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Indicators of landscape organization and functionality in semi-arid former agricultural lands under a passive restoration management over two periods of abandonment

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ABSTRACT

Abandoned lands previously used for agricultural purposes may constitute an opportunity for understanding the variables involved in the restoration of native ecosystems over time. In this study, we assessed the functional status of an abandoned farmland currently used for conservation, using a methodology based on indicators of landscape organization and soil surface. We analyzed changes in plant cover, patch and interpatches structure and several soil surface properties during two periods of land abandonment (less and more than 40 years). Using this methodology, we characterize the potential of the ecosystem to capture and transfer resources, and the state of functional properties such as infiltration capacity, soil stability and nutrient cycling.

We detected a significant development of the shrub layer and an increase of the number, type and area occupied by vegetated patches in old fields. The contribution of vegetated patches to the recovery of stability, infiltration and nutrient functions was significant at the local scale. Nonetheless, when analyzing the landscape as a whole only the nutrient cycling index was significantly higher in old fields. The lack of improvement of the stability and infiltration in old fields can lead to further degradation and indicates that even though vegetation cover may have improved over time in old fields, the current cover might not be enough to prevent further degradation by erosion. Our results reinforce the importance of using functionality indexes in future studies focused on adequate restoration measures to protect the function of desert ecosystems, especially when aimed for biodiversity conservation. Hence, the use of monitoring systems based on organization and function indicators is a useful tool to represent the current state and potential recovery of previously disturbed ecosystems, provided that the time scale is taken into account.

1. Introduction

Land degradation by agricultural activities in arid and semi-arid ecosystems is a global concern resulting of complex socio-ecological factors (Easdale and Domptail, 2014). Economic aspects, technological changes, biological modifications in crop varieties, and local depopulation have led to a growing counterpart, namely abandonment of agricultural land worldwide (McLauchlan, 2006; Benayas et al., 2007). Abandoned lands may have previously been used for a variety of purposes, for example cropping systems closely linked to livestock husbandry systems (McLauchlan, 2006). The legacy of cultivation results in biomass alteration, tillage, fertilization and altered hydrology. This disrupts the ecosystem processes as expressed through vegetation composition and structure for several years after the abandonment (Cramer et al., 2008).

Abandoned lands provide an opportunity to analyze the development of self-sustaining systems (Benayas et al., 2007), and are paramount for conservation and management of biodiversity and natural ecosystem processes (Yannelli et al., 2014). Recently it has been reported that farmland abandonment may constitute a unique opportunity to restore native forest systems and forest ecosystem services in Europe (Proença et al., 2012). These types of interventions have pointed to the importance of considering the autogenic processes, i.e. when ecological systems are likely to recover unaided through ecological succession compared to active restoration strategies (Hobbs and Cramer, 2008; Prach and Walker,

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2011). This form of management, based on passive restoration, is referred to as the 'rewilding of abandoned landscapes' and has been advocated as the most appropriate management for the conversion of abandoned land into opportunities for wilderness management and nature conservation (Hobbs and Cramer, 2008; Blanco-Fontao et al., 2011). On the other hand, passive restoration of plant communities may take decades indicating that the time required for colonization of abandoned arid lands is highly affected by factors such as climatic variability and seed dispersal (Pugnaire et al., 2006). As a result, the multiple possibilities for the emergence of alternative trajectories in the development of vegetation, may lead to cross biotic or abiotic thresholds that compromise the ability of the plant community to self-recover. This is one of the growing concerns for management because after a threshold is crossed, unassisted recovery mechanisms cannot repair the damage, and thus require vegetation manipulation (Cramer et al., 2008).

The abandonment of traditional uses, such as cattle herding, may cause a decrease in biodiversity through habitat homogenization, or conversely cause a beneficial effect by reducing the densities of cattle that affect ecosystem processes and the abundance of other species (Blanco-Fontao et al., 2011). It is highly relevant to assess the status of an ecosystem after abandonment, characterizing the composition, richness or diversity of communities, but also quantifying basic processes and functions to understand the dynamics and trajectories between states. For instance, a long-term study in semi-arid old-fields showed that litter depth, organic soil C and soil moisture were closely related with vegetation succession after abandonment (Bonet, 2004).

The detection of changes in ecosystem attributes and processes can be based on indicators of ecosystem functions that include structural characteristics, composition and functioning. These indicators, resulting from field survey measurement on the current condition of an ecosystem, can be used directly or expressed as indexes (Paul, 2003; Niemi and McDonald, 2004). Landscape function analysis (LFA) is a monitoring methodology developed by Tongway and Hindley (1995) that reflects the status of critical ecosystem processes through the integration of two phases of measures related to the organization of the landscape and 11 indicators of soil surface (Maestre and Puche, 2009). This leads to obtaining three indexes: (1) stability or resistance to erosion, (2) infiltration or water storage capacity and (3) nutrient cycling. A given ecosystem can be classified based on these indexes that indicate the state of degradation or the evaluation of the temporal response to a disturbance.

According to the LFA methodology, the structure and organization of the landscape resulting from agricultural activities and impacts on the distribution and regulation of resources, will provide information on whether the landscapes are functional or dysfunctional (van der Walt et al., 2012). The theoretical framework proposed by Ludwig and Tongway (1997) for the LFA methodology, is based on four phases: trigger, transfer, reserve and pulse, to integrate basic processes on the functioning of desert ecosystems. Rain events (trigger) drive the transfer of resources in the landscape that depend on the magnitude and intensities of the rain events, soil type and slope. Some of these resources are lost, but others are stored in the ground (reserve). As semi-arid ecosystems are organized into source-sink systems, the open areas (interpatches) act as a source of water, organic matter and topsoil erosion mobilized downslope by agents that are trapped by vegetated areas (patches), which act as obstacles to the flow and accumulate resources (Aguiar and Sala, 1999).

As a result of scarce plant cover, semi-arid ecosystems are often organized into source-sink systems. Therefore, landscape function analysis explores patterns in landscape patchiness and then links such patterns to the capture of resources by patches through wind- and water-driven processes. These processes allow the landscape to function as a biogeochemical system and also to evaluate its dysfunctionality (Tongway and Hindley, 2004). Hence, the LFA methodology has been widely applied to reflect the status of critical ecosystem processes in arid lands of Australia (Ludwig et al., 2004; van der Walt et al., 2012), Iran (Ata Rezaei et al., 2006; Bidgoli et al., 2012; Forouzeh and Sharafatmandrad, 2012; Siroosi et al., 2013), Mongolia (Addison et al., 2013), and Spain (Maestre and Cortina, 2004; Cortina et al., 2006; Maestre and Puche, 2009). In South American deserts, the land degradation is increasing due to intensive land use (Villagra et al., 2009), consequently emphasizing the interest in understanding ecosystem changes triggered by activities such as agriculture (Bertiller et al., 2002; Salazar et al., 2015). Few studies have recently described ecosystem structure and functioning, applying ecosystem indicators in grazing Patagonian steppe of southern Argentina (Gaitán et al., 2009; López et al., 2013). However, less is known about the structural and functional aspects after land abandonment.

The Monte Desert constitutes the most arid rangeland of Argentina. Human activities, with their associated disturbances, have been put forward as the main causes of degradation processes (Abraham et al., 2009; Villagra et al., 2009). During the last decade, efforts have been devoted to protect the natural resources in this biome (Vilela et al., 2009) through the creation of protected areas on land formerly intended for agricultural use. In this study we explore the functional status of fields previously submitted to agricultural use and currently part of a conservation area under passive management (El Leoncito National Park, PNEL). We aim to compare the effect of abandonment before and after the formal creation of the National Park (less and more than 40 years). Overall, the objectives of this study are to: (1) compare the changes in vegetation cover and heterogeneity within these two time frames; (2) evaluate the effects of abandonment over time on the organization of the landscape (e.g. number, type and size of patches and interpatches); (3) analyze changes related to different periods of land abandonment on the landscape functionality.

2. Material and methods

2.1. Plant communities of the study sites and neighboring communities

The study site was located in El Leoncito National Park (31°47′ S, 69°17′ W), San Juan, Argentina. Within the Park there is an altitudinal gradient of between 1900 and 4500 m.a.s.l. and includes the desert ecosystems of Monte, Puna and Altoandino. The climate is arid with annual rainfall less than 100 mm and average annual temperatures below 22 °C (Marquez and Dalmasso, 2003).

Our study was conducted along the El Leoncito stream that crosses the area in an east–west direction. The study sites were located on the sides of its range, corresponding to settlements where farming activities were developed in the past (Fig. 1). This sector presents plant communities characteristic of the lower belt of the Monte biome (1900–2500 m.a.s.l.), with shrublands of *Larrea divaricata* and *Bulnesia retama* and dense thickets of *Baccharis salicifolia* and *Tessaria absinthioides*. The presence of exotic species, indicative of former crops in the area, such as *Medicago* spp., *Melilotus* albus, *Mentha* spp., among others; are interspersed with native vegetation (Marquez and Dalmasso, 2003).

In areas far away from the vicinity of the waterbody, the vegetation is characterized by shrubland of *L. divaricata* almost pure enriched with other species as elevation increases. At 2500–3000 m.a.s.l., in contiguity with the study sites, the natural vegetation of Monte corresponds to the higher belt, where exotic species decrease significantly and native shrublands are dominated

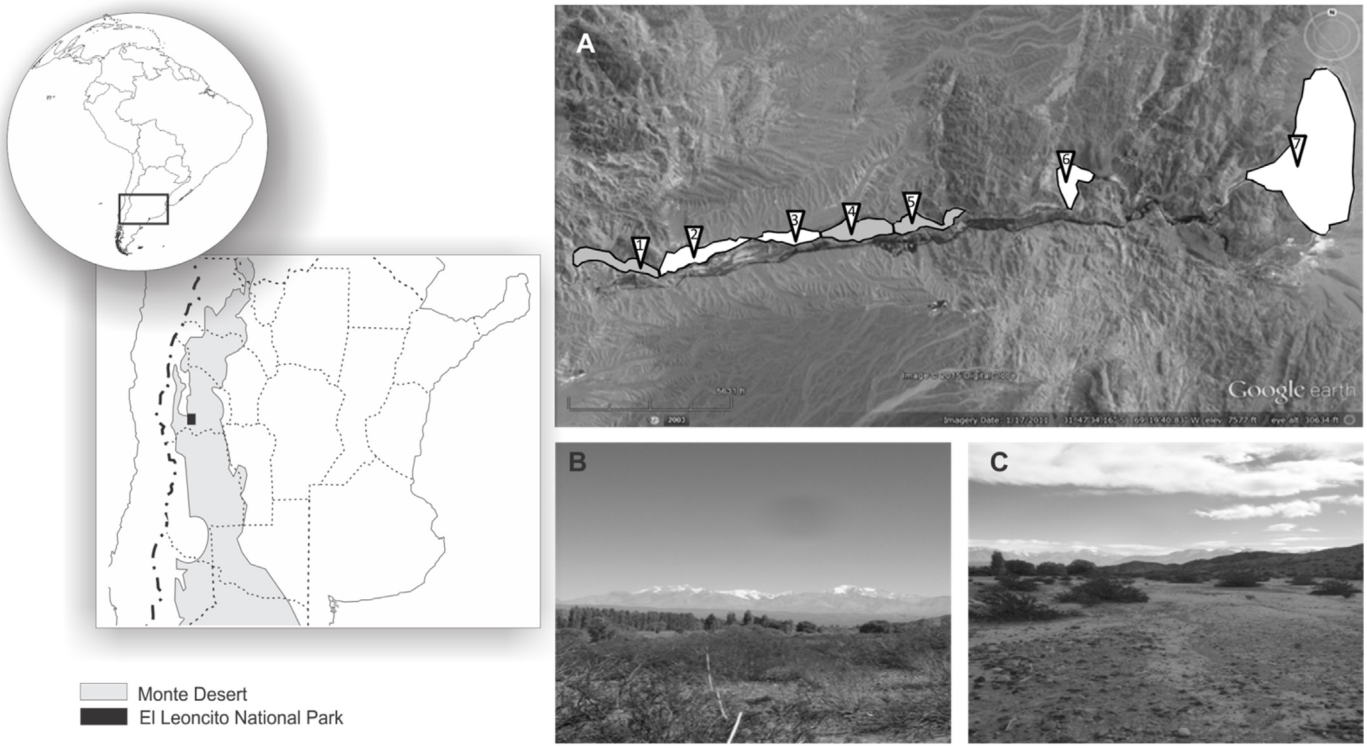

Fig. 1. Location of the study area and the Monte Desert biome. (A) The sampling sites along the El Leoncito stream with west-east orientation within the El Leoncito Nacional Park. Sites showed in gray are 'old fields' (>40 years of abandonment), while 'young fields' (<40 years of abandonment) are identified in white. Triangle shapes with numbers indicate where the first of three parallel transects aligned with the maximum slope that were carried out in each site. (B) A picture of the landscape with >40 years of abandonment and (C) with <40 years of abandonment.

by *L. divaricata*, *Junellia echegarayi*, *Larrea nitida*, *Lycium fuscum* and *B. salicifolia* (Haene, 1996; Marquez and Dalmasso, 2003).

2.2. Overview of local and regional context of land use changes

The study area belongs to the desert regions of west central Argentina. Here we can identify mainly two kinds of agricultural practices throughout the different periods of human occupation. That is, irrigated oases located in valleys where artificial irrigation allows the development of an intensive agricultural economy and concentration of urban centers; and non-irrigated lands with minimum water allocations intended for livestock activities that support a sparse population (Torres et al., 2003; Abraham et al., 2009). Scattered populations outside irrigated areas have an economy largely based on subsistence ranching and extractive use of natural resources, such as the native forest (Richard Jorba, 2003). These economic activities have shown a decrease in the last decades due to the degradation of ecosystems caused by overgrazing, fires and logging of native forests, and the loss of economic value of some products of agricultural origin (Management Plan PNEL, 2009).

The El Leoncito National Park is located in the marginal areas of the irrigated oasis, where the development of farming activities by aboriginal groups has been highly linked to the availability of permanent streams, such as the El Leoncito stream and whose records date back to prehispanic periods since 900–1200 AD (Michieli, 2008; Management Plan PNEL, 2009). From the late 17th century and with the spread of the European colonization, the few documented references indicate a development of horticultural crops and breeding fields for livestock together with alfalfa crops. These activities increased soil degradation and consequently made settlements quite ephemeral (Michieli, 2008). Since the 70s, state policy began a process of land expropriation and removal of agricultural activities with the purpose of reversing land degradation and conserving representative ecosystems of Monte, Puna and Altonandino deserts. In this context, the area became a natural reserve in 1996, which was later upgraded to a National Park in 2002 (Management Plan PNEL, 2009). The study area is immersed in a region currently undergoing intense land transformations characterized by a complex phenomenon of reconversion and land abandonment mainly linked to economic and social causes, and not to conservation (Torres, 2008). For instance, recent studies provide evidence of a trend toward concentration of production, introduction of technologies and inflows of foreign capital in livestock farming activities (Torres, 2008). This is associated with an increase of population displacement to the big cities, consequently leading to land abandonment and the loss of traditional agricultural practices as well as the ecological knowledge of rural communities (Ladio and Lozada, 2009).

2.3. Organization and functioning of the landscape and its assessment

A discontinuous spatial arrangement of vegetation cover is typical of deserts, where patches with high plant cover are scattered in a matrix of open areas (Aguiar and Sala, 1999). Following the theoretical framework adopted in this study, a patch is defined as a discrete unit that differs from contiguous areas in structure, position and function (van der Walt et al., 2012).

The term 'organization' refers to how these patches are arranged in the landscape and the types of patches that compose it, i.e. composition, represent aspects of the structure of a landscape which can be affected by land use (Ludwig et al., 2005). Patches have an important role acting as obstructions that intercept surface limiting resources in deserts such as water, sediments and nutrients, while interpatch areas allow the flow of erosive agents (Ludwig et al., 2005). The variability in the processes of trigger and resource

Table 1
Steps of LFA procedure, and indicators used in each for obtaining the landscape functionality indexes: stability, infiltration and nutrient cycling.

Steps	Indicators/measures	Indexes
Characterization of landscape organization	Patch and interpatches types; Patch and interpatches length; Patch width	Number of patches/10 m Total patch area (m^2) Patch area index Landscape organization index Average interpatch length (m) Range interpatch length (m)
(SSA) Soil surface assessment of each patch/interpatch type	Soil cover; Perennial vegetation cover; Litter cover; Cryptogam cover; Crust brokenness; Erosion type and severity; Deposited materials; Surface roughness; Surface resistance to disturbance; Slake test; Soil texture	
Landscape functionality	Landscape organization and SSA	Stability Infiltration Nutrient cycling

transfer, given the different magnitudes and intensity of rainfall, types of soil and slope, brought as consequence that resource concentration mechanisms promotes the heterogeneity of vegetation cover that we observe in arid and semiarid environments (Barbier et al., 2008).

Following the framework proposed by Ludwig and Tongway (1997), the term function describes the efficiency of a landscape to utilize and retain resources according to their own organization and composition. Consequently, within a continuum of functionality, landscapes range from highly functional to dysfunctional or leaky (Ludwig et al., 2002). Landscape function analysis procedure uses several indicators that address one or more processes by which these resources are stored and recycled. This allows for the positioning of a landscape along the continuum of functionality (Tongway and Hindley, 2004).

As a result of its distinct patch and interpatch attributes, the set of indicators is applied by direct and indirect measurements (Table 1). The individual values of the soil surface indicators are combined to obtain 3 indexes that summarize the key aspects for landscape function monitoring. The stability index provides information about the soil capacity to resist the erosive forces and to recover after disturbance. While the infiltration index evidence how rainfall is distributed in the soil between the water available for plants and the runoff water that is lost from the system. The nutrient cycling index provides information about the efficiency with which the organic matter is cycled back into the soil (Table 2).

2.4. Sampling design

Sampling was carried out along the watershed of El Leoncito stream, where the land has been formerly used for agriculture. Covering a total extension of 226 ha, sampling sites were selected with the help of local residents and rangers to identify those areas where cessation of agricultural activities occurred. While it is not currently possible to precisely define the time of abandonment, the following two situations were identified in the study area: (1) fields where the land use was interrupted before the area became protected, more than 40 years ago (‘old fields’ hereafter, *sensu* Cramer et al., 2008); and (2) fields with recent abandonment, less than 40 years (‘young fields’ hereafter) (Fig. 2). Therefore, a total of 3 old fields and 4 young fields were studied. In each site,

Table 2
Soil surface indicators used to obtain the functionality indexes.

Indexes	Indicators	
Stability	Rain splash protection	Assesses the degree of soil surface protection to rain by physical cover and plant cover
Infiltration, Nutrient cycling	Perennial vegetation cover	Assesses the contribution of biomass of perennial vegetation
Stability, Infiltration, Nutrient cycling	Litter	Assesses the amount, origin and degree of decomposition of plant litter
Nutrient cycling	Cryptogam cover	Assesses the cover of biological soil crust
Stability	Crust brokenness	Assesses the material available for erosion on surface layer
Stability	Soil erosion type and severity	Assesses the type and severity of soil erosion
Stability	Deposited materials	Assesses the nature and amount of soil and litter materials transported to and deposited
Infiltration, Nutrient cycling	Soil surface roughness	Assesses the capacity of surface to retain resources
Infiltration, Stability	Resistance to disturbance	Assesses the capacity of surface to resist the mechanical disturbance
Infiltration, Stability	Slake Test	Assess the stability of soil fragments
Infiltration	Texture	Classify the texture of soil

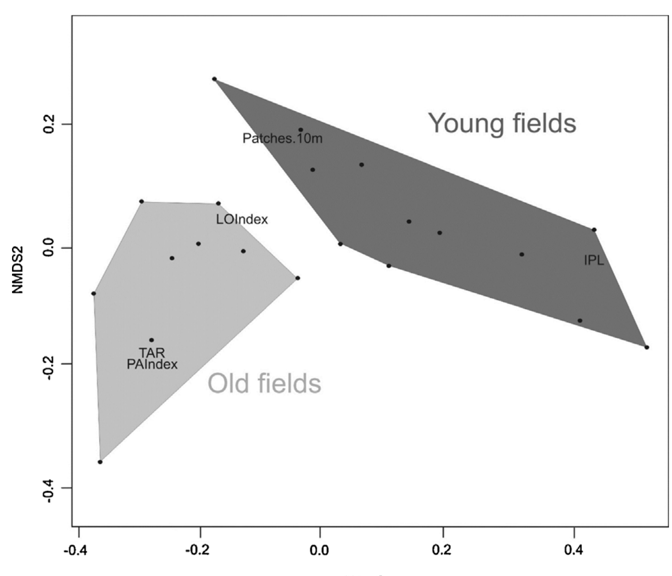

Fig. 2. Non metric multidimensional scaling plot showing the effect of time of abandonment on the landscape organization calculated using total patch area (TAR), patch area index (PAIndex), average interpatch length (IPL), no. patches/10 m (Patches 10 m) and landscape organization index (LOIndex). All sites where measurements were taken are indicated as dots.

composition and vegetation cover was characterized by recording the percentage of shrubs, sub-shrubs, litter, bare soil and forb cover using the line intercept method. For this we used a graduated rod placed vertically and recorded plant cover every 0.30 m along a 30 m transect (Passera et al., 1983).

The landscape organization and functional status were assessed in both situations using the landscape function analysis (LFA) (Tongway and Hindley, 1995). The first step involved the characterization of the spatial arrangement of patches and interpatches (i.e.

landscape organization) and the classification of types of patches and interpatches. To perform this three transects of 30 m each were arranged randomly in each situation (9 in old fields and 12 in young fields), aligned with the maximum slope. In each transect the patches and interpatches were identified and measured subsequently. We consider any plant developed enough to be able to retain resources to be a 'patch' and identified it by the name of the species. Due to the ephemeral nature in arid ecosystem we decided not to include the annual species as patches and account them as part of the interpatches along with stone and bare soil cover. The length of patches was measured along the transect line at the height of the base of the plant from the beginning to end of the base. The interpatch length was the distance between two consecutive patches and the patch width was measured perpendicular to transect. In the following step we assessed soil surface indicators in the most distinctive types of patches and interpatches present in the study area. We established 5 replicates by type of patches and interpatches in the 9 old fields and 12 young fields. Within each one we located a 50 cm × 50 cm sampling quadrat where we recorded 11 soil surface features (Table 2). In the field each soil indicator was assigned to a score following a semi-quantitative scale proposed by the LFA methodology.

2.5. Data processing and analysis

The Shannon index using richness and evenness of cover of plant growth forms was calculated as a measure of heterogeneity (Magurran, 2004) in both situations. The differences in growth forms cover and heterogeneity regarding the time of abandonment, were analyzed by performing a Wilcoxon rank sum test.

The measures of patch and interpatch surveyed in each field as well as the 11 indicators of soil condition were processed using the LFA Data Entry Software (Version 3.0; Tongway and Hindley, 2004). By combining measurements of the landscape it is possible to obtain the density of patches, patch area, and length of interpatches. Along with the soil indicators, these are then used to estimate the indexes of stability, infiltration capacity, and nutrient cycling. Differences in the landscape organization between the two situations of abandonment were assessed by the Wilcoxon rank sum test. We used the landscape organization indexes calculated in the LFA Data Entry Software: total patch area, patch area index (total patch area/maximum area of patches (transect length × 10)), average interpatch length, no. patches/10 m, and landscape organization index (length of patches/length of transect). Changes in landscape organization were visualized using non-metric multidimensional scaling ordination plots (NMDS; Kruskal, 1964). NMDS is recommended as an ecological ordination technique due to its general robustness derived from lack of assumptions about the data distribution or type (Minchin, 1987). The ordination used two dimensions and dissimilarities between the samples, described using Bray–Curtis distance. The number of iterations was based on Young's S-stress formula and iterations stopped when S-stress was less than 0.005. These analyses were done using the R package *vegan* (Oksanen et al., 2013).

We analyzed the existence of differences in stability, infiltration and nutrient cycling indexes considering the period of abandonment, the several types of patches and the interactions between these two variables within and between sites. Differences in the LFA indexes between the two situations of abandonment were assessed by the Wilcoxon test. We used the Kruskal–Wallis test in order to determine differences in these indexes among patches and interpatches. Subsequently, a multiple comparison test between the explanatory variables by pairwise comparisons was performed using the R package *pgirmess* (Giraudoux, 2013).

Table 3
Mean, standard deviation (SD) and *p* values resulting from the Wilcoxon test for percentage of types and heterogeneity of covers in young and old fields in El Leoncito National Park, Argentina.

	Young fields (<40 yrs) Mean (SD)	Old fields (>40 yrs) Mean (SD)	*p* value
Bare soil	43.4 (22.91)	33.84 (18.50)	0.41
Litter	21.3 (20.71)	16.2 (14.71)	0.86
Stone	11.2 (17.59)	15.8 (19.50)	0.43
Shrubs	12.2 (6.35)	34.2 (11.72)	**<0.01**
Sub-shrubs	4.3 (12.20)	0	0.24
Forbs	7.7 (13.28)	0	0.07
Total shrub	16.5 (13.59)	34.2 (11.72)	**<0.05**
Total vegetation	24.2 (15.38)	34.2 (11.72)	0.09
Heterogeneity	0.44 (0.16)	0.63 (0.33)	0.22

Values in bold are significant ($\alpha = 0.05$).

Table 4
Mean, standard deviation (SD) and *p* values resulting from the Wilcoxon test for the indexes that characterize the landscape organization for young and old fields in El Leoncito National Park, Argentina.

	Young fields (<40 yrs) Mean (SD)	Old fields (>40 yrs) Mean (SD)	*p* value
Number of patches/10 m	1.00 (0.78)	1.70 (0.68)	**6.58E−03**
Total patch area (m^2)	15.54 (7.42)	136.17 (126.64)	**6.80E−06**
Patch area index	0.03 (0.01)	0.28 (0.27)	**1.25E−04**
Landscape organization index	0.14 (0.07)	0.43 (0.14)	**1.89E−04**
Average interpatch length (m)	11.13 (6.96)	4.05 (1.88)	**2.44E−03**

Values in bold are significant ($\alpha = 0.05$).

All statistical analyses were performed using R version 3.1.0 (R Development Core Team, 2014).

3. Results

3.1. Vegetation response to abandonment

The cover of shrubs species significantly differed between the two abandonment situations. Results indicate that after long time abandonment, the cover of shrub species increased (Wilcoxon test, $p < 0.05$; Table 3). We found no significant differences for other soil cover variables or heterogeneity of vegetation strata, although sites with more than 40 years of abandonment showed higher mean values of total vegetation cover and heterogeneity (Table 3).

3.2. Patch and interpatch organization

The most distinctive types of patches and interpatches present in both situations in the study area were: shrubs patches of *L. nitida* and *Atriplex* spp.; and the two kinds of interpatch bare soil and soil cover by stones. We found that time, under passive restoration, has significant consequences on the distribution of resources linked to the patch and interpatch organization as shown through the landscape organization indexes (Table 4). The sites subjected to more than 40 years of abandonment increased total patch area and conversely showed a reduction in interpatch length, thus limiting the loss of resources. Likewise, we found that older abandoned sites show a spatial arrangement contrasting with younger sites. This was demonstrated by landscape organization indexes, such as the patch area index and the landscape organization index. The landscape in sites with more than 40 years of abandonment exhibited an increase of 3.3 times in the landscape organization index, representing the capacity of vegetation to avoid run-off and erosion compared to sites with less than 40 years of abandonment (Table 4).

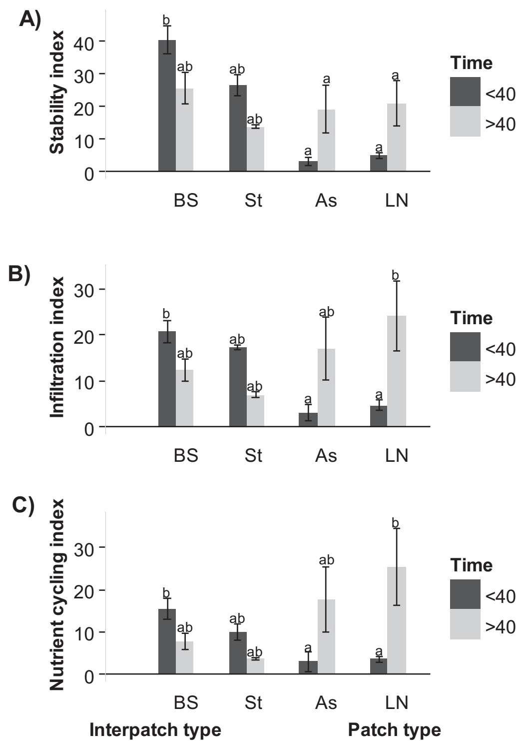

Fig. 3. Characterization of the most representative patch and interpatch types i.e. *Atriplex* spp. (As), bare soil (BS), *Larrea nitida* (LN), stone cover (St), in terms of the landscape function analysis indexes and the time after abandonment i.e. young fields (<40), old fields (>40) The *y*-axis represent the values of the stability (A), infiltration (B) and nutrient cycling (C) indexes (mean + SE, $n = 24$). Different letters indicate significant differences between patch types at different abandonment time according to each index ($p < 0.05$).

The NMDS ordination had a low stress (2%) and a high linear correlation ($R^2 = 0.998$). Here, two abandonment situations were clearly differentiated according to the landscape organization indexes supported by the two separated polygons (Fig. 2). The first axis opposed the indexes related to patch cover and the interpatch area as well as old fields to the younger fields, showing a strong dissimilarity. The second axis contrasted the patch area index and total patch area to the number of patches per 10 m. Sites with less than 40 years of abandonment were related to landscape organization variables, such as interpatch length and patches per 10 m, whereas older abandoned sites were related to the landscape organization index, total patch area and patch area index.

3.3. Landscape functionality

When landscape functionality was assessed by means of the three LFA indexes, we investigated differences among types of patches and interpatches between the two abandonment periods and the interaction between the two variables. We found significant differences in soil stability (resistance to erosion) in terms of type of patch or interpatch ($p < 0.05$). There were no differences for the other two LFA indexes, namely infiltration capacity and nutrient cycling. The two kinds of interpatches (bare soil and stones) resulted in higher values of the Stability index compared to the two patch types (*Atriplex* spp. and *L. nitida*). When the interaction between patch type and time after abandonment was analyzed, we found differences for all three indexes ($p < 0.05$; Fig. 3). Two clear patterns that suggest a positive trend for passive recovery over time were detected. In young fields, stability, infiltration and nutrient indexes were characterized by significantly lower values in vegetated patches in contrast to interpatches. However over time this trend was reversed, showing a significant increase in the functionality of vegetated patches reflected in the values of indexes (Fig. 3).

Table 5
Mean, standard deviation (SD) and *p* values resulting from the Wilcoxon test for soil surface assessment indexes showing the functional properties of young and old fields in El Leoncito National Park, Argentina.

	Young fields (<40 yrs) Mean (SD)	Old fields (>40 yrs) Mean (SD)	*p* value
Stability index	53.23 (6.29)	49.59 (2.67)	0.10
Infiltration index	31.33 (4.88)	37.42 (7.95)	0.07
Nutrient cycling	24.18 (8.23)	33.39 (7.96)	**0.02**

Values in bold are significant ($\alpha = 0.05$).

When the indexes were assessed for the landscape as a whole, significant difference were only found for the nutrient cycling index, where time resulted in higher values (Table 5).

4. Discussion

4.1. Vegetation recovery after land abandonment

We found evidence for positive changes in vegetation cover in fields under the passive management strategies. Our results show that, after 40 years of abandonment, these shrublands have duplicated the mean shrub cover without an active human intervention. This supports the findings of previous studies in North America and Central Europe, indicating that the recovery of plant structures, similar to the historical state, occurs 20–30 years after the land abandonment of land (Cramer et al., 2008; Arnaez et al., 2010). Yet in another study conducted in abandoned agricultural terraces in Mediterranean Spain, results have shown that this can take up to 60 years in some areas (Ruecker et al., 1998). Ruecker et al. found that within the first 10–20 years, vegetation of such fields initially undergoes a low cover therophyte phase. If favorable climatic conditions exist, it takes around 50–60 years to reach a climax characterized by a shrub-dominated matorral. In arid ecosystems the restoration of the shrub layer is correlated with the recovery of multiple functions such as soil stability, facilitation for the establishment of seedlings, nutrient concentration and refuge for other species. When this layer is strongly altered, restoration may prove challenging and may require active efforts for re-establishment (Porensky et al., 2014). Overall, natural regeneration of plant communities by passive management have been shown to achieve desirable levels of recovery, also in terms of conservation. Examples of successful passive vegetation recovery are useful references to further understand the factors involved in the development of these communities over time.

4.2. Effects of land abandonment on landscape organization

We detected changes in the organization of the landscape (e.g. number, type and size of patches and interpatches) in relation to abandonment over time indicating an increase in the overall organization of the landscape and the area occupied by patches. Conversely, associated to a reduction of the area occupied by interpatches, from young to older fields. These results reinforce the recovery potentiality of landscape organization without active restoration. Similar responses were observed in other drylands. For instance in Patagonia, grazing interruption for over 30 years triggered a positive response in developing patchiness, decreasing the inter-patch length and notably increasing connectivity (López et al., 2013). Plant communities in South Africa were found to have responded similarly. Here van der Walt et al. (2012) found better improvement of the landscape functionality in older slopes of tailings dams where no formal rehabilitation was carried out, which were evidenced by wider patches and shorter interpatches.

Results of the recovery of the vegetation cover are closely related to those of landscape organization. The improvement of the cover over time also involves restoring the spatial arrangement of vegetation patches and interpatches, and consequently the landscape connectivity. This ensures the transport and plant processes that keep the ecosystem structure in deserts (Okin et al., 2015). Our study reinforces these results, indicating that the landscape organization indexes reflect how the spatial organization of obstacles (patches) and open areas (interpatches) evolve with environmental change, pointing to what extent landscapes may be functional or dysfunctional.

4.3. Landscape function recovery of fields under passive restoration

The development of structure and organization of the patches-interpatches along time is directly linked with landscape functionality. Its characterization is critical to understand the potential of the ecosystem to capture and transfer resources (i.e. nutrients, water), their current state, and their trajectory under a restoration scheme. We analyzed how the soil surface conditions in the path-interpatch organization by means of the indexes of landscape function analysis (LFA) obtained for the two periods of land abandonment considered. Our findings prove a re-establishment of the functions related to nutrient cycling in old fields that was not observed at the level of the stability or infiltration indexes. These differences in the rate of recovery of ecosystem functions have also been reported in semiarid ecosystem under a sequence of degradation (Maestre and Cortina, 2004).

According to the methodology, the differences in the recovery of nutrient cycling can be derived from the singular or combined expression of the different indicators used to construct the indexes, i.e. basal cover of perennial grasses and shrub canopy cover, litter cover and degree of decomposition, biological crusts cover and microtopography. In mining areas of South Africa for example, higher levels of nutrient cycling was found to be influenced by the presence of biological soil crust patches, through nitrogen fixation and decomposition of local litter (van der Walt et al., 2012). Nevertheless, in our study the contribution to the nutrient cycling was mainly determined by the increase in the shrub canopy and microtopography, representing the surface roughness ability to retain resources; because litter or biological soil crusts were scarce or absent.

We stress that although the indexes values indicate an improvement of this functional aspect when comparing fields with different times of abandonment, the absence of some key indicators such as biocrusts suggest caution when interpreting the development of the functionality by this method. The lack of biocrusts may be explained because their recovery may take years or be poorly developed naturally in some deserts (Belnap, 1993; Schlesinger et al., 2006). However, in other regions within the Monte biome a successfully recovery of biocrust communities have been found to occur in sites where cattle have been removed for more than 40 years (Gómez et al., 2012).

When considering time after abandonment, the different types of patches and how they contribute differently to the overall functionality of the LFA index, we showed another significant result related to the influence of shrub patches. In our study, we found that time after abandonment has a clear effect by an increase in infiltration, stability and nutrient cycling indexes beneath vegetated patches when comparing old with young fields, while the opposite pattern was observed in interpatches. Consequently, the landscape functionality improves over time under vegetation patches, but in sites where vegetation is absent such as bare soil, the situation is worsened with increased time after abandonment. Our results are in agreement with the higher levels of infiltration and nutrient cycling indexes found in shrub patches in semiarid degraded steppes of Spain (Maestre and Cortina, 2004). These results can be explained by the role of shrub patches in maintaining soil stability (Bidgoli et al., 2012) and improved infiltration due to root development as found in rangeland ecosystems of Iran (Forouzeh and Sharafatmandrad, 2012).

Overall, our results show that 40 years of abandonment is enough to create significant differences in landscape functionality and concur with global patterns showing that the recovery of terrestrial ecosystems can be much faster than centuries and millennia (Jones and Schmitz, 2009). Specifically, our results agree with their postulated average time of ecosystem function recovery of not more than 50 years, following agriculture disturbances.

4.4. Passive restoration and the implications for management and conservation

Passive restoration by land abandonment has shown to be effective for the recovery of the shrub cover, the landscape organization and thus, the functionality of the landscape associated to shrub patches. However, when analyzing the landscape as a whole, only the nutrient cycling index was significantly higher in old fields. This lack of significant differences in stability and infiltration indexes, are consistent with results found in Yannelli et al. (2014). Here, we showed that even though the vegetation cover may have improved over time in old fields, the current cover might not be enough to prevent further degradation by erosion, which is related to the stability and infiltration index. Therefore, in order to restore these two components some measures targeting erosion problems should be contemplated, as for instance active revegetation in order to increase the protection against soil loss and infiltration.

Even though we are not comparing different restoration practices in our study, passive restoration has been reported to usually need a relatively lengthy period compared to active restoration, which is often perceived by people as a failure in the project (Zahawi et al., 2014). Therefore, this is a factor that should be taken into account when considering this type of management in drylands, since we showed that the development of structures that enable a more functional state of the landscape may take a considerable amount of time. Moreover, other factors such as the intensity of previous use and farming methods can affect the time needed for a successful landscape function recovery of old fields (Cramer et al., 2008). Though we did not consider the specific previous use in our study, we highlight that the area had been subjected to traditional agricultural practices, which may have helped in the recovery (Queiroz et al., 2014). Overall, when deciding whether passive restoration is the appropriate management practice for conservation of semi-arid lands, factors such as time and previous land use should be evaluated along with landscape functionality.

The role of abandoned agricultural lands now emerges as an opportunity to recover and protect the native communities and their biodiversity, but the empirical evidence about the regeneration of ecosystems, and even more so of their landscape structures and functions, are rarely reported (Grau and Aide, 2008). In this regard, a current review show that although international environmental policies emphasize the recovery of ecosystem functions, some obstacles such as lack of data quantifying ecosystem functions and standardized measurements of the same function across different ecosystems still exist (Meyer et al., 2015). More importantly, they point out that the new data should focus on a set of indicators that represent the overall functioning of ecosystems rather than individual functions. In this paper, we demonstrated that the application of monitoring systems based on organization and function indicators is a useful tool to represent the current state and potential recovery of previously disturbed ecosystems.

Our results have also important implications in the current international context for conservation, since Argentina is a party of the Convention on Biological Diversity. The Aichi Target 15, part of the Strategic plan for Biodiversity 2011–2020 adopted in 2010 by the parties, had set a restoration target of 15% of degraded lands by 2020 (see www.cbd.int). In this context we offer new evidence of passive restoration potentially being a tool to address such challenge in the case of arid ecosystems aimed for biodiversity conservation. This reinforces the importance of rewilding as a cost efficient management strategy, setting a positive example of its value in terms of conservation (Leadley et al., 2014).

5. Conclusions

In this study, we provided evidence for positive changes in vegetation cover, landscape organization features and functionality in abandoned fields under passive management strategies. Our results showed that after 40 years of abandonment, the shrublands had the potential to increase the shrub cover, patch structures and enhance its functionality, without human intervention. However, from a landscape perspective only the nutrient cycling function had improved over time. The lack of improvement of the stability and infiltration in old fields can lead to further degradation by erosion processes, while the absence of key indicators such as biocrusts indicate that the success in the development of the functionality should be carefully assessed. Overall, passive restoration can be an efficient management strategy for improving the landscape functionality of former agricultural areas within the Monte Desert, but the assessment of success should also include the soil stability and infiltration capacity in order to prevent degradation.

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