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Ecological and social consequences of the Forest Transition Theory as applied to the Argentinean Great Chaco

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ABSTRACT

Forest transition is the change from net deforestation to net reforestation. According to the Forest Transition Theory (FTT) in its original form, reforestation is triggered by the last stage of socio-economic development, when the rural population migrates to urban areas, and forest cover expands naturally on abandoned agricultural fields. The assumptions underlying the FTT have been changed to extrapolate it to the Argentinean Great Chaco (AGC). It is suggested that Indigenous people and low income peasants, who use land inefficiently, should migrate to the urban areas in search of a better life quality. Thus, the abandoned lands could be used for conservation, while the most suitable soils could be destined for food production. However, the subtropical forests in the AGC are highly vulnerable to desertification, as a consequence of rainfall irregularity and high summer evaporation rates. The probability exists that forest recovery does not occur in time scales relevant for conservation. Drawing on research data and bibliography, we tested the validity of the three main assumptions suggested for the Forest Transition Theory as applied to the AGC. Results show that original inhabitants have sustainable land use strategies; rural outmigration is driven by high-input agriculture, which pushes people toward the city skirts; and expansion of intensive agriculture is independent of soils production capacity. We discuss the social and environmental consequences of the proposed assumptions.

1. Introduction

Ever since Mather (1992) introduced the idea of forest transition for developed countries, much has been debated about its occurrence, processes and drivers (for example: Satake and Rudel, 2007; Barbier et al., 2010; Pfaff and Walker, 2010). Forest transition (FT) has been defined as a change from net deforestation to net reforestation in a given space, occurring as a gradual transition from loss to recover of native forest area (Redo et al., 2012). Reforestation is understood as spontaneous regeneration of forests on deforested lands. The Forest Transition Theory (FTT), introduced at a time of concern over forest loss in the northern hemisphere, was explained as a progressive adjustment of agriculture to land capability, resulting in less land area needed to obtain increasing amounts of agricultural products (Mather and Needle, 1998). Though initially the theory of forest transition was proposed for northern Europe it was later expanded to the tropical developing countries, where the driver was taken to be economic development (Rudel, 1998); that is, as industrialization and urbanization expands, rural to urban migration occurs, and native forest regenerates on abandoned lands (Walker, 1993; Rudel et al., 2005; Wright and Muller-Landau, 2006). For those of us who participated in the Hamburger Connection debate, it was hard to believe that development was the driver of outmigration (Matteucci, 1987; Edelman, 1995).

Recently, the Forest Transition Theory has been imported by local researchers into the seasonal dry forests of the Gran Chaco Region, in Argentina, Paraguay, Bolivia and Brazil (Aide and Grau, 2004; Grau and Aide, 2008). The process has been reformulated: it is assumed that reforestation occurs in lands that are abandoned by low-income farmers who make inefficient use of them; thus, rural–urban migration is driven by development (Grau and Aide, 2008), understood as expansion of agribusiness, urbanization, increase in food demand, foreign investment; in short, the set of interacting socioeconomic factors in a neoliberal and globalized economy. The authors state that food production should come from

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modern agriculture, practiced on the most productive soils (Grau et al., 2008). All these papers, that patronize land sparing by agricultural adjustment, do not consider other factors, such as effects of massive deforestation on long term forest ecosystem sustainability, in the climatic and edaphic conditions of the Chaco region. Neither do they take into account the rights of indigenous people to their lands, territories, culture and resources (UN, 2008). They never considered the possible consequences of deforestation on soil water loss, soil salinization and the two aquifers underlying the Chaco region. We think that the argument based on inefficient use of land is, at least, illegitimate, since it surreptitiously suggests that low-income peasants and indigenous communities should abandon the lands they have occupied for centuries, as well as their culture.

Some scientists state that the primary driver of industrial agricultural expansion is the international demand for food due to population growth and increased living standards in some countries (Grau et al., 2005, 2008; Gasparri and Grau, 2009). In Argentina, oilseeds are retained in plastic bins waiting for better international market prices. This would not happen if there were an increased food demand. As FAO (2012) reports, food production is sufficient to feed the world population. Food availability, which increased from 1850 kcal/person/day in the 1960s to 2790 kcal/person/day in 2006/08 in Latin America, helped reduce the percentage of chronically undernourished people from 34 percent in the mid-1970s to 5.1% in 2012/14 (FAO, 2014). Despite this progress, poverty and hunger still prevail in the World, while the damages caused by the advance of the agricultural frontier have continued (Pretty et al., 2006) up to date. Numbers given at international and national levels hide the situation in local communities. The problem is that food distribution is highly inequitable. Argentina plays an important role in global wheat, maize, and soybean markets, and has helped increasing the world supply of grains and oilseeds. However, the benefits of industrial production, led by major exporting companies, fail to reach small and medium farmers (Krapovickas and Longhi, 2013), while environmental setbacks (decrease in water availability and quality, loss of forest resources, lack of land for subsistence agriculture, reduction in wage labour; in short, worsening socioeconomic conditions and wellbeing) fall exclusively on them.

In this paper we will rely on partial results of projects carried out by our research team in the Argentinean Gran Chaco (AGC) to test the three assumptions relating to the FTT as applied to this region: (1) low income peasants use land inefficiently; (2) development drives rural–urban migration of low income peasants in search of a better life quality; (3) expansion of intensive agriculture occurs in the most productive lands.

2. Study area

The South American Chaco is the biggest continuous dry forest in the world; it is the second largest forest ecosystem in South America after the Amazon. It is the only subtropical dry forest on the planet; in similar latitudes (around 28° south) deserts are found in both hemispheres.

The Argentinean Great Chaco (AGC), with 608,598 sq.km, has very singular characteristics. A forest biome in this dry weather is explained by the presence of three large rivers flowing from the Andes (Pilcomayo, Bermejo and Dulce) that run from North–West to South–East on an extremely plain terrain. In geological time these rivers drifted southwards forming numerous minor streams, meanders, oxbow lakes and subsoil water deposits (Adámoli et al., 1990). Water stored in the soil has been protected by a relatively dense tree canopy with some peculiarities. (1) The three endemic quebracho tree species: chacoan red quebracho (*Schinopsis balansae* Engl.), santiaguenian red quebracho (*Schinopsis lorentzii* (Griseb.) Engl. and white quebracho (*Aspidosperma quebracho blanco* Schltdl.), are large trees, around 24 m high and 1 m in trunk diameter. Trees as large as these are unusual in a semiarid to arid climate. (2) White quebracho has persistent foliage, and red quebracho has semi persistent foliage, with a particular phenology because it sheds the leaves in late spring; i.e., it keeps the foliage throughout the winter, which is the rainless season, and protects the soils from desiccation (Ledesma, 1992). The winter deciduous trees mitigate the harsh environment of dry summers (Cáceres et al., 2004, 2007). These features play a key role in the conservation of relatively humid conditions under the canopy, favouring the persistence of the undergrowth, which protects the soil from drying out. (3) Under the canopy the microclimate is less warm and less dry than that of non-forested areas (Ledesma, 1992). One wonders if deforestation of large tracks of land would not lead to desertification, especially after harvesting. Other characteristics of the AGC are the high species and culture biodiversity, and the large spatial heterogeneity, with ecosystems interacting horizontally.

The AGC is divided in two ecoregions: the Dry Chaco to the West and the Humid Chaco to the East. There are some differences in climate, vegetation formations and land use between the two ecoregions, though they share general characteristics, such as high biodiversity, the main tree species, fauna, and cultural diversity.

The climate is subtropical, with average summer temperatures ranging from 28 °C to 22 °C from North to South. Due to the continental nature of climate, there are large temperature variations between summer and winter; maxima of 47 °C can be reached when the sun is high while frosts can occur in winter. Mean winter temperatures vary between 17 and 10 °C latitudinally, from North to South. Mean rainfall decreases from 800 to 500 mm from East to West in the Dry Chaco ecoregion, though it increases again up to 800 mm in the vicinity of the Andes, to the West. In the Humid Chaco, mean rainfall increases from 800 to 1200 mm from West to East. Rainfall concentrates in summer, but it is irregular and occasional dry periods may occur. The water balance has negative values for 10–12 months in the year.

The Dry Chaco Ecoregion is covered by xerophyte open forests, in which quebracho species, mistol (*Ziziphus mistol*) and *Prosopis* spp. are the most frequent tree species. In the driest central fringe, distinctive patches of burned vegetation stretching in a south–north direction interrupt both physiognomies. These patches originate by natural and human fires and follow prevailing wind direction. In the Humid Chaco Ecoregion, the vegetation forms a tangled mosaic of palm savannah, and dense forest patches, spotted with marshes, lagoons, flooded riverside forests, forested levees, and back swamp forests. In the parkland formation, patches of quebracho forest alternate with open grasslands. Areas dominated by palm trees (*Copernicia alba*) occupy swampy soils with salt accumulation. Low riparian forests skirt watercourses, and aquatic plants cover flooded areas. It is characterized by an alternating flood and drought regime, and many species are adapted to the natural rhythm of alternating wet and dry periods. Indigenous people plan their crops according to this alternating humid-dry conditions which they can predict in advance.

The history of land use change in the Dry Chaco is longstanding, and has been described within the framework of a historical periodization (Morello et al., 2007), though there is ample superposition between periods. The periods are: (1) local ethnic groups, (2) military activity, (3) ranching outposts, (4) railroad ties and poles, (5) tannin industry, (6) farming colonies, (7) oil exploration, (8) industrial agriculture, and (9) soybean agribusiness expansion.

Before the colonization (stage 1), indigenous people used mainly the grasslands and obtained few resources from the forest. At the beginning of colonial times (stages 1 and 2), the grasslands were again the main source of ecosystem services; cattle and horses were introduced, the former in small herds, while horses were brought in for use in rural tasks. A new social group appeared in scene, the "criollos", who are descendants of European families that settled during the 16th and 17th centuries in Salta and Santiago del Estero provinces (Sevini et al., 2013). The criollos spread to the east in due time and in some places, they intermarried with aboriginals; these colonies persist today. The criollos raised cattle and obtained honey, wax and wood for fuel from the forests. At the beginning of the 19th century (stage 2), the criollos gained power, due to the military campaigns, and land distribution benefited those who won battles. In time (stage 3), ranches settled next to river banks and outposts were established in the grasslands, along livestock grazing routes. By the mid-19th century the outpost stage became definitely established. Each outpost comprises one to few cottages, a small garden, a fence to enclose livestock, and small water reservoirs dug in the soil, all surrounded by a circle of bare soil. These outposts persist to the present.

Of the nine stages described, perhaps the most dramatic for forest subsistence have been the railroad ties and fencing poles (stage 4), the tannin industry (stage 5) and the intensive agriculture expansion (stages 8 and 9), in all of which intensive deforestation occurred and still occurs. Selective logging for the manufacture of railroad ties began by the end of the 19th century. In 1875, the tannin stage began in the eastern Chaco, with intensive exploitation of quebracho species, mainly red chacoan quebracho. Between 1940 and 1971, the red santiagenian quebracho was exploited in the west also for tannin, but deforestation was not as intense as in the previous period.

Agriculture started by the end of the 19th century, with cotton as the main product (stage 6). Plantations were established in the grasslands. By 1960, maximum area planted was reached and in 1975 the production declined. Oil exploration and exploitation (stage 7) occurred in parallel with stages 4 and 6. Its main impact was linear deforestation for the construction of a net of roads that fragmented various ecosystems and landscapes, and the conversion of rural towns to mining activities. Nowadays, these roads are used for the transport of logs illegally obtained from the forests.

By the mid-20th century, intensive agriculture began, with the entry of wheat, sorghum, beans and corn (stage 8). The most dramatic and extensive land use change started in the last quarter of 20th century, with industrial agricultural expansion and the introduction of soybean as the main, sometimes exclusive, crop (stage 9). In the AGC, 20,000 sq.km had been deforested in 1975; 65,000 sq.km in 2001 and 100,000 in 2011 (Vallejos et al., 2014). The conversion of forests to crop continues to this day, forests are cleared with bulldozer, and logs are burnt down; thus, the probability of reforestation is very low, since seed sources are either lost or located at great distances due to the large continuous tracts of denuded land.

3. Methods

Starting in 2004 we conducted a comparative study of agricultural systems in the Pampa and Chaco regions. In the former, soybean had been the main crop for several decades, in the latter this crop was advancing at a high pace. By that time we already perceived that internal migration was taking place in the AGC, and we started a research project aimed at identifying land use changes during the decade from 2001 to 2010, and their impacts on the natural and social subsystems. The methods and results in this paper are drawn from those research projects.

For the analysis presented in this paper we chose the north–west portion of the AGC, comprising 43 departments in four provinces (Salta, Chaco, Formosa, and Santiago del Estero) in the Dry Chaco Ecoregion. The total area is 276,436 sq.km (Fig. 1), representing 45.42% of the AGC. The department (county), is the smallest autarkical jurisdiction in which economic (land use) and social variables are assessed and reported by national organisms.

3.1. Land use/land cover change

In order to evaluate the extent of land use/land cover change (LUCC), we mapped land cover and land use for 2001 and 2010. Land cover maps were constructed from the Enhanced Vegetation Index Product, obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS) on board the Earth Observing System-Terra platform. We used 12 images for each year, one per month of approximately the same day, to obtain a synthetic map for each year. The original images in HDF format were pre-processed with the Modis Reprojection Tool (https://lpdaac.usgs.gov/tools/modis_reprojection_tool) to download the images and extract the EVI band (Huete et al., 2002). An unsupervised ISODATA classification was applied to obtain the cover maps, with 0.95 convergence coefficient. Landsat images downloaded from the National Institute for Space Research of Brazil (INPE, http://www.inpe.br/), field data and maps of the study area were used to reclassify the MODIS images. The final land cover categories were closed forests, open forests, closed shrub lands, open shrub lands, grasslands, water, bare soil, crop parcels, urban lands, herbaceous wetlands.

Closed and open forests, and closed and open shrub lands were aggregated for further analysis, and the less frequent cover classes were discarded since they did not suffer important changes in the decade. Thus, the cover classes included in the final analysis were forests, shrub lands, grasslands, crop parcels and urban areas.

Land use maps for 2001 and 2010 were produced using an object-oriented strategy. Urban areas, periurban areas, outposts and crop parcels were manually digitized on screen with the Landsat satellite images as backdrops. The periurban fringe around cities is a mosaic of constructed plots, small horticultural parcels, junkyards, poultry farms, slaughterhouses, yards where cars are disassembled, small industries and so on, with no characteristic spatial pattern, except for the variability in plot size and the irregularity of spatial configuration. Most of the activities in this area are illegal or, at the least, improper.

A composite land use/land cover map was obtained for each year by aggregating the land use and land cover maps for each year. The land use shapes were converted to raster format and added to the land cover maps with the function Merge in the Transform Grid option of ArcView 3.3.

In order to evaluate the rate of change in land use and land cover in each department, landscape metrics were obtained for each date from the vectorial land cover and the land use maps. The metrics were percentage of surface occupied by each cover or use type (PLAND); mean patch size in hectares (MPS); number of patches per unit area (PD); and the largest patch index (LPI) as the percentage of the department area occupied by the largest patch of each cover or use type. PD and LPI are indicators of fragmentation: the higher PD and less LPI, the more spatial fragmentation.

The annual rate of change for each land cover and land use type was calculated using the percentage rate proposed by Puyravaud (2003):

$$r = \left[\frac{1}{t_2 - t_1} \times \ln\frac{A_2}{A_1}\right] \times 100$$

where r is the annual rate of change; A_1 and A_2 are the initial and final areas occupied by the cover or use type; and $(t_2 - t_1)$ is the time interval between the two measurements. Positive values indicate increase in area, negative values indicate decrease in area and zero values indicate no change.

A large amount of demographic, social and economic variables were explored to identify their interactions with land use/land cover change. These variables were obtained from the 2001 and

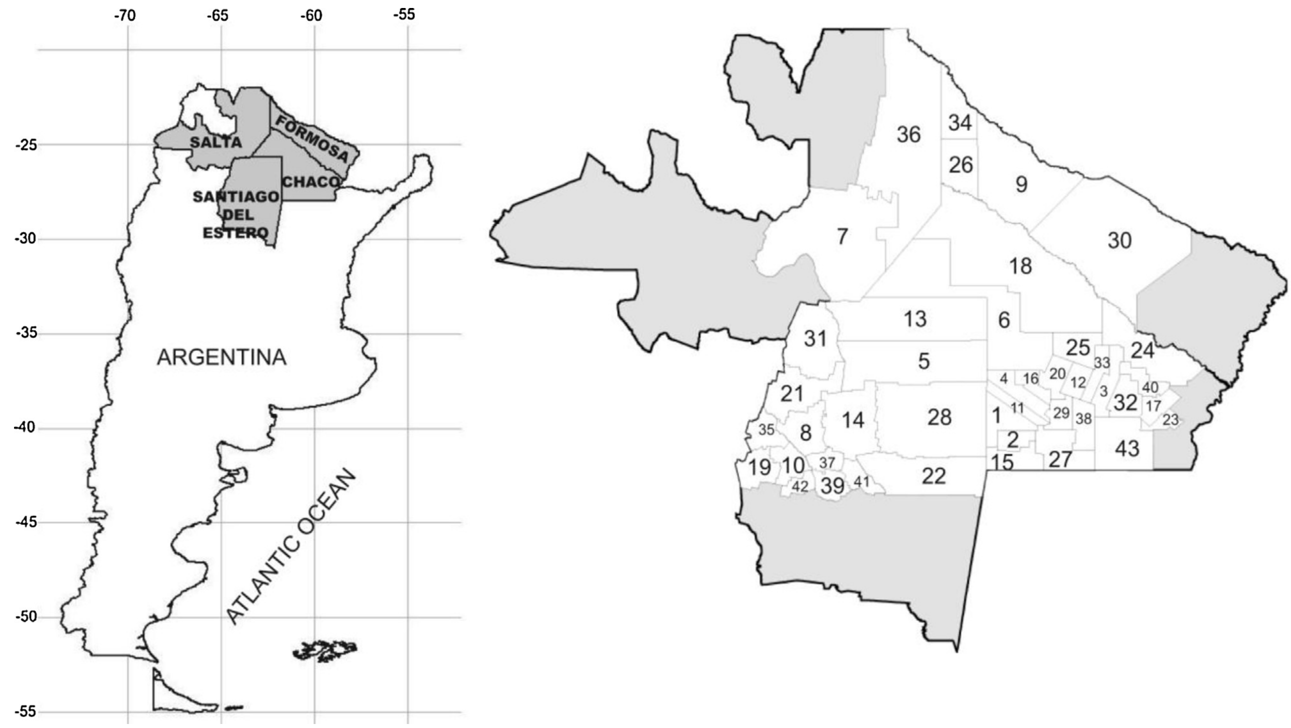

Fig. 1. The four provinces (to the left) and 43 departments (to the right) included in the study area.

2010 national censuses (INDEC, 2001, 2010). They included population, housing, education, working situation, access to goods and services. In this paper, we used social variables to test the second supposition, as described below. The Puyravaud (2003) percentage rate of change was used to describe changes in social variables. The Spearman rank correlation non-parametric test was used to evaluate the degree of association between variables (Zar, 1984).

3.2. Validation of assumptions

Various procedures were used to validate each one of the three assumptions in relation to the Forest Transition Theory in the AGC. The methods used in each case are described below.

3.2.1. Indigenous people and low income peasants use land inefficiently

If the assumption were true, forests and shrub lands would be absent or sparse in the sites inhabited by indigenous people and low income peasants. Our hypothesis is that massive deforestation is not happening in these lands, and that the expression "inefficient land use" does not apply to these people, since they sustain themselves with forest resources and low input agriculture.

We obtained maps of the Aboriginal colonies from the literature (CEDEI, 2010; La Rocca, 2011). These maps were overlaid on our 2010 land cover map in raster format and the location of indigenous communities in relation to land cover type were obtained with the Tabulate Area extension in ArcView 3.3.

Information about land use strategies by low and medium income peasants was obtained through unstructured interviewing by two doctoral students (Arístide, 2014; Totino, 2015, unpublished theses). Totino's thesis aimed at the evaluation of soybean production impact on the environment. The Emergy Synthesis Method (Odum, 1996), the Material Flow Accounting (Ascione et al., 2008) and the Embodied Energy Analysis (Hinterberger and Stiller, 1998), were applied to the whole life cycle of soybean production. The Sustainability Multi-Method Analysis (SUMMA) was used to integrate the indicators (Ulgiati et al., 2006). The study was done in a traditional agricultural socio-ecological system in which low to medium income peasants who used to produce sorghum and corn were forced to switch to soybean to maintain their financial capacity and their lands. The purpose of Arístide's thesis was to assess the spatial heterogeneity of natural resources appropriation, studying the association of land use with landscape heterogeneity, agro ecosystem properties and the access and availability of water in four low income communities in the centre of the Figueroa department (N°14 in Fig. 1), Santiago del Estero province. The data helped identifying the events that modelled the local life through their history, and that initiated or ended the various stages of productive activities and management of water and other resources.

Even though the main objectives were different, for both theses information was gathered at the family level on demographic variables, number, age and sex of family members working in the field, and data about production costs and returns. For each produce type (agriculture, ranching), data was obtained on the area devoted to the activity, plant and animal species, area per species, number of animals per area, amount and type of chemical products, type and occupation time of tools and machinery, origin and destiny of sown and harvested crop seeds, production destiny (for their own consumption, bartering, marketing), production costs, income obtained. For natural resources extraction, mainly forest products, information included type (logging, medicinal herb harvesting, honey, hunting, artisanal handicraft, and so on), species used, amount collected and converted, frequency of collection, cost of extraction or conversion, destiny and income. Additional information included distance from dwelling to working sites, and income from additional wage labour when it exists.

3.2.2. Development drives rural–urban migration of low income peasants in search of a better life quality

If this assumption were true, rural–urban migration would be detected in those departments in which large-scale mechanized agriculture expanded in the decade from 2001 to 2010. Population and housing would increase in cities and decrease in rural areas.

To study the effects of agricultural expansion on social variables, departments located in the two strips of advancing agricultural frontier during the decade 2001–2010 were selected. Twenty departments were left. Landscape metrics and the annual rate of change were used in the analyses.

The social variables included demographic indices and were obtained from the 2001 and 2010 national censuses (INDEC, 2001, 2010). The selected variables were rural, dispersed and urban population density; rural, dispersed and urban housing. Associations of each one of these variables with area under periurban land use and cropland expansion were investigated.

Rural and urban population is the number of inhabitants concentrated in small villages under 2000 inhabitants, and in cities over 2000 inhabitants, respectively. Dispersed population is the number of inhabitants in localities with few inhabitants that are spread in the territory. All variables are expressed in percentage of the total department population. The same subdivision in rural, disperse and urban is applied to housing. The variables are shown as percentage of total house number in the department. Associations between population and housing were tested with the Spearman rank correlation coefficient (Zar, 1984). The Puyravaud (2003) annual rate of change was applied to each one of these variables to evaluate change between 2001 and 2010.

Population and Housing are highly correlated in all categories (Rural, Dispersed, Urban) at $p < 0.001$ for $n = 20$; thus Population was selected for further analyses.

In order to obtain a parameter for comparison we calculated the Puyravaud annual rate of change of urban population for each selected department under the supposition that all the rural and dispersed population moved to urban areas. To achieve this we summed up rural and dispersed population in 2001 to obtain the expected urban population in 2010.

3.2.3. Expansion of intensive agriculture occurs in the most productive lands

If this assumption were true, cropland expansion would occur in land units of high IPc values and little limitations for growing crops.

The vector soil map of Argentina (INTA, 2013) was overlaid on the land use map of the study area comprising the 20 departments in which croplands expanded. The degree of overlapping between plots and soil conditions was quantified by cross tabulation with the Tabulate Areas extension of ArcView 3.3 with a 50 m resolution. The soil variables analysed were: soil Order and Subgroup (according to the taxonomic classification of the US Department of Agriculture), the cartographic productivity index (IPc) and main soil limiting factors. The cartographic productivity index (IPc) is an indicator of the predominant productive capacity (potential productivity) in each soil cartographic unit. This index takes into consideration climate, and soil variables, such as drainage, depth, texture, salinity, alkalinity, organic matter, cationic exchange capacity and erosion (Riquier et al., 1970). It is valid only within the region for which it was assessed because it shows the fraction of the maximum yield potential for the most common crops adapted to the local conditions and under a given level of management. The higher the value, the nearer is the agricultural production capacity of such land unit to the potential value. The continuous series of whole values represented in the soil map was classified into 7 classes: 0–30; 31–40; 41–50; 51–60; 61–70; 71–80; 81–100.

Table 1
Land use extension in 2001 and 2010.

	PLAND 2000			
	Croplands	Outposts	Rural areas	Urban areas
Mean	15.27	1.22	4.76	2.48
Min	0.00	0.09	0.00	0.07
Max	68.01	3.48	19.39	31.86
	PLAND 2010			
	Croplands	Outposts	Rural areas	Urban areas
Mean	23.50	1.16	5.35	2.59
Min	0.00	0.04	0.00	0.08
Max	80.99	3.05	20.90	32.63

PLAND: percentage of department area occupied by each land use type. Mean, minimum and maximum values calculated for 43 departments.

4. Results and discussion

4.1. Land use/land cover change in the study area

Both land use (Table 1) and land cover (Table 2) changed from 2001 to 2010. The land use that increased the most was industrial agriculture. The average proportion of land per department under soybean increased in 10%. The rest of the land use types changed slightly; outposts and rural lands decreased while urban lands increased.

The largest cover type in both years is the forest; however, forest land decreases. In 2010 forest fragmentation is evident; however, forest patch size increases, probably due to disappearance of small patches, and large forest patches still persist. According to official regulations, a forest border must be kept around each parcel; but, by 2010 most borders had disappeared, as recently confirmed by Ginzburg et al. (2012).

The proportion of grasslands per department decreases considerably (Table 2); some patches disappear, and patch mean size decreases. Scrublands do not change in percent cover per department; however, fragmentation occurs as shown by the increase in patch density and decrease in large patch index. The percentage of cropland increases; the increase in mean patch size and largest patch index, together with a decrease in patch density show that enlargement of parcels caused neighbouring ones to come together.

Table 2
Land-cover metrics in 2001 and 2010.

		Scrublands			Forests			Grasslands			Croplands		
		Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
2000	PLAND	10.21	0.42	46.89	44.01	12.42	85.65	12.08	0.41	56.42	20.21	0.00	73.27
	MPS	61.90	8.78	224.78	210.86	34.55	736.60	71.07	12.44	340.30	1057.98	0.00	8000.55
	DP	14.23	3.09	37.28	34.89	9.19	74.54	16.82	1.97	38.56	2.47	0.00	10.41
	LPI	3.06	0.02	37.71	22.94	0.70	78.73	3.17	0.03	34.09	12.33	0.00	72.75
2010	PLAND	6.69	0.27	29.28	42.94	9.09	85.82	4.78	0.15	34.56	29.00	0.00	81.73
	MPS	51.08	9.61	240.57	238.37	28.41	1195.93	51.40	10.12	237.93	2312.91	0.00	14938.55
	DP	32.14	0.43	155.22	52.75	1.56	286.86	8.28	1.06	19.06	1.92	0.00	5.89
	LPI	1.25	0.05	15.08	22.86	0.59	83.22	0.83	0.00	6.99	21.00	0.00	81.54

PLAND: percentage of department area occupied by each class; MPS: patch average size; PD: patch density; LPI: largest patch index. The average, minimum and maximum values for 43 departments are shown.

Both tables show broad ranges of land uses and cover type extensions, indicating that change processes differ greatly among departments. For this reason, for the following analyses we selected those departments with the most cropland expansion, considering that the aim was to identify associations between LUCC and social variables. Intensive agriculture expansion occurs in two fringes, along both the west and east borders, toward the centre of the study area.

There is no evidence of forest transition in this period in the study area. Since forest conversion to croplands in the AGC started in the mid-20th century, reforestation might have occurred before. There is only one report on reforestation of agricultural lands, showing that from 1975 to 1990 forest cover increased on abandoned croplands in Moreno Department (N°28), Santiago del Estero, from seeds of adult trees which were spared for seed production; however, in the mid-1990s large tracks of land were deforested with bulldozers and the remaining vegetation was burnt, precluding all possibility of forest recovery (Boletta et al., 2006). The results show that forest transition occurs only when small forest patches are deforested by hand followed by controlled burning. Moreno Department has the highest proportion of soils suitable for agriculture (IPc > 81).

4.1.1. Changes in land cover in selected departments

Since our concern is the impact of intensive agricultural expansion on forests and people, we selected the departments in which cropland expansion occurred between 2000 and 2010.

The area under each land use in 2001, calculated for the 20 selected departments, is of 13.2% of croplands (0.2–54%), 1.4% of outposts (0.2–2.8%); 3.7% of rural area (0.1–10.4%); 1.9% of urban areas (0.2–21.5%). It may result weird that cropland mean proportion is smaller for the 20 selected departments than for the whole study area; however, we must remember that the department selection included only those with the largest cropland expansion during the study period, and not those with lands converted to croplands before 2001. In 2010, mean area under land use types was: 25.8% of croplands (2.2–76.9%); 1.3% of outposts (0.1–2.7%); 4.3% of rural area (from 0.1–8.6%) and 2.1% of Urban area (from 0.1–23.2%).

The results show that the mean percent cropland cover almost doubled in the study period for the 20 selected departments. This observation justifies the validation of assumptions invoked in the Forest Transition Theory as applied in the AGC.

4.2. Validation of assumptions

4.2.1. Land use by indigenous people and low income peasants

Four ethnic groups in 157 indigenous colonies were found in three provinces, Salta, Chaco and Formosa; maps for colonies in Santiago del Estero are not available yet.

Most of the indigenous colonies are under forest (56%), cropland (16%) or shrub land (16%) (Table 3). Since cultivated area doubled in 10 years, the colonies on cropland might have been pushed out by agribusiness. Field work is needed to confirm this possibility.

Only four percent of the indigenous groups are located on bare soil patches surrounded by shrub lands.

The argument that indigenous people make inefficient use of land is difficult to sustain, unless inefficiency refers to food production for export. If we refer to natural ecosystems sustainability, the supposition does not hold. Indigenous people have occupied the AGC for several centuries, where they have developed a culture based on the appropriation of natural resources adapted to local environmental conditions (TNC, 2005; Suarez and Arenas, 2012). Their activities were hunting, gathering, fishing and planting. Some of the ethnic groups showed great mobility, in response to the seasonal availability of fauna, flora and water resources. The groups moved between campsites, located at the border of forests and characterized for the presence of water, food, good soil for planting, good clay for pots, river shells for spoons and ornaments, and so on (Van Dam, 2000; Arenas, 2003; Mendoza, 2003). Their lifestyle adjustment to natural cycles, as well as the diversity of activities practiced, help maintenance of ecosystem services. This life strategy had to change with the arrival of European settlers, and by 1930 indigenous people started to establish in permanent campsites. In due time, they became cheap labour for the colonizers, and by mid-20th century some of them started moving to the periurban fringe of the main cities (Fernández and Hachén, 2007), even to those outside the AGC. Native ecosystems persist up to the present as long as local native inhabitants are allowed to stay in their lands.

Table 3
Distribution of aboriginal ethnic groups.

Land-cover	Ethnic group				
	Wichi	Toba	Mocovi	Pilaga	Total
Forests	75.86	35.90	5.56	50.00	55.70
Scrublands	12.64	20.51	5.56	35.71	15.82
Cropland	6.90	25.64	50.00	0.00	15.82
Wetlands	3.45	5.13	0.00	14.29	4.43
Bare soil	1.15	7.69	11.11	0.00	3.80
Grasslands	0.00	0.00	16.67	0.00	1.90
Urban	0.00	5.13	11.11	0.00	2.53

Numbers are percentages of total number of colonies in each ethnic group. There are differences among ethnic groups. Wichi, Toba and Pilaga prefer woodlands, while Mocovi prefer grasslands; however, these preferences may be related to spaces free of industrial agriculture, where natural resources of their interest are still available; or with the degree of acceptance of the alleged modernization, especially among youngsters. Field research is needed to elucidate this issue.

The best preserved forest in the Dry Chaco, el Impenetrable, of almost 130,000 ha, has been recently declared National Park. This area used to be a preferred foraging territory for the local indigenous people, in spite of which the area was near pristine at the moment of its conversion to National Park in 2014. This is a good evidence of the sustainable use of natural resources by indigenous people.

The possibility exists that some natural woodlands inhabited by indigenous people become degraded, due to their concentration in smaller areas as they are pushed away from their lands. However, this is not a consequence of voluntary outmigration in search of better life conditions. The driver in this case is expansion of intensive agriculture, which displaces local people, forcing them to concentrate on neighbouring areas already occupied by friends or relatives. For some while, resources are overexploited, until a new steady state is reached, even by the depletion crisis model or the ecological understanding model (Berkes and Turner, 2006). The first model supposes that people acquires a conservative behaviour when a crisis brings into evidence that resources may run out. The ecological understanding model supposes that the community elaborates long-term environmental knowledge that allows them to plan a sustainable use of resources. An anthropological historical analysis is needed to elucidate which of the two models prevailed in the AGC, though most probably both played a role in the indigenous cultures survival.

On the other hand, the criollos, who share the territory with indigenous people, adapted to local environmental conditions, making intelligent use of natural resources without jeopardizing them. Nowadays, they make up the communities of low-income peasants. Most of these communities inhabit areas under forests and shrub lands. An example of this situation is in Figueroa department (N°14 in Fig. 1), where soybean occupies less than 0.3% of its territory. It is located in the department with less deforested area and less deforestation rate in recent years (Volante et al., 2012). Most of their produce is for subsistence, some is bartered and a

Table 4
Population and land-use area percentage annual rate of change.

Dept.	Population				Land use	
	Rural	Dispersed	Urban	ExpUrb	Periurban	Croplands
1	−1.03	−1.20	1.72	3.23	0.53	2.10
20	3.21	−1.83	1.53	3.22	1.65	2.89
4	0.00	−2.80	1.61	7.24	4.39	3.13
21	−0.48	0.92	2.10	2.67	3.52	4.52
31	2.04	−0.56	1.85	4.56	9.12	6.01
13	−0.60	2.76	1.21	1.90	0.64	6.79
22	2.17	−1.21	1.68	15.33	0.52	6.83
7	1.75	−2.22	2.23	0.49	−1.20	7.13
28	4.39	−2.23	2.26	5.37	8.00	7.33
8	2.33	0.29	1.09	5.70	0.59	7.59
15	6.01	−1.78	2.13	7.98	−4.80	7.87
19	0.00	−0.05	0.64	2.93	0.00	7.90
10	1.06	1.65	0.85	16.09	−0.51	7.99
39	16.74	15.18	0.00	10.23	0.00	8.05
41	0.00	−1.60	1.19	6.38	2.57	9.32
6	2.14	−1.16	2.19	3.96	2.60	9.83
31	6.25	−2.68	1.20	15.18	0.14	11.95
5	0.43	0.24	1.72	14.27	0.28	12.84
9	14.21	3.26	8.55	0.00	−0.55	14.37
36	1.25	−0.11	3.39	7.10	−1.62	18.84

Departments numbered as in Fig. 1. Data are ordered from lower to higher cropland rate of change. ExpUrb = expected urban annual rate of change supposing that all rural and dispersed population in 2001 had moved to urban areas by 2010.

Table 5
Main soil Orders in the study area as mean of department area under each soil Order.

	Mean (*n*)	Mean (*n*)
Soil Order	43	20
Mollisol	50.00	53.07
Alfisol	26.88	24.72
Entisol	12.85	12.56
Inceptisol	8.75	7.31

Other frequent and important soil limitations are the presence of a duripan horizon within one meter depth; salt accumulation below the upper mollisol horizon; high sodium exchange capacity; alkalinity at less than 50 cm depth; salinity in the first 50 cm; poor drainage; susceptibility to water erosion; susceptibility to flooding or waterlogging, among others.

small proportion is sold in the local market. As part of their activities, they keep forest stands of 1000–5000 ha under communal property, with protection regulations established by the community; i.e., a portion of the area is kept as natural reserve while the rest is used for communal silvo-pasture activities and extraction of wax, honey and medicinal plants; wood extraction from the natural reserve is forbidden (Arístide, 2014, unpublished theses). Their crops are sown in small parcels (1–5 ha per family) surrounded by live fences of shrubs or herbs, with or without wood fence. The strategy is multipurpose management, with ample diversity both in space and time, since they organize the production in order to have several vegetables, grain, alfalfa, corn, gourds, and so on, the year round. They combine agriculture with cattle, small livestock and poultry. The dwellings are surrounded by woodlands, where domestic animals spend the day and feed. This management strategy results in a permanent green cover which protects the soil from drying out and from salinization.

In a recent study Baldi et al. (2014), using 19 vegetation function metrics based on temporal series of the Normalized Difference Vegetation Index (NDVI) for 2000–2011, showed that, even though primary production does not differ greatly between lands under industrial and low income agriculture, notable differences arise regarding seasonality of green cover. Agribusiness searches for high incomes in short times; thus, they adjust the timing of planting and harvesting for the smallest time interval allowed by climate signals and the market crop cycle. The result is a fast cycle of growth and senescence, with a long interval of bare soil. The field may remain completely bare or under a sparse weed cover which turns to fallow in a short time, due to the dry climatic conditions. The authors warn about the possible consequences of maintaining the fallow for long periods in a semiarid climate in flat lands, since the deep drainage and dynamics of the groundwater could be altered, causing floods and soil salinity.

Low income peasants, keep a large crop species diversity, both in space (several crops grown in small parcels in a production unit) and in time (several crops harvested at different moments along the year). This results in the maintenance of a green cover, which protects both the soil and hydrological processes.

Other theme of dissension is that related to the outposts. In some papers (Grau et al., 2008; Macchi and Grau, 2012), outposts are considered highly damaging for vegetation. It is true that deteriorating activities are carried out in the outposts, such as logging for fences and charcoal production, cattle ranching, subsistence cropping and small livestock raising around the dwellings, all of which end up with depletion of vegetation cover around the dwellings. However, if compared to intensive agriculture, the outposts are meaningless (Table 1), both in mean area and in maximum size. Our data show that the outpost mean size is 50 ha, varying from 27 to 172 ha; there is only one outpost that exceeds 75 ha. Bare land these sizes are not difficult to recover by reforestation from the borders, once abandoned. However, by 2010, 461 outposts had disappeared under intensive agriculture. If industrial agriculture keeps expanding, outposts will not be a problem, and reforestation most probably will be extremely difficult in such large patches of bare soil. Also, ranching in outposts is not as damaging as roller-chopper in disrupting woody vegetation, followed by direct seeding of exotic grasses (Kunst et al., 2012). This management strategy converts woodland systems that capture and store CO_2 in grasslands, which are net emitters of greenhouse gases; they modify the undergrowth microclimate and introduce an exotic species whose impact on local biodiversity and other ecosystem services in the AGC have not been evaluated. Reforestation may be difficult because the seedlings and small individuals of native trees are bulldozed along with the bushes.

From the previous discussion it follows that, statements such as "subsistence farming is one of the factors contributing to deforestation in Latin America" (Chowdhury and Turner, 2006; Pan et al., 2007), seem somewhat exaggerated. In the AGC, deforestation is

Table 6
Percentage of department area under each soil limitation and CPI.

Dep	Main soil limitations						Cartographic productivity index							rCrop
	1	2	3	4	5	6	0–30	31–40	41–50	51–60	61–70	71–80	81–100	
36	–	14.03	1.57	–	–	13.72	1.00	27.40	0.94	70.65	–	–	0.01	18.84
9	28.22	–	23.67	8.06	–	1.37	48.32	18.15	33.53	–	–	–	–	14.37
5	–	10.73	11.04	2.66	0.56	18.69	6.44	32.10	5.26	37.92	–	11.91	6.36	12.84
31	21.96	–	47.04	7.85	–	17.42	49.76	24.14	22.29	3.82	–	–	–	11.95
6	3.21	15.72	55.42	1.46	21.26	1.24	41.52	53.64	2.72	1.26	–	–	–	9.83
41	–	7.55	–	24.99	–	–	29.37	3.16	–	–	67.47	–	–	9.32
39	–	23.54	–	17.99	–	–	41.53	–	–	–	58.47	–	–	8.05
10	–	–	–	–	–	–	–	–	–	0.05	73.33	–	26.62	7.99
19	–	6.17	–	–	–	–	7.73	29.65	5.36	18.60	14.63	23.28	0.75	7.90
15	14.77	22.66	42.81	8.17	6.55	4.61	61.34	15.93	22.73	–	–	–	–	7.87
8		29.26	–	12.70	3.30		30.85	12.70	3.88	16.42	36.15	–	–	7.59
28	–	0.01	3.02	9.34	11.46	32.50	15.17	28.50	0.81	17.50	6.26	0.40	31.35	7.33
7	–	14.23	12.07	–		24.69	2.13	26.51	8.46	31.96	15.09	15.85	–	7.13
22	–	13.30	–	2.15	52.57	–	3.81	4.44	26.79	53.54	11.42	–	–	6.83
13	–	7.80	4.07	0.68	1.40	38.16	0.27	48.43	3.50	38.16	–	9.63	–	6.79
31	–	17.07	3.19	–	18.13	16.79	4.44	14.65	4.30	41.42	35.19	–	–	6.01
21	9.57	0.51	89.92	–	–	–	68.99	31.01	–	–	–	–	–	4.52
4	3.94	23.26	44.17	–	28.63	–	59.90	35.28	4.82	–	–	–	–	3.13
20	4.27	7.19	6.99	7.33	2.55	21.77	27.26	17.60	1.46	29.49	16.60	–	7.58	2.89
1	–	1.02	34.09	28.07	36.69	0.13	65.11	23.75	1.50	9.64	–	–	–	2.10

Department numbers are as in Fig. 1. The data are ordered according to percent annual rate of cropland change (rCrop). Limitations: 1 = alkalinity at less than 50 cm depth; 2 = poor drainage; 3 = present water erosion; 4 = Salinity in the first 50 cm depth; 5 = susceptibility to water erosion; 6 = susceptibility to flooding or waterlogging.

caused by industrial agriculture and ranching. Unfortunately, rights and livelihood of the original inhabitants are not of concern to some scientists, planners and producers (Salamanca, 2011).

Middle-income farmers are also being affected by agribusiness. This is the case in Charata township, in Chacabuco department (N°11 in Fig. 1), where the farmers are victims of soybean expansion (Totino, 2015, unpublished theses). They used to grow sorghum and corn, in small parcels, with no irrigation or fertilization. Charata producers face many difficulties, both climatic and trade issues, as the inputs are more expensive than for cultivating sorghum and corn. In Rojas, located in Argentina's traditional agricultural lands, soybean yield is 1 ton/ha higher than in Charata, while in the latter production costs are higher than in Rojas because of distance of transport to the port, and of charges for export taxes, that are the same for both regions.

Charata producers do not apply fertilizer to offset this cost problem; it is expected that in a few years, yields will decrease due to loss of soil fertility. During dry spells, such as those of 2008 and 2009, Charata producers go into debt, and they may lose their lands in a couple of years. Producers are worried because they are harassed by wealthy landowners, who take advantage of their vulnerability and buy the land at low prices. Their concern extends to the local community because job positions are lost, since the agribusiness does not hire as much workers as medium-income farmers do. In Charata, each small crop parcel keeps a forest border; however, these protecting forests are gradually disappearing due to the need to increase production in order to keep accounts even. With soybean expansion, these borders are cleared by bulldozer, as shows by the increase in mean crop patch size (Table 2).

This example shows that agribusiness is not only pushing out indigenous people and subsistence peasants, but also middle-income producers.

4.2.2. Rural–urban migration of low income peasants

The results show that soybean expansion causes changes in annual rate of change of social variables (Table 4); however, the increase in urban population is not as much as expected under the supposition of rural–urban migration, as shown by the calculated rate of change if all rural and dispersed population in 2001 moved to urban areas by 2010. If half of the non-urban population in 2001 moved to the cities, urban population in 2010 would be larger than that given by the 2010 census in 16 of the 20 departments.

Different situations are perceived in the departments. In 15 of the departments (75% of the total) the periurban area increases as crops expand, and rural or urban population or both decrease. This means that people are migrating from the rural area or from small localities, including outposts, to the periurban area. In the other seven departments the periurban area decreases while dispersed population decreases and rural population increases. This situation probably occurs when indigenous people are pushed away from their lands and migrate to the pre-existing colonies in the rural area. Some changes are not expected. For example, in department N°39, urban, rural and dispersed population increase, as croplands increase and periurban areas decrease. In this case, interdepartmental migration may be taking place but, as census data are reported for each department, this cannot be detected.

The increase in periurban area in most departments shows that migration is not occurring from the rural area to the city, but to the city outskirts, where people live in worse conditions than in the countryside. In slums, other drawbacks have to be added to overcrowding, such as the lack of public services (water, electricity, gas, health care, social services, etc.) and the loss of self-esteem. The benefits of development (as understood by the promoters of agribusiness), do not reach the low income peasants neither to the indigenous people, nor in food provision neither in labour opportunities.

4.2.3. Expansion of intensive agriculture in relation to soil properties

There is a presumption that the soils in the AGC are as suitable for agriculture as those of the Rolling Pampa, Argentina's traditional agricultural area. This belief has been the driver of industrial agriculture transference from the Pampa to the AGC, under the same technology. However, unlike what happens in the Pampa, the Chaco soils have many limitations. Even though agricultural soils belonging to the Mollisol Order (Table 5) predominate both in the whole study area (50%) and in the 20 selected departments (53%), important constraints reduce their productivity capacity. The main limitation for agriculture in the AGC area is the climate, due to its dryness and rainfall irregularity.

Since we considered only the main limitations and the soil map reports only one primary limitation for each soil unit, we may add up the areas under various soil limitations in each department to evaluate the total area under some type of limitation. The results show that 13 departments have more than 50% of their lands with soil limitations, and six of them with more than 94% under soil limitations. In 16 departments, more than 19% of croplands are in soils of less than 40% of the potential productivity; in seven departments 66% of crops are grown in soils of less than 40% potential productivity. The IPc rarely exceeds the 71–80 range (Table 6), and if so, few plots are located in these soil conditions.

The results show that in the AGC, soybean is expanding in soils with low suitability for agriculture.

5. Conclusion

Many people, including policymakers, scientists and public, are concerned about deforestation of the dry subtropical forests because a highly vulnerable steady state exists between forest cover and microclimatic conditions under the forest canopy. An excessive deforestation might end up in desertification. However, some researchers have modified the FTT to justify agribusiness expansion in the AGC. We intended to show that their suppositions do not apply to this region. Drawing on research data and bibliography, we tested the validity of three assumptions suggested for the Forest Transition Theory as applied to the AGC.

There are two main differences between the FTT as described originally for the northern hemisphere and that applied to the AGC. In the first place, the original formulation of the FTT referred to temperate humid or sub humid forests, while subtropical dry forests prevail in the AGC. In the former, forest transition has been observed and measured, while in the AGC, it is not occurring except in relatively small localized areas. In the second place, in the temperate regions development triggered forest transitions because farmers migrated to cities on their own accord. In the ACR, development pushes people away from their lands. It seems that development has different meanings according to the period and region to which it refers, and to the user of the word. In the bibliography on FT in the AGC, development is understood as the results of an inequitable, globalized, neoliberal economy.

We do not believe that the solution is to completely ban industrial agriculture, since the health of Argentinean economy depends highly on taxation of agricultural exports. However, extensive and intensive deforestation may cause soil salinization, reduce soil water retention and fertility; all of which are harmful, not only to forest ecosystem services but also to agriculture. Deforestation in the Chaco region threatens ecosystem and landscape sustainability in detriment of natural ecosystem services, native cultures and even of agriculture, and it engenders a high risk of desertification. Conservation and food production do not need to be mutually exclusive. An intelligent land use planning should allow the combination of large scale food production, small-scale family agriculture, natural resource extraction, and conservation, into a multipurpose system. This is not going to occur unless low income peasants are provided technical assistance and educational opportunities, to get them prepared either to adjustment to urban life or to improving agro-ecological practices for both household subsistence and sale to local market. Most of the low income peasants in the AGC do not have sufficient knowledge of marketing strategies, they need instruction to identify and exploit local market opportunities avoiding middle-agents.

National and local policies have been formulated to achieve conservation of forest ecosystem services, sustainable use of forest resources and land (CDI, 2007), agro-ecological food production, the safeguard of indigenous people rights (MJDH, 2011). However, scientific papers highlighting the supposed merits of FTT as applied to the ACG results counterproductive toward the efforts of policymakers and local technicians, by giving false arguments to promoters of industrial agriculture for export.

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