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Temporal and spatial changes in plant dune diversity in urban resorts

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Abstract We investigated the temporal and spatial changes in the floristic composition and abundance in sand dunes along a coastal strip in the province of Buenos Aires (Argentina). Firstly, we analysed changes over a span of 70 years, comparing 41 of our own inventories carried out in 14 beach resorts in 2005–2006 with 18 inventories made in the first half of the *XX*th century (1930–1940) in the same study area. We grouped sampled plots into four categories for comparison, taking into account the time period (1930–1940 or 2005–2006) and location at each end of the surveyed coastal strip in the northern or southern 'tourist' sectors. Secondly, we analysed the effect of afforestation with exotic trees on extant sand dune vegetation for the period 2005–2006. A total of 74 plant inventories were carried out in afforested and natural dunes at the same resorts. In both comparisons we contrasted plant richness, percentage plant cover, similarity and diversity. A cluster analysis was used to classify categories taking into account plant abundance and composition. Significant differences in total diversity were observed between sampling years, suggesting an increase in diversity at the present time due to urbanization and recreation related activities. Nevertheless, no single exotic plant species was clearly dominant across the sampled sites, suggesting that these coastal areas are, up to now, resistant to alien invasion. Diversity indexes discriminated by plant groups indicating different habitat conditions and exotics were shown to be more sensitive to existing changes than to total richness and cover.

Keywords Vegetation cover · Afforestation · Urbanization · Atlantic coast · Argentina

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Introduction

Natural dunes are much appreciated and in demand as ideal landscapes for recreation and tourism and, consequently, a series of conflicts between the sustainability of economic activities and the conservation of coastal resources have been on the increase since the latter decades of the *XX*th century. Residential uses, sea-and-sand tourism, and recreation activities set great pressures on the natural processes that shape the landscape. The most noticeable impacts of human activities on the sedimentary cycle and vegetation dynamics can easily be detected. The principal driving forces behind biodiversity change at beach resorts are usually recognised as being changes in land use resulting from urbanization, afforestation and activities associated with tourism (Lemauviel et al. 2005; Van der Maarel and Usher 1997). As dune landscapes are highly dynamic and complex (Rust and Illenberg 1996), land use, watershed processes and biodiversity are often intricately linked to each other and are affected by several inputs. For centuries coastal san dunes have been considered to be fragile systems. To prevent sand drift and to help stabilize the dunes, planting of trees (mostly exotic) have been carried out (Doody 2005). The existence of dunes is greatly imperilled when activities such as sand extraction, dune reshaping, beach cleaning or off-road vehicle riding and hiking are carried out when damage to the vegetation is immediately evident (Curr et al. 2000; Levin and Ben Dor 2004). Loss of native taxa has the potential to cause much more homogenization than the addition of exotic plants (Schwartz et al. 2006) and the dynamics of the remnant native vegetation are modified under an urban resort environment (Sukopp et al. 1973; Pauchard et al. 2006; Mc Kinney 2006). For example, Tzatzanis et al. (2003) pointed out that while some dune specific species, e.g. *Plantago lagopus,* are resistant to human influence and are abundant on the degraded beaches of Crete, others are more vulnerable to even a low impact, and can only be found in specific areas where the human disturbance regime is indirect. Other changes in plant composition and abundance are driven by afforestation and gardening. The planting of trees and non-native shrubs changes the local small-scale environment and creates new habitats that are colonized by several new species. Unintentional seed dispersal and an increase in nutrients as a consequence of human activities are less visible but equally important factors to be considered.

Diverse attempts have been made to describe the patterns of change that underlie different levels of human pressure on dune vegetation in the transition from natural landscapes to urban resorts in different coastal regions worldwide. For example, Kutiel et al. (2004) found that the area covered by vegetation in coastal sand dunes in Israel changed at an average rate of 1.75% p.a. between 1965 and 1999. The proposed model predicted that the landscape would reach a final stage with stabilized dunes that had a dense vegetation cover with a density of between 60 and 100%.

Vegetation dynamics and diversity can be analyzed from different points of view. Some approaches emphasize the existence of significant changes in plant species composition, plant cover and phytosociological analysis (e.g., Scholten et al. 1981; Myerscough et al. 1996; Kim 2005; Fearnehough et al. 1998; García-Mora et al. 2001; Kutiel et al. 2004; Tzatzanis et al. 2003), while others focus on the quantification of change by using synthetic indexes, such as species richness and diversity (e. g., Grunewald and Schubert 2007), or indirect indicators, such as total vegetation cover (e.g., Levin and Ben Dor 2004).

In the southern Atlantic sandy coast of the Pampas ecoregion (Argentina), the beach resorts account for more than 50% of national tourism, hosting 7,500,000 arrivals per year along 1,300 km. There are over a million lodging vacancies available, of which 85% is offered as tourist housing (Dadon and Matteucci 2009).

Two tourist corridors are found in the dunes on the Pampean coast, one on the north-eastern Coastal Barrier (northern sector) and the other on the Southern Barrier (southern sector) (Fig. 1). Urbanization on the dune barriers began in the 1940s and it has grown exponentially since the 1970s. A major factor that has promoted this fast urbanization was the development of successful methods for consolidating the sandy substrate, based on afforestation with non-native, fast growing trees. Since 1950, provincial law prohibits the division of lots on virgin dunes and requires that areas are forested prior to their urbanization (*op. cit.*). This led to an increase in areas forested with alien species, such as *Acacia melanoxylon, Tamarix gallica* and *Pinus* species (Fig. 3). Real estate prices of woody lots rose due to the regional belief that sites with trees have greater aesthetic and environmental quality than grassy dunes. Although most of the cities in Buenos Aires province developed in naturally treeless environments, exotic tress were preferred in most urban plantings, reflecting the legacy of an European immigrant past in today's landscape (Faggi and Ignatieva 2009).

As a consequence of the land use changes related to afforestation and urbanization, significant changes took place in the dune vegetation. At the beginning of the *XX*th century, the pristine dune vegetation was open grassland composed of about 70 species and dominated by grasses that withstand being buried with sand and dispersed by sea water (Cabrera 1941).

The aim of this study was to analyse temporal and spatial changes in the composition of the foredune vegetation as a result of urban development, afforestation and related human activities.

For the temporal comparison we examined vegetation changes in grassy dunes, comparing the situation in 2005–2006 with historical published data (Cabrera 1941). Cabrera studied the vegetation in the thirties (1930–1940) before the advent of massive tourism, which can be considered as the typical undisturbed plant community near to the beach. He described seven plant associations for the northern part of the Pampean coast and three for the southern part, all of which were characterized by the dominance of plants with rhizomes and buds at or near the soil surface, by the scarcity of shrubs and annuals and by the absence of trees.

For the spatial comparison we analysed the changes in vegetation after the afforestation of grassy dunes by comparing the species assemblages in wooded and open dunes in 2005–2006.

We expected dune dependent species to be the most affected group, altered over time by human processes. Traditional actions and activities that occur in the dunes, such as recreation, and sand extraction but also afforestation, would change most of the dune assemblages. We hypothesized that total diversity would decrease under forest, with the depletion of the native components in the understory and that grassy dunes would be invaded by spontaneously growing exotic trees, especially those known to be invasive.

Fig. 1 Study area

Material and methods

Study area

Plant surveys were performed at 14 resorts along a coastal strip extending from 36° 18′S–56° 47′ W to 38° 59′ S–61° 18′W in the province of Buenos Aires. The coast of the *pampas* in the province of Buenos Aires has two long dune ridges extending along approximately 600 km. At the beginning of the *XX*th century, the foredunes were quite large and varied in shape and position. Dune breaches and tidal inlets were seen along the coastline. The native grassy vegetation of the foredunes remained almost untouched by humans until ca. 1940 when urban resorts began to spread along the beach-dune system. There was no maritime forest until the expansion of tourism-driven urbanization.

The coastal region is characterised by a dry subhumid climate with little or no water surplus and homogeneous temperature conditions with a mean air temperature of 14°C. Mean precipitation ranges from 1,053 mm in the north (San Clemente) to 830 mm in the south (Necochea) with maximums in spring and at the end of summer. Mean wind velocity in the south (23.8 km/h) is about twice that in the north (10.7 km/h).

On the basis of climatic and land use differences we grouped the data in two sets: a northern (S_N : 36° 18′S–37° 27′S) and a southern (S_S : 38° 34′S–38° 59′S) sector (Fig. 1, Table 1).

The S_N sector extends from San Clemente to Villa Gesell, with an area of 43,619 ha, 17.20% of which is urban. Localities such as Villa Gesell, Mar de Ajó, San Bernardo, La Lucila and Pinamar are the most important urban resorts. There are no rural areas interspersed between them and they are well interconnected by a provincial road. Administratively they belong to urban districts and have undergone important growth in the last few decades. Tourism is the main economic activity in this sector.

The S_S sector extends over 65,633 ha and is mainly rural: only 4.6% of the area is urban. Necochea and Monte Hermoso are the most important urban centres. They are not directly connected to each other and each one has its own regional area of influence (Fig. 2).

In order to identify differences between the sectors we calculated landscape metrics derived from an unsupervised classification of Land Sat ETM + images, which emphasize some differences based on land cover maps. We used land use classes and mean patch size for the following categories: vegetated sandy beach and afforested dunes, dense and dispersed urbanisation.

The S_N sector is highly urbanized and more populated than the S_S sector. Urban patch size is larger than in $S_{S;}$ there are more afforested areas and the area of dunes covered with vegetation is comparatively smaller. A lower mean patch size for areas with trees indicates that the cities have also spread over them. Although woods were planted in the 1940s the tree canopy is frequently discontinuous, leaving gaps that are very rapidly colonized by herbs and grasses.

Floristic data

We recorded all vascular plants growing on afforested and non-afforested foredunes during the summers of 2005 and 2006. Plant richness (PR) and percentage cover (CO) were estimated at 74 sites. For the spatial comparison we stratified sampling plots into “woody”—*Acacia- Tamarix* woodland—and the remaining “open dune” vegetation—*Panicum racemosum* grassland in the northern sector and *P. urvilleanum* grassland in the south. We chose this sampling

Table 1 Characteristics of the Northern and Southern sectors of a beach strip along the Atlantic coast of the Province of Buenos Aires

	Northern sector S_N 36° 18′S–37° 27′S 43,619 ha	Southern sector S_S 38° 34′S–38° 59′S 65,633 ha
Climate[a]		
Mean temperature (°C)	14.45*	14.18**
Mean wind velocity (km.h^{-1})	10.7*	23.8**
Mean annual precipitation (mm)	1,053*	830**
Soil[b]		
pH	7.8*	6***
Fe–Al oxide%*	2.38*	4.18***
Calcium carbonate%*	8.6*	0.75***
Socio-economic characteristics[c]		
Percent of urbanised area (%)	17.20	4.6
Permanent population (inhabitants)	42,654	3,420
Landscape metrics[d]		
Classes (ha)		
Sandy beach	17,540	18,901
Vegetated dunes	14,953	40,806
Afforested dunes	3,622	2,875
Dense urbanisation	5,276	2,579
Disperse urbanisation	2,228	472
Mean size patch (ha)		
Sandy beach	91	50
Vegetated dunes	383	340
Afforested dunes	9	22
Dense urbanisation	712	258
Disperse urbanisation	156	154

Resorts: *"San Clemente", ** "Necochea", ***"Monte Hermoso"

[a] SMN National Meteorological Service www.smn.gov.ar. We chose two resorts, San Clemente and Necochea as representative, of each sector

[b] Cabrera (1941)

[c] National Census (2001)

[d] Own data, see methods

design after an initial reconnaissance of the surveyed area, together with the analysis of satellite images.

We determined the size of sampled plots by estimating their minimal area. As the dune vegetation was fairly homogeneous, the sizes of the sampling areas were 10 m^2 for open sand dunes and 25 m^2 for afforested dunes.

Fig. 2 Planted woodlands

In order to analyse the different proposed hypotheses we classified species into the following categories: planted (IESP) and spontaneous trees (SET), and for spontaneously growing herbs—those characteristic of dunes (DUN) and grasslands (GRAS), species indicating moist areas (ISH: mesic plants) and exotics (EXO).

For the temporal comparison we used 18 vegetation inventories carried out by Cabrera between 1930 and 1940 (Cabrera 1941) for the pre-urbanisation state. This information was used as a reference and represents the historic "pre-urbanization" plant cover.

Data analyses

For the temporal comparison we grouped sampled plots into four categories: grassy dunes in 1930–1940 (D_{N40}; D_{S40})—former dunes—and in 2005–2006 (D_{N06}; D_{S06})—current dunes—for the northern and southern sectors.

For the spatial comparison we grouped sampled plots into four categories: afforested dunes in the northern (FN) or southern sector (FS); and open grassland dunes in the northern (DN) or southern sector (DS). In each contrast we compared the selected variables par wise.

Firstly we classified the six data sets regarding floristic composition and abundance (two for 1930–1949, four for 2005–2006) with a multivariate analysis, which are shown in a cluster analysis (dendrogram Fig. 3).

We compared the selected temporal and spatial categories in terms of four indicators: 1) total plant richness, 2) total percentage cover, 3) diversity index "H′dune" (Grunewald and Schubert 2007) and 4) Czekanowski Similarity Index (SI).

Plant richness was estimated as the number of species and cover as the percentage of ground covered by any species. We compared differences in percentage cover between afforested and open grassland dunes with two-way ANOVA tests at Error Type I, probability rate α=0.05.

Additionally we calculated the total diversity index and diversity for spontaneous natives and exotics. Natives were discriminated into three groups of plants: components of dunes, of grasslands and plants indicating moist areas. We employed the diversity index "H'_{dune}", which uses the relative species abundance as cover percentage relative to the sampled area. This value, developed by Grunewald and Schubert (2007) for studying disturbance in dune communities, is an estimate of the cover for each species relative to the constant plot size and not to the total cover of all plants.

$$H'_{dune} = -\sum pi_{dune} \times \ln(p_i)$$

pi_{dune} : cover percentage of the i^{th} species relative to plot size

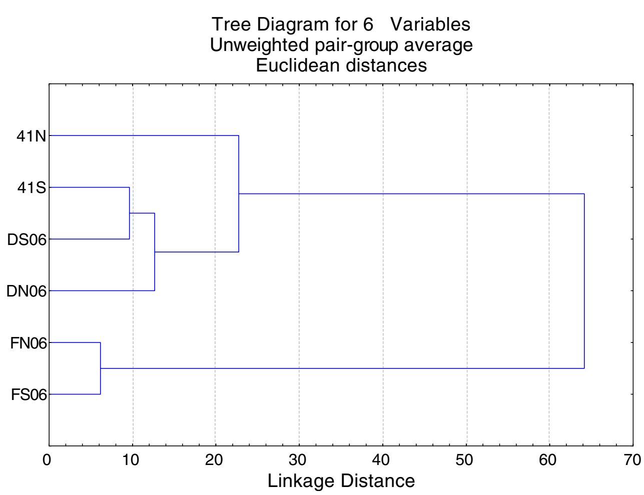

Fig. 3 Cluster analysis of plant community composition for current and former dunes. References: *41N, 41S* Sandy dunes in the northern and southern sector in 1930–1940. *DN06, DS06* sandy dunes in the northern and southern sector in 2005–2006. *FN06, FS06* forested dunes in the northern and southern sector in 2005–2006

To prove that the two compared diversity indexes were highly significantly different (p=0.05) we used the t test (Hutchenson in Zar 1996).

$$t = H_1{'}_{dune} - H_2{'}_{dune} / (\mathrm{Var}\, H_1{'}_{dune} + \mathrm{Var}\, H_2{'}_{dune})$$

where Var $H_1{'}_{dune}$ is the variance of the data set 1 and Var $H_1{'}_{dune}$ of the data set 2.

The Czekanowski Similarity index (SI) is a quantitative measure reflecting the heterogeneity of the samples (Matteucci and Colma 1982).

$$SI = 2\sum \min(xi1, xi2, ..)/\sum (xi1 + xi2, ..)$$

x1 and x2 = abundance of each species in samples 1 and 2, and min = the minimum value for the abundance of the common species in both samples. Values of this index vary from 0 to 1. The value 0 indicates that species assemblages differ totally (dissimilarity), and value1 that they are identical. If the SI coefficient is higher than 0.75 it is considered to reflect very high similarity, values in the range between 0.51 and 0.75 reflect high similarity, and values between 0.26 and 0.50 describe moderate similarity. Low similarity is described by values below 0.25 (Ratliff 1993). We calculated similarity for five groups of plants: total, exotic, dune obligate, grassland and mesic species.

Results

Cluster analysis (Euclidean distances) showed that both currently forested dune areas clearly separate from the current and former sandy dunes (Fig. 3).

Among the latter, the data sets from 2005 to 2006 (DS06, DN06) grouped together showed some differences with the dunes studied by Cabrera in the thirties. Forested dunes discriminated especially by planted and spontaneously growing trees.

Values of total richness and total plant cover were similar for all sampled areas in the past and at the present time (Fig. 4).

Temporal floristic comparison (1930–1940 vs. 2005–2006)

The plant associations described in the thirties are still present today, although some dune species such as *Thelesperma megapotamica, Baccharis artemisioides, Gamochaeta filaginea,* among others, have disappeared and the percentage cover of many species has changed. For example, *Adesmia incana, Androthichum trigynum* and *Hyalis argentea* decreased in abundance significantly. In the thirties Cabrera recorded a total of 29 plants of the *Panicum* association growing in the sandy foredunes in S_N

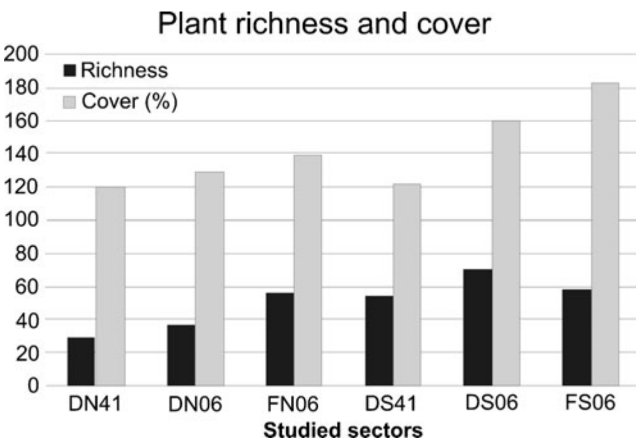

Fig. 4 Plant richness and percentage cover in former and current sandy and forested dunes in the northern and southern sector. References: *DN41, DS41* Sandy dunes in the northern and southern sector in 1930–1940. *DN06, DS06* sandy dunes in the northern and southern sector in 2005–2006. *FN06, FS06* forested dunes in the northern and southern sector in 2005–2006

and 54 in S_S. The percentage of exotics was 18%. All of them grew spontaneously and there were no planted species.

In 2005–2006 we recorded 37 (DN_{06}) and 56 (FN_{06}) species in S_N and 70 (DS_{06}) and 58 (FS_{06}) in S_S. The percentage of exotics was 42% and six species *(Tamarix gallica, Acacia melanoxylon, Myoporum laetum, Pinus* spp., *Carpobrotus chilensis*, *Yucca* sp.) have been planted for sand binding.

A similar trend in percentage cover for both sectors is seen in Figs. 5 and 6: a decrease in species characteristic of dunes and an increase in other plant groups in the current dunes.

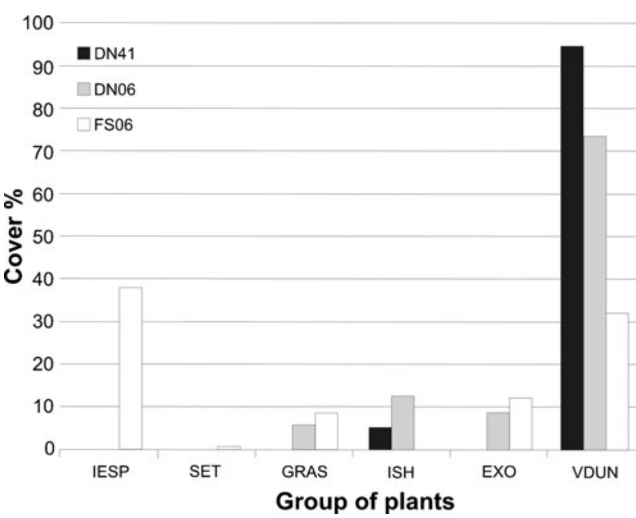

Fig. 5 Percentage cover of the defined plant groups in former and current dunes in the northern sector (N). References: *IESP* implanted exotic species for sand binding. *SET* spontaneous exotic trees. *GRAS* plants characteristic of grasslands. *ISH* plants indicating soil moisture. *EXO* exotics. *VDUN* plants characteristic of dunes

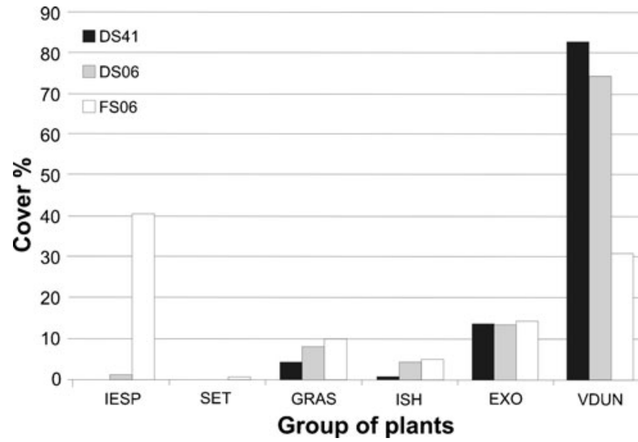

Fig. 6 Percentage cover of the defined plant groups in former and current dunes in the southern sector (S). References: *IESP* implanted exotic species for sand binding. *SET* spontaneous exotic trees. *GRAS* plants characteristic of grasslands. *ISH* plants indicating soil moisture. *EXO* exotics. *VDUN* plants characteristic of dunes

In 2005–2006 the total diversity of the grassy dunes was significantly higher in both sectors (H'_{dune} in sector N_{06} = 0.49; H'_{dune} in sector S_{06} = 0.56; p=0.01) than in the past (Table 2).

In order to analyze the differences in gains and losses of the plant groups defined in methods we calculated diversity by dividing them into categories of species that grow spontaneously. In S_N the diversity of plants characteristic of dunes and mesic soils was significantly higher in the past than today; the opposite was found for dune species in S_S. In this sector we also found greater values that were statistically significant for exotic plants (p=0.01).

Low and moderate similarity indexes (Table 3) mirrored a similar trend previously seen in diversity.

Spatial comparison: forested vs. grassy dunes (2005–2006)

There were no significant differences in the total diversity of the characteristic species of dunes and moist areas or between grassy vs. afforested dunes in 2005–2006, at a significance level of 0.05. On the contrary species characteristic of grasslands were highly significant and more disperse in the open dunes. A significantly opposite trend was seen in the diversity of exotics in both sectors (Table 4).

Total floristic similarity between woodlands and grassy dunes in both sectors (forest vs. open dunes in the northern and southern sectors) was moderate (SI = 0.38 S_N and 0.44 S_S), but it was high in the northern sector for dune species (SI = 0.51) and grassland species (SI = 0.72) (Table 5). The same trend was seen in the southern sector for dunes and mesic species. The similarity for exotic species was moderate in both sectors.

Table 2 Temporal comparison of diversity indexes in former and current grassy dunes in the northern and southern sector

	Northern sector		Southern sector	
	Grassy dunes 1930–1940	Grassy dunes 2005–2006	Grassy dunes 1930–1940	Grassy dunes 2005–2006
Diversity index	$H'_{duneN41}$	$H'_{duneN06}$	$H'_{duneS41}$	$H'_{duneS06}$
Total	0.15a*	0.49b*	0.21c*	0.56d*
Native plants characteristic of:				
Dunes	1.17a**	0.073b**	1.48c**	2.17d**
Grasslands	0.0018	0.0115	1.87	1.80
Moisture in soil	2.16a*	1.68b*	1.09	1.21
Exotic	0.63a**	1.98b**	0.39c**	2.25d**

Significant:* at .05, ** at .001

Discussion

Our results showed different trends in the selected vegetation variables comparing former vs. current grassy dunes, and current grassy vs. forested dunes. Significant differences showed that the diversity of grassy dunes increased in both sectors over the span of 70 years ($H'_{duneN41} = 0.15$ vs. $H'_{dune\,N06} = 0.49$; $H'_{duneS41} = 0.21$ vs. $H'_{dune\,S06} = 0.56$). This trend could be associated with anthropogenic disturbances, such as urbanization and recreation. Changes over time might be linked to sand extraction, dune reshaping, and also to increases in nutrient levels, soil sealing and run-off. Dune-based recreation activities, e.g. dune driving, horse riding and trampling, could be seen as moderate disturbances. These alterations occurred mostly during the summer and they allowed some new species to cohabit with the pioneer plants, so the diversity increased. A higher number of ruderal plants were reported by Grunewald and Schubert (2007) and Provoost et al. (2010) as a result of rising nutrient levels in areas with a high level of tourism, together with the influence of ornamentals escaped from cultivation (Pärtel et al. 1996). Higher plant diversity could be explained by the intermediate disturbance hypothesis of Connell (1978), which states that diversity would peak at intermediate levels of disturbance when a variety of species co-occur and disturbances are not so extreme for competitive exclusion to take place.

Table 3 Similarity indexes in former and current grassy dunes in the northern and southern sector

Similarity index (SI)	Grassy dunes 1930–1940	
	Northern sector	Southern sector
Grassy dunes 2005–2006 Total plants	0.22 (L)	0.22 (L)
Grassy dunes 2005–2006 Dune plants	0.19 (L)	0.29 (M)
Grassy dunes 2005–2006 Grasslands	0.05 (L)	0.02 (L)
Grassy dunes 2005–2006 Moisture in soil	0.28 (M)	0.03(L)
Grassy dunes 2005–2006 Exotics	0	0.09 (L)

L low; *M* moderate; *H* high similarity

Statistically significant differences were not found in the total plant richness and total cover in the temporal and spatial comparisons. Total cover in the Pampean dunes remained stable up to the present, even though the disturbance regime has changed since 1940. This result was in contrast to the studies of Kutiel et al. (2004), who reported that significant changes in the disturbance levels caused increments in vegetation cover in Israeli dunes. Even when richness remained constant over the decades, some replacement of species took place. While the presence of native herbs declined, the number of ruderal and grassland species increased. García-Mora et al. (2000) found a similar result in the dune systems in Spain and Portugal, where the total number of species per plot did not change in response to different coastal dune conditions.

Plant groups did not behave in the same way within the studied sectors. In the northern sector, the dune and moist area species were significantly more diverse during the pre urbanization period (1940) than in 2005–2006. In the first half of the *XX*th century, plants able to withstand sand burial, such as *Calycera crassifolia, Spartina coarctata, Tessaria absinthoides, Androtrichum trigynum, Adesmia incana,* and mesic species, such as *Hydrocotyle bonariensis, Gerardia communis* and Cyperaceae, were more abundant than today. In 2005–2006, native herbs were less frequent than grasses, and their cover was lower, a trend also found in other regions, e.g. in South Africa Bond and Parr (2010) reported that herbs were more sensitive to

Table 4 Spatial comparison of diversity indexes in current grassy and forested dunes in the northern and southern sector

	Northern Sector 2005–2006		Southern Sector 2005–2006	
	Forested dunes	Grassy dunes	Forested dunes	Grassy dunes
Diversity index	$H'_{\text{dune FN}}$	$H'_{\text{dune GN}}$	$H'_{\text{dune FS}}$	$H'_{\text{dune GS}}$
Total	0.25	0.49	0.23	0.56
Diversity index of native plants characteristic of:				
Dunes	3.11	3.03	1.78	1.66
Grasslands	0.01a****	1.45b****	0.65c*****	1.80d*****
Moisture in soil	1.36	1.68	1.3	1.21
Exotic	2.82a*****	1.98b*****	1.36c***	2.25d***

Significant = *** at .05, ****at .02, *****at .01

changes than grasses. They found that the diversity of herbs was less than half that of pristine grasslands in a restored grassland after afforestation.

At the present time in the southern dunes, species characteristic of dunes and exotics were significantly more diverse than in the 1940s. Higher plant dune diversity groups might be linked to latter stages of the natural succession and to lower human population and tourist pressure; exotics to the influence of agriculture. The spread of exotics, either introduced into the surroundings from pastures or as weeds from the rural environment (*Dactylis glomerata, Festuca arundinacea*, various clovers) together with ornamentals escaped from gardens (*Gazania longiflora, Lagurus ovatus*), changed the composition of the original vegetation. A similar trend was frequently observed in many Spanish coastal regions (García-Mora et al. 2000, 2001). According to these authors, the replacement of functional types would be the mechanism that operates in disturbed dunes, and species able to withstand sand burial, and rhizomatous species, are expected to be replaced by small, annual and perennial species. Such replacement was observed in our data as predicted by those authors.

Table 5 Similarity indexes in current grassy and forested dunes in the northern and southern sector

Similarity index (SI)	Forested dunes	
	Northern sector	Southern sector
Grassy dunes Total plants	0.38 (M)	0.44 (M)
Grassy dunes Dune plants	0.51 (H)	0.55 (H)
Grassy dunes Grasslands	0.72(H)	0.14 (L)
Grassy dunes Moisture in soil	0.28 (M)	0.61(H)
Grassy dunes Exotics	0.50(M)	0.49 (M)

L low; *M* moderate; *H* high similarity

Some recorded species were indicators of trampling, e.g. *Cynodon dactylon,* which was very frequently associated with intensive recreational areas, especially at resort centers, confirming the results reported by Tzatzanis et al. (2003) in sand dunes in Crete.

The similarity index values for different plant groups between current and former dunes showed low—moderate values, indicating that losses and gains took place in almost all groups, due to an increase in grassland and exotics species over time.

Afforestation of grassland areas constitutes permanent transformation which directly affects the dynamics of the natural vegetation. Several authors in recent decades provided dissimilar evidence of the consequence of such a change which depended on climatic and biogeographical peculiarities. The impact of afforestation on total diversity has pros and cons. It has been recommended for arid and semiarid regions in order to increase species richness, improve soil fertility and reduce the impact of sand storms (El-Keblawy and Ksiksi 2005; Strauss 2001). However, the expansion of planted forests and the intensification of management have raised concerns about the implications of these trends for sustainable production and the conservation of biological diversity (Carnus et al. 2006). In many regions of the world the planting of exotic trees caused irreversible damage to the local environment (Avis 1989). For that reason afforestation is no longer been implemented as dune stabilization in many countries (e.g. England, Wales, Denmark among others) (Defra 2007). Moreover restoration projects are underway, which aim to convert pine plantations into natural dune landscapes based on a dynamic dune management approach (Rooney 2010).

Ehrenfeld et al. (2001) demonstrated that exotic invasion could cause changes in the soil and discussed the effects of the ornamental woody shrub *Berberis thunbergii* that invaded forests extensively throughout the east coast of USA. Faggi et al. (2006) reported on the consequences of woodland invasions on the displacement of native grasslands in periurban areas of Buenos Aires.

Moreover, Samways and Taylor (2004) found that invasive alien *Acacia* trees destroyed the habitats of South African dragonflies that were particularly sensitive to conditions of light and shade by shading out the understory vegetation. In Atlantic sand dunes that were planted with *Acacia melanoxylon and Tamarix gallica*, grassland and rural birds were replaced by granivores and urban ones (Faggi et al. 2010). Yasue and Dearden (2006) observed that the conversion of medium height vegetation into tall monocultures on Thai beaches affected Malaysian plovers, because plovers selected wide beaches with low levels of human disturbance that had a low percentage cover of tall trees.

One of the hypotheses to be tested was that the dune groups would be impoverished in the understory of wooded Pampean dunes, since those species are more sensitive to the presence of a closed canopy. However, the results showed no significant differences for these dune groups, as compared with the non-forested areas. These results were the same for both the northern and southern sectors. Our findings showed that the wooded sites were moderately similar in floristic composition to grassy dunes, although very different in structure. The floristic composition of the characteristic dune and mesic species was similar at both forested and non-forested sites in both sectors.

Exotics showed different trends in S_N and S_S, being significantly more diverse in the grassy dunes in the southern sector. In S_S the invasion of non-native species might be associated with the dispersion of weeds from the rural environment and the escape of ornamental plants from domestic gardens (*Gazania longiflora, Lagurus ovatus, Festuca arundinacea*). The exotic plants replacing natives are of European and Asiatic origin, many of which have become widely distributed. Most of them are typical agricultural weeds which grow spontaneously on roadsides, meadows, pastures, or in modified rich soils. A similar source is reported by Kim (2005) for the species populating Korean sand dunes. He found many species, such as *Plantago lanceolata, Chenopodium album, Medicago* spp., *Vulpia myuros, Avena fatua, Dactylis glomerata, Festuca arundinacea, Lolium* spp., *Hypochaeris radicata*, that were also found in our plots.

One of the most important fast growing trees used in Pampean afforestations is *Acacia melanoxylon*, cited as an invader in other regions (Le Maitre et al. 2002). These authors reported the invasion of this tree on the South African coast. However, in the Pampean coastal region there were no clearly dominant exotic species in the sampled sites, suggesting that the stressful conditions of the studied habitats present a barrier to alien invasion (Sobrino et al. 2002). These findings were in agreement with observations by Von Holle and Motzkin (2007) from coastal sand plains in the United States, who found that few invasive plants could thrive on the xeric, poor nutrient soils in the coastal region, or compete with the native species.

Relative lower values in the similarity index, in the comparison between grassland and exotic plants, also confirmed that gains were taking place in these categories under forest. However, afforestation did not seem to evoke a great biotic homogenization as discussed by Schwartz et al. (2006) for urban and urbanizing regions of California. However, our results were in accordance with Kim (2005) who proved that anthropogenic activities, like the clearing of dunes for building projects, horse grazing, beach resorts, leisure facilities and military training, among 14 environmental variables, threatened to damage the physical and biological elements of Korean sand dunes. Of these, the beach resort was the most frequent cause of disturbance (17.6%), followed by military facilities, leisure facilities and housing, while afforestation only represented 0.6%.

In conclusion, an increase in plant diversity over time, with the replacement of species and proportional changes in cover, was observed for the Pampean coastal dune vegetation. An increase in exotic plants and characteristic grassland species in the foredunes suggested that gains were taking place in these categories, but up until 2005–2006 there was no danger of invasions. The comparison of current forested vs. open dunes showed that a canopy of trees did not significantly decrease the diversity of the understory species.

Functional groups of plants can be used as bioindicators of the quality of habitats that have been modified by humans. Along the South Atlantic coast of Argentina, changes associated with afforestation using exotic trees show modifications to the flora assemblages: two groups of plants (dune obligate and moisture indicators) were found to be sensitive to those changes.

Our results have implications for an adaptive dune management. These outcomes provide useful information for helping decision making and can help to settled up an integral plan of sustainable beach management and quality assessment to be applied in each coastal municipality.

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