FAO 2001[17]; Catterson and Fragano 2004[6]). From 1991 to 2001, as the area of soybean cultivation in Paraguay continued to grow, expanding to 7,304 km^2, deforestation continued at 1,230 km^2 per year (GLCF 2006[19]). From 1990 to 1995, Paraguay's deforestation rate was among the highest in the world and was the highest in South America (FAO 1999[20]). Maps of soy coverage in 2007 and 2008, in addition to data derived from agricultural censuses, indicate a concentration of soy production in the once-forested easternmost departments (INBIO 2009[21]). Although they also demonstrate a recent decrease in soy production by small-holder farmers in areas such as southeastern Itapua, soy production remains the domain of large-scale agriculture.

3.2 Regional and local scale changes

According with Huang et al. (2009)[15], the departments located in the easternmost area of the Eastern region are the ones that experienced the highest deforestation rates. The change of the forest cover from 1989 to 2000 in these departments ranged 39.9 - 54.5% (**Table 2**). According to the agricultural censuses, these deforested areas were turned to the major production area of soybean, and the largest tracts of agricultural fields are located in these departments.

Regarding to the protected areas, they slowed down the loss of forest within their boundary; most protected areas lost only a few percent of their forest during the same period with the maximum percent forest loss being 13.1%. Nevertheless, an analysis of forest change in areas surrounding the protected areas revealed that the protected areas did not slow down the forest loss in their surrounding areas with 30% the average percent forest loss within 5 km from the boundary of the protected area between 1989 and 2000, which was almost the same as that for the entire PAFE region (Huang et al. 2007[8], 2009[15]).

3.3 Causes of the land use changes

(a) Trans-national factors: migrations

The migration of Brazilian colonists to Eastern border region had its beginnings in the mid-1960s and accelerated after 1972. According to Nickson (1981)[22], in 1943 there were only 513 Brazilian

farmers in Paraguay and by the year 1972 the country hosted more than 12 Brazilian agricultural colonies which accounted for more than 90% of foreigners living in the departments of Canindeyú, Amambay and Alto Paraná. By 2003, 37,000 Brazilians owned about 12,000 km^2 of the eastern border departments (Lopez 2003[23]). The migration was favored by a number of structural changes that took place in the rural economy of southeastern Brazil as well as disparities in land prices and changes in world prices of soybeans, in addition to the particularly suitable soils of the eastern border region for agriculture and start of the construction of the Itaipu Dam. Richards[9] also says that the Paraguayan government proceeded with the sale of large tracts of land from former landowners to Brazilian investment firms and organized colonies for Brazilian farmers as a way to lay the path to the introduction of capitalist agriculture in Paraguay under the Brazilian control.

With their arrival, Brazilian migrants brought with them a new agricultural model based on export-oriented model, as well as working experience with capital-intensive commodity crops, and access to new markets and agricultural networks that were emerging in Brazil. This resulted in the acquisition of resources needed to convert large tracts of forests in large-scale agricultural fields. Nagel (1991)[24] suggests that farmers in Brazilian communities were clearing and cultivating twice the area of the Paraguayan populist colonies and were more likely to grow capital-intensive crops such as soybeans. This rapid colonization caused massive destruction of forests in the eastern border region, estimated in 25,000 km^2 of dense subtropical forests (Nickson 1981[22]) and the rapid growth of agricultural production in the region, where soybeans became the item that currently dominates the rural economy, positioned Paraguay as one of the worldwide largest exporters of soybeans.

(b) Agricultural development

In the early '50s, Paraguay's agricultural economy was largely based on food production for domestic consumption and intensive-labor crops for export. These intensive-labor crops were mainly coffee, snuff, tung and cotton, being the latest the main export product of the time. Nevertheless, over the following decades, the economy experienced profound changes with the introduction of land-extensive crops such as soybeans, and the labor-intensive crops gradually disappeared from the ranking of the most important export crops.

The importance of cotton as the main export crop has declined rapidly since 1990, reducing the cultivated area by more than 50% in 10 years (1990-2000). Cotton is mainly associated with small farmers or smallholders. Oppositely, soy emerged as the dominant export crop, which can be readily seen in the significant increase occurred in its cultivated area. In just 20 years (1990-2010), the soybean area has increased 4.6 times from 5,527 km^2 to 25,700 km^2 and today accounts for over 40% of total value of agricultural production. Estimates made in 2007 indicate that over 70% of soybean production takes place in the departments of Alto Paraná, Canindeyú and Itapúa, and that production declines as one moves westward to the departments of central-eastern Paraguay. In addition, it should be noted that Soybean production is usually associated with large-scale production systems.

(c) Demographic changes

Estimates of Paraguayan population indicate that in the last 60 years (1950-2009) it has nearly quintupled, exceeding 6,300,000 inhabitants (**Figure 1**) and it is expected that by 2050 it reaches about 13,000,000. The population density for 2009 is 15.6 inhabitants per km^2.

One of the most remarkable demographic phenomena that characterized Paraguay in the last decades is the rapid and unplanned urbanization (**Figure 1**). In the period 1950-2009 the urban population increased from 34 to 58% (DGEEC[25]). Since colonial times, settlements have been more intensive in the Eastern Region where 97% of the total population is inhabited and the Interior Atlantic Forest is located. The most urbanized areas are the capital Asuncion and the departments of Central and Alto Paraná, which together constitute 51% of the total national population, followed by the departments of Itapúa and Caaguazú. These four departments and the capital account for only 11% of the national territory, but they make up more than 67% of the population.

Another factor that has affected the rate of urbanization is the internal migration in recent decades. This process is closely linked to socioeconomic status as the main urban centers constitute the objectives of the poor rural population who look for opportunities to migrate to cities to find better living conditions.

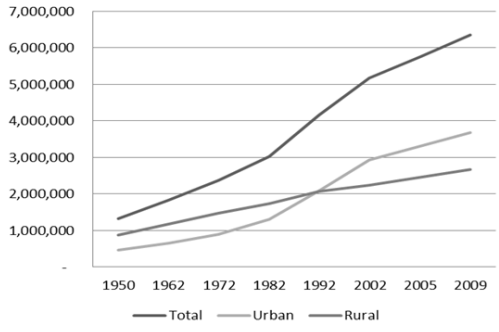

Figure 1. Population trend of Paraguay. (DGEEC)

4. CHANGES IN ECOSYSTEM SERVICES

4.1 Provisioning services

Increasing food supply was produced at expense of the conversion of forest into agricultural land. Forest area in the eastern region was reduced in 22,001 km^2 between 1990 and 2008 and soybean cultivated area increased in 19,109 km^2, which accounts for 86.9% of the total deforested area in that period (**Figure 2**).

Particularly, the easternmost departments of the eastern region with the highest soybean production in the country face the highest percentage of forest loss (**Table 2**, **Figure 3**). In Alto Parana an equivalent of 86.5% (2,115 km^2) of the deforested area between 1990 and 2000 was transformed into large tracks of soybean while in Itapua the numbers reach to 120.5% (1,945 km^2) of its total deforested area. For the departments of Caazapa, Canindeyu and Caaguazu, the percentage of deforested area converted to agricultural fields between 1990 and 2000 was 44.7, 25.6 and 24.6 respectively.

These results support the notion that large-scale agriculture, driven mainly by soybean, assumes a strong role as a driver of deforestation in the eastern region and particularly of the Paraguay's Atlantic Forest. Results like these were also found by Huang et al. (2007)[8] and Richards (2011)[9].

4.2 Regulating services

Yearly mean observed discharge at three points in two different afluents of the Parana River in the department of Alto Parana show increases in flow rates (**Figure 4**). For the period 1975 – 2007, the respective increments are 67.0%, 65.1% and 121.1% of their original volume. These changes in flow rates may be strongly associated with deforestation of the area since observed precipitation at the same points didn't show so significant changes, registering increments of 13.9% and 1.1% of their volume in 1975 for the points named Confluencia and Balsa, and for the case of Barra precipitation showed a negative tendency. Consequently, it is suggested that runoff processes were altered due to deforestation and the changes in land use.

For the particular case of Confluencia, the ratio between maximum and minimum extreme flow for the period 1975 – 2007 increased from 3.21 to 4.33 during the rainy season (October to December) and from 3.05 to 3.43 during the dried season. It can be inferred that as the ratio continues increasing, the difference between maximum and minimum flows also keeps growing. This behavior is usually associated with deforestation [26].

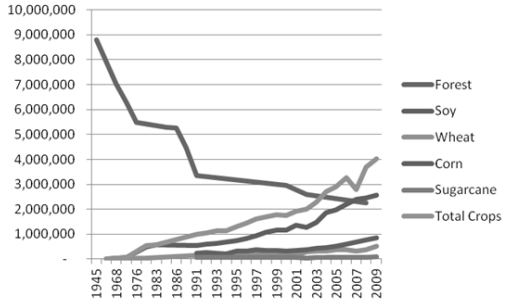

Figure 2. Forest cover and major crops of the Eastern Region (km^2)

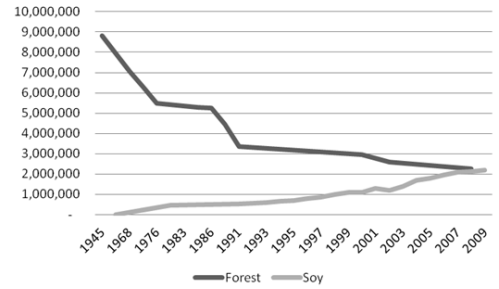

Figure 3. Forest cover of the Eastern Region and Soybean cultivated area in the easternmost departments (km^2)

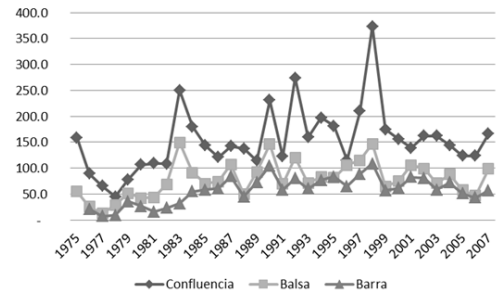

Figure 4. Average stream flow at three points in two afluents of the Parana River in the department of Alto Parana (m^3/seg)

4.3 Cultural services

Yerba Mate (*Ilex paraguariensis*) is a medium-sized evergreen tree that is widely commercially-harvested in Paraguay. It is original to subtropical South America and grows naturally between 18°C - 25°C of south latitude. Its east-west distribution is from Atlantic Ocean to the Paraguay River. In the wild, this plant needs around 30 years for its complete development, and reaches up to 12 to 16 meters, forming a tree full of leaves with a straight trunk up to 50-70 centimeter in diameter and with smooth grayish bark [28]. However, due to practical purposes its height is maintained between 3 and 6 meters when it comes to cultivation and rational exploitation, acquiring a short trunk that branches low over the ground.

The yerba mate has been used as a beverage

since the time of the ancient Indians of Paraguay and Brazil. The Mate, which is prepared using dried and milled leaves of yerba mate, is a stimulant infusion common in Paraguay and other countries such as Argentina, Brazil and Uruguay. Paraguayans have the tradition and custom of drinking Mate in a daily base, alternating the way of preparing it depending on the season. According to the Ministry of Agriculture the per capita consumption amounts to 2.5 kg per year and 99% of its production is destined for domestic consumption. Nowadays, yerba mate is mainly obtained from cultivation lands specially established for that purpose. In the past, natural yerba mate plantations could be found across the Paraguayan Atlantic forest but their area was greatly reduced due to the deforestation process, depending now on the production obtained from the cultivation fields to meet the domestic demand. **Figure 5** shows the evolution of the yerba mate cultivated area compared to the loss of forest. It can be observed that as much forest land is cleared, more cultivation land is enabled, which is coherent if the domestic demand must be met and natural yerba mate plantation are no longer available.

4.4 Supporting Services

The amount of sediments that reaches Itaipu Dam's reservoir is 42,000,000 m^3 per year[28]. This estimation is 20% higher than the one made by the consulting company Einstein & Harder in the feasibility phase of the hydroelectric during the years 1972-1974. Based on this estimation, the reservoir of Itaipu lost about 1,260,000,000 m^3 of capacity in a period of 30 years (dam's operation started in 1984). This volume represents about 4.3% of its total capacity. The Annual Report of the year 2001 of Itaipu Binacional[29] stated that reforestation of all the margins of the rivers flowing into the reservoir should be considered as a measure to prevent erosion and sediment transportation because the increase in erosion is produced by the lack of vegetation capable of sustaining soil.

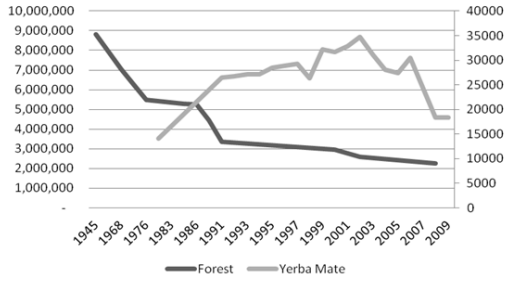

Figure 5. Forest cover of the Eastern Region and Yerba Mate cultivated area (km^2)

5. DISCUSSION AND CONCLUSION

This article reviews land cover, land cover changes, and their major drivers in Paraguay. Through the analysis of data extracted from several reports and studies as well as those provided by government institutions, impacts on ecosystem services were also assessed. Previous studies agreed that most of the Paraguay's Atlantic forest remained "intact" until 1940; and since then forest clearance became the major form of deforestation and massive loss of forest resources has been reported since 1970s, especially in eastern Paraguay [1), 8), 15), 16), 17), 18)].

The Parana Atlantic Forest region used to have extensive forest cover up to the early 1970s, with over 70%[8]. Within less than 30 years from the early 1970, the forest cover in the PAFE region was reduced to 40.7% by 1989 and to less than 25% by 2000. Of the deforested area between 1989 and 2000, 80% was converted to large tracks of agricultural fields belonging to private land owners and the rest 20% was attributed to small farmland patches by settles. Based on this, the expansion of soybean, which is related with large scale production system, played an important role as a direct or indirect driver of the land cover change process. This rapid agricultural expansion occurred simultaneously with the nation highest deforestation rates [6), 9), 17)]. Other drivers of change that were identified are the Brazilian migration to the eastern border region and population growth. Regarding to the migration of Brazilians, studies suggest that this people were the ones who introduced in Paraguay the mechanized large scale production system replacing the labor-intensive system that used to dominate the Paraguayan agriculture.

Assessment of ecosystem services changes due to land use changes suggests that increasing food production was achieved at expense of the conversion of forest into agricultural land. Forest area in the eastern region was reduced in 22,001 km^2 between 1990 and 2008 and soybean cultivated area increased in 19,109 km^2, representing 86.85% of the total deforested area in that period. Soybean expansion impacted at the same time on other agricultural crops such as cotton and yerba mate[9], which disappeared from the chart of top agricultural goods as soybean became the major export product. Natural yerba mate plantation was also strongly affected by deforestation processes, reaching to the point that the yerba mate industry depends mainly on farmlands to meet the domestic demand. Regulating and supporting services such as stream flow, erosion and sediment transportation also presented significant changes. Regarding to stream flow, the increments during the period 1975 – 2007 reached 67.0%, 65.1% and 121.1% of their original

volume in three different points located in two affluents of the Parana River in the department of Alto Parana, one of the department with highest deforestation rates. In this area, erosion was assessed by Carvalho and Catharino[28] and they estimated that the amount of sediments reaching the Itaipu Dam's reservoir is about 42,000,000 m^3 per year, quantity that is 20% higher than previous estimations. This difference in the quantifications of sediments reaching the reservoir can strongly be correlated to the land use changes suffered in the upstream part of the basin.

REFERENCE

1) Cartes, J. L.: *Brief history of conservation in the interior Atlantic forest*. In *The Atlantic forest of South America: Biodiversity status, threats, and outlook*, ed. C. Galindo-Leal and I.d. G. Camara, pp. 269−287. Washington: Island Press, 2003.
2) Food and Agriculture Organization (FAO): *Los Recursos Forestales del Paraguay; Estudio Forestal [Forest Resources in Paraguay]*, http://www.fao.org/docrep/x5344s/x5344s01.gif (last accessed 12 June 2012), 1945.
3) Fragano, F., Clay R.: *Biodiversity status of the interior Atlantic Forest of Paraguay*, In *The Atlantic Forest of South America: Biodiversity status, threats, and outlook*, ed. C. Galindo-Leal and I. Gusmao Camara, pp. 288-309. Washington, DC: Island Press, 2003.
4) Food and Agriculture Organization (FAO): *Forest Resources Assessment 2001*. FAO Forestry Paper 140, Rome: FAO of the United Nations, 2003.
5) Dros, J.M.: Managing the Soy Boom: Two Scenarios of Soy Production Expansion in South America. *AID Environment*, Amsterdam, 2004.
6) Catterson, T.M., Fragano, F.V.: *Tropical forestry and biodiversity conservation in Paraguay: Final Report of Section 118/119 Assessment, EPIQ II Task no. 1.* Asuncion, Paraguay: USAID, 2004
7) Gonzales, R.: Informe Nacional: Paraguay [National Report: Paraguay], Rome: FAO/National Forest Service, *ftp://ftp.fao.org/docrep/fao/009/j3292s/j3292s00.pdf* (last accessed 12 june 2012), 2004.
8) Huang, C., Kim, S., Alstatt, A., Townshend, J.,Davis, P., Song, K., Tucker, C., Rodas, O., Yanosky, A., Clay, A., Musinskiy, J.: Rapid loss of Paraguay's forest and the status of protected areas – A Landsat assessment. *Remote Sensing of Environment* 106 (4): pp. 460-66, 2007.
9) Richard, P.D.: Soy, Cotton, and the Final Atlantic Forest Frontier, *The Professional Geographer*, 63:3, pp. 343-363, 2011.
10) Millennium Ecosystem Assessment: *Ecosystem and Human Well-being: Synthesis.* Island Press, Washington, DC, 2005.
11) Levi, L.: *On the geography and resources of Paraguay*. Proceedings of the Royal Geographical Society of London 18 (2), pp. 117–129, 1874.
12) Morong, T.: Paraguay and its flora II. *Botanical Gazette* 14 (10), pp. 246–253, 1889.
13) Huespe Fatecha, H., Spinzi Mendica, L., Curiel, M. V., Burgos, S., Rodas Insfrán, O.: *Uso de la tierra y deforestación en la región oriental del Paraguay, Periodo 1984 – 1991* [Land use and deforestation in the eastern region of Paraguay, Period 1984 – 1991], Vol. 1. San Lorenzo, Paraguay: UNA/FIA/CIF, 1994.
14) Bozzano, B. E., Weik, J. H.: *El avance de la deforestación y el impacto económico* [The rate of forest loss and economic impact]. Proyecto de Panificación del Manejo de Recursos Naturales, Serie no. 12. Asunción, Paraguay: MAG/GT-GTZ, 2002.
15) Huang, C., Kim, S., Song, K., Townshend, J. R. G., Davis, P., Altstatt, A., Rodas, O., Yanosky, A., Clay, R., Trucker, C. J., Musinsky, J.: Assessment of Paraguay's forest cover change using Landsat observations, *Global and Planetary Change* 67, pp. 1-12, 2009.
16) Food and Agriculture Organization (FAO): *Global forest resources assessment 1990 — Tropical countries*. FAO forestry paper, vol. 112. Rome: FAO of the United Nations, 1993.
17) Food and Agriculture Organization (FAO): *State of the world's forest 2001*. Rome: FAO. http://www.fao.org/docrep/003/y0900e/y0900e01.htm (last accessed 12 june 2012), 2001
18) Sanjurjo, M., Gauto, R.: *Paraguay*. In *The conservation atlas of tropical forests: The Americas*, ed. C. S. Harcourt & J. A. Sayer, pp. 286−293. New York: Simon & Schuster, 1996
19) Global Land Cover Facility (GLCF): *Forest cover change in Paraguay, Version 1.0*, College Park, MD: University of Maryland Institute for Advanced Computer Studies. http://glcf.umiacs.umd.edu/data/Paraguay (last accessed 12 june 2012), 2006
20) Food and Agriculture Organization (FAO): Table 3. In *State of the world's forests 1999.* Rome: FAO. http://www.fao.org/docrep/W9950E/w9950e24.htm#TopOfPage (last accessed 12 june 2012), 1999.
21) Instituto de Biotecnología Agrícola (INBIO): *Estimación de Superficie Sembrada – Soja. Campaña Agrícola 2007-2008* [Estimates of soybean area; agricultural season 2007/2008]. http://www.inbio-paraguay.org/sfiles/trabajos_investigacion/10.pdf (last accessed November 2009), 2009.
22) Nickson, R. A.: Brazilian colonization in the eastern border region of Paraguay, *Journal of Latin American Studies* 13 (1): pp. 111-31, 1981.
23) Lopez, A.: *Problemas fronterizos entre Brasil y Paraguay en la Producción y Comercialización Internacional de la Soja* [Frontier problems between Brazil and Paraguay and the international commerce of Soy]. Caracas, Venezuela: Universidad Simón Bolivar, 2003.
24) Nagel, B. Y.: Socioeconomic differentiation among small cultivators on Paraguay's eastern frontier, *Latin American Research Review* 26 (2): pp. 103-32, 1991.
25) Dirección General de Estadísticas, Encuestas y Censos [Department of Statistics, Surveys and Censuses; DGEEC]: Anuario Estadístico 2009 [Statistics Yearbook 2009]. Asunción, Paraguay: DGEEC.
26) Tucci, Carlos E. M.: *Impactos da variabilidade climática e uso do solo sobre os recursos hídricos* [Impacts of climate variability and land use on water resources]. Fórum Brasileiro de Mudanças Climáticas, pp. 77-90, 2002.
27) Porter, R. H.: Mate: South American or Paraguayan Tea, *Economic Botany*, Vol. 4, pp. 37-51, 1950.
28) Carvalho, N. O., Cathatino, M. G.: *Avaliação do assoreamento de reservatório da UHE Itaipu* [Evaluation of reservoir sedimentation of Itaipu], In X Simpósio Brasileiro de Recursos Hídricos/ I Simpósio de Recursos Hídricos do Cone Sul. pp 174-183, V5, 1993.
29) Itaipu Binacional: *Memoria Anual 2001* [Annual Report 2001], Asuncion, Paraguay: Itaipu Binacional, 2001.

(Received July 18, 2012)