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Impacts of land use change on ecosystems and society in the Rio de La Plata basin

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The La Plata river basin (LPB) covers an area of 3.1 million km^2 with a population of over 100 million people of Argentina, Bolivia, Brazil, Paraguay, and Uruguay. 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. 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.

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 affects both the natural environment and society, therefore 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. There is an urgent need for interdisciplinary research, overcoming inherent conceptual and epistemologic barriers. 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.

Land use change in the LPB

Three agricultural sectors have been responsible for most of the LUC in the LPB in the last thirty years: international commodities (soybeans, etc.), forestry (eucalypt and pine), and meat (cattle). Soybean and other grain crops, as well as cultivated pasture (Brachiaria spp.) are widespread in the LPB, and have replaced portions of all of the basin´s biomes. Forestry has been concentrated in the Southern portion of the basin. Biofuel crops, such as sugarcane, are increasing as a result of the growing international market, and national policies. 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.

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 lands, although during the last 10 years cropland expansion has been greater (Alves et al., 2003). Much of this expansion has been over Cerrado land. The Cerrado covers about 2 million km^2 and 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). Several authors suggest that the Cerrado is being destroyed for grain crops and pastures (Klink and Moreira, 2002; Fearnside, 2001). Estimates vary from 40 to 50% of the Cerrado already having undergone complete destruction (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 appropriate land management strategies are adopted.

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. 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. In 15 years, 14.1 million ha of Cerrado vegetation were converted to agro-pastoral use with potential impacts to nature and society (Pinto, 2002). More recent data, compiled from the Instituto Brasileiro de Geografia (IBGE) website, show that the expansion continues in the region, with a remarkable of growth of the soybean planted area in the State of Mato Grosso, from 1990 to 2005. In 1997, 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 (IGBE). Likewise, the convertion 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. 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

Agricultural intensification has occurred throughout the Pampas in all ecosystem types, with a predominance of cash crops, often doubled, and the abandoning of the traditional mixed agriculture-livestock production system. 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. 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.

Expansion of the agricultural frontier takes place in marginal areas such as the semiarid "Espinal" savannah and in the flooded plains of Buenos Aires. In these biomes natural vegetation traditionally used for extensive livestock production is replaced by cash crops, mainly oilseeds such as soybean and sunflower varieties that are adapted to these environments. 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.

Impacts of LUC on ecosystems

The most severe impacts of land use change 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 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

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 reduces those 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 to approximately 30% of its original status in a experimental site under continuous cultivation for 20 years (Green et al., 2007). Peixoto and colleagues (2006) have shown the significant negative impact of agriculture on soil bacteria and on soil aggregation. This results in lower soil water holding capacities and water infiltration rates. Erosion is probably the most severe negative impact of land use change in the Cerrado, especially in the northern portion of the Paraguay river basin.

Impacts to the quality of water resources are also a problem. In Brazil, the Water Resource National Policy (Brazilian Law 009433-1997) has improved the management mechanisms by the creation of River Basin Committees which have the power to decide upon rights and obligations of water users, and to charge taxes depending on how much water is used, and on how the water quality is affected by users. 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. But a greater problem is non-point source pollution, such as agrochemicals, including pesticides and fertilizers.

Deforestation for crops or pastures results in increased N mineralization and mobilization, with subsequent higher N transport by streams (Williams and Melack, 1997; Neill et al., 1997). The Cerrado ecosystem needs substantial amounts of fertilizer inputs and liming to become productive as croplands. 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).

Researchers have produced a lot of data on carbon and nitrogen in agroecosystems. The natural ecosystems, that are being continuously degraded and destroyed, were the subject of much less research efforts. 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 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 are the feedbacks?

Impacts on ecosystem functions in Argentina

Semiarid soils in Argentina show losses of 22% of original pasture C after only two years of cropping. Biological activity, both microbial (Frank et al., 2004; Noellemeyer et al., 2008,) and faunal (Glizzi et al., 2006), is decreased under prolonged agricultural unless pasture is included in rotations (Eiza et al. 2006) to compensate for the C losses under cultivation. The degradation of soils with long agricultural history without pasture rotations 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 farmer 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 10-16 years) and reduced capacity for C stabilization. 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. C accretion in soils under restoration (pastures) may be rapid, but leveled 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. A return to such conservative soil management is difficult to reconcile with the objectives of farmers and corporations that take land use decisions for profit maximization in the short term. Nevertheless, some farmer's organizations (CREA) have recognized that extended oilseed monocultures caused compaction and run-off which decreased crop yields in the sub-humid and semiarid region. This showed that an adequate C balance cannot even be achieved under zero tillage without rotations with pastures.

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. Questions that arise in the context of LUC, agricultural intensification and land degradation are: 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 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. Farm residents are now increasingly paid labor. Only in regions like Catamarca, where very low technology is common, family labor is more important than hired labor. 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 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 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 financial and commercial corporations.

Integrated tools for land use change impact assessment

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, that depicts land use change drivers and impacts, their cross-scale interactions, as well as possible feedback mechanisms. This network evolved into a larger group of researchers and Institutions to develop a IAI research network on "Land use change in the Rio de La Plata basin".

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.

Conclusion

Natural sciences have produced a wealth of data demonstrating the 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 slightly changing their consumption patterns and by supporting public pressure campaigns directed at 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 from their start. Policy makers should inform scientists about requirements for knowledge and models. An example of an inter-disciplinary participatory experience is the SENSOR Project, coordinated by ZALF (Germany), and carried out by 33 institutions of 15 European countries (http://www.sensor-ip.org/). This project is the result of a demand from the European Commission for a tool to help them assess 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. An extension of the Sensor project to Brazil, Argentina and Uruguay will assess the transferability of the methodology to the LUC conditions prevalent in the La plata basin. The main challenge will be to achieve an 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.

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