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Abstract Sand dune quarries are a location of common aggregate mining activity developed in coastal areas, especially in the southeast Buenos Aires province, Argentina. In this article, spontaneous plant development after extraction activity ceased was evaluated. Five areas (three quarried and two natural/conservation areas) were sampled for plant cover and composition as well as sediment characterization. Different indexes, principal component analysis, and cluster analyses were applied to compare the areas. The dominant families observed in four of the five areas were Asteraceae, Poaceae, and Cyperaceae, and most of the species are commonly found in sandy and humid soils and/or modified/anthropized ones. Percentages of plant cover increased with time because of the cessation of active aggregate extraction. Indexes and multivariate analyses showed that it was possible to distinguish quarried and natural areas based on composition and vegetation cover. The distribution of plant species among the four areas responded to the presence of mining activity, but it also responded to the topographical position and consequently the depth of the groundwater level. Besides these differences, the four areas shared many native species. The results might indicate that once the activity has ceased, quarried areas may spontaneously and quickly develop a plant community with some similarities to those present in the nonquarried areas. However, given that the extracting activity involves the removal of the soil, revegetation of this type of environment depends on the presence of natural areas in the surroundings, which can serve as a source of seeds and propagules for plant regeneration.

Keywords Sand dunes · Quarry · Spontaneous plant succession · Reclamation · Argentina

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Introduction

Aggregate mining is one of the main activities in the supply of raw material for urban infrastructure construction and generation (Ayala Caicedo et al. 1996). Aggregates can be either natural or artificial: The former derive from geological deposits whose lithological materials or unconsolidated sediments have only undergone a mechanic process of extraction, crushing (in the case of lithics), and grain size selection; the latter derive from industrial processes or recycled concrete that has undergone some type of physicochemical modification.

In general, mining creates negative environmental consequences on different physical and biological aspects (Gallego Valcarce and Valdillo Fernández 1992; del Rio et al. 1995, 2001; ESPROMUD 1996), including geomorphological alterations; induction to instability in natural and artificial slopes; induction to soil erosion and compaction; loss in flora and fauna association; alteration in natural ecosystems, aquifers, and groundwater levels; induction to flooding or generation of swamp areas;

microclimatic changes; inadequate use of soil after the activity (e.g., technically underdeveloped landfills or dumps); and visual impact on landscape with changes in shape, volume, and color (del Río 2001).

The most commonly used aggregates in construction and manufacturing of concrete and mixes are those which belong to the sand fraction, which are added to thicker fractions, such as cement and binders, for the production of concrete. One of the areas selected for sand extraction are localized on coastal regions where human settlement is dominant. Coastal dunes are degraded and lost because of human actions and activities, which alter coastal dynamics and natural processes, eliminate topographic variability, degrade or eliminate habitats, decrease biodiversity, and threaten endemic species (Lithgow et al. 2013). The increasingly rapid loss and degradation of coastal dunes clearly shows the urgent need to preserve these ecosystems and to restore those that have been degraded as much as possible (Lithgow et al. 2013). In Buenos Aires province, Argentina, in particular in northeastern coast areas, many sand dune quarries have been active for decades due to the demand for sand for construction (López and Marcomini 2006). López and Marcomini (2006) focused on the environmentally degrading effect of aggregate mining because of the induction of erosive processes on the coast. However, the biological capacity of this type of environment to recover and/or the efficiency of the mining designs in terms of the possibilities of natural recovery of a costal dune system that has undergone sand-extraction activities have not been analyzed.

Despite the fact that in a coastal dune system there are geomorphological components that cannot recover in a relatively short period of time, some biological components, such as vegetal communities, can develop again. However, their compositional and structural characteristics may vary in relation to their initial state and are dependent on the time elapsed after the extraction activity has ceased. Reclamation and/or restoration of a disturbed site can be approached by three methodologies: (1) spontaneous succession or passive revegetation, where natural plant colonization and succession are allowed, and no human action is involved; (2) technical reclamation or active revegetation, which consists in covering sites with fertile topsoil and grass and herb mixtures and /or planting shrubs and trees; (3) or a combination of both procedures by manipulating spontaneous succession toward a target (de Steven et al. 2006; Dorrough et al. 2008; Prach and Hobbs 2008; Baasch et al. 2012). Spontaneous succession is a cheaper approach because no human action is needed, and it is adequate for sites where environmental conditions are not extreme and they are surrounded by natural vegetation (Prach and Pysek 2001; Rehounková and Prach 2007; Duan et al. 2008; Prach and Hobbs 2008). Many studies have shown the importance of the surrounding vegetation as a seed reservoir for spontaneous colonization (Novák and Konvicka 2006; Bochet et al. 2007). Instead, technical reclamation is preferred where environmental stress is high and where abiotic thresholds are apparent (Prach and Hobbs 2008).

Studies in relation to the restoration or reclamation of disturbed limestone quarries, sandy soil sites, or coastal dune sites have been conducted in different regions of Europe and Asia, and most of them pointed to spontaneous succession as an adequate methodology for site restoration (e.g., Csecserits and Redei 2001; Rehounková and Prach 2007; Duan et al. 2008; Tropek et al. 2010; Gallego-Fernández et al. 2011). In Argentina, studies of plant community reclamation after an anthropogenic disturbance (such as mining or building) are scarce (e.g., Malizia et al. 2004; Buono et al. 2005; Luque et al. 2005; Álvarez et al. 2012). These studies analyzed the natural revegetation (in some cases aided by planting actions) in different degraded areas, such as quartzite quarries, oil industry sites, or gas pipeline areas. No studies of sandy soils/coastal dune sites or sand quarries have been developed until now. This type of study represents an important issue to be addressed, especially in those areas not only affected by human settlement, but also by mining activities, such as Buenos Aires province in Argentina.

In view of the need expressed by several investigators about coastal dune conservation and restoration of disturbed sites (Lithgow et al. 2013), and taking into account the importance of spontaneous succession as a restoration methodology in these types of ecosystems (e.g., Csecserits and Redei 2001; Rehounková and Prach 2007), we analyzed the potential of the natural regeneration of plant communities in coastal sand dune areas subjected to sand extraction. The aim of the article is to describe and analyze the spontaneous development of vegetation in areas with differing times of mining activity cessation and to compare them with unaffected areas in a sand dune quarry located in the southeast of Buenos Aires province, Argentina. In this case study, mining-free areas have been considered in order to preserve unaffected natural vegetation that would work as a source for seeds and propagules, which are necessary for the restoration of the vegetation cover after the extraction activities have ceased (Álvarez et al. 2007). Although this design of the sand quarry was intended to facilitate plant recomposition, we referred to it as "natural" or "spontaneous" recomposition because no sowing or planting activities were involved. The results obtained represent the first data in relation to the potential of natural recovery of plant communities in a sand dune system affected by mining activity in Argentina. It is also a first approach to knowledge of the evolution of this type of environment when faced with a radical transformation or disturbance. Finally, the data obtained could

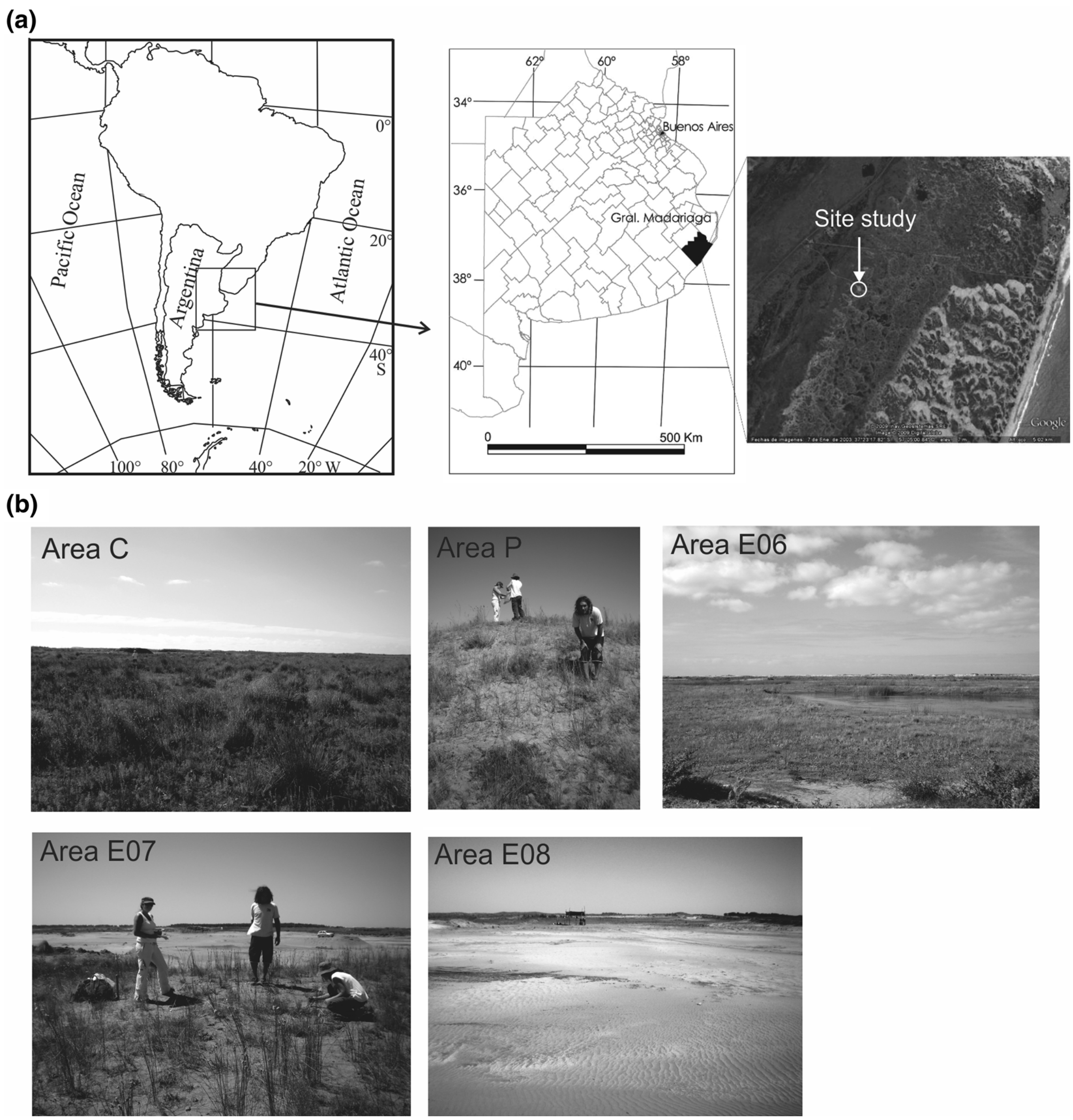

Fig. 1 **a** Location of the site study. **b** Photographs taken in 2009 from the five zones selected for the study. *C* conservation area, *P* no-mining area, *E06* area quarried until 2006, *E07* area quarried until 2007, *E08* area with extraction activity at the time of sampling

contribute to future management decisions in relation to the design and use of sand dune quarries in coastal regions in order to guarantee plant communities preservation and/or restoration.

Materials and Methods

Study Area

The mining area is located on the Atlantic Coast dune area in Buenos Aires province, Argentina (37°23′20.06″S, 57°5′37.13″W) (Fig. 1). The area has a subhumid/humid mesothermal climate with little to no water deficiency according to the Thornthwaite classification of climates (Burgos and Vidal 1951). According to the National Weather Service, Mar del Plata station (1961–1990), the region experiences 800 mm of mean annual rainfall and 14 °C mean annual temperature. Wind direction is predominant from the north.

The study area is located in the southern part of the geologic province called Salado Basin (Bracaccini 1980). Due to sea-level fluctuation during the Quaternary Period, in the Holocene age, a barrier was formed between Buenos Aires province continental sequence and the continental

platform of the Argentinian Sea (Parker 1979; Violante and Parker 1993). This barrier is called the Holocene Eastern Barrier, and it developed on estuarine environments (Isla and Bertola 2005). Fine grain size and medium grain size sand types extracted from the quarry correspond to the Late-actual Holocene Punta Médanos Formation and to a low sedimentary environment of inner wind deposit or low back-barrier. The sand strip presents, in the quarry area, such forms as transverse dunes, barchanoid ridges, and fixed and semifixed star dunes with relative heights between 3 and 5 m in relation to the surrounding land.

Soil types of the area are classified as Entisol (Soil Survey Staff 1996) or Arenosol (IUSS-WRB 2007). They are characterized by sandy loam texture, similar to the original material, and show little or no evidence of horizon development. They are also characterized by fast permeability, deep groundwater levels, and absence of flood risks (IUSS-WRB 2007). Where groundwater levels are closer to the surface, such as blowouts situated among living dunes, spontaneous growth of natural vegetation is possible, and this environment is now of the type Entisols Aquents (Soil Survey Staff 1996). Low coherence, low capacity to store nutrients, and high sensibility to erosion are serious limitations to this type of soil (IUSS-WRB 2007).

From a phytogeographic viewpoint, the study area is situated in the Eastern Pampean District, Pampa Province, Neotropical region (sensu Cabrera 1976) or in the Flooding Pampa, Río de la Plata grasslands (sensu Soriano et al. 1992). According to Cabrera (1976), the flora of the area is characterized by a pseudo-steppe of *Stipa* and *Piptochaetium* spp., which has been replaced almost entirely as a consequence of farming and cattle-breeding activities. Dominant species include *Bothriochloa lagurioides, S. neesiana, Paspalum dilatatum, Baccharis articulate*, and *Phyla canescens*. Other frequent communities include "juncales" (*Schoenoplectus californicus* communities) and "totorales" (*Typha* spp. communities), which are commonly found in aquatic environments; giant grass grasslands (*Zizaniopsis bonariensis* communities) at flooded edges; "carda" communities (*Eryngium* spp.), which are found in flooded areas that have with long dry periods; *P. quadrifarium* grasslands, which are characteristic of low and flooded lands during the rainy season; and Pampas grass (*Cortaderia selloana*) and *Spartina* sp. Grasslands, which cover great extensions of flooded clayey soil types. Also frequent in stream flood channels are species of Cyperaceae, *Distichlis spicata*, and *Juncus acutus* communities, which are characteristic of low and saline lands; *Spartina* sp. and *Panicum* sp. Steppes, which are characteristic of dunes that are close to the sea; *Androtrichium* sp. and *Tessaria* sp. grasslands, which develop in low dunes and blowouts; and psammophyte steppe, which is characteristic of fixed dunes close to the sea.

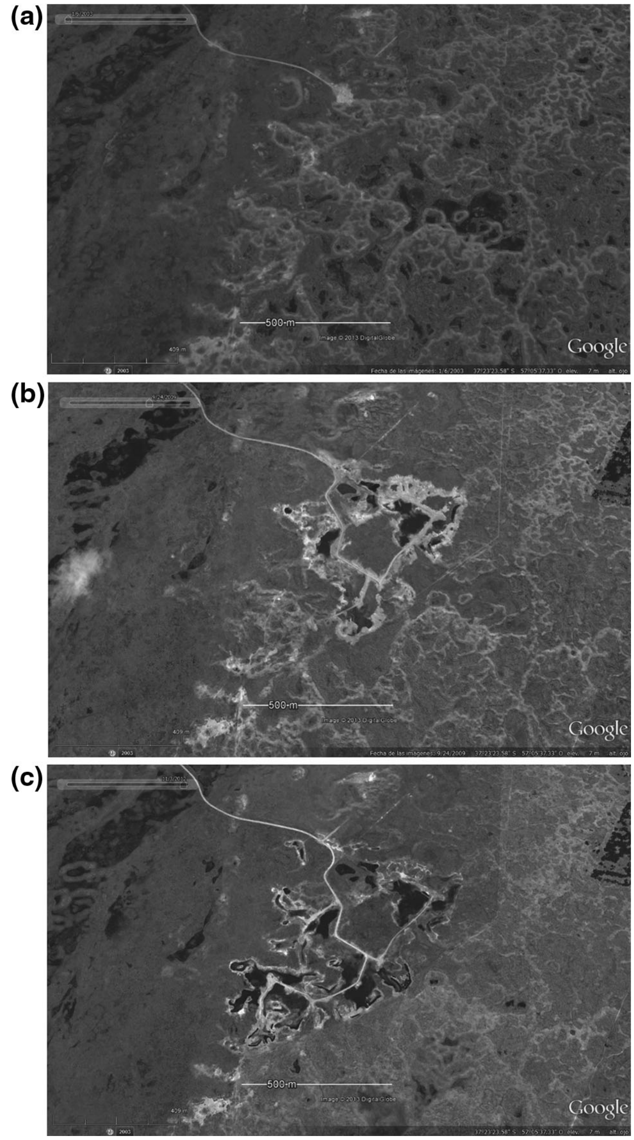

Fig. 2 Satellite images of the sand quarry area showing the evolution of the extracting area with time. **a** January 2003. **b** September 2009. **c** November 2012. (*Source* GoogleEarth)

Characteristics of Mining Activity

Mining activities started at the beginning of 2000 and have been continuous since 2006. The quarry, where the mining activity takes place, occupies 35 ha of a 739-ha farming field (Fig. 2).

The undertaking consists only of sand-dune extraction for commercial purposes. The aggregate does not undergo any kind of treatment. Approximately 3,000 m^3 of fine grain size sand are produced monthly. The design of the sand quarry included inner areas for conservation (named *conservation* area) surrounded by direct mining areas (*exploitation* areas), where sand extraction occur at different times. Once extraction activity is ceased in one area, another area begins to be

exploited. In consequence, different areas have been identified according to the mining chronology and thus have made it possible to assess vegetation succession processes in this type of extraction activity. Diachronic and synchronic analyses of vegetation cover and composition (Fig. 1) were possible due to the availability of areas with different cessation dates (areas quarried until 2006 through 2008 are designated E06, E07, and E08 *exploitation* areas, respectively) and areas not used for extraction—called area C (*conservation* area within the mining area) and area P (*no-mining* area located in the surroundings and affected only by extensive cattle activities).

Sampling Site Selection

During December 2008 through March 2009, five areas were selected and surveyed: three areas were affected by mining activity at different times (areas E06, E07, and E08), and two of them were unaffected areas with natural vegetation (areas C and P) (Fig. 1):

- C area: conservation area situated in the center of the quarry. It is a flat area with no ponds or dune sectors.
- P area: no-mining area situated on the southeast border of the quarry. It is an area with dune and interdune (narrow and small hollows between crest dunes) sectors.
- E06 area: area with mining activity until 2006 situated on the northwest border of the quarry. It is a flat area with some ponds developed as a consequence of sand extraction.
- E07 area: area with mining activity until 2007 situated on the southwest border of the quarry. It is a flat area with some ponds developed as a consequence of sand extraction.
- E08 area: area with mining activity since 2008 without vegetation situated on the southeast border of the quarry.

The study areas were identified and marked out using satellite image analysis, and photographs of the areas, planimetric and altimetric maps, field surveys using global-positioning system (GPS), and further data processing were performed using OZI Explorer software (www.oziexplorer.com).

Soil and Sediment Texture Characterization

In each zone, surface soil or sediment samples were collected for subsequent granulometric analysis according to the usual sedimentology techniques (Ingram 1971). Statistical parameters were determined according to Folk and Ward (1957).

Plant Sampling and Species Characterization

During January and March 2009, vegetation censuses in sampling areas C, P, E06, and E07 were conducted (E08 was not surveyed because it lacked vegetation; for this reason it was only considered for granulometric analysis). In each area, 10 equidistant quadrats of 2 × 2 m^2 were placed along a transect that covered the entire area. In the case of P area, where dune and interdune sectors were present, an equal number of vegetation censuses in each sector were insured. The size and number of these units were determined through the calculation of the minimum unit during previous field surveys (Mueller Dombois and Ellenberg 1974). In each sample unit, the percentage of total plant cover and species cover was calculated. Samples of different species were collected and later identified through identification keys of the region (e.g., Cabrera and Zardini 1978; Dimitri 1980, 1987; Múlgura et al. 2012; Zuloaga et al. 2012a, b). A herbarium with all the samples collected was made up and kept at the Laboratory of Geoecología de Suelos, IGCyC, FCEyN, UNMdP. In addition, the species were classified according to their status (native, endemic, adventitious/alien, naturalized, and introduced), life cycle (annual or perennial), and habit (herb, shrub, and sub-shrub) according to the Southern Cone Vascular Plants Catalogue, Darwinion Botanical Institute (http://www2.darwin.edu.ar/Proyectos/FloraArgentina/FA.asp).

Analysis of the Relation Between Plant Communities and Areas

Cluster and ordination (principal component analysis [PCA]) analyses were conducted to analyze the similarities or differences among the study areas in relation to the composition and abundance of plant species. For cluster analysis, the Morisita index was used. This index is related to Simpson Index λ, which measures the degree of dominance that species have in the composition. Thus, the Morisita index increases the association if both samples coincide in the dominant species. This index was thought to be more appropriate given that the aim was to identify if there were similarities among zones in relation to the species that formed each one of them. For PCA, data were standardized with arcsine square root transformation, and a variance–covariance matrix was used (McCune and Mefford 1999).

Five indexes were calculated to compare the study areas (Table 1). In addition, the Simpson Diversity Index and Shannon Diversity Index were calculated (Begon et al. 1988). Differences in the values of the Simpson and Shannon indexes of the different areas were evaluated by analysis of variance (ANOVA) and Tukey tests (Zar 1984).

Results

Delimitation of Study Areas

The different areas in the quarry were delimited by means of a GPS, and the surface of each area was determined to

Table 1 Values of the indexes of vegetation, native and perennials species per area, and distribution index of perennial and native species

Index	Index description	Relevance/purpose	Index values per area			
			C	P	E06	E07
Vegetation index (*V*)	V = no. of species in sampling area/no. of total species (values between 0 and 1)	Indicates the proportion of total species of the site study present in each area; values close to 1 indicate that most of the total species of the site study are developed in this particular area	0.71	0.54	0.44	0.49
Native species per area (*n*)	n = no. of native species in the area/no. of total species in the area (values between 0 and 1)	Indicates the proportion of native species in relation to total species of a specific area (C, P, E06, or E07); values close to 1 indicate that most of the species in this area are native	0.79	0.80	0.71	0.70
Perennial species per area (*p*)	P = no. of perennial species in the area/no. of total species in the area	Indicates the proportion of perennial species in relation to total species of a specific area (C, P, E06, or E07); values close to 1 indicate that most of the species in this area are perennials	0.79	0.84	0.62	0.74
Distribution index of native (*N*) and perennial (P) species	N = no. of native species in the area/no. of total native species; P = no. of perennial species in the area/no. of total perennial species	Indicates the proportion of native/perennial species of the site study that are present in an specific area (C, P, E06, or E07); values close to 1 indicate that most of the native/perennial species described for the site study are developed in this specific area	$N = 0.79$ $P = 0.81$	$N = 0.59$ $P = 0.64$	$N = 0.44$ $P = 0.39$	$N = 0.47$ $P = 0.51$

C Conservation area, *P* No-mining area, *E06* Area with extraction activity until 2006, *E07* Area with extraction activity until 2007

Fig. 3 Delimitation of areas affected and not affected by sand extraction in the quarry. *C* conservation area; *P* no-mining area; *E06*, *E07*, *E08* areas with extraction activities until 2006, 2007 and 2008, respectively; *A* areas with extraction activity at the time of this study (*Source* GoogleEarth)

be as follows: conservation area (C) = 3.9 ha; area quarried until 2006 (area E06) = 3.4 ha; area quarried until 2007 (area E07) = 1.4 ha; area quarried during 2008 (area E08) = 1.3 ha (Fig. 3).

Soil and Sediment Texture Analysis

Granulometric analysis reveals that in all five sampled areas, the sediment is fine sand (0.25–0.125 mm); in all cases of good selection, there was only one area of positive symmetry, and the remaining areas were almost symmetrical (Table 2). Kurtosis was variable, being leptokurtic for areas C and E08 and mesokurtic for areas P, E06, and E07 according to Folk and Ward (1957).

Species Characterization and Plant Cover Comparison

A total of 55 species distributed among 14 families were registered (Table 3). Taking into consideration the number of species found in the four areas, the dominant families in decreasing order are Asteraceae, Poaceae, and Cyperaceae. The analysis of species present in the study area reveals that nine of them are present in all four analyzed areas, although in variable cover percentage. These species are *Androtrichum trigynum* and *Eleocharis bonariensis* (Cyperaceae), *Centaurium pulchellum* (Gentianaceae), *P. gouinii*, *Eragrostis neesii* (Poaceae), *Hydrocotyle bonariensis* (Apiaceae), *Glandularia pulchella* (Verbenaceae), *Symphyotrichum graminifolium* (Asteraceae), and *Medicago lupulina* (Fabaceae).Of the total species identified, 74 % are native species for the Southern Cone of America and 26 % are exotic, 72 % are perennial, and 28 % are annual. Herbs are the dominant component (84 %), and no trees were identified. Total plant cover increased from affected areas (E07 41.5 %) to unaffected areas (C 69.5 %; P 64.09 %), whereas the values found in area E06 (64.5 %) were similar to those found in areas C or P.

Analysis of the Relation Between Plant Communities and Areas

The dendrogram (Fig. 4) obtained from the cluster analysis shows two major groups (I and II). Group I is formed by all samples from areas E06 and E07 (areas with mining activities in the past) and samples taken from interdunes in area P (area without mining activity); in group II the samples belong to area C and ridge sectors and dune sides from the area P (both areas without mining activity). The first group is characterized by the presence and abundance of *Bacopa monnieri*, *Mentha pulegium, Pluchea sagittalis, S. americanus*, and *H. bonariensis*. The second group is characterized by *Achyrocline satureioides*, *A. trigynum, B. spicata, G. pulchella, E. serra*, and *C. selloana*. Furthermore, the first group only included herbs, whereas in the second group there were herbs as well as shrubs and sub-shrubs species.

The separation of samples from no-mining area (P area) observed in the cluster analysis are probably due to

Table 2 Granulometric characteristics of the sediments

Zone	Location	Statistical parameters							
		Median		Mean			Selection	Symmetry	Kurtosis
		Phi	mm	Phi	mm	Classification			
C	37°23′20.9″S; 57°05′34.9″W	2.30	0.20	2.30	0.20	Fine sand	0.38	0.00	1.40
P	37°23′31.2″S; 57°05′43.8″W	2.20	0.22	2.20	0.22	Fine sand	0.45	0.10	0.95
E06	37°23′14.3″S; 57°05′32.9″W	2.35	0.20	2.35	0.20	Fine sand	0.49	0.05	1.06
E07	37°23́22.8″S; 57°05́39.1″W	2.20	0.22	2.27	0.21	Fine sand	0.50	0.27	1.04
E08	37°23́35.6″S; 57°05́49.4″W	2.30	0.20	2.30	0.20	Fine sand	0.45	0.07	1.23

differences in the geomorphology of this specific sector. As previously described, this area corresponds to the surrounding fields where dune and interdune sectors are present. The two groups obtained in the dendrogram coincided with samples taken on dunes (samples P1, P2, P3, P7, and P10) and samples taken on interdunes (samples P4, P5, P6, P8, and P9). Differences in geomorphology imply differences in groundwater depth, which condition the settlement of some species.

Axes 1, 2 and 3 explain 48.27 % of the sample variability (axis 1 21.56 %, axis 2 14.71 %, and axis 3 12 %). In Fig. 5, where axes 1 and 2 are drawn, two major groups can be distinguished along axis 1 (groups I and II): *E. bonariensis, P. gouinii, H. bonariensis*, and *Cynodon dactylon* var. *dactylon* have the major positive correlation, and *B. spicata, G. pulchella, C. selloana, A. trigynum* and *A. satureioides* have negative correlation. These two major groups coincide with the groups observed in the dendrogram (groups I and II). In group I, axis 2 separates the samples in three subgroups a, b and c. Subgroup a is formed by the pristine area (P4, 5, 6, 8, and 9); and subgroups b and c are formed by areas E and E‘, where *C. dactylon* var *dactylon, E. bonariensis*, and *C. pulchellum* have the most positive correlation, and *M. pulegium, P. sagittalis* and *S. graminifolium* have negative correlation.

Table 1 lists the values of the different indexes calculated for the four areas studied. When analyzing the vegetation index, it can be observed that the values for the unaffected areas (C and P) are greater than the ones for affected areas (E06 and E07), thus indicating a greater number of different species. Distribution of native species within each area (index of native species per area) indicates that the relation native/exotic is similar between areas; however, when analyzed over the total number of native species, we can observe that unaffected areas, especially the conservation area, have the highest value of the whole area (index of native species distribution). The same was observed for perennial species, where the highest value of the whole area is found in the conservation area. Simpson as well as Shannon indexes indicated that diversity is greater in conservation area C than in the rest of the areas (Fig. 6) (ANOVA, F 3.36 = 6.99718, $P < 0.001$ for Simpson; F 3.36 = 17.927, $P < 0.001$ for Shannon).

Discussion

The area for quarrying activities is characterized by sand dunes essentially formed by fine sand and undulating topography. The highest elevation point was found in the no-mining area (P) (elevation > 9 m.a.s.l.), whereas in the quarried and conservation areas (E06 and C) the heights are close to 9 m.a.s.l. This situation defines a greater vertical distance between land surface and groundwater level (unsaturated thickness) in the no-mining area and a much lower one in the remaining areas, an important factor that determines plant development. Groundwater level fluctuates by approximately 8.5 m.a.s.l, according to Alvarez and del Rio (personal communication) for years 2006, 2008, and 2009. Finally, as a consequence of mining activity, some ponds were formed in both quarried areas. This modification in the geomorphology (in this case with the creation of a new type of habitat: a small wetland) implies the modification of plant communities that might develop, for example, hydrophytes species.

General Characterization of Vegetation in the Area

Besides mining activity in the site study, vegetation is characterized by native (73.91 %) and perennial (71.74 %) species. The dominant families found in the site study match several research works performed on vegetation in Pampean dune and/or coastal environments (e.g., Cabrera 1941; Monserrat 2010). Species present in the area, particularly those that are equally distributed in the four areas under study, are commonly found in sandy and humid soil

Table 3 Species found in the areas studied

Family	Species	Area			
		C	P	E06	E07
Apiaceae	*Centella asiatica* (L.) Urb.	X	X		
	Eryngium sp.	X	X		
	E. serra Cham. & Schltdl.	X	X		
	H. bonariensis Lam.	X	X	X	X
Asteraceae	*A. satureioides* (Lam.) DC.	X	X		
	B. penningtonii Heering	X	X		X
	B. spicata (Lam.) Baill.	X	X		
	Asteraceae sp. 1	X			X
	Carduus acanthoides L.	X			
	Cirsium vulgare (Savi) Ten.	X	X	X	
	Conyza monorchis (Griseb.) Cabrera	X		X	X
	G. subfalcata (Cabrera) Cabrera			X	X
	Facelis retusa (Lam.) Sch. Bip.	X			
	Leontodon taraxacoides (Vill.) Mérat	X		X	X
	P. sagittalis (Lam.) Cabrera			X	X
	Senecio pampeanus Cabrera	X			
	Solidago chilensis Meyen	X	X		
	Sommerfeltia spinulosa (Spreng.) Less.	X	X	X	
	S. graminifolium (Spreng.) G.L. Nesom	X	X	X	X
	Asteraceae sp. 2	X			X
Cyperaceae	*A. trigynum* (Spreng.) H. Pfeiff.	X	X	X	X
	Cyperus eragrostis Lam. var. compactus (E. Desv.) Kük.		X		X
	C. rotundus (L.) Palla	X			
	Cyperus sp.		X		
	E. bonariensis Nees	X	X	X	X
	S. americanus (Pers.) Volkart ex Schinz & R. Keller			X	
Fabaceae	*M. lupulina* L.	X	X	X	X
Gentianaceae	*C. pulchellum* (Sw.) Druce	X	X	X	X
Juncaceae	*Juncacea* sp.	X	X		X
	J. acutus L. ssp. leopoldii (Parl.) Snogerup	X	X		
	Juncus sp.			X	
Lamiaceae	*M. pulegium* L.				X
Onagraceae	*Oenothera indecora* Cambess.		X		
Orobanchaceae	*Agalinis communis* (Cham. & Schltdl.) D'Arcy	X	X		X
Plantaginaceae	*Plantago* sp.	X			
	B. monnieri (L.) Pennell			X	
Poaceae	*Briza* sp.		X	X	
	C. selloana (Schult. & Schult. f.) Asch. & Graebn.	X	X		
	C. dactylon var *dactylon* (L.) Pers.		X	X	X
	Dactylis glomerata L.	X			
	Digitaria aequiglumis var *aequiglumis* (Hack. & Arechav.) Parodi	X		X	
	Eleusine tristachya (Lam.) Lam.				X
	E. neesii Trin.	X	X	X	X
	Stipa sp.		X		
	Imperata brasiliensis Trin.	X			
	P. gouinii E. Fourn.	X	X	X	X
	P. dilatatum Poir.	X	X		
	Poa nemoralis L.		X		X

Table 3 continued

Family	Species	Area			
		C	P	E06	E07
Sporobolus cryptandrus (Torr.) A. Gray	X				
S. indicus (L.) R. Br.	X			X	
Polygonaceae	*Polygonum* sp.			X	X
Primulaceae	*Anagalis arvensis* L.			X	X
Verbenaceae	*G. pulchella* (Sweet) Tronc.	X	X	X	X
	P. nodiflora var. *minor* (Gillies & Hook.ex Hook) N. O'Leary & Múlgura	X		X	
	Verbena intermedia Gillies & Hook. ex Hook.	X			X

Crosses indicate the presence of this species in the area.
C Conservation area; *P* No-mining area, *E06* Area with extraction activity until 2006, *E07* Area with extraction activity until 2007

types as well as in modified and/or anthropized ones (Cabrera 1941; Gutiérrez et al. 2010). Presence of exotic species in the area was expected because farming activities have been present for decades. Also, the movement of trucks for sand transportation represents a probable route of exotic species seeds arrival in the area (Mack and Lonsdale 2001). Even though sand extraction had ceased in the areas studied, they are surrounded by the roads connecting the rest of the sectors active for extraction where truck movement is frequent. Last, the predominance of herbs over shrub and sub-shrub may be due to the fact that the study area is exposed to wind action in all directions and minimum shelter areas, which benefit greatly herb habit species, are present (Cabrera 1941; Holz 1995).

Relation Between Vegetation and Study Areas

The results indicate that the time after the cessation of mining activity and the geomorphology are determinant factors in the attribute of vegetal cover. Differences in the percentage of vegetation cover between C and P (no-mining areas) might be associated mainly with geomorphological differences. P area shows greater zones (dunes), which are more exposed to wind action and sun radiation and thus are partially vegetated. Minor vegetation cover observed in quarried area E07 might be due to the little time elapsed after the cessation of mining activity plus the effect of cattle stepping on the ground.

As well as the plant cover, the distribution of plant species may respond to the presence of mining activity as well as the topographic characteristics of the site. Conservation area C showed the greatest vegetal cover and diversity and the highest percentage of native and perennial species of the four areas studied. This may reflect the important role of a protected area in a mining environment such as this one because it would act as a refuge for native species and a source of seeds and propagules for revegetation (Tropek et al. 2010). The concentration of perennial species in this area derives from lower disturbance in relation to the areas where mining activities are present. It is expected that the areas with medium and high levels of disturbance present a greater abundance of opportunistic or pioneering species, which generally have an annual life cycle (Begon et al. 1988).

Many of the species found in no-mining area P commonly develop in regional low hills and/or coastal environments, especially those sampled in the dune sectors (Holz 1995; Monserrat 2010). As mentioned before, this area presents two different topographic sectors (dunes and interdunes) with differences in two aspects: wind exposure and distance to groundwater level. Both conditions are probably responsible for the differentiation of samples in two groups within this sampling area (see Results). The samples taken from dune sectors present species that only develop in these topographic situations and are not present in conservation area C. For this reason, it would be important, if possible, to consider the protection not only of flat areas (such as conservation area C) but also dune ones in future designs of sand quarries.

Quarried areas [E06 and E07 (quarried until 2006 and 2007, respectively)] are the lowest places in topographic terms, and, because of sand extraction and the emergence of groundwater level, some ponds have developed. This situation allowed the development of aquatic species typically found in lagoons and/or wet or flooded environments from the Pampean region (Cabrera 1941; Soriano et al. 1992). Four species were found only in these two quarried areas (*Gamochaeta subfalcata, P. sagittalis, Polygonum* sp., and *Anagallis arvensis*). Even though *A. arvensis* and *M. pulegium* are two adventitious and annual species, typical of anthropized environments, the presence of *G. subfalcata* and *P. sagittalis* must be highlighted given that these are native species of the region. It is interesting how in a little time two native species, absent in the no-mining areas, have developed in the areas exploited. As occurs with hydrophytes found in the ponds, the presence of natural fields surrounding the mining area represents an important condition in the success of natural revegetation as well as the development of other native species different from the ones growing in the conservation area (C) (Prach & Hobbs 2008).

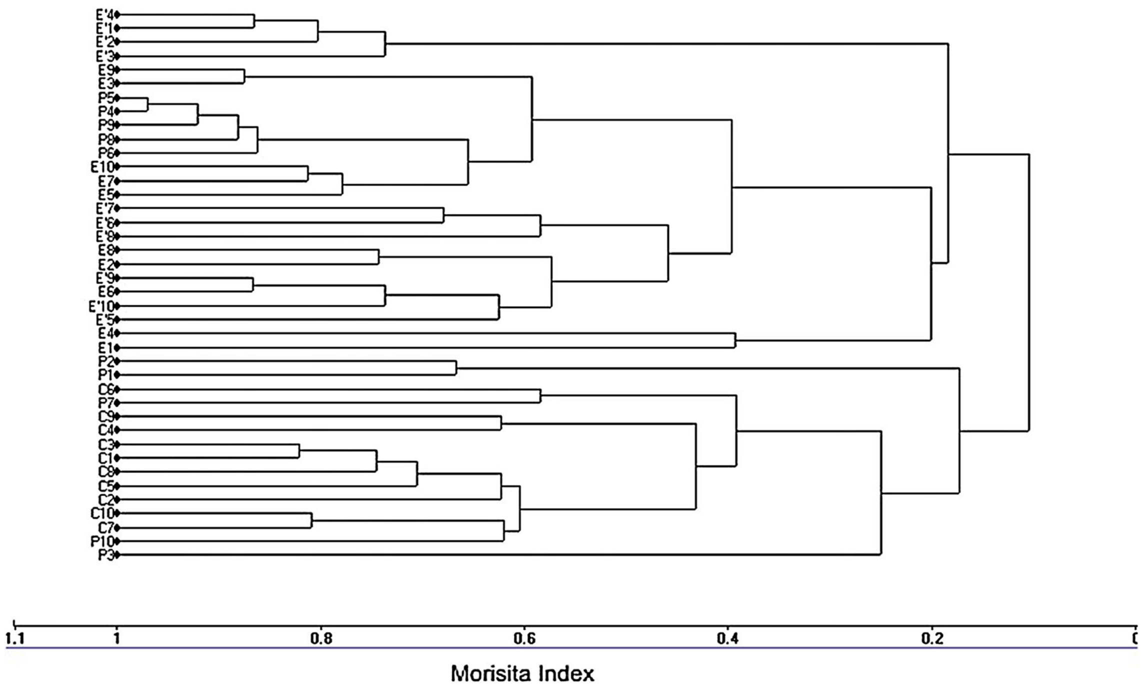

Fig. 4 Dendrogram showing census grouping based on their species composition and abundance. *C* conservation area, *P* no-mining area, *E* area with extraction activity until 2006, *E'* area with extraction activity until 2007

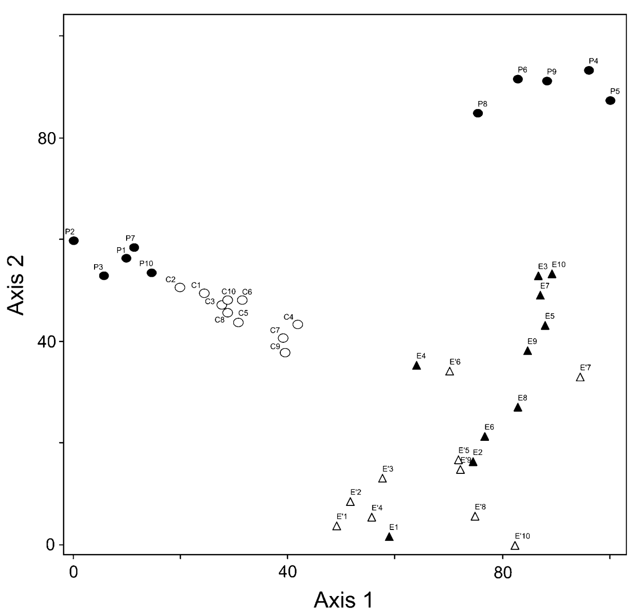

Fig. 5 PCA of census based on their species composition and abundance. *Black circles* area P, *white circles* area C, *black triangles* area with extracting activity until 2006 (E), *white triangles* area with extracting activity until 2007 (E')

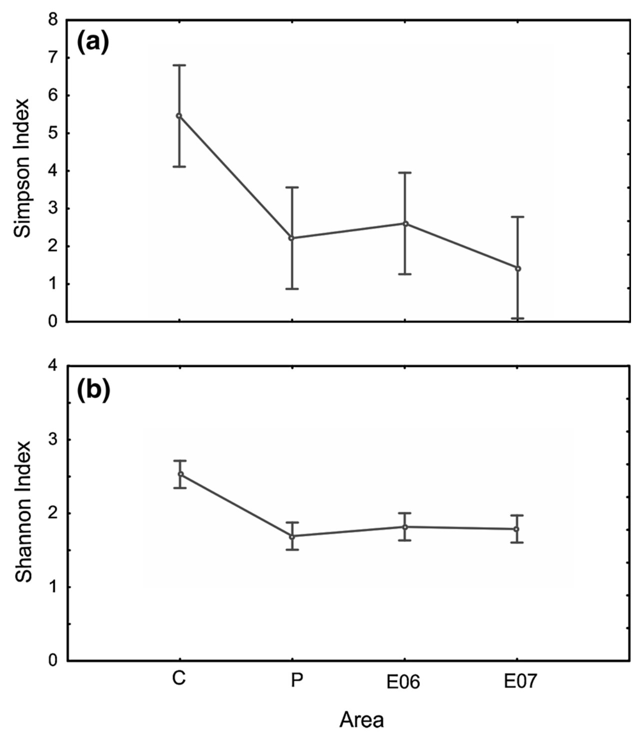

Fig. 6 **a** Simpson diversity index graphic. **b** Shannon Index graphic. *Significant difference at $P < 0.001$. *C* conservation area, *P* no-mining area, *E06* area with extracting activity until 2006; *E07* area with extracting activity until 2007

Vegetation Recovery in Areas Affected by Sand Mining

Sand extraction in coastal areas causes changes in geo-structural as well as biological components (López and Marcomini 2006). Some of them, for instance, geomorphology (e.g., dune and interdune distribution) may not be fully recovered, whereas others (such as vegetation) may return in varying degrees to their original state

depending on the reclamation methodology applied (Gallego-Fernández et al. 2011).

In general, plant recovery methodology of an area affected by mining includes three methods: (1) technical reclamation; (2) spontaneous succession; (3) a combination of both techniques, where the spontaneous succession is manipulated toward a specific target (Prach and Hobbs 2008). The preference of any of these methodologies depends on economic costs, level of degradation of the site, and productivity of the area among other factors (Prach and Hobbs 2008). Research conducted on other degraded or affected environments by diverse human activities (e.g., limestone quarries) indicates that spontaneous restored sites surpassed the technically reclaimed ones in the representation of threatened species and xeric habitats specialists (Tropek et al. 2010). Other studies suggest the combination of spontaneous succession with mechanisms to assist vegetation recovery to avoid introducing exotic and competitive species that prevent the development of native species (Baasch et al. 2012). Antecedents in plant recovery in sand-dune areas/sandy soil environments referred to the natural revegetation as an adequate and economic methodology for restoration (e.g., Gallego-Fernández et al. 2011). Species establishment in a disturbed site is largely determined by their occurrence in the surroundings and by the seed banks. A distance $\leq$100 m from a disturbed site appeared to be critical for the establishment of most species (de Steven et al. 2006; Rehounková and Prach 2007; Prach and Hobbs 2008).

In this study, we analyzed the spontaneous development of vegetation in two areas affected by sand extraction, E06 and E07, after 3 and 2 years, respectively, since the cessation of the activity. The results show that spatial recovery in terms of vegetation cover was possible in a short period of time (2–3 years). Both areas showed high values (between 40 and 60 %) with vegetation cover in zone E06 being similar to that in conservation area C. This matches other results gathered in other areas where spontaneous succession was chosen as recovery strategy and the vegetation cover recovered more rapidly (Prach and Hobbs 2008).

At a compositional level, there were differences among the group of species present in the areas with and without activity. Absence of certain species, such as *B. spicata, A. satureioides, Eryngium* sp, and *Solidago chilensis*, in quarried sites might be due to the absence of adequate habitats, difficulties in the reproduction process (for example, in dioecious species), and/or competence. Some of them are sub-shrubs and perennial plants, and biological interactions with annual herbs may play an important role in the species settlement (Begon et al. 1988; Duan et al. 2008). However, the four areas studied shared nine species, six of which were native and one (*G. pulchella*) endemic for South America (http://www2.darwin.edu.ar/Proyectos/FloraArgentina/FA.asp). These data might indicate that once the activity has ceased, the quarried areas can spontaneously develop a plant community with some qualitative and quantitative attributes similar to those of the communities present in the areas unaffected by mining. Given that the activity in this case involves the removal of an important layer of soil and sediments, it is evident that the revegetation of the area cannot depend only on its own seed bank because it has been completely removed. For this reason, the presence of an unaffected area constitutes a fundamental and determinant tool in the plant recovery of the site because it would ensure the availability of seed banks. However, in this particular case study, the surrounding areas represent the original landscape with its geomorphology features preserved (dunes and interdunes), and this may play a fundamental role in the restoration of the vegetal component (Novák and Konvicka 2006; Bochet et al. 2007).

Conclusion

Mining activity in a dune system modifies the geomorphology (eliminates dune sectors and in some cases creates ponds) and eliminates the soil and flora component, thus also affecting the associated fauna. Some of these components cannot be recomposed (such as geomorphology), but others may be restored in varying degrees, depending on time, the new conditions, and human mitigation actions among other factors.

In this particular study, the potential natural vegetation recovery was assessed as a possible methodology for plant restoration in these areas. The results showed that vegetation cover in quarried areas reached similar values to conservation area in few years (2–3). The compositional recovery depended on the time lapsed after the activity ceased, the new topography, and the distance to and availability of seeds source. Although between 40 and 50 % of the species observed in quarried areas are native and perennials, some groups did not manage to develop. Shrub and sub-shrub revegetation may be one of the main failures in the process, probably due to the lack of adequate habitats and/or competition with herbs.

Natural revegetation of sand dunes systems subjected to sand extraction seems to be possible due to the presence of a conservation area within the quarried area and to the natural neighboring fields. The studied area is surrounded by natural sand dunes and may be the main contributor to the seeds and propagules responsible for the plant recovery. For this reason, it is recommended that environments of this type, with sand-extraction activities, have preservation of areas with no mining activity. These conservation areas should include as many geomorphologic features as

possible, such as dune and interdune sectors, because they represent different potential seeds banks and plant communities typical of coastal dune systems.

Finally, the results obtained represent a contribution into the knowledge of the dynamics of coastal dune vegetation subjected to mining activity and reflect the potential of spontaneous succession as a restoration methodology in this type of ecosystems.

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