

QUANTIFYING THE LAND COVER CHANGES AND FRAGMENTATION PATTERNS IN THE ARGENTINA PAMPAS, IN THE LAST 37 YEARS (1974-2011)

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ABSTRACT

In the current work, a combination of land-cover dynamics maps and landscape pattern metrics based on remote-sensing images was employed to quantify the spatial and temporal land cover changes and fragmentation patterns in the centre of the Province of Buenos Aires, Argentina, in the period 1974-2011. This study area covers two agro-ecological zones: the Flooding Pampa and the Inland Pampa. In contrast with other regions of the Rio de La Plata Grasslands, native grasslands have been substituted by the expansion of short-grass matrix (grassland more adapted to grazing cattle): over the whole study period, the native grasslands decreased by 2,762.11 km² in a study area of 21,911.39 km². The fragmentation pattern in the landscape presented spatial differences between analysed agro-ecological zones, with better conservation status of native grasslands in the Flooding Pampa. The identification of this spatial pattern should promote policies of biodiversity conservation and sustainable management of this landscape.

Keywords: Grassland; Land-cover change; Landscape pattern; Argentina; Flooding Pampa; Inland Pampa; Landsat.

CUANTIFICANDO LOS CAMBIOS DE COBERTURA Y PATRONES DE FRAGMENTACIÓN
EN LA PAMPA ARGENTINA, EN LOS ÚLTIMOS 37 AÑOS (1974-2011)

RESUMEN

En el presente trabajo, se empleó una combinación de mapas dinámicos de coberturas y métricas de paisajes basados en imágenes satelitales para cuantificar los cambios espacio-temporales de coberturas y los patrones de fragmentación en el centro de la provincia de Buenos Aires, Argentina, en el período de 1974 a 2011. Esta área de estudio cubre dos zonas agro-ecológicas: la Pampa Deprimida y la Pampa Interior. A diferencia de otras regiones de Los Pastizales del Río de La Plata, el pastizal nativo ha sido reemplazado por una matriz de pastos

cortos (más adaptada al pastoreo vacuno): durante todo el período de estudio, el pastizal nativo decreció 2.762,11 km² en un área de estudio de 21.911,39 km². El patrón de fragmentación en el paisaje presentó diferencias espaciales significativas entre las zonas agro-ecológicas analizadas, con un mejor estado de conservación de los pastizales en la Pampa Deprimida. La identificación de este patrón espacial debería promover políticas de conservación de la biodiversidad y manejo sustentables de este paisaje.

Palabras clave: Pastizal; cambio de cobertura; patrón del paisaje; Argentina; Pampa Deprimida; Pampa Interior; Landsat.

1. Introduction

Grasslands are one of the most extensive biomes on the planet (Sala and Paruelo, 1997). In general, these systems are limited by water availability at certain times during the year and possess an herbaceous layer dominated by species from the Poaceae family. Typical grassland of the centre of the Province of Buenos Aires in Argentina is the pajonal (grassland dominated by the tall-tussock grass, *Paspalum quadrifarium*) whose distribution is characterized as being in a wide range of topographies (Lara and Gandini 2013), in which different vegetation units form (Perelman *et al.*, 2003, 2005). During the past five centuries this grassland has been used as a resource for domestic cattle.

Because of the low cattle receptivity from the mature pajonal community, current management is based on periodical burning, which induces short-term enhancement in net productivity, quality and accessibility of resprouting forage (Latterra *et al.* 2003). The interaction of fire with cattle grazing causes deep changes that can be perceived at different scales of analysis (Herrera *et al.*, 2009, Lara and Gandini, 2011).

This management induces the loss and fragmentation of pajonal, a process that involves changes in the composition, configuration and function of the landscape (McGarigal *et al.*, 2005). Furthermore, the fragmentation changes the floristic composition of the community promoting the introduction of exotic species, many of them non-palatable (Latterra and Maceira, 1996; Paruelo *et al.*, 2004; Lara and Gandini, 2011), and affects numerous ecosystem services such as carbon sequestration, genetic resources, soil conservation, hydrological regulation and maintenance of habitat for various species of birds and mammals (Ameghino, 1884; Costanza *et al.*, 1997; Sala and Paruelo, 1997; Bilencia and Miñarro, 2004; Nabinger *et al.*, 2013).

Similar studies have been carried out on other regions of the Rio de La Plata Grasslands (Soriano *et al.*, 1991; Demaría *et al.*, 2008), where the native grasslands were substituted by annual crops. However, in the centre of the Province of Buenos Aires (Argentina), core of production activities in the region, has not been evaluated the pajonal replacement at landscape scale.

The world's socio-economic and political context of the past 40 years, mainly in terms of the relative grain prices on livestock products, led Argentina Pampas to a profound change in the agrarian structure, causing a reduction in the area under this activity (Barsky, 1993; Tsakoumagkos, 2003). According Bilello (2005) the process of productive transformation of the Argentine Pampas,

known as "agriculturization" began in the 70s with the modernization of corn culture, and followed in the 80-90 by the addition of soybean in soils at mixed areas historically occupied by livestock. This process causes a concentration of livestock activity in soils of low agricultural potential, causing an intensification of use, which leads to the replacement or modification of natural grasslands. This change in types of coverage and area under different uses can be monitored using remote sensing techniques (Oetter *et al.*, 2000; Shi *et al.*, 2012; Tovar *et al.*, 2012).

Information on the growth in productive practices involving the replacement of native grasslands (Cañibano *et al.*, 2004, Vazquez *et al.*, 2012) is required in order to determine the magnitude and rate at which the landscape has changed over recent decades. This knowledge is key for estimating the spatiotemporal scale at which processes operate and becomes essential for the implementation of conservation strategies and sustainable management of grasslands in the region.

Remote sensing is a powerful tool for assessing the spatial and temporal dynamics of land use and land cover across a landscape (Adams and Gillespie, 2006, Horning *et al.*, 2010, Shi *et al.*, 2012). Besides, landscape metrics are important for providing an overall measure of the ecological processes and effects of land use and land cover on landscape fragmentation (Wu and Hobbs, 2002, Southworth *et al.*, 2004, Cushman *et al.*, 2008, Herrera *et al.*, 2009, Shi *et al.*, 2012).

The aims of the present work were to identify land cover changes over 37 years (1974 – 2011) and to evaluate the fragmentation status of pajonal in the centre of the Province of Buenos Aires, Argentina.

2. Materials and methods

2.1. Study area characteristics

This work was carried out in the central region of the original distribution of pajonal (called the core area) in the Province of Buenos Aires, Argentina (Vervoorst, 1967), which covers two agro-ecological zones: the Flooding Pampa and the Inland Pampa (Gandini *et al.*, 2012) (figure 1). The study area is a notably flat plain of 21 911.39 km², with gradients between 0.025% and 0.5% (IHLLA, 2003). Aeolian silt deposits (loess) of the Pleistocene and Holocene cover this region, with halomorphic and hydromorphic soils that are affected by floods. Natural or semi-natural grasslands dedicated to cattle grazing cover most of the region (Tricart, 1973).

The climate is humid and temperate, with a mean annual precipitation of 970 mm (IHLLA, 2003). The mean annual temperature is 13.9°C; the coldest month is July with a mean minimum temperature of 6.3°C and the hottest is January with a mean maximum of 21.2°C (Köppen, 1918).

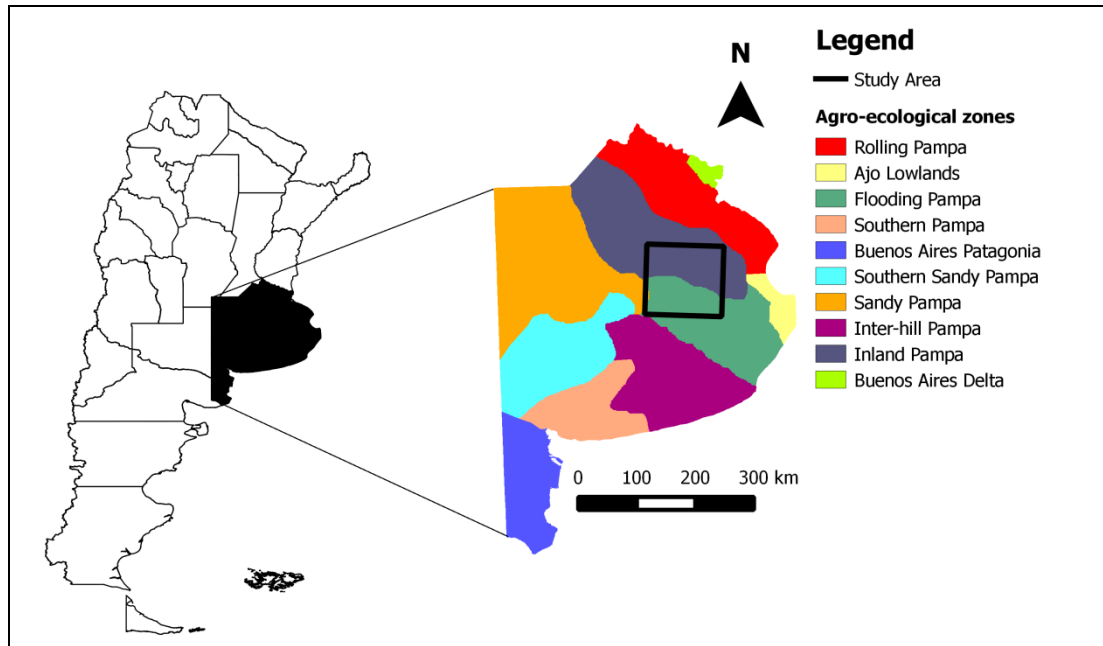


Figure 1. Study area in the centre of the Province of Buenos Aires, Argentina.

2.2. Data acquisition, pre-processing and land cover classification

A time series of four Landsat images (path 225, row 85) for the years 1974 (MSS sensor), 1988 (TM sensor), 2000 (ETM⁺ sensor) and 2011 (TM sensor) was used. We focused on a temporal optimal scale of 11-14 years because changes in the pajonal occur relatively slowly (Herrera *et al.*, 2005).

The digital numbers (DN) were converted to reflectance (except the thermal band) according Chander *et al.* (2009), and the reflectance values were then adjusted for atmospheric scatter using the Improved Dark Object Subtraction method described by Chavez (1996).

In accordance with previous reports (Herrera *et al.*, 2005, 2009, Lara and Gandini, 2013), the land cover types used were: pajonal (PJ), short-grass matrix (SGM), pastures (P), crops (C) and water bodies (WB) (table 1). To identify the land cover types, supervised classifications were employed using the maximum likelihood algorithm. The classifications were performed using all reflective Landsat bands; for 1974: MSS4, MSS5, MSS6 and MSS7; for 1988 and 2011: TM1, TM2, TM3, TM4, TM5 and TM7; for 2000: ETM⁺1, ETM⁺2, ETM⁺3, ETM⁺4, ETM⁺5 and ETM⁺7. The thermal band of TM and ETM⁺ sensors was discarded.

For 1988, the training sites were located by visual interpretation on 44 aerial infra-red photographs (scale 1: 20,000), following criteria such as texture, shape and colour (Chuvieco, 2010). For 2011, the control points were selected using a global positioning system (GPS) in the field within relatively homogeneous areas. For 1974 and 2000, the training sites were selected by visual analysis following the medium spectral signature for each land cover type (figure 2) and

using areas with similar spectral characteristics –land cover remained unchanged- (Chuvienco, 2010; Schulz *et al.*, 2010).

Classification results were filtered using a 7 x 7 median filter to remove isolated pixels (the “salt and pepper” effect). Later, the MSS classification (1974) was re-sampled to a 30 x 30 m pixel size to allow multi-temporal comparison with the rest of the series.

The accuracy of the classification maps was assessed with the use of quantity disagreement and allocation disagreement (Pontius and Millones, 2011). These indexes are more useful and simpler than standard Kappa –given by Congalton (1991) and allow us to focus on two components of disagreement between maps and reference points in terms of the quantity and spatial allocation of the land cover types.

Pontius and Millones (2011) define quantity disagreement “as the amount of difference between the reference map and a comparison map that is due to the less than perfect match in the proportions of the categories”, and allocation disagreement “as the amount of difference between the reference map and a comparison map that is due to the less than optimal match in the spatial allocation of the categories, given the proportions of the categories in the reference and comparison maps”.

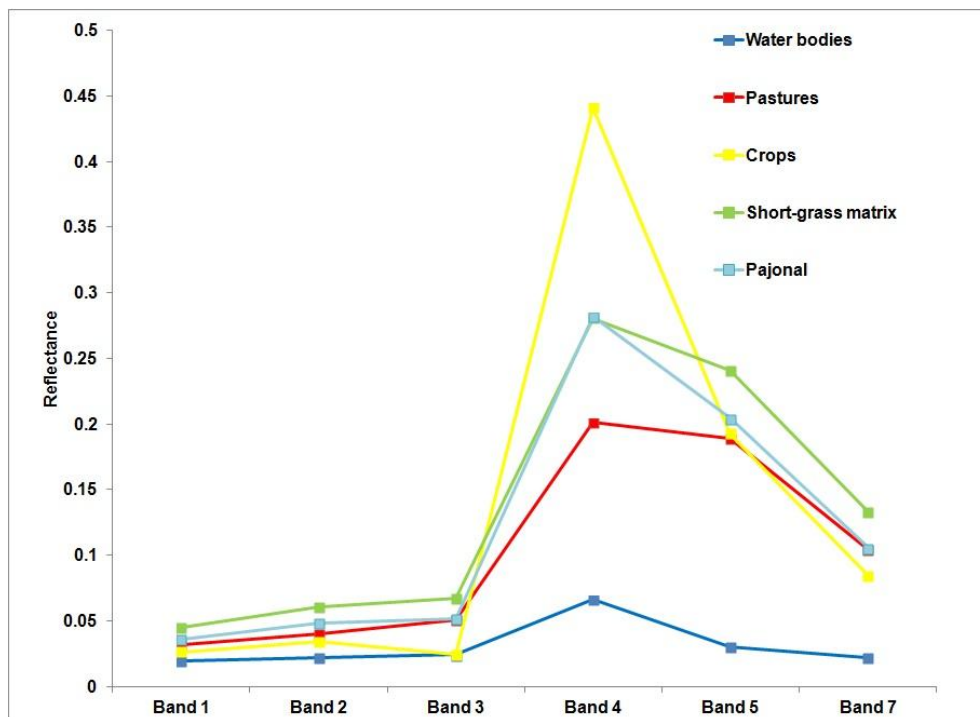


Figure 2. Spectral signatures of land cover types used in this work.

Table 1. Description of land cover classes used in this work, adapted from Herrera *et al.*, 2005

Land cover classes	Description
Pastures (P)	Pastures are generally part of the crop-rotation system. Where soil conditions are not appropriate for cropping, it is frequent that native grasslands are intersown with <i>Festuca sp.</i> , <i>Agropyron sp.</i> , <i>Lotus sp.</i> , <i>Trifolium sp.</i>
Crops (C)	Annual crops such as wheat, oats, corn, soybean and sunflower.
Water bodies (WB)	Permanent o semi-permanent lagoons, as well as, flooded lands.
Short-grass matrix (SGM)	Grassland used for grazing, or successional stages from old crops or old pastures. Common species found are: <i>Stipa sp.</i> , <i>Melica sp.</i> , <i>Mentha sp.</i> , <i>Oxalis sp.</i> , <i>Phyla sp.</i> , <i>Cirsium sp.</i> , <i>Cypella sp.</i>
Pajonal (PJ)	Grassland partially or completely dominated by <i>Paspalum quadrifarium</i> , describing a mosaic over short-grass matrix.

2.3. Analyses of land cover change

The determination of land cover changes were elaborated with Land Change Modeller (LCM) from Idrisi (Eastman, 2009). LCM is a vertical application that examines and estimates changes (and transitions) through the cross-tabulation matrix (Pontius *et al.*, 2004).

Finally, mapping of the spatial distribution of transitions, persistence, gains and losses were obtained with LCM. Binary change/no change maps were performed for each period to create a map of persistence and changes for the study area. The three resulting maps were added to obtain a map of persistence and intensity of changes for the whole period. Persistent pixels represent those never changed land cover type, and the intensity of changes is given by pixels that shown 1, 2 or 3 changes across for the studied periods (1974 -1988, 1988 – 2000 and 2000 – 2011). Thus, a value 3 is associated with a greater degree of intensity and a value 1 with the lowest degree of intensity.

2.4. Landscape fragmentation analysis

Landscape patterns were quantified for the two agro-ecological zones of the study area (Flooding Pampa and Inland Pampa). Inside each sector, 10 subsets (analysis windows) of 12 x 12 km (14 400 ha, each one considered like a landscape) were delimited and each one was analyzed with FragStats 4.1 (McGarigal and Ene, 2012).

Landscape metrics have been criticized by many researchers (Wu y Hobbs, 2002; Li and Wu, 2004; Frohn and Hao, 2006). However, there is no objective way to discard some metrics or a "prescription" to group the most important of them (Mateucci and , 2005). In this sense, we used metrics that represent greater variability in the landscape and allow us to know easily and quickly the structural configuration of our study area (Lara, 2014). Besides, most of them have shown useful to quantify the principal aspects of structural configuration from different landscapes

(McGarigal and Marks, 1995, Heilman *et al.*, 2002, Mateucci and Silva, 2005, McGarigal *et al.*, 2005, Cushman *et al.*, 2008).

Hence, in this study, eight metrics were analyzed, of which all were obtained only for the pajonal class. Metrics were: 1) percentage of landscape (PLAND); 2) patch density (PD); 3) largest patch index (LPI); 4) edge density (ED); 5) landscape shape index (LSI); 6) total class area (CA – medium value-); 7) Euclidean nearest-neighbour distance (ENN –medium value-); and 8) interspersions and juxtaposition index (IJI). A brief description of these is shown in table 2.

Table 2. Description of the landscape metrics used following McGarigal and Marks (1995)

Abbreviation	Description
PLAND	Percentage of the landscape comprised of the corresponding class type.
PD	Number of total patches divided by total landscape area. This metric is expressed in number per 100 ha.
LPI	Largest patch index: largest patch divided by total landscape area (%).
ED	Edge density: sum of the lengths (m) of all edge segments divided by the total landscape area (m), multiplied by 10 000 (to convert to ha). Units: m.ha ⁻¹
LSI	Landscape shape index: equals 0.25 (adjustment for raster format) multiplied by the sum of the total edge in landscape between patch types (m), divided by the square root of the total landscape area (m ²).
CA	Sum of the areas (m ²) of all patches of the corresponding patch type, divided by 10 000 (to convert to ha).
ENN	Euclidean nearest-neighbour distance: distance (m) to the nearest neighbouring patch of the same type, based on shortest edge-to-edge distance. Units: m
IJI	Interspersions and juxtaposition index: this index is based on patch adjacencies. This index quantifies as one patch type is scattered in space. Units: %

At the landscape scale, patterns of landscape fragmentation of the pajonal class were evaluated between agro-ecological zones with the use of Student's t test mean comparisons. This method was done for both the initial map (1974) and the final map (2011).

3. Results and discussion

3.1. Accuracy assessment

Good thematic accuracies were obtained. Figure 3 shows the two components of disagreement for four classifications performed. The two components of disagreement are stacked to show how they sum to the total disagreement. So, the figure gives information about percent correct, since percent correct is 100 minus the total percent disagreement.

In this study is particularly more important the quantity disagreement than allocation disagreement because of one of the main aims of this work is to quantify the land cover changes among the three periods. Thereby, allocation disagreement is much less important than quantity

disagreement (Pontius and Millones, 2011). Besides, the separation of overall disagreement into two components can be used to learn about sources of error and give guidance on how to improve each one classification, which the Kappa index not allow.

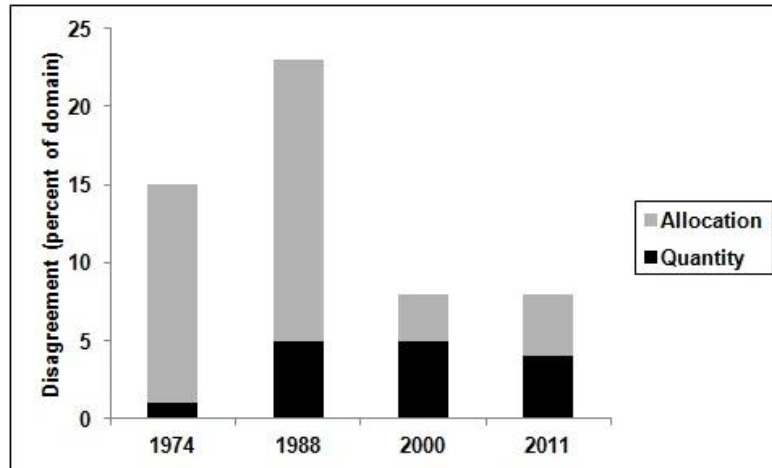


Figure 3. Quantity disagreement and allocation disagreement for each one of classifications performed.

On the other hand, the pajonal class was very well discriminated from other land cover types; the producer and user accuracies are shown in table 3.

In general, the main confusion is between pajonal and short-grass matrix classes, because of their similar spectral behaviour, regardless of the growing season (Lara and Gandini, 2013). The spatial distribution of grasslands is complex and rarely homogeneous (Vervoort, 1967). Furthermore, the study area is an environment where pure pixels are rare, which contributes to the spectral heterogeneity of the landscape. These are inherent problems in grassland classification, especially in medium-resolution images such as those used in this work. However, the classification employed allowed us to obtain very good user and producer accuracies for the pajonal class, similar to that found by other researchers (Oetter *et al.*, 2000, Price *et al.*, 2002, Herrera *et al.*, 2005, Demaría *et al.*, 2008, Argañaraz and Entraigas, 2011, Shi *et al.*, 2012, Tovar *et al.*, 2012).

Table 3. Producer and user accuracies (%) for pajonal class

Map 1974		Map 1988		Map 2000		Map 2011	
Producer	User	Producer	User	Producer	User	Producer	User
acc.	acc.	acc.	acc.	acc.	acc.	acc.	acc.
74.3	78.5	78.4	73.3	98.5	63.9	69.0	92.8

3.2. Land cover change and spatial distribution of changes

Over the whole study period (1974 – 2011), the pajonal class decreased by 2,762.11 km². This cover type occupied 43.2% and 30.6% of the study area in 1974 and 2011, respectively. This

loss was not constant: for the 1974-1988 period, 801.9 km² were converted into other cover types; for 1988-2000, this value increased to 1,589.6 km², whereas, for 2000-2011, it decreased to 370.7 km².

For the whole period (1974 – 2011), a large increase of 5,179.9 km² (23.6% of the study area) in the short-grass matrix was observed. An increase in the surface intended for annual crops was also obtained (403.9 km²; 1.8% of the study area), whereas a considerable decrease of pastures was observed (2,509.5 km²; 11.5% of the study area) (figure 4).

On the other hand, the pajonal class was mainly substituted with short-grass matrix (3,214.5 km²) and to a lesser extent with crops (213.4 km²). Also, a transition pasture-to-pajonal was observed (576.7 km²) (figure 5). In contrast with other regions of the Rio de La Plata grasslands, where native grasslands were substituted by croplands (Soriano *et al.*, 1991, Demaría *et al.*, 2008), pajonal replacement in this work was better explained by the expansion of short-grass matrix (grassland more adapted to cattle grazing; figure 6). This is because, in this region, the soils have a low agricultural capacity, with severe limitations, such as periodic floods, high salinity and a calcareous layer.

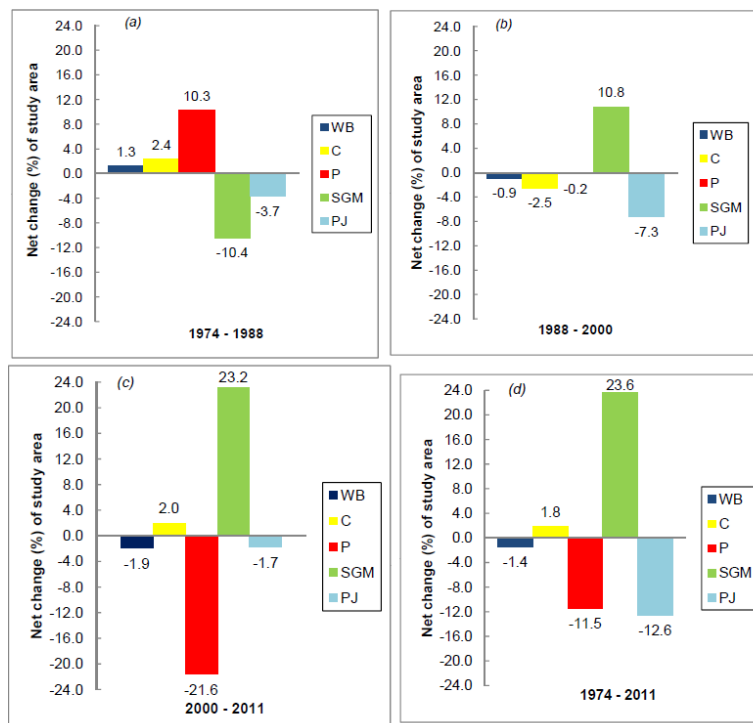


Figure 4. Net change (gains minus losses) for each land cover class as a percentage of the study area. Period 1974-1988 (a), period 1988-2000 (b), period 2000-2011 (c), and the whole period, 1974-2011 (d). Land cover classes: Water bodies (WB), Crops (C), Pastures (P), Short-grass matrix (SGM), Pajonal (PJ). Note: The extent of the study area was 21,911.39 km².

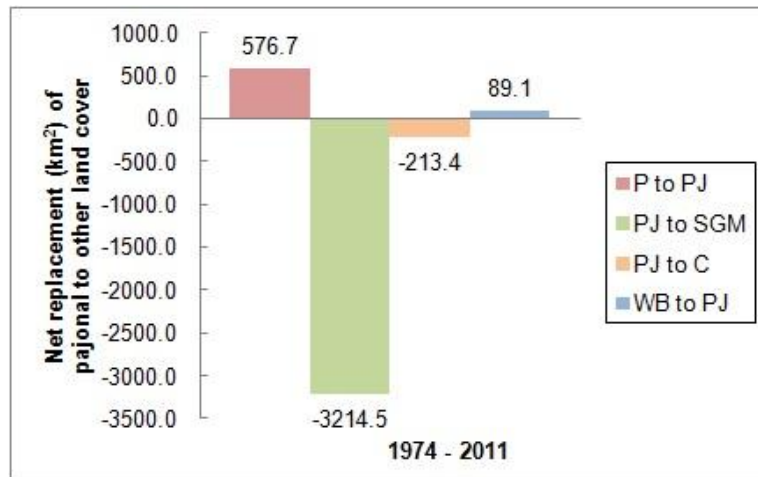


Figure 5. Net replacement of pajonal to other land cover for the whole period (1974-2011). Positive values indicate a net gain and negative values indicate a net loss. Water bodies (WB), Crops (C), Pastures (P), Short-grass matrix (SGM), Pajonal (PJ).

The spatial distribution of the intensity and patterns of land cover changes and persistence is shown in figure 6b and 6c; 23.4% of the study area was subject to only one change, 45.2% was subject to two changes, 27.3% changed in all three time periods and only 4.3% of the pixels remained unchanged (table 4). Most of the unchanged pixels were pajonal (55.1%) and pastures (26.4%), followed by short-grass matrix (18.5%), water bodies (0.02%) and crops (0.005%).

The intensity of land cover changes did not show a definite pattern, but was randomly distributed in the study area. This non-spatial pattern could be associated with management strategies based upon several fire and crop/pasture cycles that allowed the establishment of alternative stationary grassland states (Laterra *et al.*, 1998, Laterra *et al.*, 2003). This result is different to that produced by the intensification of agriculture, which proceeds on the best soils and shows a characteristic spatial pattern (Schulz *et al.*, 2010).

The spatial distribution of land cover changes observed in this study is related to physical and socio-economic factors. The global context has stimulated the advancement of agriculture on areas historically occupied by livestock, concentrating grazing on soils of very low agricultural suitability (Barsky, 1993; Tsakoumagkos, 2003; Bilello, 2005). This process has led to an unprecedented intensification, which lead to loss and fragmentation of natural grasslands.

At the present, it is carrying out the project "Grasslands and Savannas of the Southern Cone of South America: Initiatives for their conservation in Argentina" co-executed by Aves Argentinas-AOP (AA) and Fundacion Vida Silvestre Argentina (FVSA) with funding from the Global Environmental Fund (GEF) through the International Bank for Reconstruction and Development (World Bank). The objective of this project is to promote sustainable rangeland cattle production by promoting the integration of nature conservation and agricultural production (<http://www.alianzadelpastizal.org/en/>). Thus, it could achieve a management that links production and conservation of natural grasslands.

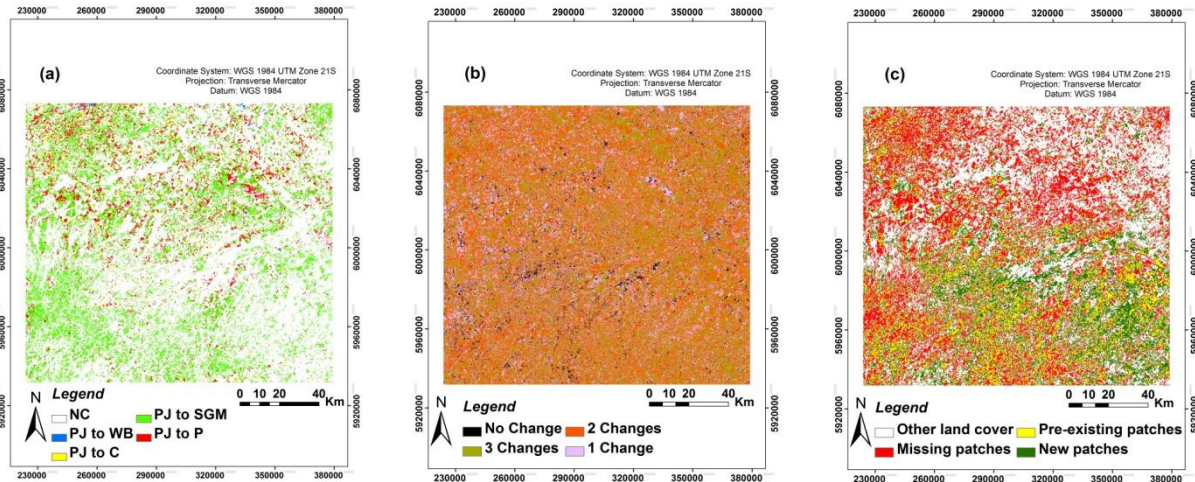


Figure 6. (a) Spatial distribution of transition of pajonal to other land cover for the period 1974-2011. Water bodies (WB), Crops (C), Pastures (P), Short-grass matrix (SGM), Pajonal (PJ), No Change or other land cover (NC). (b) Spatial distribution of intensity and patterns of land cover changes and persistence across the three periods analyzed from 1974 to 2011. (c) Colonization and missing patterns of pajonal patches, including pre-existing patches.

3.3. Re-colonization of pajonal

A large number of new patches of pajonal were found where there were other land cover types (figure 6c). These patches were associated with large pre-existent patches of pajonal. This fact supports the idea that the conservation of large pajonal remnants is essential for landscape restoration, since *Paspalum quadrifarium* possesses poor seed dispersion capacity (Lattera *et al.*, 1998). Moreover, this process, provided it is accompanied by an integral management regime, would help to ensure stability of different ecosystem services at the landscape scale (Costanza *et al.*, 1997, Bilencia and Miñarro, 2004).

This re-colonization of pajonal has been observed in a state and transition model based on short-term observations. Following Lattera *et al.* (1998), *Paspalum quadrifarium* can successfully establish of seeds on sites disturbed by fire and with low cattle stock.

Landscape planning and ecosystem conservation in this area is currently of major importance in Argentina, due to the growing pressure on natural resources of agricultural intensification and cattle production.

3.4. Landscape fragmentation analysis

No significant differences in the spatial patterns of pajonal fragmentation between both agro-ecological zones for the 1974 map were found (table 4). However, the pajonal in the Flooding Pampa presented higher values than the Inland Pampa as percentage of landscape (PLAND) and largest patch index (LPI), which are metrics of considerable conservation value (McGarigal *et al.*, 2005).

There were significant differences in some spatial patterns of pajonal fragmentation between agro-ecological zones for the 2011 map (table 4). Percentage of landscape occupied by pajonal (PLAND) was higher in the Flooding Pampa than in the Inland Pampa (medium values of 42.0% and 17.1%, respectively). The largest patch index (LPI) differed between agro-ecological zones, being higher in the Flooding Pampa. Also, the Euclidean nearest-neighbour distance (ENN) between pajonal patches was higher in the Inland Pampa than in the Flooding Pampa. However, no significant differences were found between agro-ecological zones for medium value of total class area (CA) and landscape shape index (LSI). Interspersion and juxtaposition index (IJI) presented significant differences between zones, but both values were low (table 4), indicating that pajonal class is interspersed with a few land cover types (possibly short-grass matrix and pastures).

The temporal variation of the principal metrics presented the same tendency (results not shown), indicating a sustained loss of large pajonal patches. However, the fragmentation pattern was significantly different between agro-ecological zones, being higher in the Inland Pampa. This zone showed a decrease in the percentage of landscape occupied by pajonal and the largest patch index for this class, accompanied by an increase in isolation between pajonal patches. These results are comparable to descriptions made by several researchers (Forman and Godron, 1986, Forman, 1995, McGarigal and Marks, 1995, Li and Wu, 2004, McGarigal *et al.*, 2005), who indicated similar patterns in fragmented landscapes.

In the Flooding Pampa, the pajonal presents a lower degree of fragmentation, indicating a better status for conservation, possibly due to a lower intensification of productive practices, presumably because adverse soil conditions.

In the study area, it prevail private establishments and the constant replacement of pajonal is the main issue for the conservation of this native grassland, because this community is not represented within protected areas, neither publics nor privates (Bilenca and Miñarro, 2004; Lara and Gandini, 2013). The patches of pajonal found in this work represent structural similarity to the original tall grasslands that defined the Argentina Pampas landscape in the past and play an important role in maintenance of biodiversity, ecosystem services and structuring species diversity patterns (Costanza *et al.*, 1997; Laterra *et al.*, 2003; Perelman *et al.*, 2003; Bilenca and Miñarro, 2004).

Despite the efforts to regulate cattle stock and to improve the availability of forage (Vecchio *et al.*, 2008, Rodríguez and Jacobo, 2012), the implementation of integrated management plans still remains one of the major challenges for the conservation of natural grassland at landscape scale.

Table 4. Spatial patterns of pajonal fragmentation between agro-ecological zones for maps 1974 and 2011. p-value < 0.05 show significant differences

Landscape metrics	Map 1974			Map 2011		
	Flooding Pampa (medium value)	Inland Pampa (medium value)	p-value	Flooding Pampa (medium value)	Inland Pampa (medium value)	p-value
PLAND	57.5%	50.0%	0.20	42.0%	17.1%	0.00005
PD	0.5	0.6	0.64	0.9	1.2	0.07
	patches.100 ha ⁻¹	patches.100 ha ⁻¹		patches.100 ha ⁻¹	patches.100 ha ⁻¹	
LPI	48.3%	35.4%	0.16	22.8%	3.7%	0.009
ED	32.7 m.ha ⁻¹	31.2 m.ha ⁻¹	0.30	31.2 m.ha ⁻¹	20.6 m.ha ⁻¹	0.0003
LSI	13.8	14.1	0.74	15.5	15.5	0.98
CA	169.9 ha	191.2 ha	0.86	68.0 ha	14.1 ha	0.06
ENN	149.5 m	149.3 m	0.99	153.9 m	215.3 m	0.0009
IJI	39.6%	32.8%	0.18	26.7%	39.4%	0.009

The availability of time series of medium-resolution images is an important source of information for solving the problem of the acquisition of reliable ground data for distant past dates. In our case, this was resolved by the interpretation of aerial photographs and historical field data. Furthermore, the consistency between the different Landsat missions assured the identification of environments with independence of sensor or platform.

4. Conclusions

Based on land cover maps derived from remotely sensed data, the spatial distribution of the landscape pattern and its changes in the centre of the Province of Buenos Aires, Argentina, have been quantified and evaluated with the help of land-use dynamics (Land Change Modeller) and landscape pattern metrics. In contrast with other regions of the country, where native grasslands have been substituted by croplands, pajonal replacement (a native community of the region) is better explained by the expansion of grassland more adapted to cattle grazing, i.e., short-grass matrix. Over the whole study period, the native grassland decreased by 2,762.11 km² in a study area of 21,911.39 km² and the short-grass matrix increased by 5,179.9 km². Instead, the surface of annual crops only increased 403.9 km².

Although, in the Inland Pampa the pajonal presents a high degree of fragmentation, in the Flooding Pampa it still remains in a relatively good state for conservation. The pajonal, in the Inland Pampa, showed a high decreased in the percentage of landscape (from 50.0% to 17.1%) and largest patch index (from 35.4% to 3.7%). Instead, in the Flooding Pampa, the pajonal showed a very low decreased in the percentage of landscape (from 57.5% to 42.0%) and largest patch index (from 48.3% to 22.8%). These results suggest that fragmentation process was more severe on the Inland Pampa, indicating a better status for conservation in the Flooding Pampa. Besides, metrics

above mentioned are some of the most important for maintenance of ecosystem services and biodiversity (animal and vegetal).

Furthermore, the conservation of large patches of pajonal was shown to be very important for re-colonization due to its limited seed dispersion capacity. The identification of this spatial pattern of pajonal fragmentation and re-colonization should help to promote policies of biodiversity conservation and sustainable management of this landscape.

The main contributions of this work are to quantify, to locate and to map the land cover changes in the Argentina Pampas (productive core of the country), across the last 37 years. Besides, the analysis of fragmentation patterns allowed us to characterize the intensity of use of natural grassland by cattle grazing and their associated practices. Thus, the best preserved patches should be taken into account for the implementation of protected areas of native grasslands.

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