

Impacts of Land Use Change on Ecosystems and Society in the Rio de La Plata Basin

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Introduction

The La Plata river basin (LPB) covers an area of 3.1 million km² in the South American territory, hosting a population of over 100 million people of Argentina, Bolivia, Brazil, Paraguay, and Uruguay. It can be divided in four main sub-basins, corresponding to the drainage areas of the Paraguay, Parana, Uruguay, and La Plata rivers (figure 1). With the exception of Bolivia, all other countries have their national capitals, political decision centres and other major cities located in the LPB (Brasília, São Paulo, Assuncion, Montevideo, and Buenos Aires). The LPB covers a wide geographical area, spanning a South to North latitudinal gradient, resulting in the establishment of a variety of soil - vegetation configurations, as a response to different climates. In addition to that, the inherent topographic heterogeneity of the LPB adds natural complexity to the basin, resulting in a combination of extensive savannah-like plateaus (cerrado) and grasslands and open fields (pampas) in its Northern and Southern portions, respectively, the largest tropical wetland area in the world in the Northwest (pantanal), as well as both dry and humid forest biomes (chaco and Atlantic forests, respectively). This varied composition of biomes and ecosystems, added to the different social and cultural setup of the LPB, resulted in diverse histories and complex patterns of land use in the basin.

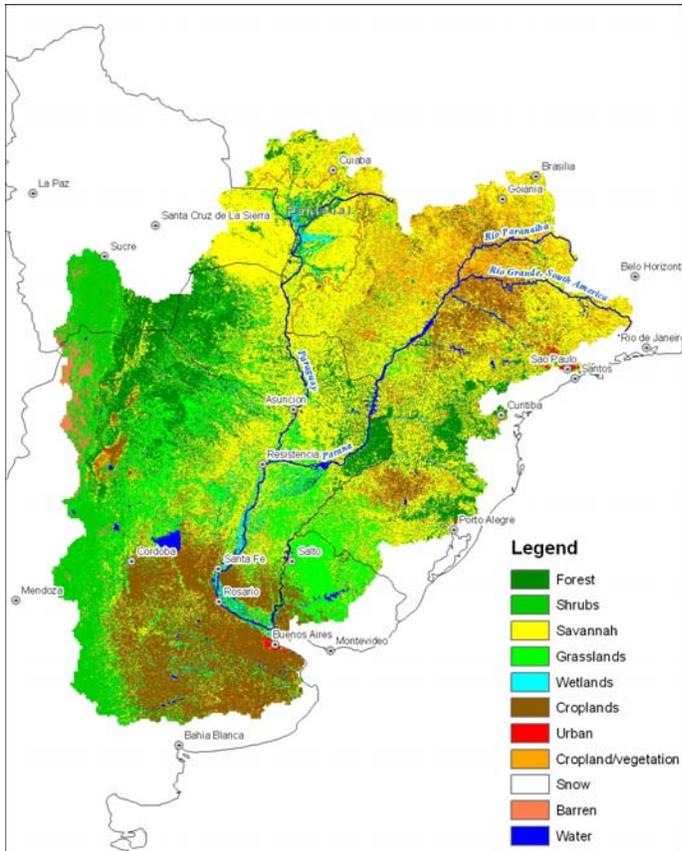


Figure 1. Land cover assessment of the entire Rio de la Plata Basin, as of 2004 (source: adapted from the MODIS/Terra Land Cover Type Product - MOD12Q1, produced by the Boston University Land Cover Research Team, <http://edcdaac.usgs.gov/modis/mod12q1v4.asp>)

Rural land use and industry in the basin are responsible for 70% of the Gross National Products of the LPB countries and are in a process of continuous change, as a response to drivers such as international market trends, infra-structure and technology developments, societal evolution, and the dynamics of national policies. Possible land use changes (LUC) are limited by biophysical constraints such as unsuitable soil type, topography, or climate. However, technology development can overcome some of these limitations, as was the case of the soybean expansion to the Cerrado region of Brazil, in the eighties.

Effective and sustainable management of the LPB depends on the ability of land managers from the five nations to predict the impacts LUCs on nature and society. Modeling efforts to predict environmental impacts in the LPB can benefit from knowledge acquired from impact assessments of major LUC processes. Land use change processes affect both the natural environment and society, therefore the ideal set of impact indicators should represent both dimensions. The human and natural dimensions interact both as drivers and as recipients of the impacts of LUC. The altered state of the impacted human and natural dimensions will reconfigure them as altered LUC drivers. Understanding these feedback mechanisms is a great challenge that integrates natural and social sciences alike. There is an urgent need for interdisciplinary research, overcoming the inherent conceptual and epistemologic barriers

between those two dimensions. Decision makers and society will only act on response to global change science results, when social and natural scientists achieve an effective integrated research framework.

This article will highlight impacts of the major land use change processes occurring in Brazilian and Argentinian biomes of the La Plata river basin. Based on current knowledge, we estimate possible impacts to nature and society, and finally, suggest a conceptual framework for cross-scale LUC research. We focus on rural LUC processes, even though significant urbanization has been reported in the LPB, with potential impacts to the water resources associated with the low investment in sanitation infra-structure, and to the local and regional climate, due to the increase in albedo and reduction in evapotranspiration. Intensive urbanization also represents a positive feedback as a LUC driver, since the demand for food and energy increases.

Land Use Change in the LPB

Three major agricultural sectors have been responsible for most of the LUC occurring in the LPB in the last thirty years: international commodities (soybeans, etc.), forestry (eucalipts and pines), and meat (cattle). Soybean and other grain crops, as well as cultivated pasture (*Brachiaria* spp.) are widespread in the LPB, and has replaced portions of all of the basin's biomes. Forestry, on the other hand, has been concentrated in the Southern portion of the basin. Biofuel crops, such as sugarcane, are increasing its cropped area, as a result of drivers represented by technological development (innovative car engines that operates with multiple types of fuel), the growing international market, and national policies, specially in Brazil. A land cover classification of the La Plata river basin, produced by the Boston University Land Cover Research Team, and based on medium-resolution satellite images (MODIS), as of 2004 is shown in figure 1 (<http://edcdaac.usgs.gov/modis/mod12q1v4.asp>).

Impacts of LUC processes will vary according to the biophysical and social configurations of the altered sites. During the last 30 years massive changes have occurred in the whole basin, with significant impacts both to nature and society. An overview of the main land use changes in Brazil and Argentina will be given. The Brazilian analysis will focus on LUC and its major impacts to soil and water in the Cerrado. The Argentinian analysis also shows impacts to the social and economic systems of that country.

Land use changes in Brazil

Agricultural use of the land has expanded 100 million ha during the last 40 years, with an average 3 million ha/year in Brazil (Filoso et al., 2006). Most of this expansion was caused by increases in pasture cultivation, although during the last 10 years cropland expansion has been greater (Alves et al., 2003). A lot of this expansion has been over Cerrado land. Several authors suggest that the Cerrado is being destroyed due to land use expansion, particularly for grain crops and pastures (Klink and Moreira, 2002; Fearnside, 2001) Estimates vary from 40 to 50% of complete destruction already established (Joly et al., 1999; Alho and Souza Martins, 1995). Jepson (2005) argues that regeneration rates of Cerrado vegetation are very high, and that this

may render this biome particularly resilient, enabling its recovery if proper land management strategies are adopted. The same author recommends the use of higher resolution satellite images and the consideration in the land use classifications of the class “regenerating cerrado”. Recent studies indicate that LUC processes could be effectively monitored for the Cerrado by use of multitemporal data from moderate resolution sensors (Jonathan et al, 2006a,b).

The Cerrado covers about 2 million km², which represents approximately 25% of the Brazilian territory (figure 2). A vast portion of it contains the headwaters of the Parana and Paraguay river sub-basins, components of the La Plata river basin.

The Cerrado is a complex environment, with different types of vegetation formations. They vary mainly with soil type and water availability (water table depth). Coutinho (1978) suggested the following classification, based mainly on vegetation structure: campo limpo, campo sujo, campo cerrado (*cerradinho*), cerrado *stricto sensu*, e cerrado.

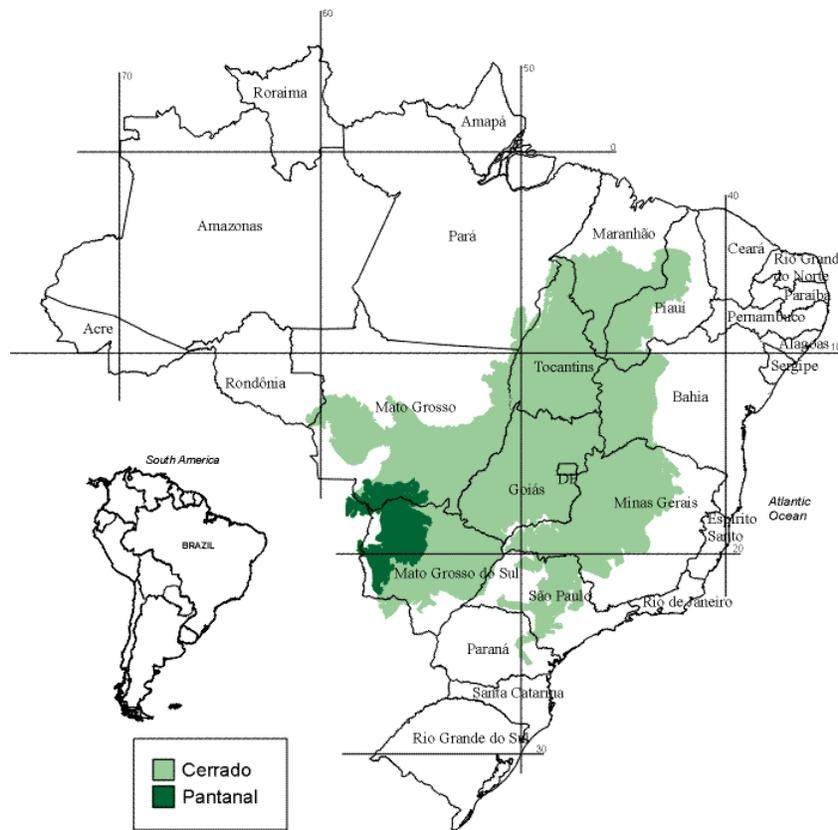


Figura 02. Localization of the cerrado and pantanal biomes in cerrado in Brazil (source: <http://www.bdt.fat.org.br/workshop/cerrado/br/mapatem>)

The seventies were characterized by agriculture expansion to the cerrado biome, driven by incentives of the Brazilian Federal Government as well as multilateral funding agencies. The POLOCENTRO (Cerrado Development Programme) invested USD 250 million between 1975

and 1984. The PRODECER (Nipo-Brazilian Cooperation Programme for the Development of the Cerrado), the CONDEPE (Cattle Raising Development Council) and the PROÁLCOOL (Alcohol Programme), also configured as significant drivers of the major land use changes imposed to the second largest ecosystem of Brazil, after the Amazon (Pinto, 2002). Scientific and technological development enabled the agricultural occupation of the Cerrado, correcting the high acidity and low fertility of its soils, and also adapting soybean varieties to the Cerrado environment. The basis for the occupation of the Cerrado was the transfer of the Brazilian capital to Brasilia, built in 1960. The road system built to link the new capital to the rest of the country enabled the entry of agricultural inputs and discharge of its products. The importance of the Cerrado to the agriculture-based Brazilian economy is evidenced by the data collected from the IBGE (Brazilian Institute of Geography and Statistics) in 1997 and compiled by Resck (2002): 52% of the soybean, 34% of the rice, 26% of the maize, 21% of the coffee, and 41% of the cattle meat produced in Brazil came from the Cerrado.

In the Cerrado areas of the Brazilian States of Tocantins and Goiás, the area occupied by crops showed a four-fold increase between 1960 and 1985. In the same period, land converted to cultivated pastures increased 4.7 times. This means that in 15 years, 14.1 million ha of Cerrado vegetation were converted to agro-pastoral use in those States with potential impacts to nature and society (Pinto, 2002). More recent data, compiled from the IBGE website, show that the expansion continues in the region, with a remarkable growth of the soybean planted area in the State of Mato Grosso, from 1990 to 2005 (figure 3).

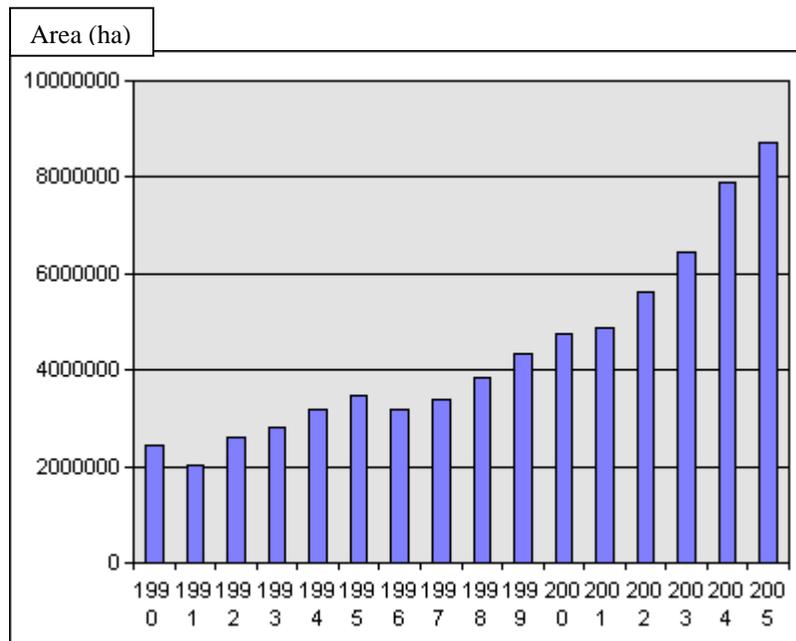


Figure 3. Area occupied by soybean plantations in the State of Mato Grosso, in the period 1990-2005 (<http://www.ibge.gov.br>)

Likewise, the conversion of Cerrado ecosystems into cultivated pastures, most of it African grasses of the genus *Brachiaria*, has shown a steady growth rate during the last 3 decades. According to FAOSTAT (2004) Brazil has a total of 265 million ha of agricultural land, being 187 million ha under pasture, out of which 80 million ha are occupied by *Brachiaria* spp. Macedo (1996) estimated that 45 to 50 million ha of the Cerrado were occupied with pastures at the second half of the nineties.

Land use changes in Argentina

The main trends of land use change in the Argentinean part of the La Plata basin are agricultural intensification, expansion of the agricultural frontier and commercial forestation. Agricultural intensification has occurred throughout the Pampas in all ecosystem types, and implies the predominance of cash crops, often in a double crop sequence in one year, and the abandoning of the traditional mixed agriculture-livestock production system where cash crops were usually rotated with perennial pastures. The most important grain producing provinces are Buenos Aires, Córdoba and Santa Fe (Figure 4). Higher gains through grain and oilseed production, low beef prices and reduced markets for beef, as well as the exceptionally high agricultural suitability of the La Plata basin lands drove farmers into more intensive agricultural land use. This becomes evident observing that even the traditional fences have completely disappeared in some regions.

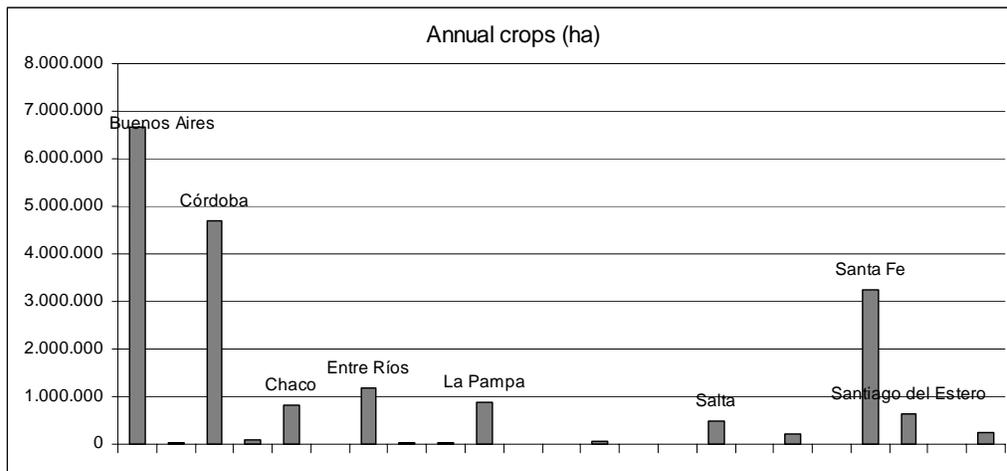


Figure 4: Agricultural provinces of Argentina.

The introduction of direct seeding or zero tillage favored this trend, since maintaining a reasonable level of soil cover helps to prevent erosion and thus minimizes the visible impact of agricultural intensification. Yields of all major cash crops have steadily increased over the past 30 years, especially for sunflower and soybean (Figure 5), which also contributes to over estimate the sustainability of continued cash cropping and also induces more farmers into monoculture cash cropping.

Yield increase and favorable global commodity prices paired with a convenient currency exchange rate have accelerated the intensification of agricultural land use in recent years. These factors also combined to favor the expansion of agriculture into more marginal lands.

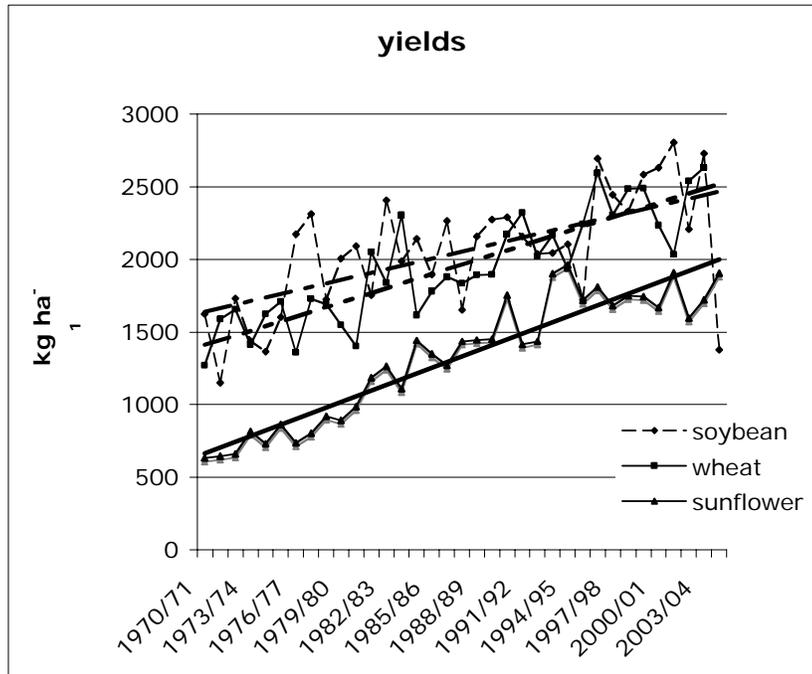


Figure 5: Major cash crop yields during the past three decades in Argentina. (Source SAGPYA)

Expansion of the agricultural frontier takes place in marginal areas such as the semiarid “Espinal” savannah of La Pampa, San Luis, Chaco, northern Cordoba and Santa Fe, as well in the flooded plains of Buenos Aires. In all of these biomes natural vegetation used for extensive livestock production is replaced by cash crops, mainly oilseeds such as soybean and sunflower. The area sown to soybean has increased steadily from the early 1970ies in the traditional agricultural provinces (Figure 6). In more marginal regions this trend starts around 2000, accompanied by very fast development of new varieties that are adapted to these environments.

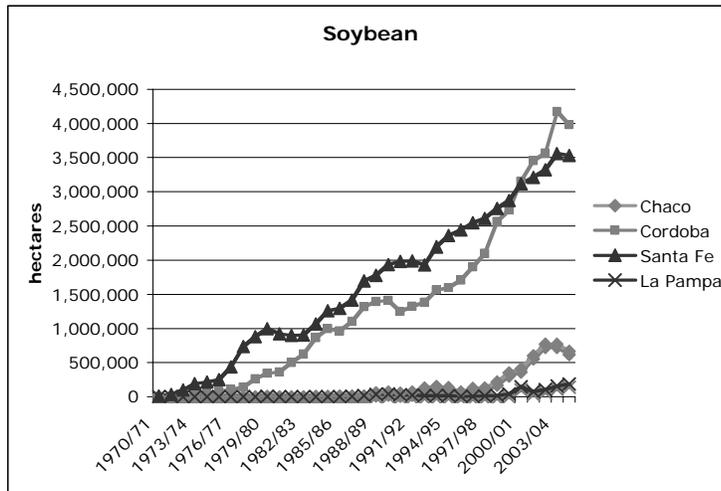


Figure 6: Area sown to soybean in selected La Plata basin provinces of Argentina. (Source SAGPYA)

Advances in genetics and other technological developments that improve the feasibility of cash crops in marginal lands accelerated the clearing of savannahs in all sub-humid to semiarid environments and the appearance of vast cultivated areas in former rangelands. Whereas in the flooded plains of the Rio Salado basin the non-flooding plateaus of natural grasslands are converted to cash crops and also to commercial pine or eucalypt forests for paper pulp.

The fastest rate of conversion to commercial forests, however, occurs in the subtropical humid regions, Misiones, Corrientes and Entre Rios, where grasslands and subtropical forests are affected (Figure 7).

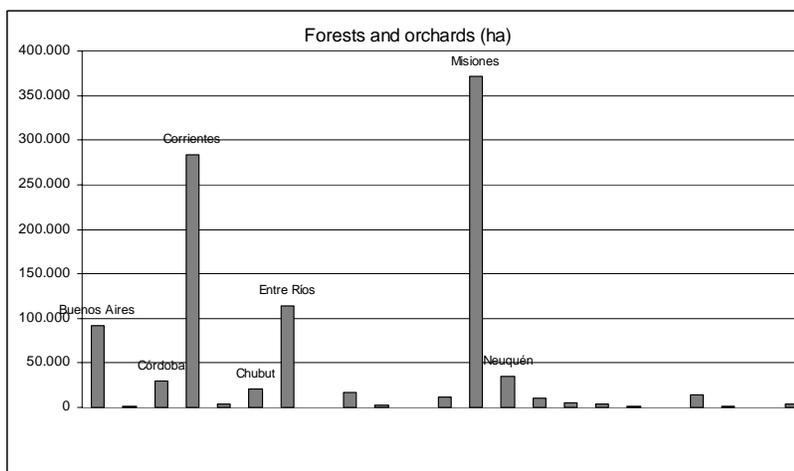


Figure 7: Area of commercial forests and orchards in Argentina (2002. Source INDEC)

Impacts of LUC on ecosystems

Land use changes can affect ecosystems and their functions in a variety of ways. The most striking effects are on soil and water resources and on biodiversity. We highlight the impacts to soil and water resources.

The most severe impacts on soil resources are: depletion of soil organic matter, and consequent loss of fertility and reduction of carbon stocks; erosion and desertification; and biological degradation. Water resources suffers degradation of its quality, through agrochemical contamination, increases in the organic load, increase in sediment transport and siltation, increase in the amplitude between river flow upper and lower limits along the year, increasing damages caused by flooding events and dry spells (water shortages).

Impacts on Ecosystem Functions in Brazil

Global warming caused by the increase in CO₂ emissions resulted in widespread concern with the conservation of current carbon stocks in the soil resources. Bernoux et al. (2002) mapped the carbon stocks in Brazilian soils and concluded that the whole country has a potential of stocking 36.4 Pg C in the 0- to 30-cm layer, if vegetation had been kept original. This figure represents the potential carbon stocking capacity of Brazilian soils, which could be achieved by proper land use and soil management.

Cerrado conversion to cropland results in reduction of soil organic matter content, aggregation stability indices, and biological activity and diversity (Madari et al., 2005; Peixoto et al., 2006; Green et al., 2007). Although the adoption of no tillage practices ameliorates slightly those harsh effects on soil quality, the impacts of land use change in the Cerrado are highly significant. Soil organic carbon content in the 0- to 5-cm layer was reduced in approximately 30% of its original status in a experimental site under continuous cultivation for 20 years (Green et al., 2007). Significant reductions were also observed in fluorescein diacetate hydrolysis (an indicator for total soil enzymatic activity), arylamidase (N-cycle) and arylsulfatase (S-cycle) activities. Soil aggregation is highly impacted. Green and colleagues (2007) showed a reduction of at least 35% of the mean weight diameter of 1 - 2 mm aggregates in the 0 – 5 cm layer in soils under grain crops (maize and soybeans) for 20 years. Their results agreed with those of Madari and colleagues (2005), that also showed greater carbon content in larger aggregate fractions of soils under no tillage management, even though the overall organic carbon content in the bulk soil didn't show any difference. These chemical and physical changes in the soil upon land use change result in an altered environment for the development and maintenance of the soil biota. Peixoto and colleagues (2006) have shown the significant impact of agricultural use on the bacterial community structure of Cerrado soils. Changes in bacterial community structure were closely related to a reduction in the soil aggregation indices. The works mentioned above were not done simultaneously, at the same sites, but it is very reasonable to suggest that the observed soil physical, chemical, and biological impacts resulting from land use changes in the Cerrado interact affecting ecosystem functioning. How would these changes affect gas emissions from the pedosphere? How do the altered soil microbial community structures impact elemental cycles

and climate change processes? These are unanswered questions that need serious interdisciplinary scientific approach.

The reduced organic content and aggregation status of soils under the conventional forms of agricultural use result in lower soil water holding capacities and water infiltration rates. Considering the climatic characteristics of the Cerrado, one can conclude the effects the heavy summer storms will cause on tropical areas deprived from their natural vegetation. Erosion and soil loss is probably the most severe negative impact of land use change in the Cerrado, concentrating in croplands under conventional tillage practices and on sandy soils converted to pasture. The main form of degradation observed in Brazil is soil erosion. Bahia and colleagues (1992) estimated an yearly soil loss of 600 million ha in Brazil. Manzatto and Hernani (2005), using the 1995/1996 land use census data of IBGE (Brazilian Institute of Geography and Statistics) and the average rate of soil loss due to erosion in Brazilian pastures (0.4 ton/ha; Bertoni and Lombardi Neto, 1990), estimated a soil loss of 71.1 million tons per year, only from land cultivated with pastures. Part of this (~ 21.3 million tons/year) ends up deposited on roads, lakes, and reservoirs, or is carried by streams and rivers (Hernani *et al.*, 2002). Erosion represents a complex environmental problem, since not only the soil is affected but also the water resources. Water loss (portion not infiltrated through the soil profile that would otherwise feed the region's aquifers) in areas under pasture is estimated to be as high as 251.9 m³ ha⁻¹ year⁻¹ (De Maria, 1999). Considering the area under pasture in Brazil in 1995/1996, an estimated yearly water loss of 44.8 billion m³ was envisioned (Hernani *et al.*, 2002). These estimates and calculations were made considering available soil loss data obtained by research groups working in the Southeast region of Brazil. Data is scarce from the Brazilian Midwest, where the problem is more severe, especially in the northern portion of the Paraguay river basin (figure 8 and 9)



Figure 8. Widespread erosion and gullies in a pastureland in the municipality of Alcinópolis, state of Mato Grosso do Sul, Brazil, northern part of the Paraguay river basin.



Figure 9. Siltation process, as a result of erosion upstream of a river in the municipality of Alcínópolis, state of Mato Grosso do Sul, Brazil, northern part of the Paraguay river basin.

Impacts to the quality of water resources are also a problem to be considered. The point sources of pollution that are most common in the LPB are those derived from urban (sewage) and industrial centers. In Brazil, the Water Resource National Policy (Brazilian Law 009433-1997) has improved the management mechanisms by the creation of River Basin Committees, integrating member from the public and private sectors, including representatives from the urban and rural societies that are located in the basin. These Committees have the power to decide upon matters such as the rights and obligations of water users, and even to charge them with a tax depending on how much water is used, and on how the water quality is affected by each type of user. The idea is to gather funds to invest on degraded land recovery and on the environmental recovery of the river basin. It is a very ambitious model of water management due to the complexity of its mechanisms, and the need of intense participation from the societies. So far, only one river basin of Brazil has applied most of the legal instruments predicted by the National Policy, the Paraíba do Sul river basin, in the Brazilian Southeast. The result has been greater participation of society in decision making, and a slight improvement in the awareness of industry and urban managers regarding environmental problems, mostly related to point source pollution. The greatest problem is non-point source pollution, such as agrochemicals, including pesticides and fertilizers.

The increased cropped area in Brazil resulted in a significant enhancement of the nitrogen load of rivers and streams. The trend of deforestation and installation of crops or pastures results in increased N mineralization and mobilization, with subsequent higher transport by streams (Williams and Melack, 1997; Neill et al., 1997). Croplands in Brazil are mostly occupied by

soybean plantations, that highly depend on biological fixation to derive nitrogen for its development (Boddey et al., 1997). The result is an increased input of nitrogen to the system and to the water resources (Downing et al., 1999; Filoso et al., 2006).

The Cerrado ecosystems, that occupies large part of the La Plata basin headwaters, need substantial amounts of fertilizer inputs and liming to become productive as croplands. In fact, N-fertilizer use has grown 30% in the last 40 years in Brazil (Filoso et al., 2006). Most of the Cerrado land belonging to the LPB contributes to the Paraná river, responsible for 75% of the water discharge to the La Plata river downstream. Land use changes in the basin have been indicated as responsible for observed changes in phosphorous concentrations and depositions due to change in pH, increase in sediment content due to erosion, and increased nitrogen exports in the water (Villar et al., 1998).

There is a huge knowledge gap regarding the nitrogen and carbon cycles in natural ecosystems throughout the LPB. Soil fertility and organic matter researchers have produced a lot of data regarding these elements in agroecosystems, due to the economic interests devoted to increasing crop yields and to base the technological advices to be given to the agricultural sector. The natural ecosystems, that are being continuously degraded and destroyed, were the subject of much less research efforts. Currently, the scientific community is putting greater effort in natural systems research, so as to understand and quantify land use change impacts to the element cycles and their feedback to climate change processes. Some urgent questions to be answered are: What are the rates of biological nitrogen fixation in tropical natural ecosystems? How do they compare to those observed in agricultural ecosystems? How do these changes in the N cycle affect plant metabolism, phenology, primary productivity of ecosystems, and the global carbon cycle? How do they affect the local, regional, and global climate? What and how are the feedbacks?

Impacts on Ecosystem Functions in Argentina

Agricultural intensification and abandoning of rotations that include perennial pastures caused strong disturbances of the carbon cycle in soils. Our studies in the semiarid marginal region showed that after only two years of cropping soils can lose 22% of original pasture C, most of which is due to labile C (Figure 10) In these coarse texture soils however, C losses in this very short period of cultivation also diminished the stable C fraction.

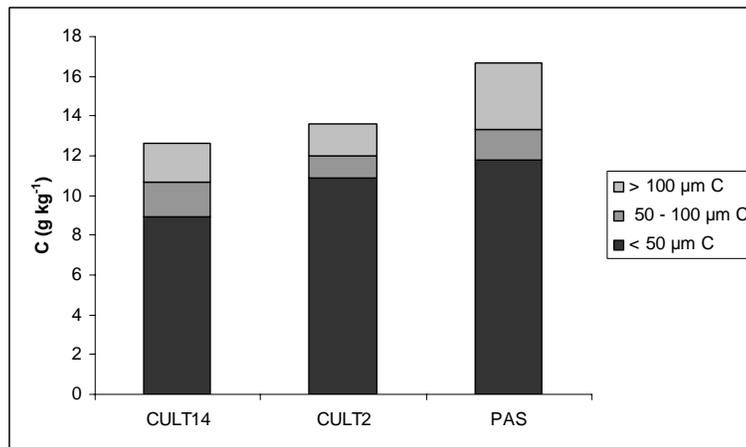


Figure 10 Carbon fractions in a loam soil of the semiarid Pampa after two (CULT2) and fourteen (CULT14) years of cultivation and in a perennial pasture.

Frank et al. (2004) found considerably lower biological activity in the recently cultivated soil, similar to that of the long term cultivated one. Glizzi et al. (2006) reported decrease of meso- and macro fauna due to prolonged agricultural use, while soils under rotation had higher populations. These authors found no difference between direct drilling and conventional tillage with respect to soil fauna abundance and diversity. Eiza et al. (2006b) found that pasture rotations were able to maintain adequate SOC levels due to increases of between 10 to 15 % during the pasture phase that compensated for the C losses caused by cultivation. These changes in carbon dynamics affect soil physical properties, especially aggregate stability (Eiza et al., 2006b; Alvarez et al., 2004), bulk density, water infiltration and water holding capacity (Alvarez et al., 2004). The degradation of soils with long agricultural history without pasture rotations therefore results in higher susceptibility for wind and water erosion, lower water availability due to lower infiltration and water retention and susceptibility to compaction. This results in lower crop productivity (Quiroga et al., 2006; Funaro et al., 2006; Funaro et al., 2005) and thus directly affects farmers' income and regional economy.

Zach et al. (2006) showed that in the coarse texture illitic soils of the semiarid Pampa potentially irreversible soil degradation can occur after prolonged intensive cultivation. Soil carbon in these soils is less stable than that of more humid grasslands, with very rapid turnover rates (half lives of around 10 years) and reduced capacity for C stabilization.

Expansion of cash cropping into areas of "Espinal" savannah implies removal of natural woody vegetation and plowing of grasslands. Data from La Pampa provide evidence of total C and labile POC losses of 56% and 75%, respectively, after 12 to 18 years of cultivation (Zach et al., 2006). Thus, these soils lost half their C content in 10-16 years. Available P also resulted 47% less in cultivated soils, compared with their native pairs (Malsam et al., 2006). The associated decrease in soil quality and productivity, the reduction of biological activity and diversity (Stromberger et al., 2006) characterize the trends of agricultural intensification and expansion. Valuable resources are being degraded, perhaps to an extent where the thresholds of resilience

are exceeded and no or very little chances of restoration are left. In these marginal environments a history of overexploitation exists, and as Zach et al. (2006) indicate, C accretion in soils under restoration practices (pastures) may be very rapid, but levels off well below original C levels.

Management practices that have shown to prevent excessive degradation are rotations with perennial pastures and cash crop intervals that depend on climate, soil parent material and texture and the type of crops that are used. Oilseeds generally leave fewer residues, need more aggressive tillage practices and expose the soil during the hottest period of the year and therefore have a stronger effect on degradation than winter cereals. However, a return to this more conservative soil management is very difficult to reconcile with the immediate objectives of farmers and corporations that take land use decisions in a global context of profit maximization in the short term and state policies would be needed to induce land owners to adopt conservation management. Nevertheless, some examples of farmer's organizations (CREA) have recognized the detrimental effect of oilseed monocultures on soil productivity, since problems with excessive compaction and run-off decreased crop yields in the sub-humid and semiarid region which showed that an adequate C balance cannot even be achieved under zero tillage without rotations with pastures.

The introduction of fast growing tree species for commercial plantations has been relatively recent in the Rio De La Plata Basin, and therefore little attention has been paid to the effect of the forestation on soil and water quality in the region.

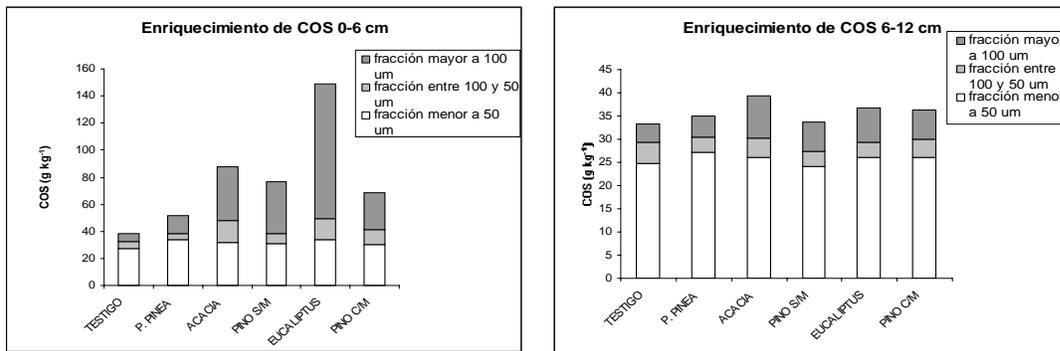


Figure 11: Carbon fraction under different forest species.

Recent studies show that forestation can increase soil C contents on degraded soils in the semiarid region (Morazzo et al., 2006 a and b), but the distribution of C in different fractions gives evidence that most of this carbon is not stabilized in the soil and located in the top 6 cm of the profiles (Figure 11).

Soils under eucalypt plantations in the Pampas and Uruguay often display a strong acidification (Jobbágy & Jackson 2003). Higher calcium cycling after tree establishment (trees use and cycle more Ca than grasses) is the dominant cause of acidification, suggesting that the management of this nutrient in plants and soils will become crucial for the sustainability of forestry in the region in the near future. Tree plantations had striking effects on groundwater hydrology and salt

dynamics in many of our study sites in the Pampas. Depending on the texture and hydraulic properties of sediments, tree plantations sustain large groundwater consumptions (Engel et al. 2005). In association with groundwater uptake, large salt accumulation in soils and aquifers occur.

Economic changes in the agricultural system of Argentina

One of the most concerning trends of land tenure in the Argentinean Pampas is the concentration of agricultural lands and ownership by corporations. Buenos Aires shows the highest percentage of land owned by companies (30%) in the Pampa provinces. However, very high proportions of corporate land are also found in Entre Ríos (23%), San Luis (27%) and Catamarca (22%). Other provinces like Misiones (34%) and Corrientes (39%) have even higher proportion of corporate-owned land. This might be explained by the high incidence of forestry and large-scale fruit production in these provinces (Figure 12).

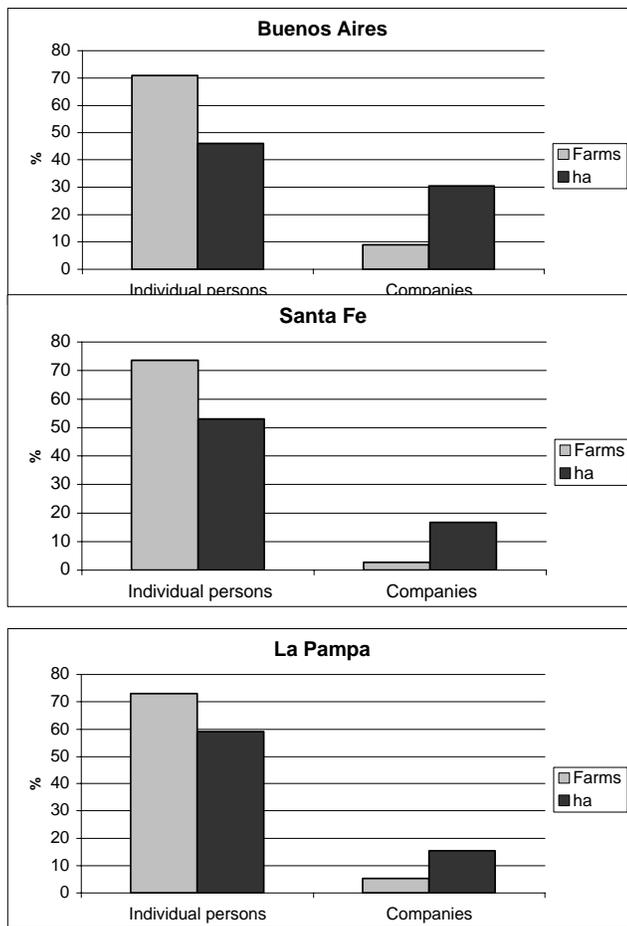


Figure 12: Land tenure in some Rio de La Plata provinces

Social changes in the Río de La Plata Basin associated to agricultural intensification:

One of the questions that arise in the context of LUC, agricultural intensification and land degradation is: How do LUC processes affect the farmer’s social environment and rural population in general? How is the land-owner connected to his land? And in which social context does he take decisions?

The answers to these questions would give important insight for extension and policy strategies aimed to prevent land resource degradation. The 2002 agricultural census reveals some important developments that characterize the rural population and the social environment of farmers / land owners: the traditional concept of “family farms” that prevailed in the Argentinean rural environment is changing. Apparently the role of the farm family is decreasing in the most developed, most productive and fastest changing areas of the Argentinean rural landscape: the Rio De La Plata Basin.

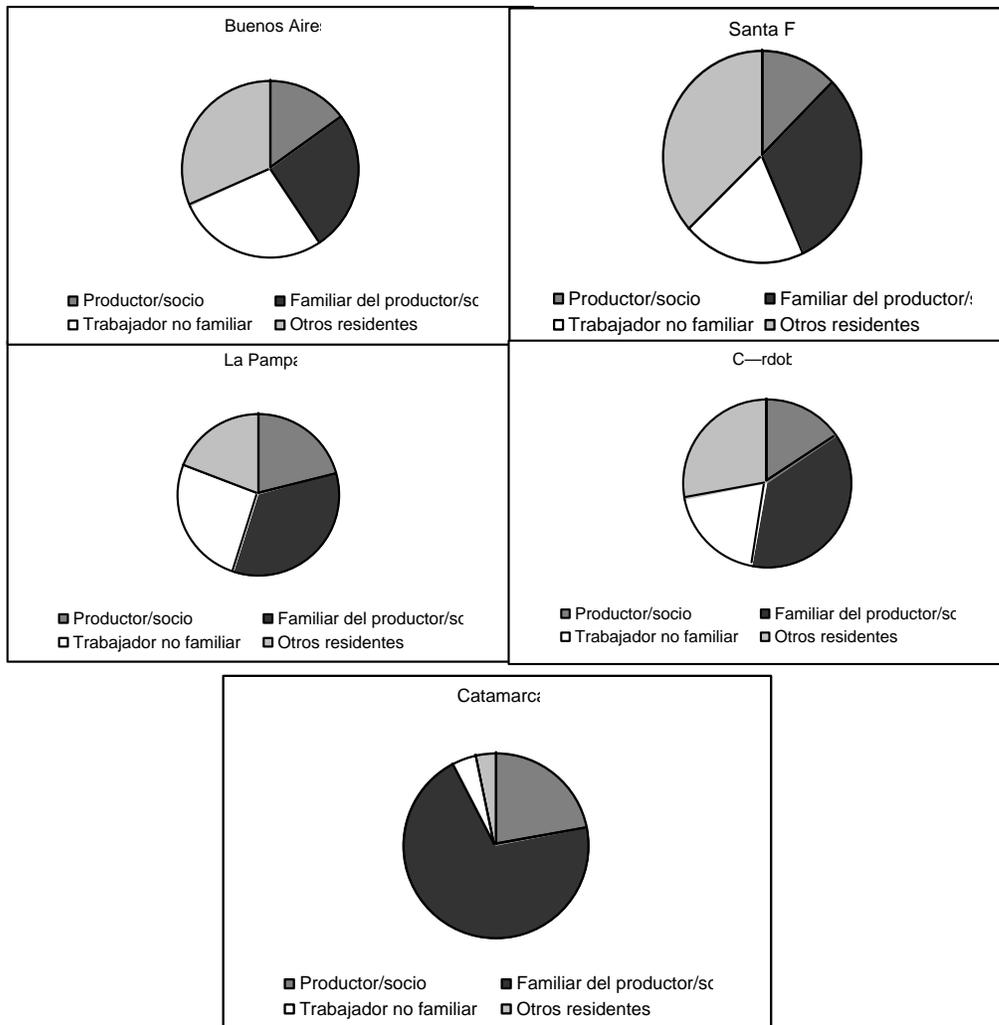


Figure 13: Characteristics of farm residents in different provinces of Argentina.

Farm residents are now increasingly paid labor and “other residents”, besides the farm owner (Figure 13). The most representative examples are Buenos Aires and Santa Fé, where hired labor and “other residents” sum a higher proportion than owner and their families together. La Pampa and Córdoba are similar to the country’s average, in the sense that the farmer’s family makes up about 50% of the farm residents. In other provinces that have a more recent history of agriculture expansion, as for instance Chaco, and even more in the north-western provinces, a typical example is Catamarca, where very low technology input is common, family labor is more important than hired labor.

The observed trend in the La Plata provinces indicates that agricultural intensification also led to social changes in the rural environment. Farm work is carried out by non family workers, and the agricultural enterprise becomes increasingly detached from the family unit. What are the implications of this development for resource management? If increasing number of farmers literally live “off” their land and their families are firmly established in an urban lifestyle? Under these circumstances, can the land be considered a heritage to be conserved for future generations? Or is the land only one of the capital resources that produces the required income? If this is true, what are the policies that could be effective to control and mitigate land degradation?

Another interesting phenomenon is the so called “other residents” rural population, which in both Buenos Aires and Santa Fé represent a high proportion of farm residents. Most likely these are the different types of share croppers, share tenants and other forms of organization that have become common in Argentinean farm exploitations with high technological input (Neiman & Quaranta, 2001). Benencia and Quaranta (2003) studied this new type of labor organization and found that the increasing importance of shared profit arrangements responds to the goals of land owners to obtain high labor yield in terms of production and quality of products, loyalty to the enterprise at low transaction costs. This reinforces the idea that farmers who evolved in and survived the transformation of the agricultural sector in the Pampas have a decidedly entrepreneurial attitude towards land use and production.

Many authors who studied the transformation of the rural sector in the La Plata Basin link these changes to the socio economic component of global change. The consolidation of a global agro-food system steered by big transnational corporations, paired with policies of economic liberalization and adjustments in the agricultural sector of Argentina led to severe crisis, impoverishment and the rise of a “new rurality”(Teubal, 2006). Piñeyro (2001) and Mignone (2000) also associate rural exodus and urbanization to agricultural intensification and economic crisis for the cases of Uruguay and Chaco. Giarracca and Teubal (2005) hold that if these globalizing tendencies continue, the development is towards a rural environment that continuously loses more of its agrarian contents; globalization of the agri-food chains and businesses tends to produce impoverishment and disappearance of the traditional social actors of the rural environment such as small and medium size family farmers, farm workers and subsistence farmers.

If this scenario of increasingly industrialized agricultural production and disappearance of family farms is considered the framework for future land use change, it becomes clear that the current trends of agricultural intensification and expansion will continue. The associated social costs of land degradation and environmental destruction will have to be mitigated through policies that take into account the socio economic characteristics of the new “rurality”, specifically the decision makers of this newly emerging agricultural system, which in many cases are not the land owners but managers of transnational financial and commercial corporations.

Integrated tools for land use change impact assessment

Environmental phenomena occur over a wide range of spatial and temporal scales, ranging from global to local and from geologic time to hours. In a watershed, LUC impacts to the soil system may significantly affect the water system, and vice-versa. Impairment of the ecosystem functions of a watershed may affect the functioning of the whole river basin where it is embedded. Similarly, the temporal resolution of impact indicators can also vary significantly. Hydrosedimentologic data, such as river flow and turbidity, can be acquired continuously, while soil aggregation or organic carbon content, at time intervals determined by the adopted sampling scheme. At each scale, a different set of biophysical and social constraints affects the structure and behavior of natural resources and anthropogenic ecosystems (Wessman 1992). While ecologists have been dealing with the scaling issue for decades, and built relatively well-defined hierarchical systems of analysis, scaling in the social sciences has not been so well defined (Gibson *et al.* 2000). Ecologists and social scientists must develop a common research framework to examine the interactions between humans and the natural environment, and how these interactions drive LUC. Impacts to ecosystems have consequences on the social systems, and vice-versa. However, many key relationships between ecosystems and human systems remain poorly understood (Ayensu *et al.*, 1999). These impacts also may be linked to feedback mechanisms that alter the land use change dynamics, altering rates and extent of both social and ecological impacts. Land use change drivers and impacts are part of a complex web of interacting factors, with clear consequences to global change processes. This complexity is evidenced by the links between spatial patterns of land use and the function and services of ecosystems, the extent to which social and economic drivers interact with or even outweigh biophysical constraints for LUC, and the feedback processes by which the social and environmental impacts of land use dynamics drive further changes in the human and natural systems. Establishing effective policies to manage these systems requires understanding of coupled human and environmental drivers and impacts of LUC. A central obstacle to understanding, predicting, and assessing the interactions between human and natural systems that govern LUC in heterogeneous landscapes is the lack of a comprehensive and integrated research framework capable of addressing the inherent complexity of the system (Vitousek *et al.* 1997). It is a big challenge to the scientific community to deliver innovative concepts, methodologies and tools to help society cope with the uncertainties posed by current trends of global environmental degradation.

Computer-based and spatially explicit simulation models could be useful to inform decision makers about scenarios of land use change and their potential ecological and social

consequences. Models like these require extensive data bases and implementation efforts. Several spatially explicit models have been developed to simulate land use changes, based mainly on biophysical potentials. An improvement was the development of models (Kerr et al. 2003) that explored possible changes in land use as a function of driving forces other than biophysics. Verburg et al. (1999) included a multi-scale approach into what they called the Conversion of Land Use and its Effects (CLUE) modeling framework. However, little attention has been paid to the human behavioral component driving the changes (Irwin and Geoghegan 2001), and research has been particularly lacking regarding the spatial and temporal scales across which the social component interacts with the biophysical component. Further development of simulation models, which better account for the human aspects of LUC, is necessary for improving research frameworks on the interactions of ecosystems and humans.

Since 2002, a network of scientists across the Americas has been discussing these issues under the guidance of the American Association for the Advancement of Science (AAAS), through its Ecosystem Dynamics and Essential Human Needs (EDEHN) program. The outcome was the development of a conceptual framework (figure 14), that depicts land use change drivers and impacts, their cross-scale interactions, as well as possible feedback mechanisms. This network evolved to a larger group of researchers and Institutions to develop the IAI - Collaborative Research Network project “Land use change in the Rio de La Plata basin: Linking biophysical and human factors to understand trends, assess impacts, and support viable strategies for the future”, currently under implementation.

Part of the research questions formulated along this text will be explored by this project. Paired watersheds under contrasting land uses in the chaco, pampas, and cerrado biomes will be monitored. Integrated soil and hydrological monitoring will be applied to the watersheds, so that data will inform decision makers about the effects of LUCs on the carbon dynamics, as well as on water quality and quantity. On a regional scale, ecosystem functioning will be evaluated through measurements of evapotranspiration and primary productivity by remote sensing. Knowledge on land use patterns and their biophysical and socio-economic characteristics will allow the development of models to predict impacts across the scales, from individual watersheds to the la Plata river basin, days to years, and from society to nature.

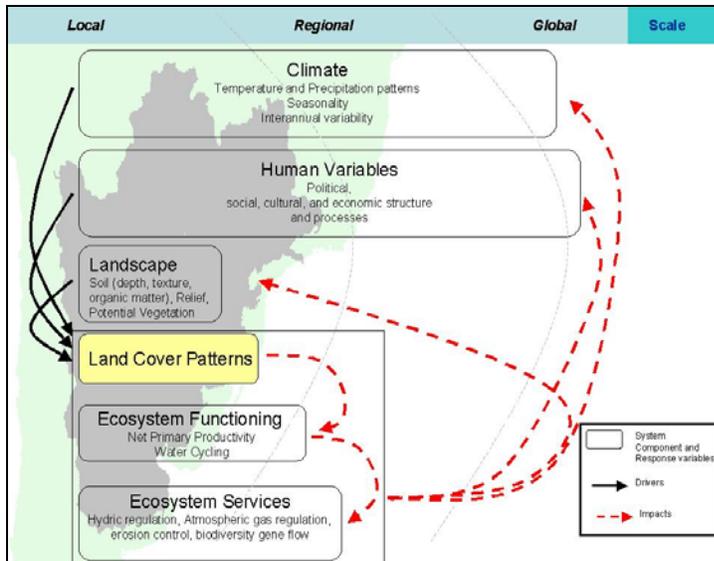


Figure 14. Conceptual framework showing the main drivers and impacts of LULC changes superimposed on the Rio de la Plata Basin

Conclusion

Natural sciences have produced to date a wealth of data demonstrating the wide scale effects of different types of land use change on ecosystems variables, such as nutrient cycling parameters, conservation status of biodiversity, hydrological disturbances, soil and water quality degradation, contamination, climate change, among others. However, although some more informed sectors of society react by changing slightly their consumption patterns and by supporting public pressure campaigns directed to policy makers, in general there is very little response from society.

As computer technology and the global electronic network places information at a grasping distance from any school student, global change scientists face the challenge of generating research results that are at the same time of high scientific standard, and also seen as of practical value by society. Effective inter-disciplinary research connecting natural and social sciences, based on a common conceptual ground, may help to bridge the current gap, and generate scientific results that effectively inform decision making. Model development should rely on participatory methods since their start. Policy makers should inform scientists on their requirements for knowledge and models. They should specify what parameters they are able to collect data for and what outputs they would expect, what kind of options they have, how much computational power is available at their offices, and so on. An example of an inter-disciplinary participatory experience such as this is the SENSOR Project, coordinated by ZALF (Germany), and carried out by 33 institutions of 15 European countries (<http://www.sensor-ip.org/>). Funded by the European Commission, this project is the result of a demand from the European Commissioners for a tool to help them in assessing the economic, social and environmental impacts of multifunctional land use in Europe. The model and computational tool being developed is tailor-made according to the needs of policy makers. It is expected that the end

product will be directly applicable by society, through its legislators, and is developed based on high quality scientific knowledge. Recently, an extension of the Sensor project to Brazil, Argentina and Uruguay was approved by the EC, and will assess the transferability of the methodology to the LUC conditions prevalent in the LPB area. The main challenge will be to achieve a similar interaction between scientists and policy makers in the Mercosur countries.

The huge challenges posed by the dynamics of LUC in the La Plata basin as well as their impacts demand innovative and integrative procedures and attitudes from both natural and social scientists, as well as from decision makers. The advance of global change processes demands a quick response from society. Measuring and modeling ecosystem services of natural and modified environments, as well as estimating their economic value, is essential. Transforming this knowledge in effective changes of sociological behaviour is crucial.

Acknowledgements

The authors gratefully acknowledge support from the IAI CRN programme for funding the research, and the AAAS EDEHN programme for funding initial meetings that created the scientific network.

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