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ANALYSIS

Land-use options for Del Plata Basin in South America: Tradeoffs analysis based on ecosystem service provision

Ernesto F. Viglizzo[a,b,*], Federico C. Frank[a]

[a]Instituto Nacional de Tecnología Agropecuaria, Santa Rosa, La Pampa, Argentina
[b]Av. Spinetto 785, CC 302 (6300) Santa Rosa, La Pampa, Argentina

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Abstract

The Del Plata Basin is one of the largest watersheds in the world and is the epicenter of MERCOSUR activities in the Southern Cone of South America. Because of the quick expansion of agricultural activities during the 1990s, the imbalanced provision of economic and ecological services has become an issue of increasing concern in the area. In this work, we propose a policy-oriented methodological approach to harmonize land-use options and prevent potential trans-boundary problems among countries. The approach is based on the analysis of tradeoffs between various economic and ecological services that are differentially provided by trans-boundary, interconnected biomes. Data on land-use/land-cover for different biomes have been obtained from different statistical and literature sources. The value of ecosystem services in the study biomes has been obtained from the classical study by Costanza et al. (1997) [Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Shahid, Naeem, O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P., van den Belt, M., 1997. The value of the world's ecosystem services and natural capital. Nature 387, 253–260], and profit estimations for crop and livestock production has been collected from various economic studies. The results show that the difference between biomes to supply both economic and ecological services in Del Plata Basin is enormous, and cultivation of new lands in some biomes would neither compensate nor justify the loss of irreplaceable ecological services. However, although agricultural exploitation may drastically affect the supply of ecological services in some biomes, not all of them would be equally affected. For example, due to its smaller sensitivity, the environmental cost of cultivation in the Argentine Pampas seems to be rather negligible in relation to the Pantanal or the Cerrado. Then, the functional complementation of biomes across the area through tradeoffs analysis seems to be a viable broad scale strategy to identify sustainable land-use options in Del Plata Basin.

Keywords: Economic and ecological services; Land-use options; Tradeoffs analysis; Del Plata Basin

1. Introduction

The basic functions of agriculture in the Southern Cone of South America are food and fiber production

* Corresponding author. Instituto Nacional de Tecnología Agropecuaria, Santa Rosa, La Pampa, Argentina. Tel./fax: +54 2954 434222.
E-mail address: evigliz@cpenet.com.ar (E.F. Viglizzo).

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for domestic use and export, and the provision of work and income for the rural population. Despite spatial and temporal asymmetries, the cropland expansion and the increasing use of external inputs in response to economic needs have been the main drivers of food and fiber production in the region (Viglizzo et al., 2003). On the other hand, the provision of ecosystem services that are essential for human well-being, such as gas, climate and water regulation, water supply, erosion control, nutrient cycling, waste treatment, etc. has not still been seriously considered. Because of the quick expansion of agricultural and agro-industrial activities in Del Plata Basin during the 1990s, the imbalanced provision of economic and ecological services has become an issue of increasing concern.

The Del Plata Basin (Fig. 1), one of the largest watersheds in the world, is the epicenter of MERCOSUR (Common Market of South America) activities. This complex basin interconnects the rivers Paraná, Paraguay, Pilcomayo, Bermejo and Uruguay, as well as their small tributaries. The area comprises very important biomes interconnected by waterways, such as tropical and subtropical forests, subtropical savannas and temperate fertile plains. The Del Plata Basin stretches more than 5 million km^2 and provides interior countries direct access to the Atlantic Ocean. The basin waterways are very important to facilitate people movement and the exchange of goods and services, but also they are a vehicle to externalize environmental problems (Bonetto, 1986). Today, land-use change in rural areas is driven by market-dependent forces, while other relevant ecosystem functions are set aside. The consideration of other essential ecosystem services in the design of sustainable land-use strategies in the region is not still a priority for policymakers.

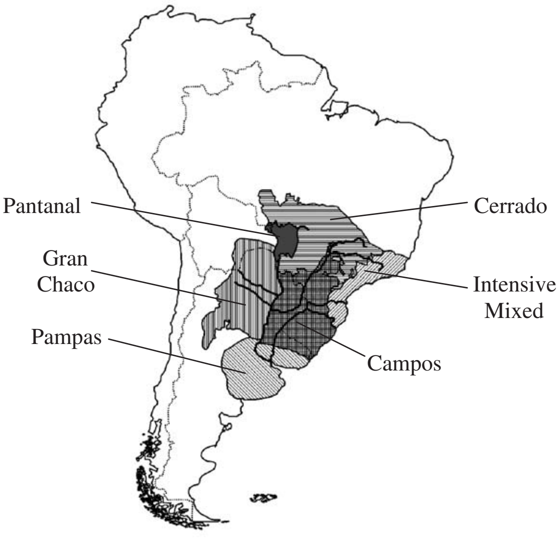

Fig. 1. Location of Del Plata Basin in the Southern Cone of South America and its six dominant interconnected biomes.

With the increasing pressure on land, policymakers would need to monitor land-use changes and influence these changes in response to society needs. Changes in policy decision can either mitigate or aggravate land-use conflicts (Stoorvogel and Antle, 2001), and this in turn has socioeconomic, environmental and even cultural consequences. Various methodologies based on simulation models (Crissman et al., 1998), linear programming (Bouman et al., 1999), multiple goal programming (van Latesteijn, 1992), statistical techniques (De Koning et al., 1999) and a mix of combined tools like simulation models, GIS and database analysis (Stoorvogel and Antle, 2001) have been developed to explore land-use options in agriculture. But no antecedents that include ecosystem services analysis have been found in literature.

The central purpose of this work is to propose a multidisciplinary, policy-oriented methodological approach to harmonize land-use options in rural areas of Del Plata Basin, and prevent potential trans-boundary problems among countries. The methodological approach is focused on the analysis of critical tradeoffs between various economic and ecological services that are differentially provided by interconnected biomes that are shared among two or more countries in the basin.

2. Materials and methods

2.1. The study area

The Del Plata Basin comprises six dominant biomes (Fig. 1) that provide both agricultural products and essential environmental services. The most relevant national and trans-boundary biomes are (i) Pantanal (Bolivia, Brazil, Paraguay), (ii) Campos (Argentina, Brazil, Paraguay, Uruguay), (iii) Brazilian Cerrado,

(iv) Brazilian Intensive Mixed agro-eco-region, (v) Gran Chaco (Argentina, Bolivia, Paraguay) and (vi) South American Pampas (Argentina, Uruguay). The information on their capacity to provide essential services (such as gases, climate and water regulation, soil erosion control, nutrient cycling, genetic resources, etc.) is rather incomplete and heterogeneous. This is because private and public organizations in the region have not shown concern on ecological problems other than those related to soil degradation (Viglizzo, 2001).

Because of its large variability in bio-physical conditions, the Del Plata Basin has one of the most diverse and complex range of biomes in the world (Fig. 1). The six most important ecoregions that comprise a mix of predominant biomes are the following.

The *Pantanal* (meaning "great swamp" in Portuguese), which is considered the largest freshwater wetland in the world, is home of an extremely rich biodiversity. The vegetation contains elements of the Brazilian Cerrado, the Bolivian Chaco, the Amazonian forest and the Paraguayan Campos (Adámoli, 1982). Periods of severe floods follow extreme droughts, but only a portion of the Pantanal remains inundated throughout the year (Hamilton et al., 1996). Because of its powerful water regulation capacity, it is an integral and critical part of the hydrological cycle in the Del Plata Basin (Gottgens et al., 2001). Despite its inaccessibility, the area is increasingly threatened by human activities such as deforestation, ranching, cultivation, mining, illegal hunting and fishing.

The so-called *Campos* ecoregion (shared by S. Brazil, E. Paraguay, most of Uruguay and NE Argentina) comprises a gradation of moisture and soil quality conditions that allows intensive agricultural production on the East and extensive ranching on the West (PROCISUR, 1995). The area is strongly oriented to livestock and rice production (IBGE, 1997). Different policies of land-use and land management in countries that share this biome have determined the loss of its ecological unity. Nowadays, critical ecosystem services are affected by strong human intervention.

The Brazilian *Cerrado* is a central plateau that represents about 25% of the total area of the country (Villachica et al., 1990). Cerrado denotes a savanna region where annual rainfall ranges from 900 to 2000 mm and vegetation is characterized by a high diversity which comprises a mosaic of grasslands, savannas, woodlands and forests (Andrade de Castro and Kauffman, 1998; Resk et al., 2000). Although the Biome contributes significantly to national agricultural and forestry production, crop yields still remain relatively low despite technological advances. Soils are degraded in a vast portion of the area.

The *Intensive Mixed* biome, located on Central-Eastern Brazil, with around 24% of croplands, is the heartland of the Brazilian agriculture (IBGE, 1997). Coffee, horticulture and fruit are important products. The per hectare gross annual value of its agricultural production is the highest in the country. The more concerning environmental problems associated with agriculture are soil degradation and water contamination by fertilizers and pesticides.

Gran Chaco stretches from Central W. Argentina, through Central W. Paraguay and E. Bolivia. Ranging from 1200 mm on the East to 400 mm on the West, the biome can be divided into well-defined humid, subhumid and semiarid zones (Naumann, 1999). The potential of Chaco to cultivation is severely constrained by soil conditions and by rainfall limitations on the western part of the area (Alvarez and Lavado, 1998). Although the region is still developing, natural vegetation and soil quality are showing noticeable signs of degradation.

The so-called South American *Pampas* is a vast, flat plain that is located in Central E. Argentina and S. Uruguay. The biome is not homogeneous, since rainfall and soil quality declines from East to West. Rainfall regime varies in space and time, and is cause of long-term cycles comprising periods of droughts and water excess. They affect both crop and cattle production. Although continuous cropping predominates on the NE and cattle production on the W, the mixed grain crop-cattle production systems have extended over most of the area. The Pampas have the highest potential for agricultural production in the Del Plata Basin. However, moderate soil degradation is visible all over the ecoregion (Solbrig and Viglizzo, 1999) and agro-chemical contamination will be cause of increasing concern in areas of continuous cropping (Viglizzo et al., 2003).

2.2. Data sources

As it was expected, data sources from different countries that share the same biome are normally heterogeneous because they did not follow similar criteria for data collection. Inevitably, data sources are organized more in terms of political boundaries than in terms of the ecological ones. Heterogeneous management is a challenge to face when trans-boundary shared biomes are considered. The problem of data unifying becomes even more critical if we consider that a same biome, beyond its natural ecological integrity, is asymmetrically managed on one and other side of national boundaries.

Our study was strongly based on existing literature and statistical data. Data on land-use/land-cover for different biomes were obtained from different sources: for the Pantanal biome, information have been obtained from Adámoli (1982), Bucher and Huszar (1995), Gottgens et al. (2001), Hamilton et al. (1996), IBGE (1997), Mourào et al. (2000), Seidl and Moraes (2000) and Seidl et al. (2001). For Campos, sources have been DCE (1994) and Krapovickas and Di Giacomo (1998), and for the Brazilian Cerrado they have been Adámoli et al. (1985), Andrade de Castro and Kauffman (1998), Bozzano and Weik (1994), IBGE (1997), Macedo (1994), Resk et al. (2000) and Villachica et al. (1990). Data on the Chaco were provided by Alvarez and Lavado (1998), Bozzano and Weik (1994) and Naumann (1999). Likewise, different sources have been used for the Pampas (DCE, 1994; SIIAP, 1994; Solbrig and Viglizzo, 1999; Viglizzo et al., 2002, 2003).

2.3. Valuation of ecosystem services

The value of the flow of ecosystem services in the study biomes was estimated from figures provided by Costanza et al. (1997) in a classical study. Based on published studies and original calculations, they have estimated the economic value of 17 ecosystem services for 16 biomes. Many methodological troubles and uncertainties have been found by the authors in doing so. Although putting a price on services having a market value was rather straight, different methods had to be used to estimate the non-market value of intangible ecosystem services. Considering that such data was the best information available for our purpose, we have based our study on the pricing framework proposed by those authors. Within such framework, four biomes that predominate in Del Plata Basin have been analyzed: (a) tropical forest, (b) grasslands/rangelands, (c) swamps/floodplains and (d) croplands. The relative conversion (% of land) of one biome into a different one, and the corresponding alteration of the economic value due to the changing provision of ecosystem services, were the inputs for our analysis.

The method is focused on the identification of tradeoffs and critical thresholds between the value of agricultural and ecological services in response to different typologies of biome replacement due to human intervention. In this study, a critical threshold involves an assumption: as cropland (% of total land) increases at the expense of natural land and cultivated grassland, a threshold point occurs where the curve that represents the decreasing value of ecosystem services crosses with the curve that represents the increasing value of agricultural services. In other terms, as we displace toward the right sector of *X*-axis, the annual provision of agricultural services increase at the expense of ecological services per unit of area (see Fig. 3 below). On the contrary, total ecological services increase at the expense of agricultural services when we displace toward the left sector of *X*-axis. Thus, thresholds are located where the provision of agricultural and ecological services keeps a well-balanced annual economic value per hectare.

2.4. The Argentine Pampas case study

A simple, detailed study based on the Pampas of Argentina was considered a reference case for comparing different biomes. The farming history of the Pampas shows different typologies of substitution of one biome (rangeland/grassland) into another one (cropland).

Different sources of information have been utilized to reconstruct the history of land-use in the study region: (1) six general agricultural censuses of years 1881, 1914, 1937, 1947, 1960 and 1988 that comprised the totality of farms scattered in 147 political districts, and (2) one national survey for 1996 that comprised a sample of farms in different areas. Data on land-use were analyzed for all districts. Land-use was expressed in terms of the relative area (%) of crops, pastures and natural grasslands with respect to the total area devoted to farming activities. The analysis was based only on dominant (crop and beef production) activities: wheat (*Triticum aestivum* L.), maize (*Zea mays* L.), soybean (*Glycine max* L. Merr.) and sunflower (*Helianthus annuus* L.).

Based on the above-mentioned conventional value for ecosystem services, and on gross margin estimations for crop and livestock production collected from farmers magazines, the changing economic and environmental value (tradeoffs) of agro-ecosystems in response to the increasing human intervention was estimated. A human intervention factor was calculated through technical coefficients reflecting the relative impact of different land-use/land-cover percentage on ecosystem services disruption. Such impact coefficients, which are the result of a second-generation calculation from Costanza et al. (1997) figures, were as follows: (i) forest: 0.1, (ii) rangeland/grassland: 0.24 and (iii) annual crops: 1.05. These figures simply represent the relative weight of environmental services that are disrupted when biomes are intervened. In practical terms, this means that the conversion of a pristine land into a cultivated forest has an impact that is 2.4 and 10.5 times lower, respectively, than the conversion of such pristine land into grassland and cropland. Thus, the human intervention factor was the result of multiplying the percentage of a certain biome on total land area, by its corresponding impact coefficient. Once tradeoffs have been determined, a theoretical threshold point was proposed and located where the curves for ecosystem and agricultural service cross each other.

2.5. Biomes comparison

The Pampas case has been selected as a baseline study for biomes comparison. A similar procedure was applied to analyze the tradeoffs between environmental and agricultural services in the other four intervened biomes. However, it should be mentioned that historical data sources available for other biomes have not been as complete as those for the Argentine Pampas. To resolve this, the economic value of ecosystem services provision under pristine conditions was estimated, in all cases, by moving back to 100% natural lands.

The spatial aspects of the analysis include the comparison of both the potential environmental value of biomes and the expected economic benefit from the biome intervention. The environmental value (S) of the ecological service j offered by biome i in a time t can be described as follows:

$$S_{ijt} = f\left(c_{ijt}, l_{ijt}, e_{it}\right) \tag{1}$$

where c is a vector of land conversion, l is a vector of unconverted land and e is a vector that represents the environmental attributes of biome i in a period t.

Eq. (2) represents the total ecological value of biome i, which is the sum of the value of all ecological services. Eq. (3), on the other hand, represents the total ecological value of the basin B, which is the sum of the value of its respective biomes.

$$S_{\mathrm{bit}} = \sum_{j=1}^{n} S_{ijt} \tag{2}$$

$$S_{Bt} = \sum_{i=1}^{m} S_{bit} \tag{3}$$

Likewise, if we assume that human intervention looks at maximizing the expected profit, the corresponding expected profit (∂) function for each commercial output k in biome i in period t can be described as follows:

$$\partial_{ijt} = f\left(p_{ikt}, w_{ikt}, y_{it}\right) \tag{4}$$

where p is the expected output price, w is a vector of input prices and y is the vector that represents the productivity of biome i in a period t. Then, Eqs. (5) and (6) keep similar structure than Eqs. (2) and (3):

$$\partial_{\mathrm{bit}} = \sum_{k=1}^{z} \partial_{ikt} \tag{5}$$

$$\partial_{Bt} = \sum_{i=1}^{m} \partial_{\mathrm{bit}} \tag{6}$$

In our case, tradeoffs analysis (Ω) could be conceived as a dynamic relation between the sum of economic and environmental services of all biomes in the whole basin B.

$$\Omega_{Bt} = f\left(S_{Bt} / \partial_{Bt}\right) \tag{7}$$

Taking into account the highest intervened area (the Pampas) and its critical threshold, a family of theoretical trajectories aiming at such threshold point has been projected for the rest of biomes in response to human intervention. Thus, the relative sensitivity of different biomes to provide ecological and agricultural services has been compared, and this comparison in turn provides conceptual elements for identifying alternative land-use strategies.

3. Results and discussion

3.1. Land-use change and the value of ecosystems in the Pampas

A significant shift in the regional pattern of land-use has taken place during the 20th century. Elaborated on national censuses data, Fig. 2 shows the evolution of rangelands, cultivated grasslands and croplands during this period. After finishing the so-called conquest of desert in 1879, most of the area remained for decades as a wide rangeland with little human intervention. Approximately one half of the region showed less than 10% of the land cultivated with annual crops in the 1880s, while the rest was exclusively covered by natural grassland. The majority of the land was utilized for cattle grazing with different levels of managerial organization (from open fields to varying ranching schemes). No areas completely free of annual crops were recorded during the 1930s, with a crop occupation of lands that ranged between 20% and 60%, even in the marginal and fragile western lands. Although an extensive flooding had produced major alterations on land-use (especially in the flooding pampas) at the end of the 1980s and part of the 1990s, the area of annual crops ranged between 40% and more than 60%, specially in the most fertile lands of the rolling, the central and the southern pampas.

Despite average figures, it should be noted that the conversion of natural grasslands into cultivated grasslands and croplands was not homogeneous in all biomes. Conversion occurred very early in the rolling pampas, given that more than 60% of natural lands had been transformed in the 1910s. Only 10% of the land has no agricultural use nowadays. On the other

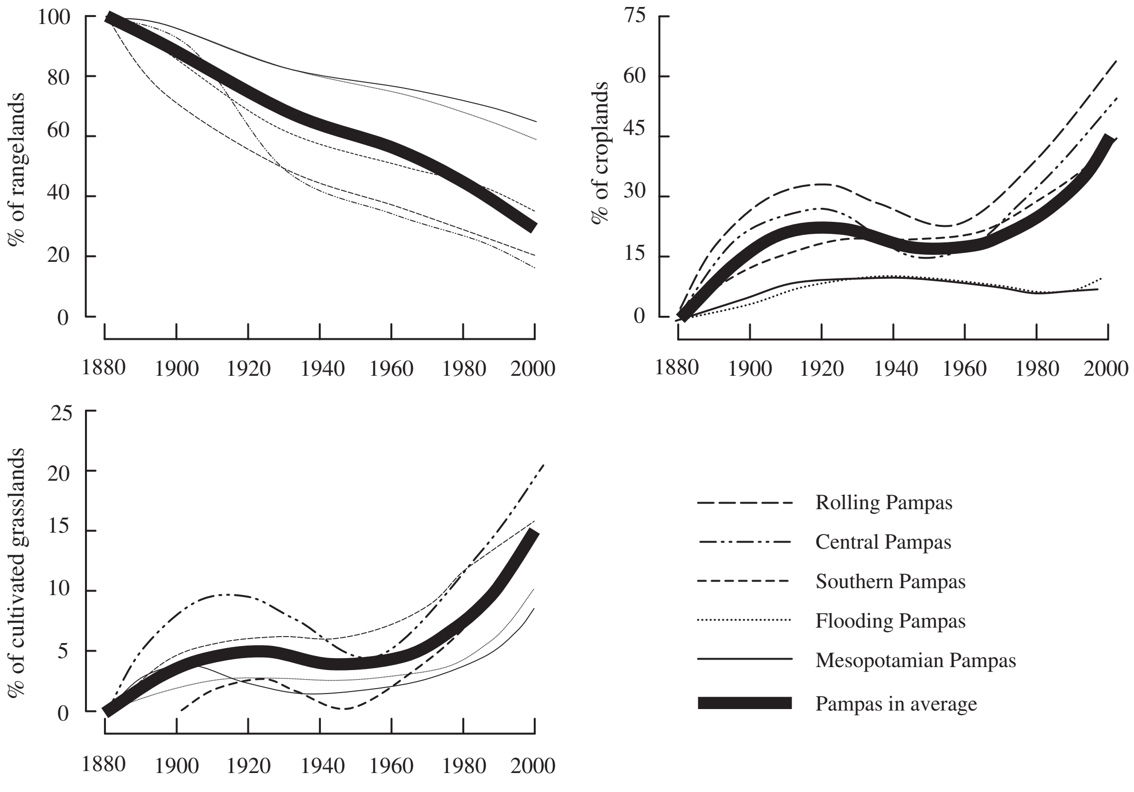

Fig. 2. Historical changes in land-use (rangeland, cropland and cultivated grassland) in five homogeneous ecosystems of the Argentine Pampas.

extreme, the flooding pampas has experienced the lowest conversion rate where, in average, 60% of land remained as modified natural grassland at the end of the 1980s. The other biomes showed different degrees of land transformation. With the only exception of the rolling pampas, where the cropland raised steeply between the 1960s and the 1990s, the other areas had maintained a rather stable cropland after a wave of rapid increase during the 1920s. Again, with the exception of the rolling pampas, the rest of the zones showed a persistent increase of cultivated pastures, contradicting the belief that croplands had expanded all over the pampas since the 1950s, with the result of displacing cattle production to the marginal lands of the western pampas. Neither the cropland has expanded all over the region, nor has the grazing area for livestock production been displaced to marginal lands.

Because of land transformation, natural habitats have been deeply fragmented with still unknown consequences on biodiversity. The land-cover pattern, which refers to physical attributes of the land surface, was modified in a few decades especially in the rolling, the central and the southern pampas, where pulses have been modulated by the short life cycle of crops that have expanded during the 20th century (Viglizzo et al., 2001). This was particularly evident when the wheat–soybean rotation was introduced in the rolling pampas. Land-cover and biological alteration have been less severe in the flooding and the Mesopotamian pampas, where a diversity of natural and perennial species has persisted until now.

From an ecological succession perspective, the anthropogenic disturbance that began at the end of the 19th century pushed the pampas away from their climax condition. Over one century of farming intervention, landscapes have been altered by human- and nature-driven forces that have led to mosaics and patches comprising different succession stages. They represent, in variable degree, a backward movement of succession to younger serial stages with major alteration of structure and function. Such backward movement that has been induced by humans aiming at utilitarian objectives has represented, in practice, a simplification of structures and functions that resembles the younger succession stages of centuries ago. Nowadays, different degrees of regression in the ecological succession can be detected all over the region. Extreme cases of over-rejuvenation can be found in the highly simplified crop rotation schemes (wheat–soybean) of the rolling pampas, where the energy flow and the productivity are enhanced, the nutrient and water cycles are opened, habitat and biodiversity are altered, and the lifetime of the principal biological activities (crops, in this case) is short and discontinuous. Beyond the spatial heterogeneity, these major alterations have strong implications on the provision of ecological and agricultural services.

Fig. 3 shows an estimation of tradeoffs between the economic value of agricultural and ecological services in response to cropland increase. While the gross margin (that depends on the growing provision of agricultural services) increases with the expansion of the cropping area, the provision and value of ecological services persistently decline. A decreasing provision of essential ecological services is the price that society has to pay for increasing the economic productivity of the land. Different areas in the Pampas can be located nowadays within this land-use range. A potentially critical threshold for ecosystem resilience is identified where both curves cross each other.

3.2. The comparative behavior of biomes in Del Plata Basin

The comparison of the Pampas (the highest intervened biome and a baseline case study) with the rest of the study biomes provides a helpful exercise to orient the identification of land-use options. In Table 1, the physical and economic characteristic of five dominant biomes in Del Plata Basin is presented. Different authors and literature sources have been utilized to reconstruct such figures.

As can be appreciated from the economic values presented in Fig. 4, biomes greatly differ in their capacity to supply ecological as well as agricultural services. Of particular interest seems to be the analysis of their sensitivity to human intervention, especially in the case of contrasting biomes such as the Pampas and the Pantanal. According to Costanza et al. (1997) estimations, wetlands like those of Pantanal may reach a very high economic value as supplier of ecological services. On the other hand and despite of its agricultural value, croplands like those that predominate in the Pampas have, as provider of ecological services, a relatively low economic value.

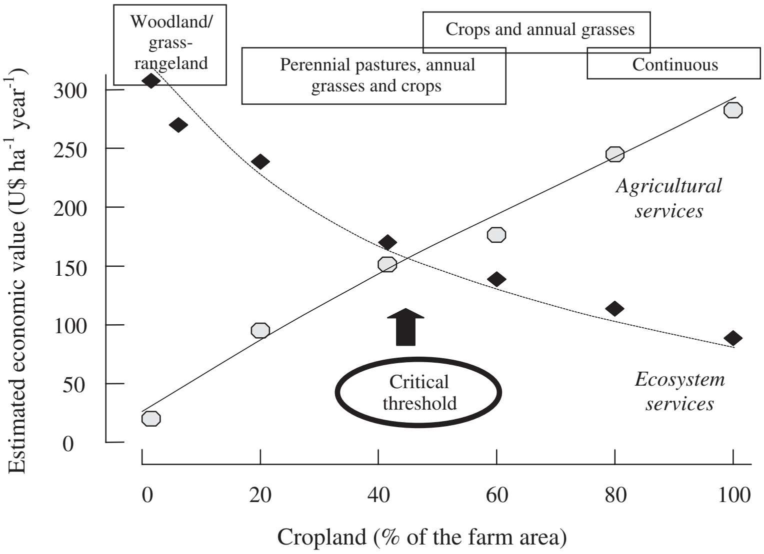

Fig. 3. Relationship between the value of agricultural (gross margin) and ecosystem services in the Argentine Pampas under different agro-ecosystem typologies. Gross margin figures have been obtained from economic reports. Agro-ecosystem services were estimated through data from Costanza et al. (1997). A potentially critical threshold for ecosystems resilience has been identified were curves cross each other.

Then, while the Pampas tend to be rather insensitive to increasing cultivation, the Pantanal appears to be extremely sensitive to such intervention. Our estimations indicate that the Pantanal may be losing more than 30 times of its pristine environmental value before reaching a gross margin that is equivalent to that of the Pampas cropland. Then, if we have to lose more than to gain, we can argue that it might be not justifiable the conversion of natural land into cultivated land in a sensitive ecoregion like the Pantanal, but not in the Pampas. Considering the powerful water regulation capacity of wetlands in Pantanal during the tropical rainfall season, the disruption of such service may potentially be cause of severe downstream flood-

Table 1
Main physical and economic characteristics of five predominant biomes in Del Plata Basin

Biome	Study area (km^2)	Land-use/land-cover (%)				Gross annual value ($US\$ ha^{-1} year^{-1}$)		Human intervention factor	Sources
		Forest	Grass/ rangeland	Wetlands and useless lands	Croplands	Ecosystem services	Agriculture		
Pantanal	138,000	–	66.7	13.5	–	5726.9	23.5	28.0	5, 7, 10, 15, 16
Campos	1,039,670	10.4	51.7	33.3	24.4	1893.2	93.2	44.7	6, 8, 9, 17
Cerrado	2,040,000	50.0	43.0	–	7.0	1052.0	31.3	30.5	1, 3, 8, 10, 14, 19
Gran Chaco	668,360	0.5	93.0	–	6.5	557.2	27.0	31.0	2, 4, 12
Pampas	540,000	–	60.0	40.0	–	181.3	156.7	67.2	17, 18, 20, 21

References: (1) Adámoli et al. (1985), (2) Alvarez and Lavado (1998), (3) Andrade de Castro and Kauffman (1998), (4) Bozzano and Weik (1994), (5) Bucher and Huszar (1995), (6) DCE (1994), (7) Gottgens et al. (2001), (8) IBGE (1997), (9) Krapovickas and Di Giacomo (1998), (10) Macedo (1994), (11) Mourào et al. (2000), (12) Naumann (1999), (13) PROCISUR (1995), (14) Resk et al. (2000), (15) Seidl and Moraes (2000), (16) Seidl and Moraes (2000), (17) SIIAP (1994), (18) Solbrig and Viglizzo (1999), (19) Villachica et al. (1990), (20) Viglizzo et al. (2003), (21) Viglizzo et al. (2002).
Data on land-use/land-cover and the economic value of agriculture have been obtained from various national statistical sources and different authors. Data on the economic value of ecosystem services have been obtained from different sources and own estimations. In all cases, estimations have been based on figures from Costanza et al. (1997). The human intervention factor has been estimated by technical coefficients that reflect the relative impact of different land-use/land-cover (%) patterns on the provision of ecosystem services.

ing on many important economic areas of Argentina (even in the Pampas), Paraguay and Uruguay (Bucher and Huszar, 1995). On large scale basis (as in the case of Del Plata Basin), the consideration of tradeoffs between ecological and agricultural services in contrasting, interconnected biomes, appears to be essential for balancing the potential market benefit with the environmental cost.

Certainly, the identification of threshold points in the way we did may be cause of controversy because of the unquestionable contribution of cropping expansion to the regional economy. No doubt policies promoting farmers to set aside croplands for conservation purposes can displace the production model towards the left part of Fig. 4. While such policies may be sound in rich countries that can subsidize a conservative land-use strategy, it might not be a feasible in developing countries that heavily rely on agricultural export surpluses.

3.3. Analytical consistency and uncertainty sources

The real or potential depletion of ecosystem services should be weighted against the economic benefits that can be obtained from farming in the study biomes. It is difficult, however, to place a value on

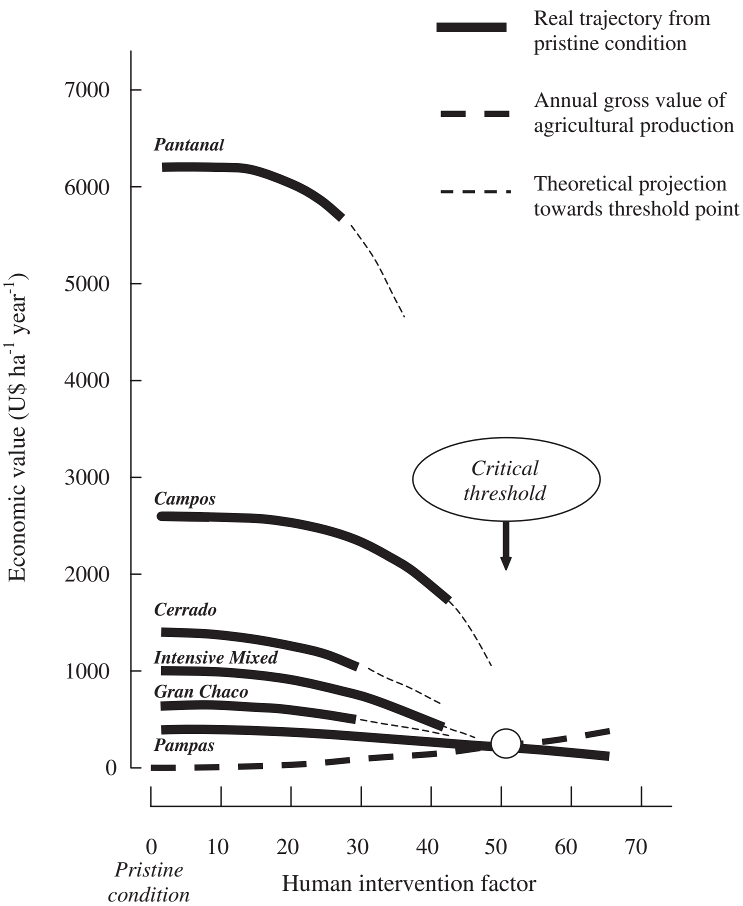

Fig. 4. Estimated tradeoffs between the economic value of ecosystem services and the gross value of agricultural services in response to increased human intervention in five critical biomes of the Del Plata Basin in Southern America. Based on the data of Costanza et al. (1997), the human intervention factor was estimated by applying technical coefficients that reflect the relative impact of different land-use/land-cover percentage on ecosystem services disruption. Impact coefficients were the following: (i) forest: 0.1, (ii) rangeland/grassland: 0.42, (iii) perennial crops: 0.58, (iv) annual crops: 1.05. The larger the value of services supplied by each biome, the greater its sensitivity to human intervention.

ecosystem services that often are ignored or undervalued in a free-market context, and this unavoidably is cause of uncertainty.

In our work, we are proposing a method to identify land-use options through tradeoffs analysis involving both ecosystem and economic service provision. Given that we have strictly used Costanza et al. (1997) ecosystem service values to support our analytical framework, the use of such figures was only instrumental. In other terms, in this work, such values were an instrument to support our methodological development, and not an end in itself. So, the validity of figures was not a discussion matter. Following this reasoning line, it is understandable the concern that may arise with respect to the discount rate in ecosystem service valuation. Apparently, discount rate was not a critical issue in Costanza et al.'s (1997) work. Moreover, they explicitly argued that many types of ecosystem services are neither easily traceable nor always visible in well functioning markets. Given that such services are normally intangible and thus have no market value, available methods for price estimation are unavoidably uncertain. Then, the calculation of discount rate may not have any sense in this context. This situation may change if public awareness about intangible values increases and methods for price estimation improve in future.

In our case, we accept that the detection of uncertainty sources is unavoidable when new approaches, methods or techniques are proposed. At least three noticeable uncertainty sources in our analysis should be pointed out: (i) the adopted value of ecological services that have been selected from literature was based on single ecosystem functions, setting aside possible interactions and interdependence between two or more ecological functions; (ii) the selected value of ecosystem services corresponds to average figures in literature, and this means that potential values that may arise under variable spatial and temporal conditions have been ignored; (iii) the contribution (% of the total area) of different ecosystems to ecological service provision has relatively been well-established only in the case of the Argentine Pampas, but this has not been the case for the rest of the biomes.

The determination of a critical threshold may be cause of controversy. We have adopted a simplistic criterion only to facilitate the understanding of our analytical framework. The argument behind crossing curves can be acceptable in biomes where there is not a large disparity between the total value of ecological and agricultural services (as it happens with croplands in the Pampas). But this assumption could become unviable or at least questionable in biomes (e.g., wetlands in Pantanal) where the total value of the ecological and the agricultural services largely differ. In this case, a small increase in the provision of agricultural services can generate a disproportionate decrease in the provision of ecological services. So, a well-balanced threshold might be extremely difficult to identify in cases of this type. Certainly, this issue should deserve more attention and discussion in future.

One may agree with critical opinions (Turner et al., 1998, 2003) arguing that a failure in the estimation of the economic value of environmental services might fully invalidate the analytical procedure. However, our purpose in this paper has not been to critically review methods and techniques to put price on such services. Independently of the price of ecological services in different biomes, the objective of this work has been primarily to support the identification of land-use options through an ecosystem service-based approach. Such analytical exercise can be accomplished beyond the reliability of basic data. The uncertainty around data integrity should not invalidate the consistency of the method applied. This does not mean to ignore that reliable figures are critically necessary to provide consistency to the analytical job.

4. Conclusions

In economic terms, the difference between biomes to supply ecosystem services in Del Plata Basin is enormous. On the other hand, such difference is not equally important in the case of agricultural services. The cultivation of new lands in some biomes would neither compensate nor justify the loss of irreplaceable ecological services.

Beyond the economic demand of countries, common sense suggests that the economic exploitation of biomes should not ignore their comparative environmental advantage. For example, due to its smaller sensitivity, the environmental cost of cultivation in the Argentine Pampas seems of minor importance in relation to its potential impact on the Pantanal or the Cerrado. Then, the functional complementation of biomes seems to be a smart strategy to explore on land-use options on broad scale basis.

Who should pay for ecosystem services that today do not have a market price? Given that such question does not still have a convincing answer, we should try to explore and mimic promising mechanisms. Carbon-offset funds paid to countries that maintain or increase their forest area are likely to become an important strategy to promote forest conservation. Why not to think in a similar mechanism for ameliorating floods, conserving soils, preserving biodiversity or regulating climate? If we look at pricing ecosystem services, it is relevant to consider the whole basin as an integrated ecological unit. The concept of *basin unit* sounds particularly suitable for the Del Plata Basin. Sensitive biomes that differ in their functional role, but are closely interconnected by waterways, may be benefited from a multi-biome land-use approach. The functional complementation of disparate biomes to provide agricultural and ecological services seems to be critical to explore the myriad of economic benefits and environmental costs emerging from alternative land-use strategies.

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