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Assessment of rates of deforestation classes in the Paraguayan Chaco (Great South American Chaco) with comments on the vulnerability of forests fragments to climate change

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Abstract A large portion of the Occidental Region of Paraguay consists of a semi-arid territory with vegetation adapted to the features of this region. For just over a decade, a process of intense deforestation has resulted from the expansion of mechanized farming, carried out without any form of land management or planning; this has led to the fragmentation of the forests in this region. This study has taken satellite imagery from 1975, 1990, 2000 and 2007 with the purpose of determining the average size of the fragments and the rate of forest discontinuity; the results of this multi-temporal imagery analysis show that (a) in some areas of the Central Chaco, the forest matrix was transformed principally into cropped areas; (b) the majority of the fragments are isolated from one other; and (c) the areas mostly covered by forests are in the north-northeastern and northwestern areas and this is mainly as a result of a greater concentration of protected areas. In conclusion, the vulnerability of the vegetation formations increases with the fragmentation process, to which we should add an increased frequency of fires, a reduced resilience and homeostasis of the vegetation formations; thus these are highly exposed to climate change factors. It is imperative that the forest landscapes be restored, through the implementation biological corridors, to ensure the continuity of the remaining forests.

1 Introduction

Paraguay, a landlocked country located in the centre of South America, has an approximate surface area of 406,700 km^2, with two very distinct natural regions, both physically and biologically. These are separated by the Paraguay River: the Oriental region and the Occidental

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region, also known as Chaco. The Oriental region has an average temperature of 21–22 °C and rainfall ranging between 1,400–2,000 mm/year.

The country's current population is approximately 6.7 million, of which only 8 % inhabits the Chaco; these are comprised mainly by the indigenous peoples of various ethnic groups, followed by Mennonite immigrants, who first settled in the region during the 1920s and carried out intensive farming activities that have resulted in the Chaco becoming the main producer of dairy products in the country, and finally the local mestizos called "Paraguayans".

The main productive activity in this region is cattle ranching; the Paraguayan Chaco is not only the largest dairy region in the country, run mainly by the Mennonite groups, but is also renowned for its meat production. In recent years, both industries have grown substantially as a result of improved prices in the international market. This has led to an overall increase in the cattle ranching activities in the region, consequently generating a greater demand for the cultivation of pastures, which are gradually replacing the natural vegetation, thus resulting in an increased forest fragmentation of the Chaco.

The fragmentation of natural ecosystems, particularly forests, is a global change that is observed with increasing intensity in countries with forest cover; the logging and clearing of forest cover, the transformation of natural grasslands into arable fields, and the creation of permanent housing developments, all reduce wildlife habitat. In fact, fragmentation and habitat reduction are two different phenomena, but occur simultaneously; anthropogenic activities such as deforestation, urban expansion, etc., breakup the natural ecosystem resulting in these pristine habitats being reduced to a smaller size, leaving them practically in complete isolation, transforming them into islands, and thus generating considerable ecological damage of which we still have little knowledge in the Paraguayan Chaco.

According to Bustamante & Grez (1995), a fragmented forest can be described by elements such as the number of fragments, and their size, shape and degree of isolation, as well as the type of matrix that surrounds the system; these can be variable, such as crops, human settlements, secondary vegetation, amongst others.

Other activities that have contributed to the fragmentation of the natural ecosystems of the Chaco have been oil prospection, particularly in the northern part of the territory, and the construction of highways and main roads, resulting in the fragmentation of large forest blocks.

1.1 Physical aspects

In terms of climate, a part of this territory lies within the semi-arid region with an average rainfall of 400 mm/year. Rain is unevenly distributed; the north and north-western areas are the driest, with rainfall ranging from 400–800 mm/year which falls during the months of spring and particularly summer (November to February); to the northeast, east and southeast of the region, closer to the Paraguay River, rainfall reaches 1,300–1,400 mm/year and is more regularly distributed.

Winters are very dry and rainfall during the months of July-August does not exceed 3–4 mm/year. The average temperature is about 25 °C, with maximum temperatures reaching 45 - 48 °C during the summer season while minimum temperatures reach−3 to–7 °C during the winter season. For the most part, the daily thermal variation range can be considerable, often spanning 20° or more, particularly in summer.

The soils are generally clayey, with clay contents varying up to about 40 % (Gleysols, Vertisols, Luvisols and Regosols) in most areas; however, sandy soil intrusions can be found in an area of sand dunes known as "*médanos*" in the NW and N, (Arenosols from different origins; aeolic or hydric) (Barboza et al. 1998).

1.2 Biotic communities

a) Vegetation

The vegetation develops within the context of the climate; the denser woodland areas occur between the 800–1,300 mm/year climatic range, while the remaining areas (shrubland with different densities) occur below 800 mm/year. Others formations respond to an edaphic climax, as is the case of the hydromorphic and savannah-like expanses of *Copernicia alba*, “carandá’y”, which occur within the mesopotamia of the Paraguay and Pilcomayo Rivers and along the banks of the Paraguay River from approximately 23° South latitude.

The main vegetation types are:

1.3 Forests

Sub-humid and semi-deciduous forests they occur along the western bank of the Paraguay River and within the Paraguay-Pilcomayo mesopotamia, with an average rainfall reaching 1,400 mm in the floodplain of the Paraguay River; the substrate is predominantly clayey. They were described as a “dense monospecific forest” by Morello & Adámoli (1974) and as a “xeromesophilous forest” by Spichiger et al. (1991)). This forest type is well known by the vernacular name “quebrachal with quebracho colorado”, referring to the dominant presence of “quebracho colorado” *Schinopsis balansae*, which dominate the higher grounds on the right bank of the Paraguay River, from the town of Bahia Negra, located on the Paraguay River at the north-easternmost point of the Chaco 20° 25′S, 58° 15′W, to about Villa Hayes, located on the very same river at the southernmost tip of the region, 25° 06′S, 57° 30′W, and extend westward as far as rainfall and soil are favourable. These forests are characterized as being very dense, with lianas, occasionally with a flooded understory caused by rainfall or the flooding of local rivers. This formation is a transition between the xeromorphic areas of the drier Chaco and the more humid forests of the eastern region (Mereles, 1998), and its predominant species: *Astronium urundeuva* (urunde’y), *Caesalpinia paraguariensis* (guayacán), *Diplokeleba floribunda* (palo piedra), *Enterolobium contortisiliquum* (timbó), *Gleditsia amorphoides* (espina de corona), amongst others.

Riparian hygrophilous forests and floodable forests these are formations that are closely associated with water, whether from flooding or water logging. They can be found along the main rivers (Pilcomayo, Paraguay), as well as other smaller-sized rivers, streams and other waterways and bodies of water like ponds and waterholes, whether these be permanent or temporary. In some cases they are located in land depressions, usually with soil rich in clay, such as the so-called “*palo bobales*”, dominated by “*palo bobo*” (*Tessaria integrifolia*); “*chañarales*”, with dominance of “*chañar*” (*Geoffroea decorticans*); “*labonales*”, dominated by “*labón*” (*Tabebuia nodosa*); amongst others (Mereles 2004, 2005). The land depressions that harbour these particular formations are distributed throughout most of the Chacoan territory; their species are characterized by the capacity to tolerate some degree of asphyxia in the soil caused by the temporary flooding which they are subjected to. Along the Paraguay River, the occurrence of the following species can be mentioned: *Albizia inundata* (timbóý), *Aporosella chacoensis*, *Calycophyllum multiflorum* (palo blanco), *Celtis pubescens* (yuasy’y), *Crataeva tapia* (payaguá naranja, yacaré pito), amongst others.

Xeromorphic forests they develop under conditions of variable rainfall ranging between 500 and 800 mm, on very hard and structured clay soils when dry. The vertical structure of the forest is comprised of 3–4 species in the canopy; the second layer being the richest in species and commonly known by the name of "*matorral*" (scrubland); and finally a very scattered understory typically comprised by very thorny and succulent species; such as: *Acanthosyris falcata* (yvá he'é), *Achatocarpus praecox*, *Aspidosperma quebracho-blanco* (quebracho blanco), *Bougainvillea campanulata*, *Sideroxylon obtusifolium* (palo negro), Ceiba chodatii (samuhú blanco), *Cercidium praecox* (verde olivo, brea), *Salta triflora* (guaimí piré), *Schinopsis quebracho colorado* (quebracho colorado), *Stetsonia coryne* (cardón), amongst the most common species, (Mereles, 2005).

When soils become more sandy, there is a consequent substantial decrease in succulent species; new species appear and some remain, showing plasticity; these include: *Acosmium cardenasii*, *Aloysia virgata*, *Anadenanthera colubrina var. cebil* (curupa'y), *Anadenanthera peregrina* (curupaý curú), and *Amburana cearensis* (trébol), (Mereles, 2005).

1.3.1 The cerrados and cerradones

These are savannah-like formations, which develop on very loose, sandy and acid soils; they harbour islands of trees in transition to become forests, with suffrutescent and rhizomatous species. Some islands of trees and shrubs can be denser, forming the so-called "*cerradones*" or *cerrados* in transition to forest formations, where the tree-like vegetation stands out over the fields. These occur in the northern Chaco, and are very similar to the vegetation developed on the border with Bolivia (Navarro & Maldonado 2002, Jardim & al. 2003), with the following species: *Caryocar brasiliense* (aguará yu'á), *Cochlospermum regium* (mandyjú sayjú), *Commiphora leptophloeos* (Pérez de Molas & Mereles 2004), *Eriotheca gracilipes*, *Gomphrena macrocephala* (rosa del campo), *Helicteres guazumaefolia*, *Hymenaea coubaril*, *Jacaranda decurrens* (carová'í), *Magonia pubescens*, *Mandevilla polaina*, *Pseudobombax tomentosum*, *Riedeliella graciliflora*, *Senna paradyction*, *Sida cerradoensis*, *Simira sampaioana* (Mereles & al. 2004), *Capparis flexuosa*, *Sterculia striata*, *Syagrus petraea* (coquillo), *Tabebuia ochracea* (tajy say'yú), *Taccarum weddelianum*, *Viguiera linearifolia* (árnica del campo, falsa árnica), *Zeyheria tuberculosa* (González Parini & al. 2004), amongst others.

1.3.2 Savannahs

They are very frequent formations in the Chaco and according to the prevailing soil types, the most common of these include: palm savannahs, known as "*palmares*" (with or without hydromorphic soils), *espartillo* savannahs or "*espartillares*", and sand dune savannahs or "*médanos savannahs*", amongst others (Mereles 1998, 2005).

Sand dune savannahs ("médanos savannahs") these occur in the northwest of the Chaco, in an area of sand dunes known as "*médanos*", located northwest of the Occidental region, within the department of Alto Paraguay. Here the morphology of the land is predominantly made up of dunes, with crests reaching a height of between 300–400 m, typical of the area, and consisting solely of aeolian sands from the rivers Grande and Parapití in Bolivia; rainfall is about 400 mm/year. The shrublands are no more than 5 m in height, mostly deciduous during the dry season and provide a very discontinuous cover (Mereles, 2005); some of the more predominant species include: *Acacia aroma* (aromita), *Agonandra excelsa*, *Aspidosperma pyrifolium*, *Bauhinia argentinensis*, *Caesalpinia coluteifolia*, *Caesalpinia stuckertii*, *Gymnocalycium megate*, *Heliotropium dunaense*, *Jacaranda mimosifolia*, *Opuntia quimilo*, *Chloroleucon chacoense*, *Schinopsis cornuta*, *Senna chlorochlada*, *Sacoila argentina*, *Stachytarpheta sp.* and *Ximenia americana*.

Espartillo savannahs ("espartillares") these develop on alluvial sediments (sand and clay) found in the silted paleobasins of the central Chaco, in the form of a savannah with scattered trees on a layer dominated by *Elionurus muticus*, known as "espartillo", and other characteristically rhizomatous herbaceous species, sometimes with xylopodia and coriaceous or pubescent leaves. Other predominant species include: *Astronium fraxinifolium*, *Cnidoscolus albomaculatus*, *Craniolaria integrifolia*, *Evolvolus sericeus*, *Jacaranda mimosifolia*, *Lobelia xalepensis*, *Mimosa chacoensis*, *Pterogyne nitens*, *Schinopsis cornuta*, *Tabebuia aurea*, *Waltheria indica*, *Zornia gemella*, amongst others (Mereles 2005).

Hydromorphic savannahs of caranda'y these develop on highly structured and hard soils when dry, with a high content of clay and salt, easily prone to waterlogging and flooding at highly variable periods of time. The only woody species in the upper strata, providing there has been no anthropogenic disturbance, is the *Copernicia alba* palm (caranda'y), along with a rich herbaceous layer comprised of species that can withstand asphyxia in the soil for short periods. These are typical of the lower Chaco, also called humid Chaco, and the riparian areas of the Paraguay River, on both banks; however some areas of the eastern region remain only as relict formations due to human modifications, (Mereles, 1998 and 2005). Predominant species include: *Canna glauca*, *Cleome spinosa*, *Copernicia alba*, *Diodia kuntzei*, *Eleocharis elegans*, *Eleocharis montana*, *Pfaffia glomerata*, *Phyla reptans*, *Rhynchospora scutellata*, *Setaria geniculata* and *Solanum spinosum*, (Mereles, 2005).

Salt savannahs these salt flats, known as "*saladares*" typical of this area and occur mainly in the central-eastern region, in the departments of Boqueron and Presidente Hayes (Mereles 2004); they are most likely of endorheic origin; soils can be quite soft when wet and are characterized by a high content of salt, which sometimes forms a crust 1–2 cm thick, or more. These salt flats are usually areas of temporary flooding and are typically near bodies of water; the vegetation is made up of a shrub layer that does not exceed 2.5 m in height, rather stocky, with species characterized by having fleshy and deciduous leaves, and that can withstand high salt content, which in turn is subject to the rainfall zone. Predominant species include: *Cyclolepis genistoides*, *Grabowskia duplicata*, *Heterostachys ritteriana*, *Heliotropium procumbens*, *Holmbergia tweedii*, *Lophocarpinia aculiatifolia*, *Lycium cuneatum*, *Maytenus vitis-idaea*, *Sarcocornia perennis*, *Sesuvium portulacastrum* and *Tillandsia mereliana* (Schinini, 2008).

1.4 Wetlands

These are highly dynamic ecosystems characterized by the presence of standing or flowing water and with boundaries that are hard to define. Different descriptions for the vegetation types have already been addressed for Paraguay (Mereles 2004), and these are directly related to the type of water (lotic or lentic). The vegetation types are:

Vegetation of marshes and cascades these are directly dependent on water as the sole substrate and the characteristic species are unable to survive without the presence of water. These may have several habits: free-floating on the body of water, rooted with water covering the base of the plant, immersed within the body of water, etc. Species found below the falls or 'cascades' are characterized by their photosynthetic roots (evergreen), flat leaves like moss and liverworts, stems often very short and strongly attached to rocks, often forming cushions, very variable morphologically.

The following are some of the species which occur within the environment types mentioned above: *Apinagia guairaensis*, *Begonia cucullata* var. *cucullata*, *Callitriche deflexa*, *Canna glauca*, *Ceratopteris pteridoides*, *Costus arabicus*, *Cyperus giganteus*, *Drosera communis*, *Eichhornia azurea*, *Eichhornia crassipes*, *Eleocharis montana*, *Eryngium floribundum*, *Heteranthera limosa*, *Heteranthera reniformis*, *Heteranthera zozterifolia*, amongst others (Mereles 1998, 2004, 2005).

b) Land use change in the Chacoan territory

Land use changes in the Paraguayan Chaco began several decades ago, as far back as the 1940s, and particularly strong in the central area known as Chaco central (a large portion of the department of Boquerón) as a result of extensive mechanization processes where the three Mennonite colonies have implemented extensive and intensive livestock systems for the flourishing dairy and meat production. During the last two decades, and particularly in the 2000s, the department of Alto Paraguay has intensified its land use change, mainly as a result of new investing immigrants arriving from Brazil with the purpose of increasing meat production.

The process of land use change in the Chaco has increased for the most part, regardless of the ongoing recommendations that have arisen as more ecological knowledge on the region has been generated. The risks that soil and the environment in general are exposed to after the drastic changes caused by deforestation, without taking into consideration the consequences of such changes, are well known, as well as the risks in each of the areas of this vast territory such as; the particularly strong wind erosion to the west, in the area of dunes known as '*medanos*', where sandy sediments from the rivers Grande and Parapití in Bolivia have been accumulating and forming sand dunes which are constantly shifting to the south and east of the territory, fuelled by the almost relentless and intense action of winds from the north and northwest.

Another very high risk factor is that of soil salinization, especially around the central, eastern and northeastern parts of the territory, where the saltwater layer is located almost at the surface or at a very shallow depth and ascends by means of capillarity.

Unaware of all this, the fragmentation process continues to advance, leaving discontinuous islands throughout the territory.

The objectives of this study are: to broadly describe the main vegetation communities of the Paraguayan Chaco, including its most characteristic species and their current status of vulnerability resulting from the effects of forest fragmentation, and to present considerations on the effects that can cause extreme climatic events resulting from the forest deforestation and fragmentation processes.

2 Methodology

2.1 Office work

To obtain the forest remnants fragment size, total area and other geographic parameters in 1990 and 2000, and special geospatial database product were used, accessible at http://www.glcf.umd.edu/data/paraguay/. This geodatabase was reprocessed using the default statistical algorithms including in the ARCMAP module of the ARGIS 9.0 ESRI software package, in order to geographically separate the Chaco administrative region former the rest of the Paraguayan country area. The mentioned product technical name is Paraguay Forest Change Product, and is available as GIS Esri GRID format geodatabase.

The Paraguay Forest Change Product shows where deforestation occurred in Paraguay during 1990–2000. It is derived from Landsat TM and ETM+imagery at a resolution of 28.5 m for the two time periods. Six classes such as Atlantic forest, Chaco woodland, water, non-forest, and deforestation are identified. The product can be used as an example to assess land cover change quantitatively and to help determine the process and pattern of forest cover change.

The iterative clustering-supervised labeling method consisted of two major processes: unsupervised isodata clustering and supervised labeling of clusters based on defined training pixels. During the initial clustering, an image-pair was classified using up to 250 clusters.

The visual interpretation of Landsat images was then performed to identify training pixels for all clusters with the assistance of local experts. An in-house program called "supervised labeling" was used to count the training pixels within each cluster (GLCF, 2006).

To identify 2006 forest remnants and isodata clustering for unsupervised classification was used, applying the pre-ensemble isodata algorithm of the ARGIS 9.0 Image Analysis module, to a MODIS sensor image, using size classes and then reclassifying in two classes (forest and not-forest) under expert supervision.

The MODIS image used was the Aqua/MODIS – bands 1,4 and 3 - True color, 500 m pixel size, 2006/233- 08/21/2006 -17:40 UTC in GEOTIFF format. Available at: http://rapidfire.sci.gsfc.nasa.gov/cgibin/imagery/single.cgi?image=crefl2_143.A2006233174000-2006233174500.500m.jpg

The average sizes of the existing fragments were determined for each of these years (1990, 2000 and 2006).

Within the area of the central Chaco, where the Mennonite colonies are located, the smaller and larger fragments were studied.

2.2 Fieldwork

Field work consisted solely of qualitative observations carried out over a year. During this period, the sites mentioned below were visited every two month and in some cases, such as the Mennonites Colonies where most impacts are observed, every month.

a) Matrix change: observations of the progress of colonizing and pioneer species over the xerophytic forest remnants in the central Chaco, around the Mennonite colonies Neuland (Department of Boquerón, 22° 38'S, 60° 08'W), Filadelfia (Department of Boquerón 22° 21'S, 60° 02'W), north of Parque Cué surroundings (Department of Alto Paraguay, 20° 10'S, 61° 51'W), Teniente A. Picco (Department of Alto Paraguay, 19° 40'S, 59° 40'W); in the northwest, Teniente A. Enciso (Department of Alto Paraguay, 21° 10'S, 61° 40'W); in the northeast, Bahia Negra and Fuerte Olimpo (Department of Alto Paraguay, 20° 25'S, 58° 15'W and 21° 0.0'S, 57° 50'W); in the centre east, near Cerro Galvan (Department of Presidente Hayes, 22° 20'S, 58° 00'W), and; in the *cerrado* and *cerradones* communities located to the extreme north (Chovoreka, Department of Alto Paraguay, 19° 20'S, 59° 10'W), Fig. 1.
b) Border effect: observed on the remnants of the areas mentioned in the previous paragraph.

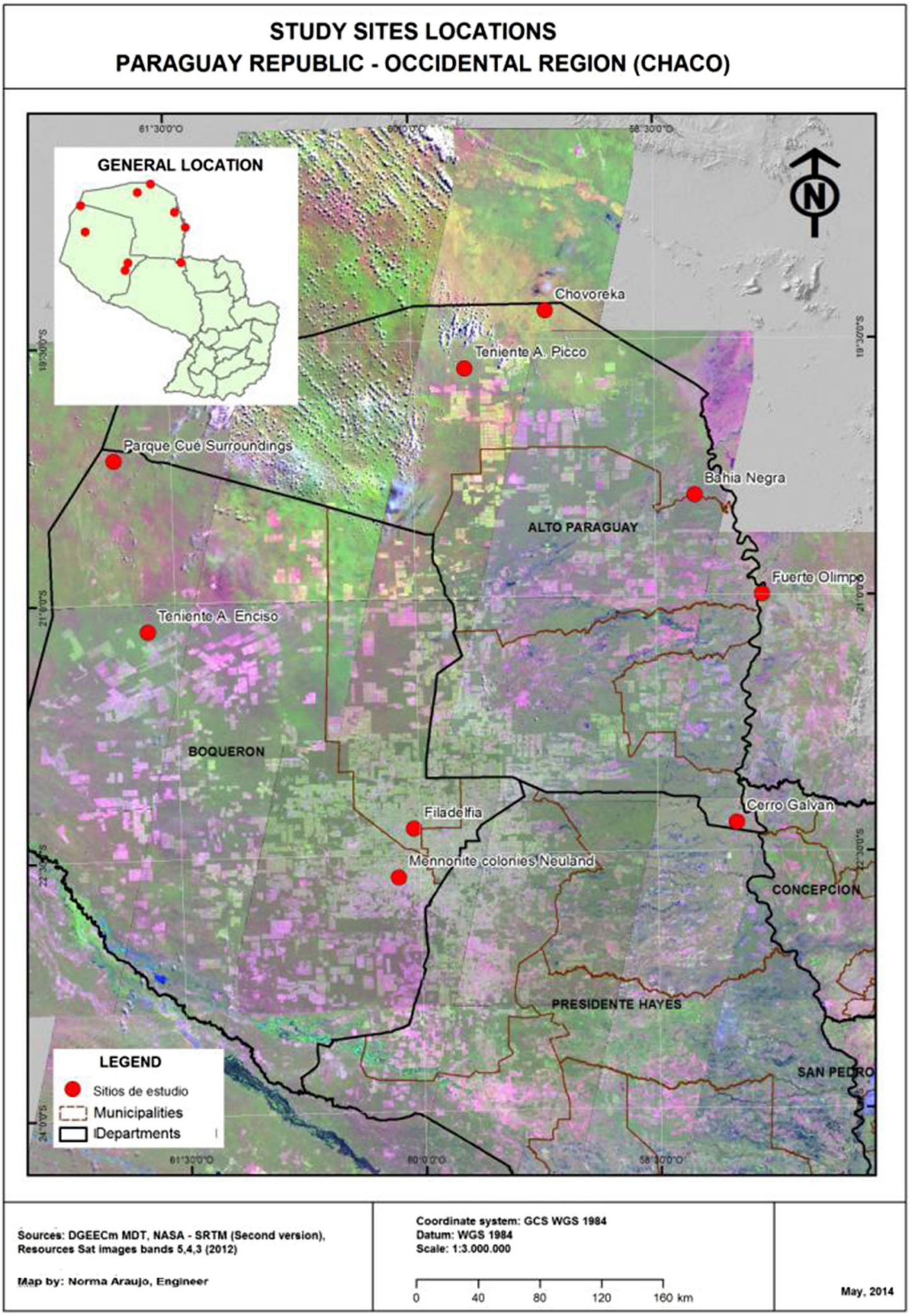

Fig. 1 Study Sites Locations

c) Effects on wildlife: carried out through qualitative observations of feces, footprints and other traces of large mammals, amongst others.

3 Results

The results presented here are obviously partial, since as a result of the fragmentation process. There are consequences that are difficult to corroborate, many of these due to the short lapse of time of the study, while others will are hardly quantifiable.

The analysis of the satellite images showed that in 1990 the average size of the fragments was of five thousand hectares, with a total of approximately 364,900 fragments; even for the year 2008, about 9 million hectares of continuous forest cover existed, particularly towards the north-central, northeast and northwest of the territory.

According to the analysis carried out by classifying the Landsat images, the Chaco had 15,450,687 ha of forest in 1990, which decreased to an area of 14,455,110 ha by the year 2000, representing a total deforestation of 1,055,577 ha at an average rate of 105,557 ha per year over a 10-year period (1990–2008). In a new study carried out by Guyra Paraguay, using images from MODIS over a one-year period, between May 2005 and May 2006 the average annual rate of deforestation increased to 130,000 ha, (Fig. 2 and Table 1).

The current rate of deforestation has increased yet again, according to results of Guyra Paraguay, which detected an average deforestation of 477 ha per day between August and September 2008, which taken as an average daily rate could be extrapolated to an annual rate of 174,292 ha.

During the last quarter of 2013, deforestation rates in the Paraguayan Chaco, were; 989 ha per day in October (47 % of the total area deforested in the South American Chaco Region), 549 ha per day in November (36 % of the total area deforested in the South American Chaco Region) and 559 ha per day in December (30 % of the total area deforested in the South American Chaco Region).

4 Environmental changes

Matrix change in the Central Chaco area (Neuland, Loma Plata and Filadelfia colonies), the remaining forest fragments are so small that it can be confirmed that they are already surrounded by an anthropogenic matrix; in other words, the forest matrix around which the urban areas developed has disappeared, as can be seen in this Landsat satellite image (Fig. 3).

Changes in forest matrix in other areas of the Chaco can clearly be seen in images of the territory between the periods 1975–2007 (Fig. 4).

5 FEffects on the flora

Border effect other consequences observed within forest fragments are those related to the increase in the border effect, where pioneer species typical of modified soils are progressing rapidly. Indeed, fragmenting habitat increases the borders throughout the landscape; a greater number of edges implies that the fragments are more influenced by the surrounding matrix.

Depending on soil types, different pioneer species quickly spread throughout the fragments, resulting in a greater border effect; thus, it is common to observe *Senna chlorochlada*, *Acacia aroma*, *Pithecellobium chacöense* and *Bauhinia argentinensis* gaining ground on the sandy soils of the '*medanos*' area. Even where soils become more compact due to increased clay content, these species are replaced by *Mimosa castanoclada*; in other areas near the '*medanos*', the degree of fragmentation in shrublands is such that the *Opuntia quimilo* is virtually the only surviving species; however, there is no certainty that *O. quimilo* is a native and pioneer species; it may be an invasive alien species in spite of not being mentioned as such.

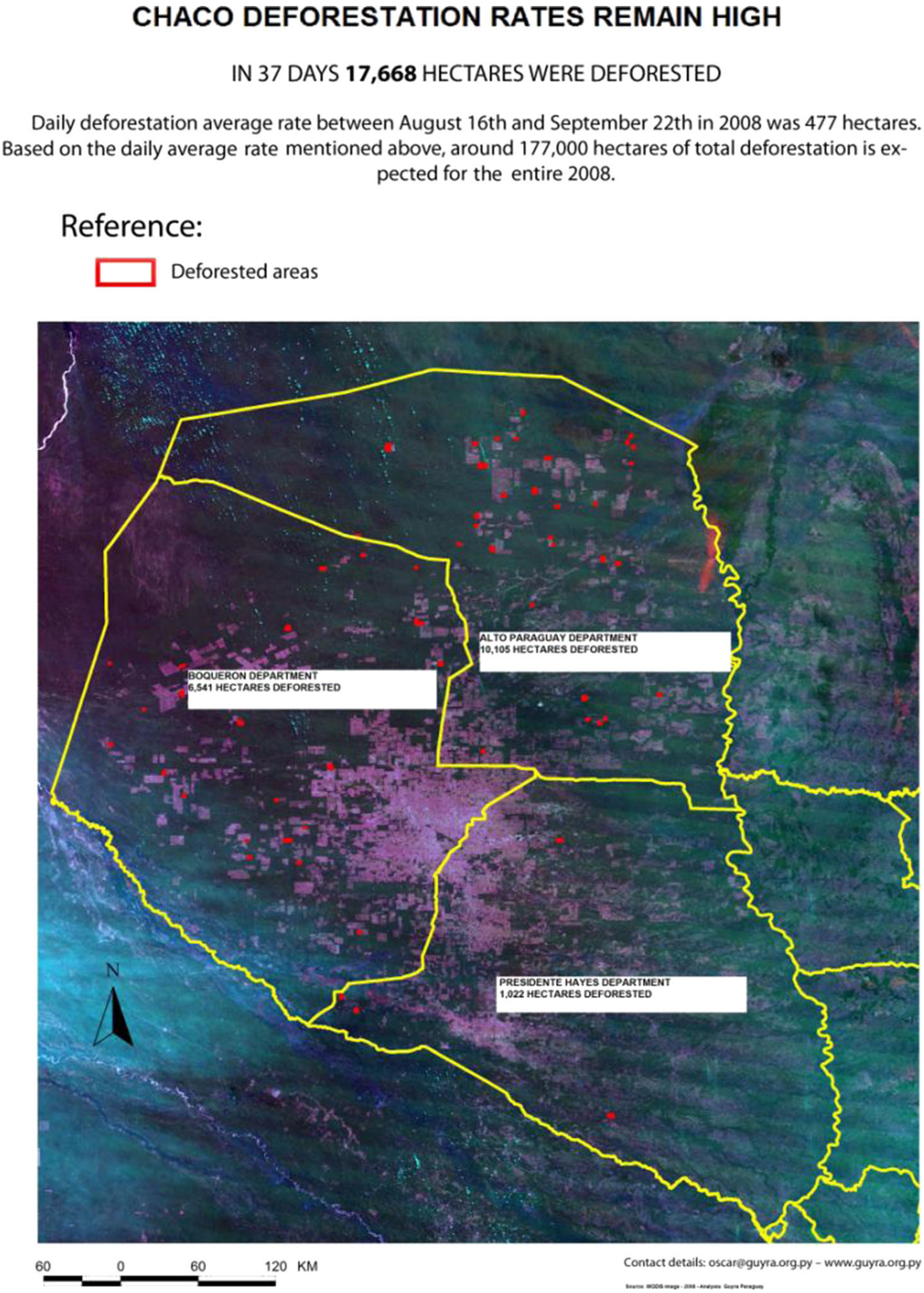

Fig. 2 Satellite image where the consequences of high levels of deforestation can be observed. Source for satellite image: Landsat 7 ETM bands 3,4 and 5

The border effect on xeromorphic forests developed on more compact soils can also be observed through the intrusion of pioneer and opportunistic species in modified soils, as in the case of *Bougainvillea campanulata*, *B. praecox*, *Cercidium praecox*, *Capparis speciosa* and *Castela coccinea*.

Table 1 Number of has in changes land use

*Total area of the Occidental region, according to DGEEC: 24.100.753,374 ha

Forest cover area in the Occidental region			
Year	Area covered by forests (ha)	Area without forest cover (ha)	% without forest cover
1990	15.750.850	8.349.899	35
2000	14.697.060	9.403.698	39
2013	11.071.035	13.032.530	54

When soils increase in salt content, which happens frequently in the western part of the region near the Pilcomayo River, *Bulnesia foliosa*, *B. bonariensis* and *Geoffroea decorticans* quickly gain ground in the forest, the latter particularly appearing in the modified and more humid soils, sometimes transforming these fragments into true "*chañarales*", originating from the vernacular name of the species, "*chañar*".

The hydromorphic savannahs of *Copernicia alba*, to the south and southeast of the territory, are not impervious to the border effect and complete transformation from palm savannahs of the aforementioned species into shrublands dominated by *Prosopis ruscifolia*, are sometimes already transformed into true "*vinalares*". Another species that quickly colonizes these soils is *Acacia caven*; both *A. caven* and *P. ruscifolia* compete over the colonization of these savannahs as soon as changes in land use occur, particularly from those, which are mechanized.

Towards the north and northeast, in the area of wooded savannahs (*cerrado*) on very sandy soils of hydrological origin, *Caesalpinia peltophoroides* is one of the most aggressive colonizing species, as is *Cochlospermum regium*, while in the transitional forests between xeromorphic and sub-humid, *Tabebuia impetiginosa* is another noteworthy pioneer species.

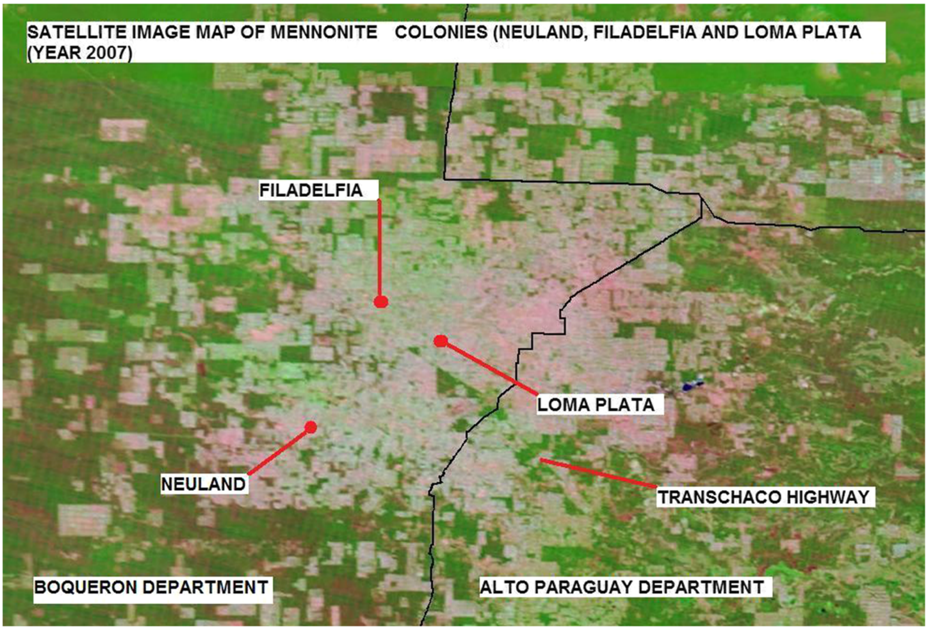

Fig. 3 Matrix changes caused by deforestation in the area of Mennonite colonies

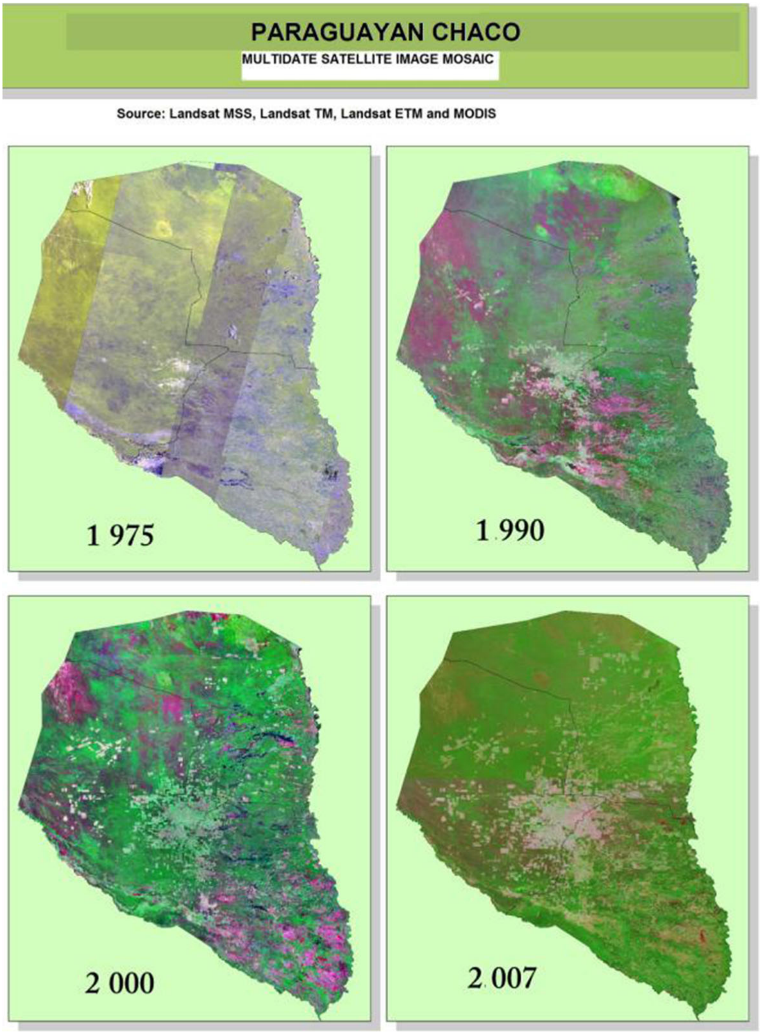

Fig. 4 The time-lapsed trend showing the effect of the changing forest matrix in other sectors of the Chaco between 1975 and 2007

This is highly evident in some places, such as one of the checkpoints in the Defensores del Chaco National Park, where pure stands of *T. impetiginosa* replace the modified forest formations.

In some very specific cases, ecosystem fragmentation occurs naturally, which is quite commonly observed towards the west in the floodplain of the Pilcomayo River. Indeed, during the summer season, which coincides with floodwater surges and depending on the volume of water, the vegetation of the riverbanks and that of the sandy-loam sandbanks is quickly washed away; in this case, *Tessaria integrifolia* and *T. dodonaefolia* rapidly colonize the new banks formed by the accumulation of new sediments, often displacing well-established species such as *Vallesia glabra*, *Solanum argentinum* and *Salix humboldtiana var. martiana*.

In the following Landsat image interpretation (Fig. 5), the border effect increases in the natural formations in the northern Chaco area.

Increase and expansion of invasive alien species another observation made over the last ten years is the gradual increase in some invasive alien species, as is the case of *Calotropis procera*, a small-sized tree first recorded for the Chacoan forests in 1990 decade. This species was first found in a farm just north of the town of Filadelfia, and is now rapidly spreading to the north, west and northeast in places where forests are in the process of fragmentation.

The risk of extinction of some endangered plant species the fragmentation and subsequent reduction of wildlife habitat results in a greater vulnerability of the endangered species, whose numbers have been and continue to be reduced as a result of the fragmentation problem. Such is the case of three species of cacti of the genus *Gymnocalycium*; the first of these, *G. megatae*, from the '*medanos*' area and wooded savannahs in paleobasins (*espartillares*), and *G. pflanzii* and *G. mihanovichii*, which are species that develop only within xeromorphic forest. Another species, which could be considerably threatened is *Arachis batizocoi* (Fabaceae), apparently observed but not recorded and included in the red list of species for Paraguay.

Under the same level of risk, some species found only in the *cerrado* area of the Chaco with a very restricted distribution can be included, such as *Commiphora leptophloeos*, *Zeyheria tuberculosa* and *Simira sampaioana*, as well as those ephemeral species whose vegetative parts appear only during the flowering period, such as *Sacoila argentina* and *Hippeastrum belladonna*.

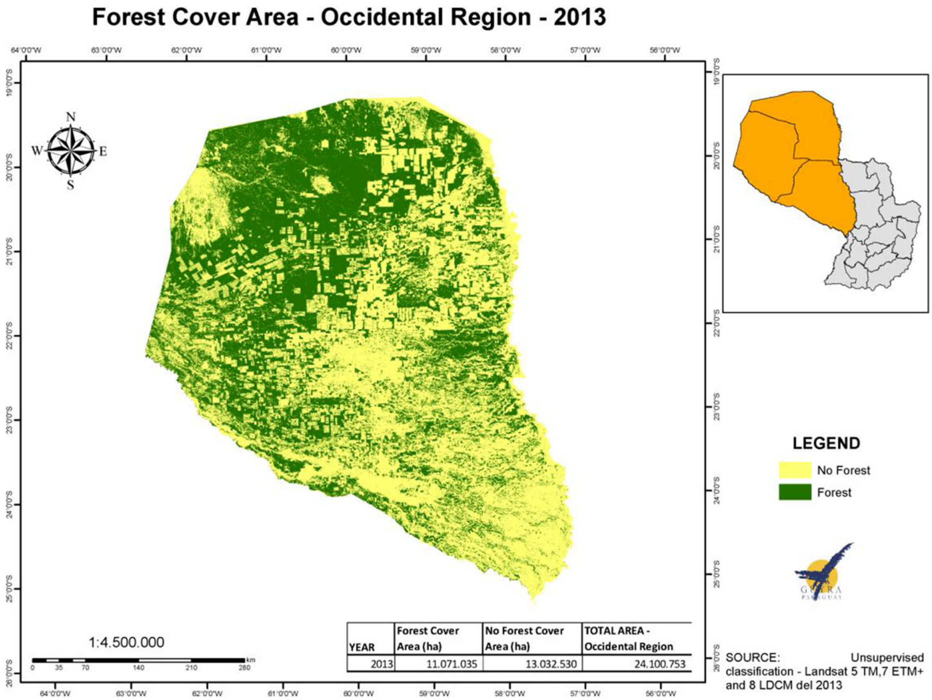

Fig. 5 Increasing forest loss and continuous fragmentation in the Occidental region of Paraguay. Source: Guyra Paraguay (in press). Análisis Multitemporal: Infraestructura vial y cambio de uso de la tierra en el Chaco Paraguayo

Degradation within fragments another consequence of forest fragmentation is the permanent removal of wood in the form of timber (*rollos*); a DBH (diameter at breast height) of between 25–30 cm is used as a parameter for harvesting all timber species. Some species whose wood is very valuable, such as *Bulnesia sarmientoi* (*palo santo*), are in the Appendix II of CITES due to an excessive volume of export for its essential oil, other species such as *Prosopis nigra* (*algarrobo negro*) and *Schinopsis balansae* (*quebracho colorado*), could face the same problems in future.

As a result of these being relatively large diameter species, timber extraction greatly contributes towards increasing the fragments' vulnerability regarding exposure to major climatic events, as well as also increasing levels of CO_2 due to degradation.

6 Effects on wildlife

In some more remote areas, where forest formations have been fragmented, there is a growing tendency for habitat reduction and consequently a greater concentration of wildlife, particularly of mammals, known as "island effect". In the larger fragments, big herds were observed of at least 2 species of peccaries (*Catagonus wagneri*, *Tayassu peccary*), big cats such as puma (*Felis concolor*), amongst others.

7 Discussion and conclusions

It is highly likely that the fragmentation of forests and other natural systems already have their effects not only on biodiversity but also on the physical aspects within the fragments, such as luminosity, humidity, temperature and evapotranspiration; these will in turn have their effects on species of fauna and flora which will be affected by the changes. These may result in population reductions, as these species are unable to adapt to these new changes in such a short space of time.

Not only might there be a decrease in populations, but also an increase in the number of species and individuals due to the "invasion" of pioneer and opportunistic species from the surrounding matrix, affecting the native flora and fauna either through direct competition or simply being consumed as food in the case of wildlife (Mereles & Degen 1997a, b).

Although the term 'fragments' is used, it must be made clear that these are not immune to changes resulting from logging activities; in fact, several species are in strong demand in the domestic and international markets, such as *Bulnesia sarmientoi* "palo santo", a species that has been included in the red list of the SEAM, Paraguay's Ministry of Environment. Other hardwoods in demand include *Aspidosperma quebracho-blanco* "white quebracho", *Astronium urundeuva* "urunde'y", *Schinopsis balansae* "quebracho colorado", *Schinopsis quebracho-colorado* "coronillo" and *Prosopis nigra* "black algarrobo", amongst other species that are simply extracted in the form of logs.

In order to extract the logs, it is necessary to open up an access for vehicles and other machinery. In addition, the lack of control regarding minimum cutting diameters contributes further to the permanent deterioration of the fragments, giving rise to the danger of intrusion by invasive alien species and opportunistic species, thus increasing the fragility of the forest remnants and decreasing their resilience. In this sense, Matlack (1993) mentions that the human impact on the fragments can be observed up to about 70 m within the fragment, and the damage is even further exacerbated with the presence of vehicle accesses.

Although this study has not given much emphasis on the shapes of the fragments, a characteristic that has a strong influence on the advance of the border effect, the analysis of the satellite images shows that in most cases these fragments are made up of straight edges, and that there are fewer elongated and irregular shaped fragments, which could make them less susceptible to border effects, according to Bustamante & Grez, (1995).

Highly specialized species, as in the case of some of the ground-dwelling Cactaceae and Orchidaceae mentioned in the results, are more prone to suffering the consequences than more generalist species, which are more flexible and tolerant to environmental changes.

We can also add that fragmentation and reduction in forest cover are not just problems within Paraguay and the region, but also widespread (Thomlinson et al. (1996); López et al. (2001). The northern Chaco has the particularity of being a very flat area, which further aggravates the situation, since other authors mention that this type of disturbance to natural habitats, and particularly in forests, occurs on steep slopes with more than a 60 % gradient (Sader and Joyce, 1988).

The main risks of fragmentation and habitat reduction make up one of the driving forces behind the extinction of species, beginning locally within the interior of the fragments and gradually evolving towards a total extinction.

From the centre to the south of the territory, the risks increase, since the northern part has large fragments that make up the National Parks, core areas of the Gran Chaco Biosphere Reserve and as considerable in size as Parque Ka'ia in Bolivia. To the south, the so-called "private reserves" are beginning to emerge as a way of alleviating the growing environmental degradation.

Other potential consequences for the Chaco forest fragments are related to the genetic effects on wildlife, and as a result of this concentration, increased problems related to inbreeding among species becomes more likely. Another possibility is the partial reduction of herbivorous mammalian fauna, such as *Tapirus terrestris*, due to the decreased diversity of plants in their diets.

Another problem that is already an issue for the fragments in the Chaco are the distances between the individual fragments, although the type of matrix that surrounds these should be analyzed. Another challenge for the future is to better understand the process of fragmentation in the Chaco and its consequences.

In addition to this, the fragmentation of forests is not the only cause of problems suffered in this region; others such as the inappropriate construction of roads which slice through the middle of forested areas without previous studies and planning assessments, upsetting of the natural surface runoff, thus increasing the risk of salinization, as can be observed in the central-eastern region, can also be mentioned.

The intentional burning of grasslands is also a great concern that directly affects the pristine biodiversity habitats. It is also worth mentioning the lack of action and concern on behalf of the authorities; the Chaco is an area that is suffering from a lack of land use planning and the consequent threats resulting from fragmentation: such as wind erosion effects rapidly taking over the semi-arid areas of the northwest.

In order to have a better understanding of the problem, one of the recommendations is to promote the collection of quantitative data within the fragments, for both flora and fauna, as well as the knowledge on microclimatic variations; all this information may provide a more complete idea of the consequences of fragmentation.

More drastic measures need to be taken, such as generating a "vision of the biodiversity" of the Chacoan territory, in an attempt to visualize how we want to see the Chaco in the next 50 years or more. This should contemplate the connectivity between the forest remnants by means of biological corridors, so vital to maintaining biodiversity over time. Measures should be taken in implementing steps towards improved land use planning of the Chaco in Paraguay; some steps have already been taken in this area, and the process must continue.

The establishment of a Management Committee for the Paraguayan Gran Chaco Biosphere Reserve would be of great help for the territory, and whose main responsibility, amongst others, would be the enforcement of legal mandates so that the remaining native forests in the Chaco are preserved; in effect, a functional Biosphere Reserve is key to a sustainable development, especially in this region where it is still possible to combine biodiversity conservation and agricultural production.

Finally, in the case of extreme weather events in the Chaco region, due to climate change, the fragmented vegetation formations, as well as the unconnected forest fragments, become even more vulnerable to each of the consequences mentioned.

On the other hand, it is clear that as the forest fragments become reduced in size, an increased vulnerability is expected as a result of different climatic events that may occur in the area, such as the constant winds from the north, heavy rains in the summer, as well as the penetration of fires, which are so common in this region.

As mentioned the majority of fragments are made up of straight edges, given higher vulnerability to climate change effects within fragments, as consequence of border, with and higher exposure to extreme climate events to be expected at the Chaco region.

Finally, is important to mention than the loss and fragmentation of large forest areas in the Chaco region contributes in a significant manner to the global climate change phenomena as the degradation of the forest fragment; projects such as Reducing Emissions from Deforestation and Forest Degradation should be implemented.

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