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Assessing Degradation of Abandoned Farmlands for Conservation of the Monte Desert Biome in Argentina

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Abstract Land abandonment is a major issue worldwide. In Argentina, the Monte Desert is the most arid rangeland, where the traditional conservation practices are based on successional management of areas excluded to disturbances or abandoned. Some areas subjected to this kind of management may be too degraded, and thus require active restoration. Therefore, the aim of this study was to assess whether passive succession-based management is a suitable approach by evaluating the status of land degradation in a protected area after 17–41 years of farming abandonment. Soil traits and plant growth forms were quantified and compared between sites according to time since abandonment and former land use (cultivation and grazing). Two variables were calculated using the CORINE-CEC method, i.e., potential (PSER) and actual (ASER) soil erosion risk. PSER indicates the erosion risk when no vegetation is present, while ASER includes the protective role of vegetation cover. Results showed that land use history had no significant effect on plant growth forms or soil traits ($p > 0.05$). After more than 25 years since abandonment of farming activities, soil conditions and vegetation cover had improved, thus having a lower ASER. Nevertheless, the present soil physical crusts may have delayed the full development of vegetation, enhancing erosion processes. Overall, this study indicates that succession-based management may not be the best practice in terms of conservation. Therefore, any effort for conservation in the Monte Desert should contemplate the current status of land degradation and potential vegetation recovery.

Keywords Drylands · Protected areas · Succession-based management · CORINE-CEC · Land use

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Introduction

Land abandonment as a consequence of socio-economic and environmental changes, is a major issue worldwide (Bonet 2004). Arid lands are no exception to this situation, worsened as a result of their historical use including scattered cultivation and livestock grazing which may turn land vulnerable to degradation (Lesschen et al. 2008). The impact of land abandonment on biodiversity and ecosystem functions is variable according to local environmental conditions and historical use. The dry marginal areas of the Mediterranean region, northern China as well as some areas in Africa, are some of the most broadly studied drylands in terms of land abandonment and degradation (Dregne 2002; García-Ruiz and Lana-Renault 2011; Zhao et al. 2005).

After abandonment, a slow complex secondary succession always occurs hindered by the environmental characteristics such as species dispersal ability (Standish et al. 2007), soil and climate conditions, irrespective of former land use (Bonet 2004; Pugnaire et al. 2006). For instance, the vegetation in abandoned terraces in Spain shifted from an annual low plant cover to shrubland in 10–20 years (Ruecker et al. 1998). This progressive increase in plant colonization following farmland abandonment leads to an improvement in soil characteristics such as organic matter and soil structure (Linstädter and Baumann 2013; Nunes et al. 2010; Ruecker et al. 1998; Zhao et al. 2005). Thus, a general decrease in soil erosion and higher infiltration rates compared to fields subjected to intensive agriculture may occur (Cammeraat and Imeson 1999; García-Ruiz 2010). Otherwise, land abandonment carries negatives consequences such as a decreased in plant density due to the development of soil physical crusts (Lasanta et al. 2000; Ries and Hirt 2008), which reduces infiltration and enhances overland flow, leading to a depletion of soil organic matter and to further erosion processes such as rills and gullies (Ries 2009; Seeger and Ries 2008). Consequently, when disturbed arid ecosystems are abandoned and subjected to erosion processes, there is a loss of resilience in the system that reduces potential land productivity, and may be responsible for shifts to a new state that cannot be passively restored to the previous conditions (Suding et al. 2004). In some extreme cases, if the impact of disturbances is high, the recovery time needed by these ecosystems may be rather long on a human time scale (Villagra et al. 2009).

The Monte Desert is a South American temperate dryland in Western Argentina. Typical land use in this region is farming, carried out in interspersed irrigated valleys where fruit, vegetables, and forage crops are grown under intensive cultivation (Abraham et al. 2009). Several areas of the Monte Desert have experienced moderate to severe land degradation, caused mainly by human activities and associated disturbances (Villagra et al. 2009). The traditional conservation practice in this area is succession-based management of areas excluded to disturbances or abandoned (Aschero and Garcia 2012; Villagra et al. 2009). Accordingly, it is expected due to the absence of human-related disturbances, that successional processes will drive the recovery of the system (Suding et al. 2004). Land abandonment is therefore considered a challenging opportunity to develop self-sustaining systems, protecting native biodiversity and natural ecosystem processes (Benayas et al. 2007; Cramer et al. 2008). This passive management of ecological succession is sometimes referred to as the “rewilding of abandoned landscapes” and suggests trying to turn the threats of land abandonment into opportunities for both people and nature conservation (Blanco-Fontao et al. 2011; Navarro and Pereira 2012). The comparison of sites with different times since abandonment and former land use can be used to assess recovery patterns of degraded vegetation and abiotic conditions in degraded lands (Grau et al. 2003). Overall, the aim of this study was to assess whether passive succession-based management is a suitable approach for the Monte Desert, by evaluating the status of current land degradation in a protected area after 17–41 years of abandonment of farming activities. As such, we (1) evaluated soil traits and the cover of plant growth forms by relating them to the time since abandonment of farming activities; (2) vegetation, litter, and bare soil cover response after abandonment of the former land use (cultivation and livestock grazing); and (3) the potential and actual soil erosion risk through an integrated approach that includes indicators of soil, vegetation, and topography.

Material and Methods

Study Area

The study area is located within the Monte Desert in the “El Leoncito National Park,” in the south-western part of San Juan Province in Argentina (Fig. 1). It became a protected area in 1996 and was established as National Park in 2002 to protect typical ecosystems of the southern Andean steppe and central Andean Puna, as well as associated paleontological and historical sites. Previously the land was a part of the ranch “El Leoncito,” where the main activities since the seventeenth century were scattered cultivation and livestock grazing (Marquez 1999), whereas current land use is tourism, research, and conservation. The park covers 76,000 ha with an altitudinal range of 1,900–4,390 m a.s.l. (Taraborelli 2007). The climate is dry-arid and precipitation varies with altitude, determining three eco-regions represented in the Park, i.e., “Monte,” “Puna,” and “Altoandina” (Köppen 1900; Marquez and Dalmasso 2003).

The study area corresponds to the lower belt of the Monte Desert (1,900–2,500 m a.s.l.), where mean annual temperature is 13.0 $\pm$ 5.7 °C with marked daily and seasonal variation. Mean annual precipitation does not exceed 100 mm; up to 75 mm in winter, partly as snow and hail, and less than 10 mm in summer (Marquez and Dalmasso 2003). The vegetation is characterized as shrub steppe dominated by *Larrea divaricata* (nomenclature according to Morello 1956), associated to a herbaceous layer dominated by *Hoffmanseggia* sp. and grasses such as *Distichlis* sp. Wetland areas are characterized by *Bulnesia retama* with dense shrub patches of *Tesaria absinthioides* and *Baccharis salicifolia* (Haene 1996).

Vegetation Measurements and Land Degradation Indicators

Soil sampling and vegetation measurements were conducted within El Leoncito stream’s watershed (Fig. 2),

Fig. 1 Location of the study area (El Leoncito National Park) in the Monte Desert biome, Argentina

where the land had formerly been used for farming. Seven sampling sites with west–east orientation were selected randomly, with a total analyzed area of 226 ha (Table 1). To estimate vegetation cover, three parallel transects 50-m long and north-south oriented were established at each sampling site. The Point-Quadrat method was used in each transect (Passera et al. 1983), recording every 50 cm cover of all plant species, litter, stones, and bare soil. Species were grouped into plant growth forms (shrub, sub-shrub, and herb). Edaphic conditions were characterized from soil samples collected from the topsoil only (0–30 cm from soil surface) with a 7.5 cm diameter auger, randomly replicating the procedure three times on each of the seven sampling sites and totalizing 21 samples. The samples were taken from areas with no vegetation cover, because it was considered that these were the critical ones in terms of soil erosion risk. All samples were analyzed in the laboratory within 48 h of collection, where they were air-dried and later subjected to the following analyses: particle-size analysis using the Bouyoucos densimeter method (Day 1965), oxidizable organic matter (Walkley and Black 1934), and carbonate content by Calcimeter method (Hesse 1971). In addition, on each sampling site a soil profile was exposed and described for additional information on soil characteristics, i.e., depth of the soil profile, number of layers, differences in structure, texture, color, accumulation of carbonates, and cementation (according to Soil Survey Division Staff 1993).

At each site, the presence or absence of soil erosion signs such as gullies, sheet, and rill erosion was recorded following the descriptions in the USDA Soil Survey Manual (Soil Survey Division Staff 1993). Soil physical crusts, defined as rather thin layers of the soil surface that frequently restrict water infiltration, air entry, and seedling emergence from the soil were identified based on the USDA soil quality indicator information sheet from the

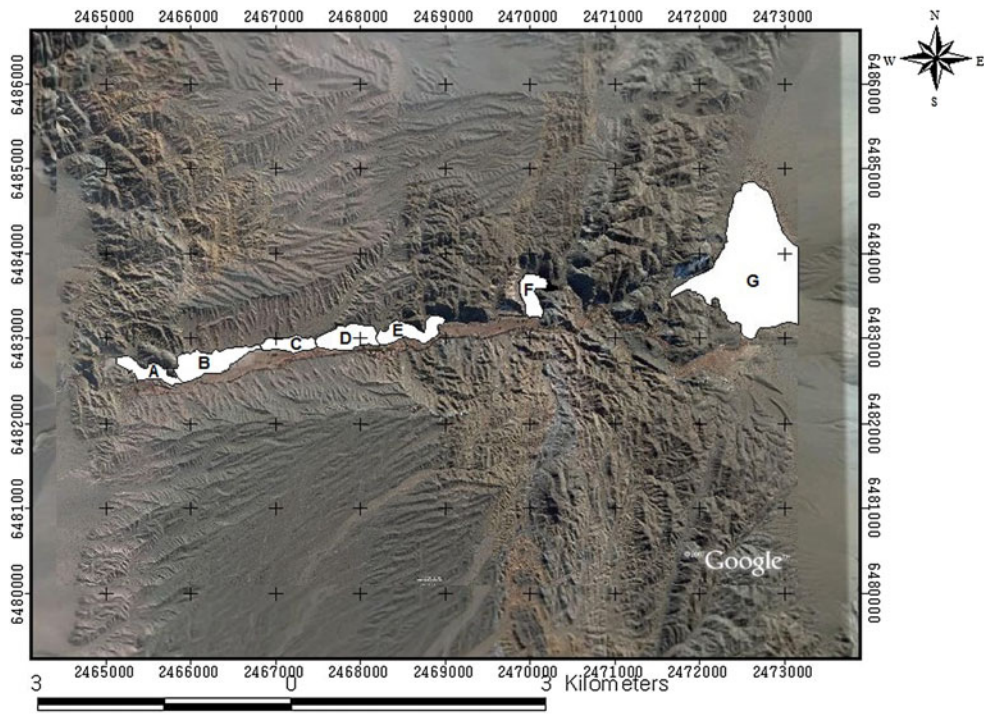

Fig. 2 The seven sampling sites with west-east orientation randomly selected within the El Leoncito National Park, Argentina

Table 1 Previous land use, years since abandonment of farming activities, the predominant type of vegetation and signs of active erosion processes at each sampling sites within El Leoncito National Park, Argentina

Sampling sites	Previous land use	Years since abandonment	Type of vegetation	Signs of erosion
A	Pig breeding	41	Shrubland of *Atriplex lampa*	Soil physical crusts, rills and gullies
B	Wheat cultivation	25	Shrubland of *Larrea nitida*	Soil physical crusts, gullies
C	Cultivation	25	Shrubland of *Larrea nitida*	Soil physical crusts, rills
D	Unknown	40	Shrubland of *Larrea nitida*	Soil physical crusts, rills
E	Unknown	41	Shrubland of *Atriplex lampa*	Soil physical crusts, rills and stabilized gullies
F	Potato, garlic and anise cultivation	19	Annual herbaceous species	Soil physical crusts, gullies
G	Grazing (cattle, goats)	17	Sub-shrubs dominated by *Lycium sp.*	Soil physical crusts, severe gullies

website http://soils.usda.gov (based on Soil Survey Division Staff 1993). Climatic data for the period 2005–2009 was provided by the Cerro Burek Weather Station. The topographic analysis was made using a radar satellite image from ASTER GDEM, downloaded from the website http://wist.echo.nasa.gov. Technical specifications were as follows: GeoTIFF format with geographical coordinates and one arc second (30 m) of spatial resolution. This digital elevation model (DEM) was referenced in the WGS-84/EGM96 geoid projected into the geodetic system, which was later re-projected into the Gauss–Kruger system. A digital terrain model (DTM) was built from this DEM, which included the slope degree map.

Soil erosion was assessed using the CORINE erosion risk model for Mediterranean Europe (see CORINE-CEC 1992). Four indicators were used to assess both potential and actual soil erosion risk in an area by providing a score for soil erodibility, rainfall erosivity (climate erosivity), topography (T), and vegetation cover (Fig. 3). Erodibility depends primarily on the structural stability of the soil and on its ability to absorb rainfall, thus the soil erodibility index (EI) was estimated from soil particle size, soil depth, and surface stoniness. The granulometric characteristics of the soil were classified using the soil texture triangle from the United States Department of Agriculture (USDA). Soil depth was established as the distance between top and bottom of the soil profile, and surface stoniness was derived from the percentage of surface stone cover (larger than 20 mm diameter (CORINE-CEC 1992). Climate erosivity (CE) was obtained from the modified Fournier–Arnoldus index and the Bagnouls–Gaussen aridity

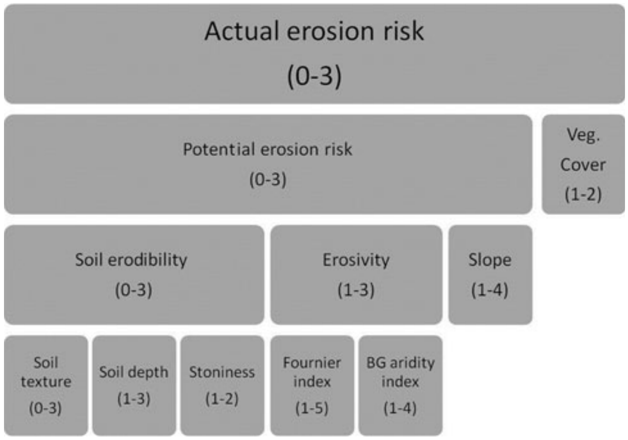

Fig. 3 Main indicators of the CORINE-CEC methodology and their possible values

index (BGI; see CORINE-CEC 1992). The BGI was calculated from the monthly moisture balance, using temperature to estimate evapotranspiration. In the case of T, regional slope angle (%) was measured using the DTM on each sampling site.

PSER was calculated by multiplying the scores for the first three indicators (EI, CE, and T). This represents the worst case possible because it only considers the physic characteristics of the soil and not the vegetation cover. Subsequently, the PSER was modified into ASER by the vegetation cover indicator due to the likely protective role of plant life. Previously, vegetation cover was divided into two classes: fully protected and not fully protected. ASER assessment was made by dividing the results into four classes, i.e., high, moderate, low, or no erosion risk (Aydın and Tecimen 2010; Bayramüng et al. 2006; Vente and Poesen 2005).

Statistical Analyses

Differences in total vegetation cover, oxidizable organic matter and calcium carbonate content among sites were verified using the Kruskal–Wallis one-way analysis of variance ($p = 0.05$). In order to test the correlations between the vegetation and soil variables and time since abandonment, Pearson regressions were performed for each pair of variables, previously assessed for linearity by examining a scatterplot of the data points ($p = 0.05$). Variables used were time since abandonment, soil calcium carbonate content, soil organic matter content, bare soil, litter cover, herb, shrub, sub-shrub, and total vegetation cover. Whereas, cover of plant growth forms, litter and bare soil was compared between types of farming activities (i.e., cultivation, livestock grazing) by means of the Wilcox test ($p = 0.05$). The statistical analyses were performed using Infostat software (Di Rienzo et al. 2008).

Results

Soil and Vegetation Characteristics of Sampling Sites

Soil texture ranged from loam to sandy loam (Table 2). Sites with 40 years of abandonment had the highest mean values of organic matter content, but showing no significant differences between them. The quantities of calcium carbonate differed significantly between sampling sites where the highest values were found for sites A and D (Table 2). Mean total vegetation cover did not exceed 39 % at any of the sampling sites. Although there were no significant differences in this variable between sites, those with more than 40 years of abandonment of farming had more than 30 % of mean total vegetation cover, which was mainly shrub species.

Table 2 Soil texture, mean, and SD of the percentage of vegetation cover (VC), oxidizable organic matter (OM), and carbonate ($CaCO_3$) at the various sampling sites in El Leoncito National Park, Argentina

Sites	Texture	VC (%)	OM (%)	$CaCO_3$ (%)*
A	Loam	34 ± 21.17	3.75 ± 1.30	15.19 ± 15.51 c
B	Sandy loam	12.67 ± 2.31	2.36 ± 0.56	2.32 ± 0.24 ab
C	Loam	20.00 ± 6.00	2.11 ± 0.82	3.15 ± 0.33 abc
D	Sandy loam	39.33 ± 3.06	2.79 ± 0.10	3.96 ± 0.75 bc
E	Loam	29.33 ± 4.16	3.07 ± 0.09	1.42 ± 1.33 a
F	Loam	30.67 ± 16.29	2.61 ± 0.69	1.13 ± 0.61 a
G	Loam	33.33 ± 24.11	2.75 ± 0.52	1.09 ± 0.84 a

* Values of calcium carbonate ($CaCO_3$) followed by the same lower case letters, comparing differences between sampling sites, are not significantly different at $p < 0.05$

Mean values between sites for VC and OM were not significantly different at $p < 0.05$

According to Pearson's analysis, time since abandonment was positively correlated with percentage of shrub cover ($r = 0.81$, $p < 0.05$, $n = 3$) and negatively correlated with percentage of herb cover ($r = -0.48$, $p < 0.05$, $n = 3$). Moreover, Wilcox's test showed no differences between the values for bare soil, total vegetation, shrub, herb, and litter cover in relation to the former use of the sampling sites ($p > 0.05$).

Soil Erosion Risk Assessment

In terms of the CORINE-CEC main erodibility indicators, soil texture at all sites was described by the methodology as highly erodible (Table 3). All soil profiles analyzed were deep and only stoniness values differed among sites. This means that when all sites had a soil texture defined as highly erodible and deep soil profiles described as slightly erodible, those with more than 10 % of surface stone cover were considered to have low erodibility, while the others had moderate erodibility. Furthermore, erosivity was high for all sites, because the climate range includes the entire study area. This is a consequence of the low and highly variable rainfall pattern and the very dry type of environment (Morello 1958). Regarding T, the regional slope angle was less than 5° for all sites, thus described as gentle. Consequently, PSER results showed that the variable producing the difference among sites was erodibility, and the high erosivity of the region worsened the methodology description for all sites. The sites with the greatest PSER were A (41 years of abandonment of livestock grazing activities), E (41 years of abandonment, unknown previous land use), and F (19 years of abandonment of farming activities); while the other sites presented moderate PSER. As noted previously, this situation was modified by vegetation cover to obtain the ASER.

Vegetation cover at sampling sites with 40 years or more of abandonment and additionally site G with 17 years with no farming activities were considered fully protected. Consequently, the actual erosion risk of sites A and E changed from high to moderate; D and G changed from moderate to low; B and C remained moderate and F high (Table 3). Overall, considering the ASER for the total surface area analyzed, 70 % of this area had low, 25 % moderate, and 5 % high risk. The sites with 40 years or more of exclusion had moderate to low ASER (site D); whereas sites with less than 25 years of exclusion had moderate to high actual soil erosion risk, with the exception of Site G which had low ASER (Table 3).

Table 3 Assessment of erodibility index (EI), potential soil erosion risk (PSER), and actual soil erosion risk (ASER) in each sample site, using the CORINE-CEC methodology

Site	EI	PSER	VC	ASER
A	++	+++	FP	++
B	+	++	Not FP	++
C	+	++	Not FP	++
D	+	++	FP	+
E	++	+++	FP	++
F	++	+++	Not FP	+++
G	+	++	FP	+

Vegetation cover (VC) was classified as fully protected (FP) or not fully protected (Not FP). The main indicators are classified as: low (+), moderate (++) and high (+++)

Discussion

Soil-Vegetation Responses after Land Abandonment

Although there were no significant correlations between the selected soil traits and time since abandonment, all sites presented high values of organic matter compared to other locations within the Monte Desert, where mean values of 1.8–2.4 % were found after grazing exclusion (Abril et al. 2009). Organic matter content is related to vegetation recovery (Bonet 2004; Chen et al. 2012; Nunes et al. 2010) and contributes to prevent further land degradation because it enriches the soil with nutrients and provides a better macrostructure (Ritchie et al. 2005; Stavi et al. 2009), enhancing infiltration, and water-holding capacity (Ludwig et al. 2005). Whereas, the high contents of calcium carbonate found especially on site A are usually present in abandoned arid and semi-arid environments (García-Ruiz and Lana-Renault 2011), occasionally representing an obstruction to root development and seedling emergence (Lasanta et al. 2000; Zhou and Chafetz 2009). Combination of high calcium dissolution in soil and high evaporation rates after the wet season leads to the formation of physical crusts, which are frequent in semiarid abandoned lands and associated to the low density of plant cover during the first years after abandonment (García-Ruiz and Lana-Renault 2011).

Time since abandonment of farming activities had an overall positive effect on vegetation cover. Moreover, a high positive correlation was found between time since abandonment and shrub vegetation, which proved to be the main growth form contributing to total vegetation cover on sites abandoned for more than 20 years. These results were expected under secondary-succession management, where the oldest fields have plant growth forms not yet occurring or not totally expressed in the youngest ones (Horn 1974), and agree with studies that show shrubland recovery 10–60 years after abandonment (Arnaez et al. 2010; Bonet 2004; Ruecker et al. 1998).

Regarding former land use, there were no significant differences in total vegetation cover values, litter or bare soil to prove a different response after abandonment of either cultivation or livestock. Nevertheless, evidence of divergent responses of vegetation to land abandonment was found between initially grazing habitats and initially arable sites in Mediterranean semi-arid old fields reflecting different successional drivers (Bonet 2004). Additionally, land use history resulted in different susceptibility to erosion processes, where even though grazed fields were not immune to such processes, abandoned crop fields were much more susceptible to potential gully erosion (Kakembo and Rowntree 2003).

Soil Erosion Risk Assessment

The only differences found in terms of erodibility were related to stoniness, which is relevant to the assessment because the numerous stones on the surface function as an obstacle to runoff, enhancing infiltration, trapping sediments, and nutrients (Ludwig et al. 2005; Seeger 2007). This variable was independent of time after abandonment, but related to the stone material loosened from the surrounding hills. The region evidenced high climate erosivity as a consequence of the low and highly variable rainfall pattern and the very dry-type of environment (Morello 1958). Despite these conditions, in this study area slopes were gentle (<5 %), thus not critical in terms of erosion risk.

The improvement of vegetation over time was reflected in the results for ASER, since sites abandoned for more than 25 years had moderate to low ASER and, as expected, one of the last sampling sites to be abandoned had the highest ASER. Although vegetation responded positively to abandonment, almost all sites presented physical crusts, rills, and gullies; thus, showing that at none of these sites was the current vegetation enough to prevent erosion. Therefore, our results are consistent with those found in the north of Spain after about 40–70 years of abandonment and plant cover expansion, where erosion processes are increasing, and so is the extent of degraded areas (Arnaez et al. 2010; Ries 2009). A possible explanation is that a decrease in soil infiltration due to physical crust development during the first years of abandonment hinders secondary succession (García-Ruiz and Lana-Renault 2011; Lasanta et al. 2000; Lesschen et al. 2007). For instance, in set-aside lands in the Central Ebro basin, after 5 years of fallow, soil crusts occupied 70 % of the area and were responsible for at least 50 % of the decrease in soil infiltration rates, thus increasing runoff formation and leading to further erosion (Ries and Hirt 2008). However, since this study did not focus on a detailed investigation of soil physical crusts and their effect on vegetation development, it is not possible to certainly explain the current degradation status by development of these crusts.

Implications for Management and Conservation

The traditional conservation management practice based only on secondary succession through exclusion of disturbances or farming abandonment is proven not to be very efficient to prevent further degradation processes in our study area. This is consistent with what other studies argue regarding this management practice, but in terms of biodiversity or vegetation recovery of the Monte Desert (Aschero and Garcia 2012; Villagra et al. 2009). Results would then suggest either that abandonment may not be a sufficient management measure to restore this area or that more time is needed for recovery. Ultimately, understanding how long it takes to recover these ecosystems is crucial in order to then define whether they will recover passively or whether it is necessary to apply active restoration techniques. Our results suggest that an integrated approach with multiple indicators at local and landscape scales, that considers factors such as current status of land degradation, soil health, and potential vegetation recovery, would be helpful for monitoring the change in land use or land management after abandonment. Additionally, maps of erosion risk can aid in monitoring such changes at a given time scale (Aydın and Tecimen 2010), providing valuable information to plan a sustainable use of the region.

Conclusions

This study showed that passive succession-based management may not be the most suitable approach for rehabilitating or "rewilding" these degraded desert shrublands. After more than 25 years without any farming activity the soil quality of the study area improved due to an accumulation of organic matter and vegetation cover, leading to a lower soil erosion risk index. However, a decrease in soil infiltration as a consequence of physical crust development may have prevented vegetation cover improvement. Thus, leading to severe erosion processes such as rills and gullies. In order to recover the biotic potential of these areas, it is suggested that any effort for conservation in the Monte Desert should contemplate the current status of land degradation and potential vegetation recovery.

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