Agriculture, Ecosystems and Environment 154 (2012) 34–43

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Land-use planning based on ecosystem service assessment: A case study in the Southeast Pampas of Argentina

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ARTICLE INFO

Article history:
Received 3 August 2010
Received in revised form 23 June 2011
Accepted 19 July 2011
Available online 15 August 2011

Keywords:
Strategic environmental assessment
Ecosystem services
Land use planning

ABSTRACT

A methodological protocol of strategic environmental assessment was developed to incorporate the valuation of ecosystem services in land use plans. The protocol was applied in rural land planning at Balcarce, a department representative of the Southeast Pampas Region (Argentina). The ecosystem services approach was used as valuation criteria of the 14 principal ecosystems classified in the studied area, where agricultural is the predominant economic activity. The provision of seven principal ecosystem services related to regulation functions or food production was estimated for each ecosystem using a set of indicators integrating climatic, vegetation and terrain variables. The assessment of land use changes showed a significant increase in agriculture in the past 20 years, which affected mainly natural grasslands. The environmental impact of this replacement varied according to the ecosystem and the area. Hills and riparian zones were identified as key areas for grassland conservation in order to provide regulation ecosystem services in agricultural landscapes. On the basis of this analysis, a preliminary zoning was proposed, aimed to retain critical support and regulation ecosystem services without significantly sacrificing food production for humans. Strategic environmental assessment based on ecosystem services appears as a powerful tool to prevent negative environmental costs of land use plans which can remain unnoticed under traditional environmental impact assessment techniques.

1. Introduction

Expansion and intensification of cultivated lands are among the predominantly global changes of this century (Matson et al., 1997). Depending on the estimations, croplands increased globally by four- to fivefold from the 1700s to the mid-1980s at the expense of forests, grasslands and wetlands (Viglizzo et al., 1997).

The Argentine Pampas were not an exception to this global trend. During the last decades, the use of agrochemicals, no tillage techniques and transgenic seeds have increased in the region, and rotation between crops and pastures have been replaced either by rotation between crops (wheat and soy primarily) or by soy monocultures (Filloy and Bellocq, 2007). Cattle breeding (cow–calf systems) on natural grasslands combined with sown pastures remained in non-agricultural lands but cattle fattening is progressively being performed under intensive livestock systems (feed-lots; Viglizzo et al., 2001). All these changes in the production systems have resulted both in social costs, such as concentration of land ownership and migration of small farmers into cities (Joensen et al., 2005), and in environmental costs, such as the increase in soil and water contamination risk and in biodiversity loss (Viglizzo et al., 2001, 2003).

In this context, land use planning (LUP) appears as a necessary tool to increase sustainability of agricultural development balancing economic competitiveness, social equity and environmental health. Experience in LUP in Argentina is very recent and has so far focused on forest conservation, especially in the Northern Provinces (Ley Nacional No. 26331). In the rest of the territory, there are neither LUP normative nor accepted political criteria for its application.

The ecosystem services (ES) approach (MEA, 2005) provides an integrated basis to address LUP in different environments. The identification and measurement of ES variations as a consequence of land use changes seems to be an adequate way to evaluate environmental costs and benefits of different land planning decisions. Since Strategic Environmental Assessment (SEA) is defined as a systematic on-going process to evaluate the environmental effects of alternative decisions in policies, plans and programs, ensuring full integration of relevant biophysical, economic, social and political considerations from the beginning of the decision process (Brown and Therevil, 2000; Chaker et al., 2006; Partidario, 2003; Tao et al., 2007), it can be used to integrate ES in LUP. While there are many studies on the theory of SEA, reports on its methodological development and practical application are scarce (González et al., 2006; Habib, 2005; Partidario, 2003).

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doi:10.1016/j.agee.2011.07.010

The aim of this study was to develop a methodological protocol of strategic environmental assessment based on an ecosystem services approach to be used in land use planning for agricultural development. The protocol was applied to evaluate the current land use and to develop criteria and guidelines for LUP at Balcarce, a predominantly rural department of 412,000 ha considered representative of the Southeast Pampas Region of Argentina.

2. Methods

2.1. Study area

The Argentine Pampas is a vast, flat region that comprises more that 50 million ha suitable for crop and cattle production. The region is divided into five homogeneous ecological sub-regions according to their rainfall and soil quality patterns: Rolling Pampas, Central Pampas, Southern Pampas, Flooding Pampas and Mesopotamian Pampas (León, 1991). Agriculture in the Pampas has a short history (a little more than 100 years) and shares common features with the agricultural history of the Great American Plains. Both regions were mostly native rangelands until the end of the 19th century and the beginning of the 20th, and land was then allocated to crop (cereal crops and oil seeds) and cattle production under low input farming conditions (Viglizzo et al., 2001).

Balcarce is considered representative of the predominant land uses in the Southeast Pampas Region. It includes part of the Flooding Pampas (FP), mostly a cattle-breeding area dominated by lowlands with small differences in topography, soil quality, problems of salinity, water drainage and flood risk, and part of the Southern Pampa (SP) characterized by the presence of the Tandilia hill system and the croplands surrounding hills (Soriano et al., 1991) (Fig. 1).

2.2. SEA methodology

The SEA methodological protocol presented here is a self-developed set of five steps containing one or more procedures in each step (Fig. 2). It is supported by published reports on SEA (Brown and Therevil, 2000; Partidario, 2003), LUP (Kessler, 2000; Tao et al., 2007) and ES (Carreño et al., in press; MEA, 2005; Viglizzo et al., 2011), and was designed to be applied in the formulation of rural land use planning at department level in Argentina.

Since the main objective of this work was not to develop a methodology to assess ES, but to incorporate this approach in conjunction with SEA for LUP, we used a set of ES indicators adapted from a procedure proposed by Viglizzo et al. (2011) and Carreño et al. (in press). In some cases, to complement our analysis, we referred to professionals from different areas of the National Institute of Agricultural Technology (INTA) and the National University of Mar del Plata (expert criteria).

2.2.1. Screening and scoping

The screening and scoping phase sets the general framework and assessment procedure for SEA: stakeholders, relevant aspects to assess, degree of detail needed, information sources, baseline to consider and informatics support.

Since no LUP had been performed in Balcarce before, we considered the current rural land use as the baseline, from which LUP alternatives were generated. Agricultural activities and ES were the focus of assessment.

Spatial information relevant to the study was provided by the Geomatics Laboratory at the INTA Balcarce. These data were organized in a Geographic Information System (GIS), including agricultural aptitude of soils, a digital terrain model, land cover classifications, hydrology, geomorphology, watersheds, roads, towns and cities. To study land cover 224-86 LandSat satellite scenes were used (sensors Multi-Spectral Scanner, bands 5 and 6, and Thematic Mapper, bands 3, 4, 5 and 7; Zelaya and Maceira, 2007). Two agricultural seasons were analyzed (1986–1987 and 2005–2006) using the following images: December 15, 1986; October 16, 2005 and February 5, 2006. We chose these periods because they reflect the main land use changes that took place in the region in the last 20 years, and because they were periods with normal rainfall.

The classification process involved two steps; first an unsupervised classification method was applied (for both agricultural seasons) and then classes were grouped using field data (only for the 2005–2006 agricultural season). Five cover classes were discriminated:

- *Crop*: Areas covered with summer or winter annual agricultural crops (or their residues). The principal crops were wheat, soybean, corn and sunflower.
- *Pasture*: Areas covered with sown pastures, without discrimination of age. Normally, pastures are composed of one to four exotic perennial grasses and legumes.
- *Grassland*: Areas covered with natural grasslands, affected by variable degrees by human intervention. Grasslands constitute the original ecosystem of the Pampas, dominated by perennial tall grasses combined with short grasses and the presence of shrubs, especially in hills.
- *Forest*: Areas with natural (*Celtis tala*, Salix) or planted (Eucalyptus, Pine) tree vegetation for commercial purposes or for protection.
- *Water*: Areas with presence of surface water (lakes, streams, canals and flooded areas).

2.2.2. Territory description

The biophysical environment and major socio-economic aspects of Balcarce were described by using GIS spatial information and existing data (INDEC, 2001, 2002; Tomás et al., 2005).

The main components of this step were the definition of major ecosystem types and the estimation of the principal ES provided by each ecosystem. Major ecosystems were defined by the combination of natural (biophysical) regions and land cover types of the studied area. To assess ES provision we used a simple set of indicators adapted from Viglizzo et al. (2011) and Carreño et al. (in press) integrating climatic, vegetation and terrain variables (Table 1). We then ranked the ecosystem types on a relative 0–1000 scale according to their ability to provide each specific ES considered in the analysis.

Total ES provision for each ecosystem resulted from the sum of seven ES values.

Viglizzo et al. (2011) and Carreño et al. (in press) supported these indicators in different bibliographic sources. Following de Groot et al. (2002), these authors assumed that a set of ecosystem services is directly associated with the amount of biomass covering the land (we used net primary production, NPP, as an indicator of biomass) and its variability (VC_{NPP}).

Ecosystem services related to water availability, such as water regulation or water provision, were considered to vary according to the proportion of the landscape covered by water bodies (MEA, 2005). Water input (I_w) was used as a principal factor in the disturbance control equation.

To adjust calculations based on NPP or I_w according to the prevailing environmental conditions that may affect the supply of ES, the estimates were modified by correction factors that ranged between 0 and 1. The slope average correction factor (S_{cf}) was used in Eq. (1), because the steeper the slope, the more important the biomass coverage for soil protection (Sidle et al., 2006). In Eq. (3),

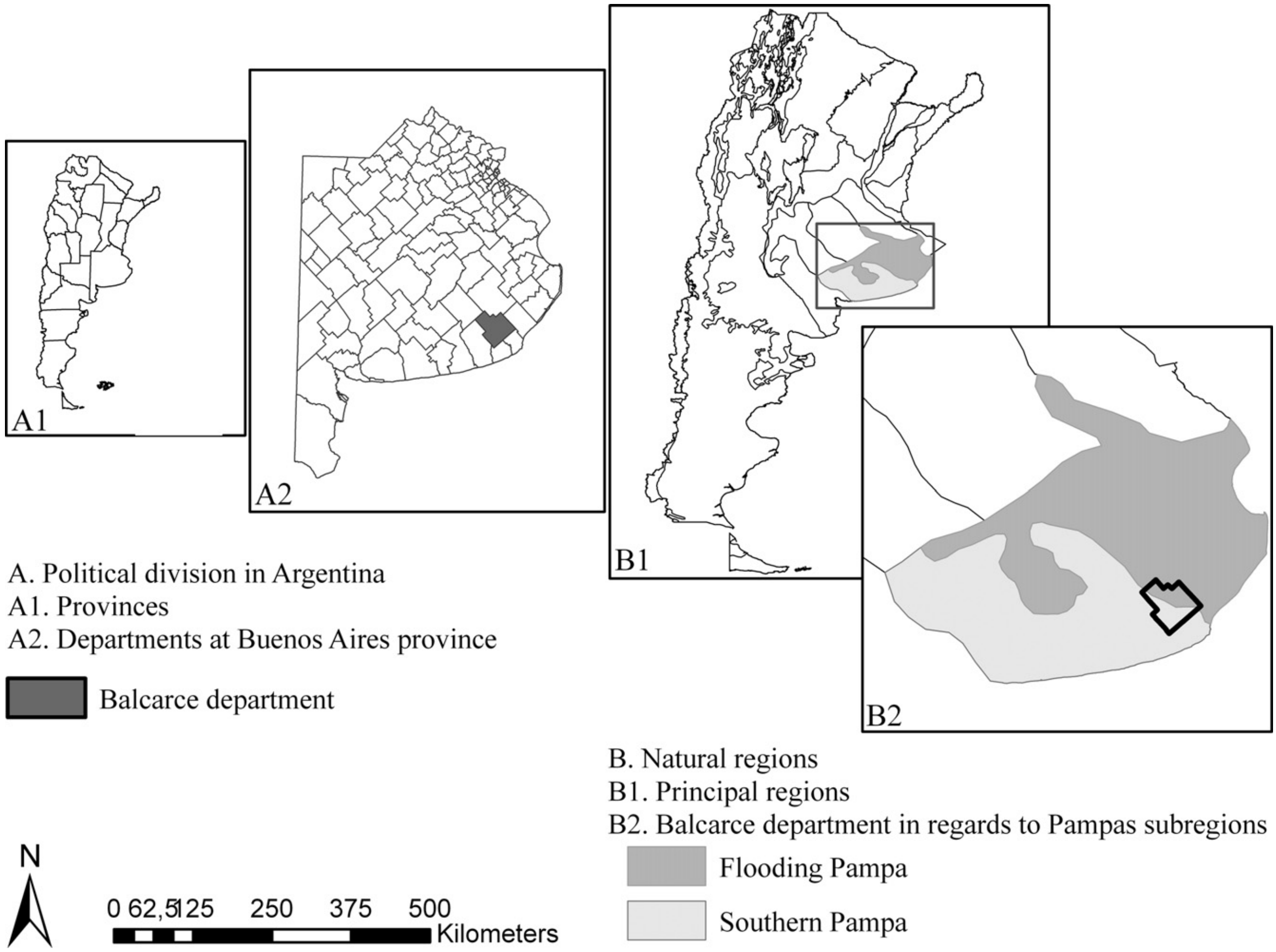

Fig. 1. The left side of the figure shows the location of Balcarce department in Buenos Aires province, Argentina (political division). The right side of the figure shows Balcarce department in regards to Pampas sub-regions (natural division).

this factor was used because of the capacity of biomass to intercept, retain and infiltrate the incoming water declines with the slope as this factor reduced the residence time of water within the landscape (Carreño and Viglizzo, 2007).

The soil infiltration capacity factor (IC_s) was used in Eq. (3) because of its importance in water recharge. The water body occupancy and flat floodplain area factor (O_w) was used in Eq. (2) because it was negatively associated with plant cover and there-

Table 1
Indicators (equations) used to assess ecosystem services provision at Balcarce department.

Ecosystem service name	Equation		Variables
Soil protection	$NPP \times (1 - VC_{NNP}) \times (1 - S_{cf}) \times 1.5$	(1)	NPP: net primary production (0–1000)[a]. VC_{NPP}: coefficient of variation of NPP (0–1)[b]. S_{cf}: slope average correction factor of the study area (0–1).
Carbon capture	$NPP \times (1 - VC_{NNP}) \times (1 - O_w) \times 1.5$	(2)	O_w: water bodies occupancy percentage and flat floodplain area (0–1).
Water purification and provision	$NPP \times (1 - VC_{NNP}) \times IC_s \times S_{cf} \times 1.75$	(3)	IC_s: soil infiltration capacity (0–1).
Biodiversity conservation	$NPP \times (1 - VC_{NNP}) \times I_w \times N_f \times 1.75$	(4)	I_w: water input to the system (0–1)[c]. N_f: naturalness factor; considering naturalness and structural complexity of the ecosystem (0–1)
Disturbance control	$I_w \times O_w \times 1.25$	(5)	I_w: water input to the system (0–1000)[c].
Waste purification	$NPP \times (1 - VC_{NNP}) \times I_w \times O_w \times 1.75$	(6)	
Direct goods provision	$NPP \times H \times Q_f \times 1.5$	(7)	H: harvest index by men (grain, meat, wood) (0–1) (Table 2). Q_f: quality factor of primary outputs.

Numerical coefficients: since the more correction factors are used calculation values degrade and lose relative weight, compensation coefficients that depend on the number of multiplicative factors (1.25, 1.50, 1.75) were applied in each ES equation to maintain the balance between equations.

[a] NNP: estimated through the Normalized Differential Vegetation Index (NDVI) for Spring-Summer, expressed on a relative scale. NDVI data were calculated from the LandSat TM image (band 3 and 4; 16 October 2005).

[b] VC_{NPP}: expresses the spatial variation in NDVI of the different covers, associated with different environmental and management conditions. In the case of crops, it also reflects the seasonal alternation between winter and summer crops.

[c] I_w: rain × (1 − runoff coefficient). In Eq. (5): (0–1000), in Eqs. (4) and (6): (0–1); depending upon its role as principal or affecting variable in the equation.

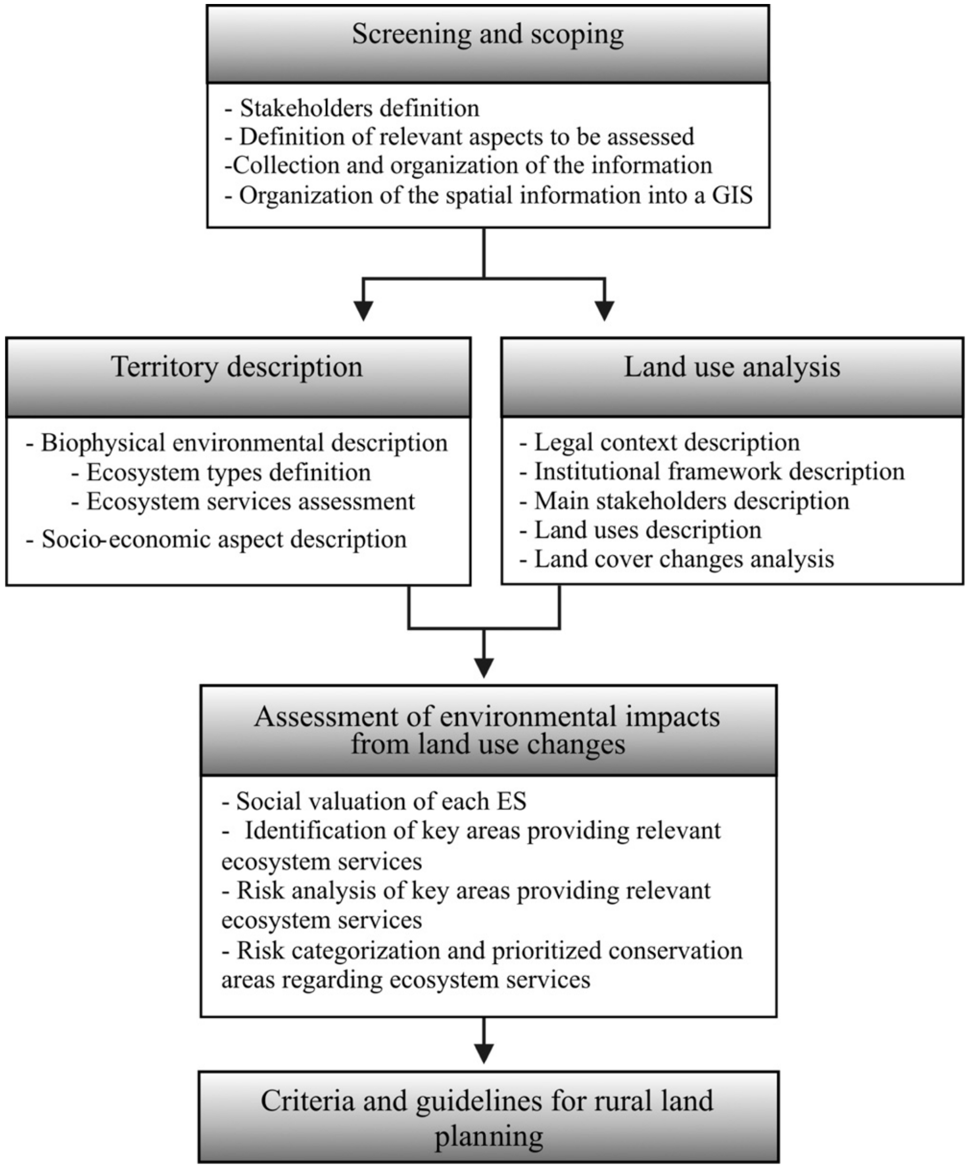

Fig. 2. Strategic environmental assessment methodology proposed to be applied in rural land use planning.

fore, with carbon capture. This factor was also used in Eqs. (5) and (6) because of the ability of wetlands to purify and provide water and because of the capacity of water bodies to expand their size and absorb the impact of water excess (Verhoeven et al., 2006).

The differences regarding the procedures of Viglizzo et al. (2011) and Carreño et al. (in press) were the addition of Eq. (7) and the inclusion of the N_f factor in Eq. (4).

In Eq. (4), N_f assigned a relative value to the naturalness and structural complexity of the ecosystem (considered as favorable traits for biodiversity) using the following scale: natural grasslands and grasslands-shrubs communities in hill environments: 1; wetlands and plain mixed natural grasslands composed of short and tall grasses, small forest galleries in streams, rivers and lagoons: 0.75; plain short natural grasslands and planted forests: 0.5; implanted perennial pastures: 0.25, and seasonal harvest crops: 0.1. In Eq. (4), the thermal and altitude factors (present in the original equation of Viglizzo et al., 2011; Carreño et al., in press) were removed because they were not relevant to the spatial scale of the study.

The quality factor in Eq. (7) weighs the quality of energy produced under a human use perspective; we assigned an arbitrary value of 1 to animal productivity, 0.25 to agricultural productivity and 0.05 to forest productivity, considering their direct value for human alimentation and other human uses.

In Eq. (7), Harvest index was calculated as follows (Table 2):

Final equation to calculate ES total offer in an ecosystem is (S):

$$S = [(S_{soil}) + (S_{Carbon}) + (S_{water}) + (S_{biod}) + (S_{dist}) + (S_{waste}) + (S_{good})] \times 0.1428$$

Then, ES values were standardized considering 1000 as the maximum value obtained for each ES in all ecosystems.

The numerical value (0.1428) is a correction coefficient used by Viglizzo et al. (2011) and Carreño et al. (in press) to give equal weight to all factors that integrate the equation and so that no events exceed the sum of the value of 1000; it is calculated as 1 divided by the number of factors from the equation (1/7).

Finally, ES provision was mapped assigning the standardized values to the coverage of each ecosystem.

Table 2
Harvest index by men in crop, livestock and forest systems. In the case of crop production, weighted average harvest index was estimated considering the four main regional crops (wheat, sunflower, corn and soybeans). In the case of livestock, average annual meat yield per hectare was estimated for two cattle production systems: those based on cultivated pastures and those based on natural grasslands. In afforestation, wood production was estimated considering the average harvest yield for eucalyptus plantations (typical afforestation of the region) divided by their average aerial biomass in Flooding Pampa, Southern Pampa and hills.

Harvest index (H)			
Crop production	Cultivated systems	$H = (H_{wheat} \times A_{wheat} + H_{sunflower} \times A_{sunflower} + H_{corn} \times A_{corn} + H_{soybean} \times A_{soybean})/DA$	H_i: (average crop yield)[a]/(average crop biomass) A_i: average crop area[b] DA: department area
Livestock	Cultivated pasture systems	$H = MY_p/B_p$	MY_p: average annual meat yield per hectare in cattle production systems based on cultivated pastures[c]. B_p: average biomass of such pastures for Flooding Pampa, Southern Pampa and hills[c].
	Natural grasslands systems	$H = MY_g/B_g$	MY_g: average annual meat yield per hectare in cattle production systems based on natural grasslands[c]. B_g: average biomass of such grasslands for Flooding Pampa, Southern Pampa and hills[c].
Afforestation	Forest systems	$H = (Y/AB)/10$	Y: average harvest yield for eucalyptus plantations (typical afforestation of the region)[c,d]. AB: average aerial biomass for Flooding Pampa, Southern Pampa and hills[c,d]. 10: to calculate an annual average harvest, the values were divided by 10 years, which is the growth cycle.

[a] National Statistics, Ministerio de Agricultura, 2006.
[b] Obtained from the land cover classification 2005–2006.
[c] INTA expert consultation.
[d] Since most of the forests planted in the department are for protection and timber harvesting is casual, it was considered that only 10% of forest plantations in Flooding Pampa and Southern Pampa and 5% of forests in hills were harvested.

2.2.3. *Land use analysis*

A description of the legal context, the institutional framework and the main stakeholders was summarized. We also studied land uses other than agriculture, such as mining, tourism and industrial activities (not considered in this work).

Then, land uses were described using the land cover classification (2005–2006) and statistical data from the national census (INDEC, 2002).

Historical trends in land use explain the current land cover patterns, so we analyzed changes in land cover at Balcarce department between the 1986–1987 and 2005–2006 agricultural periods, to determine trends in land use dynamics and ES provision.

2.2.4. *Assessment of environmental impacts from land use changes*

In this step, major impacts on ES provision were estimated as a result of land use changes. The procedures used were:

(a) *Social valuation of each ES.* Consultation with stakeholders about the importance assigned to each ES is a step that should be incorporated in ES evaluation processes. Since the principal aim of this study was to develop and test a methodology, only a small number of people (20 professionals and employees from INTA) were consulted. We used a questionnaire in which each person was asked to arrange the set of ES considered in the study according to the relative importance assigned to them. The questionnaire was accompanied by a brief description of each ES (see Appendix A).
(b) Identification of key areas providing relevant ES. To narrow the analysis we considered only the three ES ranked first in social valuation. Then, on the basis of ES provision maps generated in Section 2.2.2, land capability classes (LCCs), and expert consultation, we identified the areas with higher provision values for those three ES. LCCs range from I to VIII. Class I has no significant limitations for raising crops. Classes II and III are suited for cultivated crops but have limitations such as poor drainage, limited root zones, climatic restrictions, or erosion potential. Class IV is suitable for crops but only under selected cropping practices. Classes V–VII are best suited for pastures and ranges while Class VIII is suited only for wildlife habitat, recreation, and other non-agricultural uses (USDA, 1989).
Expert consultation was used to identify areas which were considered relevant for the provision of regulation ES according to their physical location; geomorphology and proximity to streams and water bodies were taken into account by experts to prioritize these areas. LCCs were used to set priorities and restrictions regarding goods provision services (agriculture and cattle production). In addition, we explored the potential for the expansion of agriculture and intensification of cattle production in areas that were not exploited in their maximum productive expression, considering two options: (3.1) agricultural production areas: non-cultivated areas on soils with LCCs from I to IV, and (3.2) agricultural and cattle production areas: areas without crops or implanted pastures on soils with LCCs from I to IV.
(c) Risk analysis of key areas providing relevant ES. Consistency between the current use of the key areas and their appropriate use according to the conservation of the three relevant ES were compared by overlaying the land cover map and the key areas map, using GIS. Risk areas were defined as those where the current use was in conflict with the proper use to ensure the provision of ES.

(d) Risk categorization and prioritized conservation areas regarding ES provision. Depending on risk analysis, ES provision areas were classified in terms of current land use along a relative risk scale (low, medium and high risk), where higher risk areas deserve higher conservational measures.

2.2.5. Criteria and guidelines for rural land planning

Results of the technical analysis were compiled as criteria and guidelines to be considered in a rural LUP proposal for Balcarce, based on the combination of land use alternatives and critical areas for ES provision. The main objective of this rural LUP proposal was based on the appreciation and conservation of the most relevant ES as a basis for a rural development model which preserves natural capital in the long term.

3. Results

Balcarce department presented a great variety of environments that were classified into 14 ecosystems, considering both natural regions and land covers (Table 3).

These ecosystems provided a variety of ES, in most cases simultaneously. The applied methodology showed that the ecosystems that provided more ES were forest plantations, cultivated pastures and grasslands, mainly in hill areas (Table 4).

According to the survey, the three social priorities regarding provision and regulation ES were: water purification and provision, soil protection and direct goods provision (food mainly from agriculture).

Gains and losses in hectares for each land cover type in the 20-year period of analysis are shown in Table 5. Crops were the ecosystems that gained more hectares, while natural grasslands were the most negatively affected by land use changes. These results reflect a trend toward agricultural land use, a general trend in vast humid and sub-humid lands of Argentina during the last decades (Baldi and Paruelo, 2008; Herrera et al., 2009). The environmental cost of this change was a significant loss of key ES, which, in our case, were provided by the most affected ecosystem: natural grasslands. The environmental impact of the replacement varied according to grassland location: the replacement of 1 ha of natural grasslands by annual crops in livestock flat areas meant an increase of 685 ES units in agricultural production and a loss of 942 ES units in environmental regulation, while in hill grasslands, the same relationship was 508 against 1993 SE units (Table 6).

The priority areas identified for key ES provision were:

(1) *Water provision and purification:* Key areas were hills, piedmonts (slopes between 3° and 6°) and highlands (slopes between 1° and 2.5°), because of their relevant contribution to groundwater natural recharge (expert consultation) and that all water streams originate in hills. Also streams with riparian (grassland) vegetation (50 m buffer areas) were prioritized for their importance in water purification (expert consultation). The resulting map showed that 24% of Balcarce department has a high potential for the provision of this ES.
(2) *Soil protection:* Key areas were hills and piedmonts with perennial vegetation cover, since vegetation is the main protection against erosion. Accordingly, the steeper the slope, the more relevant the vegetation cover.
(3) *Goods provision service (agriculture and livestock):* Key areas for agriculture were all lands included in LCCs I–IV not included in previous key areas for ES regulations, while key areas for cattle production were all lands included in LCCs V–VII not included in previous key areas for ES regulations. Regarding the potential for the expansion of agriculture and cattle production on areas not exploited in their maximum productive expression, 42% of the department corresponded to non-crop areas on soils with LCCs from I to IV and 21% to areas without crops or implanted pastures on soils with LCCs from I to IV.

Risk analysis showed that 23% of water bodies and riparian vegetation and 8% of hills and piedmonts were high-risk areas. In the case of agricultural lands, 13% were classified as high risk because LCCs were V–VII.

Finally, after identifying the potential and limitations of the territory, we suggest some criteria to incorporate into a Land Use Planning proposal for Balcarce department. A basic zoning aimed to ensure the sustainable provision of the different types of ES could consider the following areas (Fig. 3):

- *Type 1 areas*: Defined by hills and piedmonts, streams and riparian vegetation. These are key environments for the provision of the following ES: water purification and provision, soil protection and biodiversity conservation. These areas could also be important for other ES, not analyzed in this study, such as recreation and tourism.
- *Type 2 areas*: Defined by the highlands surrounding hills. These are key environments for the water purification and provision service and for the agricultural production service.
- *Type 3 areas*: Basically defined by the provision of agricultural goods. The LCCs type in these areas determines the sustainability or unsustainability of each kind of activity. They include two sub-areas:
  - 3.1. Predominantly annual crop production areas: LCCs I–IV.
  - 3.2. Predominantly cattle production areas: LCCs V–VII.

The zoning of areas considering their ES provision assumes that the assigned use should not affect this provision. For example, a 3.2 area should not be used for crop production because this activity will not be sustainable in this area. However, a 3.1 area could be used for crop or cattle production or any another activity involving a land use pressure equal to or lower than that from crop agriculture. Meanwhile, lands in type 2 areas engaged in agriculture should be managed under strict sustainability criteria, so that purification and provision of water is not being affected. On the other hand, in type 1 areas, activities that maintain or increase the permanent vegetation cover, such as sustainable cattle production, sustainable forestry and ecotourism, should be promoted.

4. Discussion

Although this is a preliminary study, results indicate that even if Balcarce has land available to expand agricultural activities, the current land use scenario is biased toward the maximization of direct-use goods provision, especially agricultural products. This aligns with findings by Sala and Paruelo (1997) and Viglizzo et al. (2003) for the Pampas region as a whole, who demonstrated that the agriculture expansion and intensification are negatively affecting the provision of other key ES such as water purification and provision, soil protection, carbon capture, biodiversity conservation and cultural and amenity services (Viglizzo and Frank, 2006). For this reason, only the scenarios that take into account key ES provision areas represent real alternatives for rural development of the study area and the Pampas as a whole.

According to our data, keeping regulation and provision ES in the Southeast Pampas depends strongly on the conservation of natural grasslands and forest in key areas. Several studies agree on the importance of grassland ecosystems in the provision of regulation and support ES (Heidenreich, 2009; Pan et al., 2005; Sala and Paruelo, 1997). Sala and Paruelo (1997) concluded that grasslands provide humans with many services, most of which have currently

Table 3
Ecosystem classification for Balcarce department considering the physiographic units and the types of coverage.

Physiographic unit	Type of coverage[a]	Resulting ecosystem
Flooding Pampa (between 0 and 100 m.a.s.l.)	Grassland	Grassland in Flooding Pampa
	Cultivated pasture	Cultivated pasture in Flooding Pampa
	Annual crops	Crop in Flooding Pampa
	Afforestation	Afforestation in Flooding Pampa
	Water	Water in Flooding Pampa
Southern Pampa – highlands (over 100 m.a.s.l.)	Grassland	Grassland in Southern Pampa
	Cultivated pasture	Cultivated pasture in Southern Pampa
	Annual crops	Crop in Southern Pampa
	Afforestation	Afforestation in Southern Pampa
	Water	Water in Southern Pampa
Southern Pampa – hills	Grassland-shrubland	Grassland in hills
	Cultivated pasture	Cultivated pasture in hills
	Crops	Crop in hills
	Afforestation	Afforestation in hills

[a] The first coverage type within each physiographic unit corresponds to the original ecosystem.

Table 4
Estimated values for ecosystem services at Balcarce department. Ecosystems are ordered from high to low considering the total sum of ecosystem provision.

Ecosystem	ES							
	$S_{soil\ protection}$	$S_{C\ capture}$	S_{goods}	S_{water}	$S_{disturb}$	S_{biodiv}	S_{waste}	Total
Afforestation in hills	947	947	2	1000	7	495	10	3408
Cultivated pasture in hills	1000	1000	337	792	4	174	7	3314
Grassland in hills	786	786	147	726	6	684	7	3141
Water in Flooding Pampa	57	0	0	8	778	1000	1000	2842
Afforestation in Flooding Pampa	21	376	4	648	467	568	681	2765
Cultivated pasture in Southern Pampa	189	786	403	924	56	188	75	2621
Grassland in Flooding Pampa	19	331	282	408	433	464	557	2495
Cultivated pasture in Flooding Pampa	20	358	327	565	400	232	556	2458
Crop in Flooding Pampa	13	227	967	357	333	49	293	2239
Grassland in Southern Pampa	150	625	361	362	67	539	72	2175
Crop in Southern Pampa	91	378	1000	479	44	29	29	2051
Afforestation in Southern Pampa	140	585	4	581	67	336	67	1780
Crop in hills	367	367	656	242	3	18	2	1656
Water in Southern Pampa	0	0	0	0	1000	0	0	1000

Table 5
Coverage transition matrix between 1986–1987 and 2005–2006 (ha) at Balcarce department.

Land cover classes in 1986	Land cover classes in 2006						
	Crops	Pastures	Grasslands	Forests	Water	Total 1986	% of total land area
Crops	64,918	34,872	16,052	802	628	117,271	33.1
Pastures	53,190	49,123	21,614	1190	1538	126,655	35.8
Grasslands	36,064	39,663	21,917	1322	2231	101,197	28.6
Forests	1792	1447	731	90	125	4185	1.2
Water	1378	1716	1033	71	757	4955	1.4
Total 2006	157,342	126,820	61,347	3475	5279	354,263	
% of total land area	44.4	35.8	17.3	1.0	1.5		

Table 6
Gains and losses of ecosystem services associated with the replacement of natural grasslands by annual crops in different physiographic environments. The seven ecosystem services studied were group in two categories: environmental regulation ecosystem services (soil protection, carbon capture, water purification and provision, biodiversity conservation, disturbance control and waste purification) and production ecosystem services (grain, meat and wood provision). The values obtained through the indicators (Table 1) were added for grasslands and annual crops in each physiographic unit (Flooding Pampa, Southern Pampa and hills).

	Grasslands	Annual crops	Difference
Flooding Pampa			
Environmental regulation ecosystem services	2213	1271	−942
Production ecosystem services	282	967	685
Southern Pampa			
Environmental regulation ecosystem services	1814	1051	−763
Production ecosystem services	361	1000	639
Hills			
Environmental regulation ecosystem services	2993	1000	−1993
Production ecosystem services	147	656	508

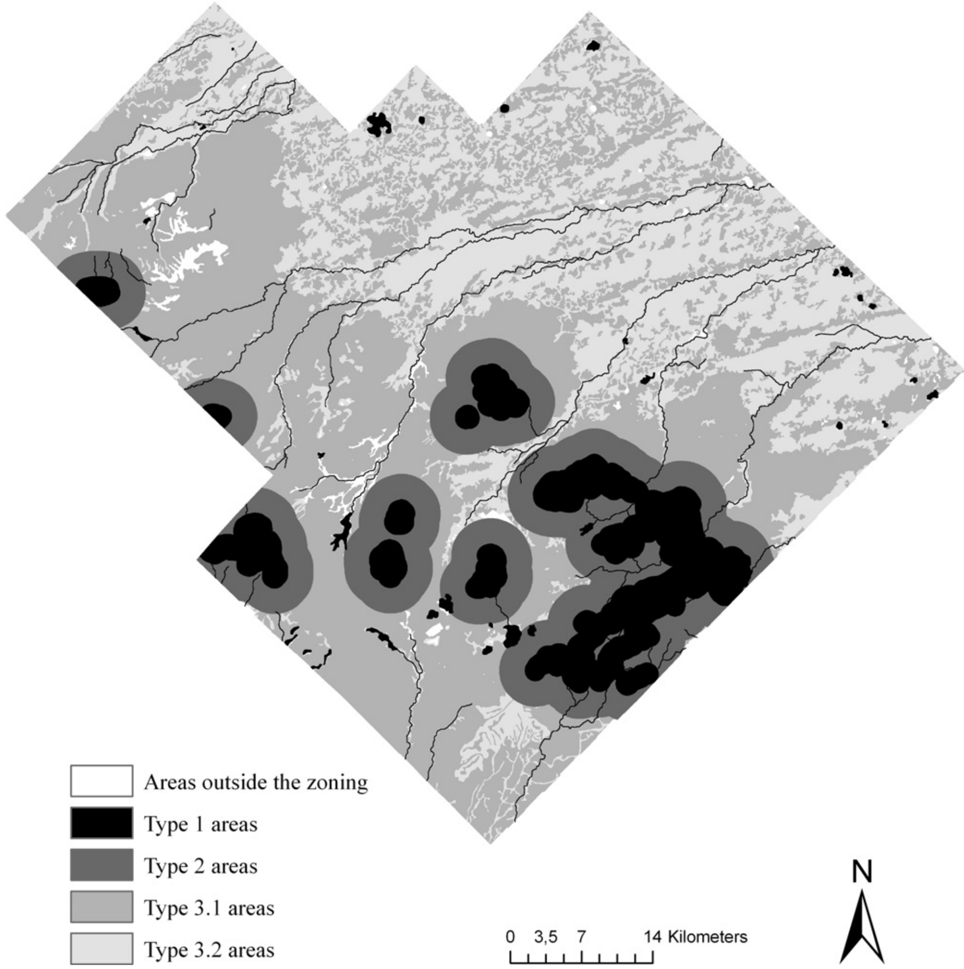

Fig. 3. Balcarce proposed zoning aimed to ensure the sustainable provision of ecosystem services. Type 1 areas are key environments for water purification and provision, soil protection and biodiversity conservation. Type 2 areas are key environments for water purification and provision and agricultural production. Type 3 areas are key environments for agricultural production.

no market value such as the maintenance of the atmosphere composition, genetic library, amelioration of regional climate, and soil protection from devastating erosion. Heidenreich (2009) assessed the current state of knowledge about the total value of goods and services provided by native temperate grasslands and reached similar conclusions. Our results showed that forest ecosystems in hills are also very important in carbon capture and water regulation services. This is consistent with data by Laclau et al. (2008) for forests in Patagonia and by Lara et al. (2009) for native forests in Chile. However, the area in the present work is not a natural forest region and there is evidence that forest plantations with exotic species (Eucalyptus and pine) can negatively affect the provision of some ES (Jackson et al., 2005; Jobbágy et al., 2006). For this reason, afforestation in pampas hills requires further studies before being recommended as a policy for ES improvement.

SEA based on ES analysis must technically support a LUP designed to retain critical support and regulation ES without significantly sacrificing direct food production. To achieve this, in our study we considered both the general capacity of each ecosystem to provide different ES and the importance of key areas such as riparian grasslands and piedmonts for regulation ES. Even if we had used expert criteria to define these key areas, results would align with findings by Laterra et al. (2009), showing the importance of spatial location in the ability of grasslands to provide several ES.

SEA based on ES approach is strongly dependent on the techniques used to assess ES, to set ES priorities and to classify ecosystem types. The equations used in this study as indicators of ES provision, the ecosystems defined by the combination between biogeographic areas and cover types, and the key areas based on expert criteria, were useful for the scope of this analysis, allowing us to differentiate skills and restrictions of different environmental units in the study area. However, spatially explicit methods, such as INVEST (Tallis et al., 2010) and ECOSER (Laterra et al., 2011), may be necessary for detailed studies, such as watershed planning or infrastructure projects.

On the other hand, social valuation of ES is a critical step when priority areas are defined (Bryan et al., 2010). In this study, the social group consulted was small and biased to professionals and employees related to agricultural sciences. Nevertheless, the results were consistent with other studies that used a wider consultation base (Dagnino et al., 2011; Loomis et al., 2000), indicating that people in general tend to prioritize long-term sustainability and environmental quality. Furthermore, although this study emphasized only the ecological axis, economic and social dimensions could be integrated in further studies, so as to provide an integral tool for the decision-making process in rural LUP.

To ensure sustainability, SEA should be established and applied by local authorities on a regular basis (Habib, 2005). To use this information for rural land planning, a strategic plan leading to the desired goals must be developed and applied. Appropriate uses (including appropriate technologies) for each ecosystem type should be identified, and measures to reduce pressures generated by inappropriate uses should be implemented. Key ecosystems for critical functions should be specially addressed.

Linking spatial planning with SEA should be considered as a crucial condition for sound development, and an important opportunity to move 'sustainability' up the ladder of decision making (Eggenberger and Partidário, 2000). The SEA protocol developed in this work allowed for the organization and interpretation of available and generated information, the analyses of current land use patterns and the proposal of land planning criteria and priorities. This confirms that SEA can be an appropriate conceptual and methodological support to incorporate the environmental dimension in land use planning, as it has been reported in other studies using this approach (Kessler, 2000; Leng Ng and Obbard, 2005; Tao et al., 2007; Zhu and Ru, 2008). SEA was not only useful to assess the impact of current land use models in the territory, but also to analyze rural land use alternatives according to different social priorities in developmental goals. This flexibility in analysis is crucial in land planning considered as a social process (Chaker et al., 2006).

However, the distinctive trait of this SEA study was the incorporation of the ES approach to assess the environmental impact of land use patterns. While there are many applications of SEA in land use plans, especially in European countries (Comisión Europea, 2001), environmental aspects in those plans were normally incorporated in the planning procedure by means of traditional environmental impact assessment techniques such as impact matrices, checklists, economic methods and cost–benefit analyses (Partidario, 2003). To our knowledge, this is the first work using ES evaluation in SEA studies.

5. Conclusions

Land use in the Southeast Pampas of Argentina, as in many agricultural regions of the world, is biased to maximize direct economic benefits, without considering the total human benefits provided by ecosystems, conceptually described under the ES approach.

The ES approach coupled with SEA showed to be a powerful tool to assess the ecological contribution of lands to human welfare on a wider basis and to prevent negative environmental costs of land use plans which can remain unnoticed under traditional environmental impact assessment techniques.

The SEA protocol developed in this work allowed combining mathematical estimations, expert criteria and social priorities, and determining a zoning of the area studied as a guide for rural planning, regarding the relative value of lands to provide different ecosystem services.

The incorporation of SEA protocols can be an important contribution regarding the current municipal legislation in Argentina and many other countries, where environmental impact assessment to minimize the adverse environmental effects of human actions are considered only at the project scale.

Acknowledgements

We thank Ernesto Viglizzo for his assistance in the ecosystem services assessment and Karina Zelaya for her GIS advice. This research was funded by Instituto Nacional de Tecnología Agropecuaria (INTA, Programa Nacional Ecorregiones and Área Estratégica Gestión Ambiental).

Appendix A. Survey on the relative valuation of ecosystem services

In your opinion, in which order would you prioritize the protection and conservation of these ecosystem services?

- Soil protection service: consider erosion control, avoided reservoir sedimentation and land slides.
- Carbon capture service: services link to primary productivity and carbon sequestration.
- Water provision and purification service: consider biomass, soil infiltration capacity and slope.
- Biodiversity conservation service: services link to habitat provision and biodiversity refuge. Consider biomass, water input to the system and naturalness and structural complexity of the ecosystem.
- Disturbance control service: services link to flood mitigation and water regulation. Consider water input to the system and flat floodplain areas.
- Waste purification: services link to metabolic waste such as neutralization of pollutants in biomass, elimination and removal of toxic elements. Consider biomass, water input to the system and flat floodplain areas.
- Direct goods provision: service link to grains, meats and wood.

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