Sand Dunes system of Southern South America
Red List of Ecosystems Assessment

Authors: Marinez Scherer, Tatiana Silva, Eduardo Martins, Eleonora Veron, Daniel Conde, Vitor de Souza, Carolina Marques, Vinicius Silveira, Tomaz Brentano, Flavia Farina, João Nicolodi, Lucrecia Allega, Milton Asmus, Nelson Gruber, Fabricio Almeida, Martina Camiolo

This assessment is the result of a project called LEAP - Leveraging Ecosystem-based Approaches for Priority-setting (South Atlantic Coast). The project gathered a panel of experts from Brazil, Uruguay and Argentina to apply the IUCN Red List of Ecosystems Categories and Criteria for the risk assessment of a regional ecosystem.

The implementation of the project was led by the Federal University of Santa Catarina (UFSC) and focused on the sand dunes systems of the southern South Atlantic Coast as a first step towards an approach that can be replicated in other regions. **The project was supported by the Bio-Bridge Initiative (BBI) of the Convention on Biological Diversity (CBD)** and counted with a close collaboration with the IUCN Commission on Ecosystem Management (CEM).

Figure 1. Sand dune system at Cabo Polonio National Park, Uruguay. Source: WikiMedia Commons

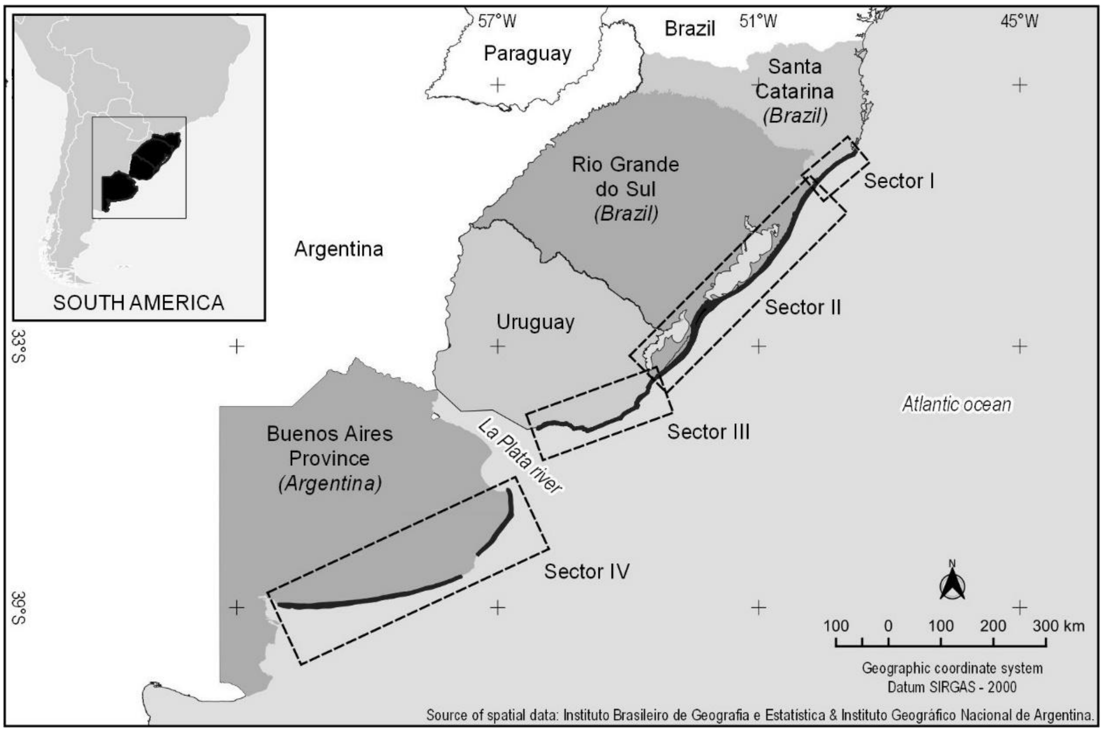
CLASSIFICATION

According to v 1.01 of the IUCN Global Ecosystem Typology (Keith et al., 2020), the coastal sand dunes of Southern America are a subunit of the Coastal shrublands and grasslands (MT2.1) Ecosystem Functional Group. Nevertheless, coastal processes (Morton, 1977; 2003) make the relationship with the adjacent ecosystem (Sandy Shorelines - MT1.3) interdependent. On the other hand, according to the IUCN Habitat Classification Scheme v3.1, the target ecosystem is classified in the category Coastal Sand Dunes, including humid dune slacks (M13.3.). In this case, the relevance of salinity, sea spray and wind for biota is highlighted (Wells, 1938; Boyde, 1954).

DISTRIBUTION

The target ecosystem covers 5,275 km^2 and is distributed in a continental strip adjacent to the Atlantic Ocean, of variable width (0,3 - 15 km), between parallels 28 - 39° S between the cape of Santa Marta Grande (State of Santa Catarina/Brazil) and the town of Bahía Blanca (Province of Buenos Aires/Argentina), thus expanding through the coastlines of Brazil, Uruguay and Argentina. Its continuity is interrupted by exhutories, highlands and capes (local scale), as well as by more frequent erosive features and human infrastructures in the vicinity of the city of Mar del Plata/Argentina and by the estuary of the La Plata river (regional scale). The data were obtained from regional mapping (scale 1: 100,000), suitable for historical assessments of large areas by service satellite images.

In this study we divided the dune system in four distinct sectors. Sectors I and II comprises Santa Catarina and Rio Grande do Sul States, respectively, in Brazil. Sector III ranges over the coast of Uruguay and Sector IV extends up to the southernmost point of the dune system in South America, in Argentina. The ecosystem sectorization was performed in order to indicate the most appropriate management strategies across three different countries according to their characteristics and own environmental legislation. In this context, we applied the IUCN Red List of Ecosystem for both the regional ecosystem, but also for each sector separately.



ECOSYSTEM DESCRIPTION

Characteristic native biota

The characteristic biota for dune complexes includes a range of taxa that are resultant from interactions between tolerant plant species and sandy substrate, high wind velocities, salt spray, salt accretion and environmental heterogeneity (Marcomini & López, 2013). Propagules of many plant species are dispersed and deposited along the dune system, but the establishment, growth and reproduction are restricted to species that are able to cope with environmental stresses associated with the sand movement.

Foredune is a highly unstable environment constantly subjected to erosion caused by the wind. Coastal foredunes do not reflect autogenic succession and habitat types tend to be a result of differences between their initial environmental conditions and changes of abiotic factors thereafter. In consequence, the associated vegetation reflects characteristics of pioneer communities (Doing, 1981, 1985). Species that dominate this habitat are *Panicum racemosum* associated with *Blutaparon portulacoides* and *Senecio crassiflorus* in places with more stability (Cordazzo & Seeliger, 1993). Other species that occur in this ecosystem are *Ammophila arenaria, A. littoralis, Carex sp. Festuca sp. Elymus farctus, Spinifex sp., Panicum sp., Spartina sp., Sporobolus sp*. and other species such as *Eryngium* (Hesp, 2009).

Fauna of coastal dunes is dominated by arthropods and vertebrates, particularly insects, lizards, birds and mammals (McLachlan, 1991; Bujes & Verrastro 2008). Also, arachnids can be found along the ecosystem, whereas crustaceans occur near the beach (Barnes, 1953). Backshore and dunes are important colonization areas for other crustaceans, especially talitrid amphipods and oniscid isopods (McLachlan *et al.*, 1987). Frogs may also occur in lime-rich soils (Roberts, 1984). Still, insects are dominant throughout the ecosystem, especially the orders Hymenoptera, Coleoptera and Diptera (Ardö, 1957). Bacteria and fungi are the primary colonizers of supralittoral and dune sands and exhibit a landward succession (Webley et al., 1952; Forster & Nicholson, 1981). Mammals often traverse dunes temporarily to forage carcasses or wrack at the beach.

Abiotic Environment

The target ecosystem consists of coastal dune fields, composed of different dune types and subaerial landforms, located in the Holocene Barrier IV, referring to the most recent Laguna-Barrier System (Villwock & Tomazeli, 1995); formed by the slow drop in the relative sea level after reach its maximum level (+1 - 4m) between 5 - 6 thousand years before the present (Isla et al., 1996; Dillenburg et al., 2009; Hesp et al., 2009; Bracco et al., 2011; Isla, 2017).

The wind regime is an important variable for the target ecosystem, as it is the main transport agent for, mostly, medium to very fine sands (Isla et al., 2001; Dillenburg et al., 2009). The predominant winds vary according to the latitudinal and seasonal variations: from NE in Brazil to N - NW in Argentina (Cortizo & Isla, 2007; Dillenburg et al., 2009).

Other relevant variables that influence the availability of sediment are: (a) the wave regime, with a predominance of the South to East directions (Bird, 2010; Dillenburg et al., 2009); (b) the microtidal regime, with the occurrence of semidiurnal tides (Schnack et al., 2008; Dillenburg et al., 2009; Bracco et al., 2011); (c) fluvial inputs as sources of fine sediments, and the shoreface and continental shelf as sources of sandy sediments, and d) storm events (overwash). The sediment transport in the coastal zone occurs through littoral drift (S - N) and cross-shore processes (Dillenburg et al., 2000;

2009; Isla, 2017).

Regarding the occurrence *per se* of the target ecosystem, coastal erosion is a recurring phenomenon (Barboza et al., 2011; Goso et al., 2011; Isla, 2017) that has influenced the area “available” to the ecosystem. However, in large areas, this problem is of local importance, since the dynamics of the different transport agents end up redistributing the sediment volume; obviously with possible outputs (and inputs) of sedimentary material in the coastal system.

Interactions and Processes

Sand dunes are dynamic ecosystems, characterized by mobile (primary) and fixed (secondary) dunes and by the subjacent sandy beaches (Figure 2). Sediment balance is the key process that shapes this ecosystem, since it determines erosion or accretion of sand to the dune system. If the sediment balance is negative, the system is eroded and, therefore, it culminates in distribution decline. On the other hand, if there is a positive sediment balance, there is accretion of sand into the system and its distribution increases. Positive sediment balance also promotes pedogenesis. Sediment balance is promoted by physical oceanographic phenomena (i.e. waves, tides and currents) and by climatic phenomena (i.e. rain, winds, humidity and river discharge). These phenomena are greatly influenced by climate change, which shifts current patterns of erosion and accretion in the system.

Sediment balance is also influenced by the topography and granulometry, since they define the sizes of sand grains that are retained and the ones that are transported, besides how this transportation occurs. The volume of available sediment is also a result of sediment fixation, promoted by the vegetation on the system which traps sediments under its coverage. Native vegetation suppression promotes colonization by ruderals and other invasive species, which reduces native vegetation. Groundwater table level both influences and is influenced by the native vegetation, since the higher the density of vegetation, higher is the potential for the soil to retain water. Native fauna is also influenced by and influences the native vegetation.

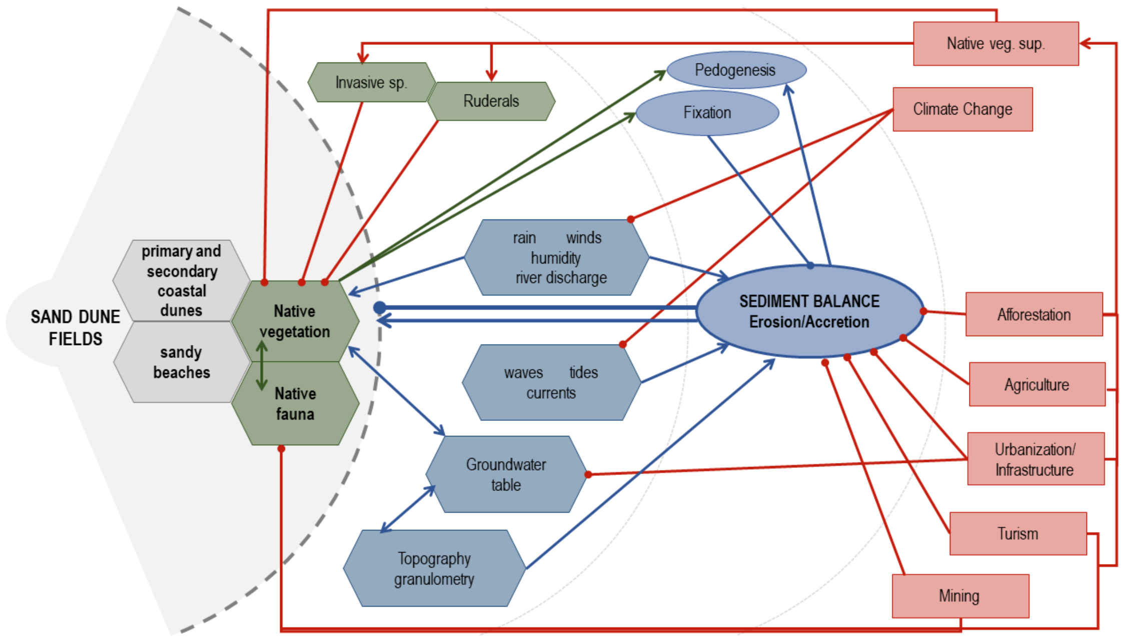


Figure 2. Cause-effect model of ecosystem dynamics for coastal dunes in Southern South America, showing biotic (green) and abiotic (blue) components of the ecosystem. Threats to the ecosystem are shown in red. Arrows symbolizes promotion, whereas dots refer to reduction of certain aspect.

Threatening processes

Three major threats currently affect dune systems in Southern South America. Two of the main threatening processes are the urbanization in Sectors I and IV and afforestation in Sectors II and III. Also, climate change has a significant impact on the dune system, although the quantification of its severity and extent of occurrence are still challenging.

Artificialization of the coastal zone was described to have significant negative impacts on coastal dynamics and has played a remarkable role in Santa Catarina State (Sector I) and Argentina (Sector IV) (Dadon, 1999; Ferreira *et al.*, 2009). Urbanization processes affects parts of the ecosystem that border urban areas (, since they block wind flows and, therefore, hinder sediment transportation (Marcomini & Lopéz, 1997). In addition, urbanization poses a major threat to groundwater table reservoirs, due to the extraction of water to supply population demands (Foster *et al.*, 1994). Ratings of urbanization in coastal areas within this region have been increasing in the last 50 years (Barragán *et al.,* 2003; de Andrés & Barragán, 2016) and is likely to cause rapid declines in the ecosystem.

A.

B.

Figure 3 A. Aerial photograph of a dune system near an urban area in Cidreira, Rio Grande do Sul State. Source: Coastal Oceanography Laboratory (FURG). Figure 3 B. Urban allotment in Jaguaruna, Santa Catarina State. Photo: Eduardo Martins.

Afforestation has been described as a major threat to dune ecosystem worldwide (Sturgess & Atkinson, 1993). It alters the dune landscape, increasing stabilization of dune fields and changing wind transport rates within the ecosystem and toward the beach (Marcomini & López, 2013, Codignotto *et al*., 2012). It also has negative impacts on native flora, spreading throughout the dune system with little control (Hill & Wallace, 1989; Lasta *et al*, 2019). In addition, afforestation reduces groundwater table volume, causing the drying of dune slacks and resulting in the loss of vegetation (Bakker, 1990, Capítulo *et al.,* 2018) and affecting dune dynamics (Seeliger *et al.*, 2000). In Rio Grande do Sul State, afforestation has been accounted as one of the major threats to the State's shoreline (Esteves, 2004), occupying 9.5% of the study area in 2018 (unpl. data). On the other hand, Uruguay has gone under a program to promote afforestation since the beginning of the twentieth century (Latorre & Canavero, 2014), which occupies 27.6% of the study area (unpl. data). The species cultivated are mainly flooded gum (Eucalyptus grandis), blue gum (Eucalyptus globulus), and loblolly pine (Pinus taeda) (Geary, 2001). Its impacts have a major influence on the dune system borders, but it is potentially harmful to the ecosystem in general, since artificial forests have a great spreading potential (Castiñera *et al.*, 2013; Panario & Gutiérrez, 2005). Since the demand for wood materials worldwide is increasing, it is likely that the reclamation of dunes for afforestation will increase in the next years (Gautreau, 2010).

Dune coasts are very sensitive to climate changes especially in relation to wind regime, rainfall, water-table and sea level variations that condition dune activity by changes in the sand supply to the littoral system (Marcomini & López, 2013). Aeolian processes and landforms result from the interaction between winds and land surfaces and changes in atmospheric parameters and surface conditions can potentially modify transportation patterns. It is still challenging to assess the rate of climate change impact on the dune ecosystem, since the ecosystem response is known to lag behind climatic change (Hugenholtz and Wolfe, 2005). Still, it can be assumed that this threat will likely impact the whole ecosystem, since it is a global phenomenon. Also, climate change is expected to increase in the next decades, being characterized as an ongoing threat.

ASSESSMENT

Summary

Criterion	A	B	C	D	E	Overall
Regional Ecosystem						LC
Subcriterion 1	DD	LC	DD	DD	NE	
Subcriterion 2		LC	DD	DD		
Subcriterion 2.a	DD					
Subcriterion 2.b	LC					
Subcriterion 3	DD	LC	DD	DD		
Sector I - Santa Catarina State						VU (VU - EN)
Subcriterion 1	DD	CR	DD	DD	NE	
Subcriterion 2		EN	DD	DD		
Subcriterion 2.a	DD					
Subcriterion 2.b	VU(VU-EN)					
Subcriterion 3	DD	LC	DD	DD		
Sector II - Rio Grande do Sul State						LC (EN - LC)
Subcriterion 1	DD	EN	DD	DD	NE	
Subcriterion 2		LC	DD	DD		
Subcriterion 2.a	DD					
Subcriterion 2.b	LC					
Subcriterion 3	DD	LC	DD	DD		
Sector III - Uruguay						EN (LC - EN)
Subcriterion 1	DD	EN	DD	DD	NE	
Subcriterion 2		VU	DD	DD		
Subcriterion 2.a	DD					
Subcriterion 2.b	EN (LC-EN)					
Subcriterion 3	DD	LC	DD	DD		
Sector IV - Argentina						LC
Subcriterion 1	DD	LC	DD	DD	NE	
Subcriterion 2		LC	DD	DD		
Subcriterion 2.a	DD					
Subcriterion 2.b	LC					
Subcriterion 3	DD	LC	DD	DD		

**Criterion B was not considered on the overall assignment of category for the subsectors, because the criterion was designed to detect restricted distribution and we know the ecosystem is a continuum that we split for a matter of understanding local processes. Further information on the respective section.*

Criterion A

Current decline: Sand dunes evolved during the Pleistocene-Holocene sea level fluctuation, limited by water bodies on the continent and by the ocean. Changes in distribution were assessed using spatial coverage estimates from LANDSAT images from the USGS repository (U.S. Geological Survey, 2020). In addition, we combined vector data from MapBiomas (Projeto MapBiomas, 2020), Instituto Geográfico Nacional (IGN) from Argentina and Dirección Nacional de Minería y Geologia (DINAMIGE, 2017). Four time periods were analyzed – 1985, 1991, 2000 and 2018 – and changes in distribution are compiled in Table 1.

Data analysis point for a 45.39% decline in Sector I (Table 1), with the highest percentage observed between the period of 2000 and 2018. Within this area, urban expansion is shown to be the major threat to the ecosystem (unpubl. data) and was responsible for the major decline after 2000's. Sector II shows a decline of 13.83% in distribution, with higher rates of loss between 2000 and 2018, mainly due to the expansion of silviculture areas within the sector. Sector III demonstrated 33.32% of decline in dunes distribution during the period of analysis and had the highest percentage of decline amongst sectors. In contrast, Sector IV had the lowest percentage of decline during the period, although it presented the highest decline in area – 20,217 ha. Overall, the total area of decline was 48,593 ha, which represents 16.34% of the sand dunes ecosystem in the study area. Figure 4 summarizes ecosystem loss from 1985 to 2008, presented in this analysis.

Although the time frame analyzed (between 1985 and 2018) was not sufficient to subside the application of criterion A1, the rate of decline along the period was used to project expected changes in the future. In this context, the criterion A1 was classified as Data Deficient for all sectors and the regional ecosystem.

Table 1. Estimated extent and decline (in ha) in distribution of sand dunes on South Brazil, Uruguay and Argentina

Year	Sector I (Santa Catarina)	% decline	Sector II (Rio G. do Sul)	% decline	Sector III (Uruguay)	% decline	Sector IV (Argentina)	% decline	Total	% decline
1985	13,364		101,753		24,734		157,498		297,348	
		-0.45		3.62		14.26		3.91		4.47
1991	13,424		98,073		21,208		151,337		284,042	
		2.00		4.16		11.07		3.88		4.42
2000	13,156		93,993		18,860		145,468		271,477	
		44.53		6.71		12.56		5.63		8.37
2018	7,298		87,684		16,492		137,281		248,754	
Total decline (ha)	6,066		14,069		8,242		20,217		48,594	
Total % decline	45.39		13.83		33.32		12.84		16.34	

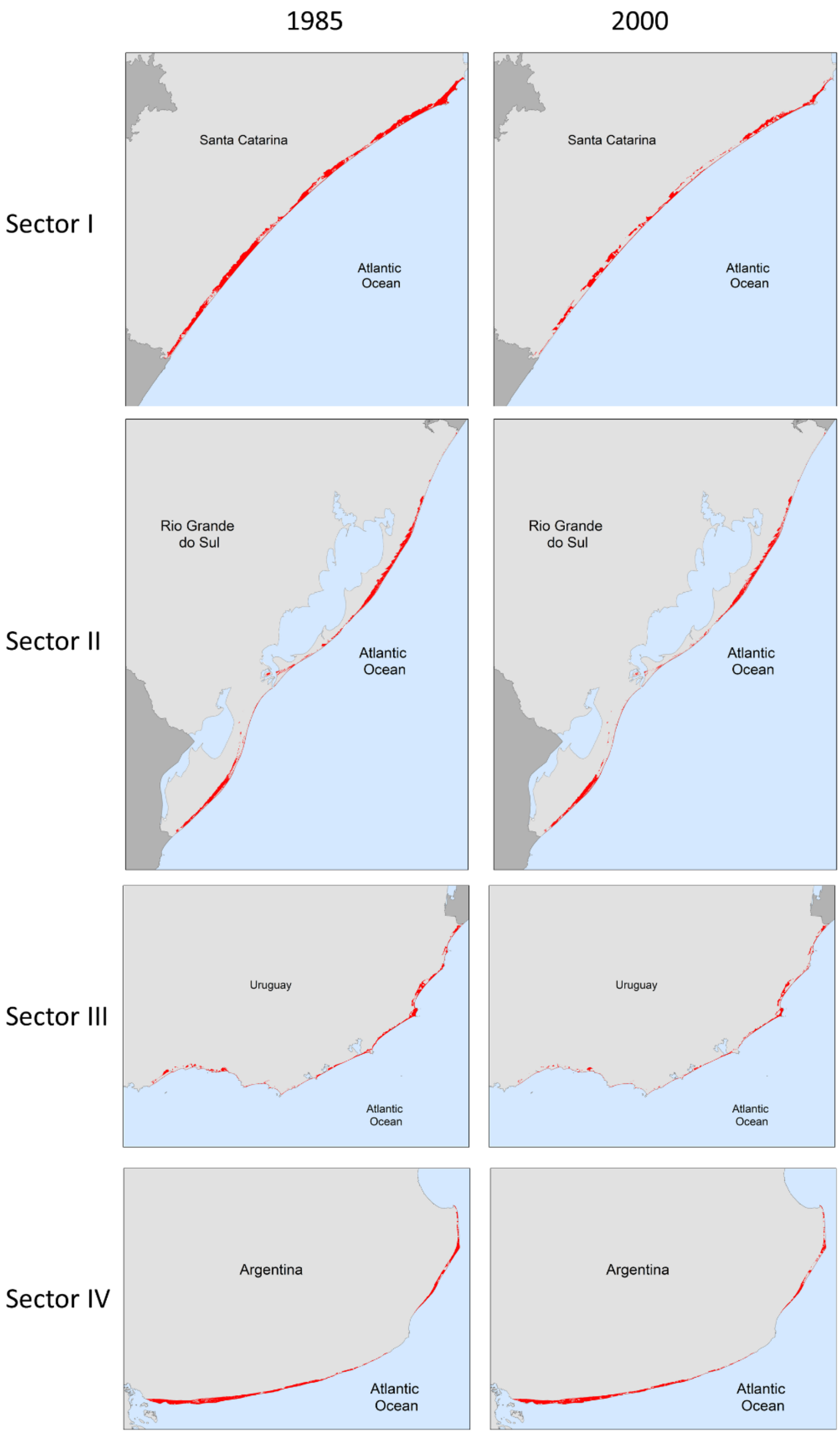


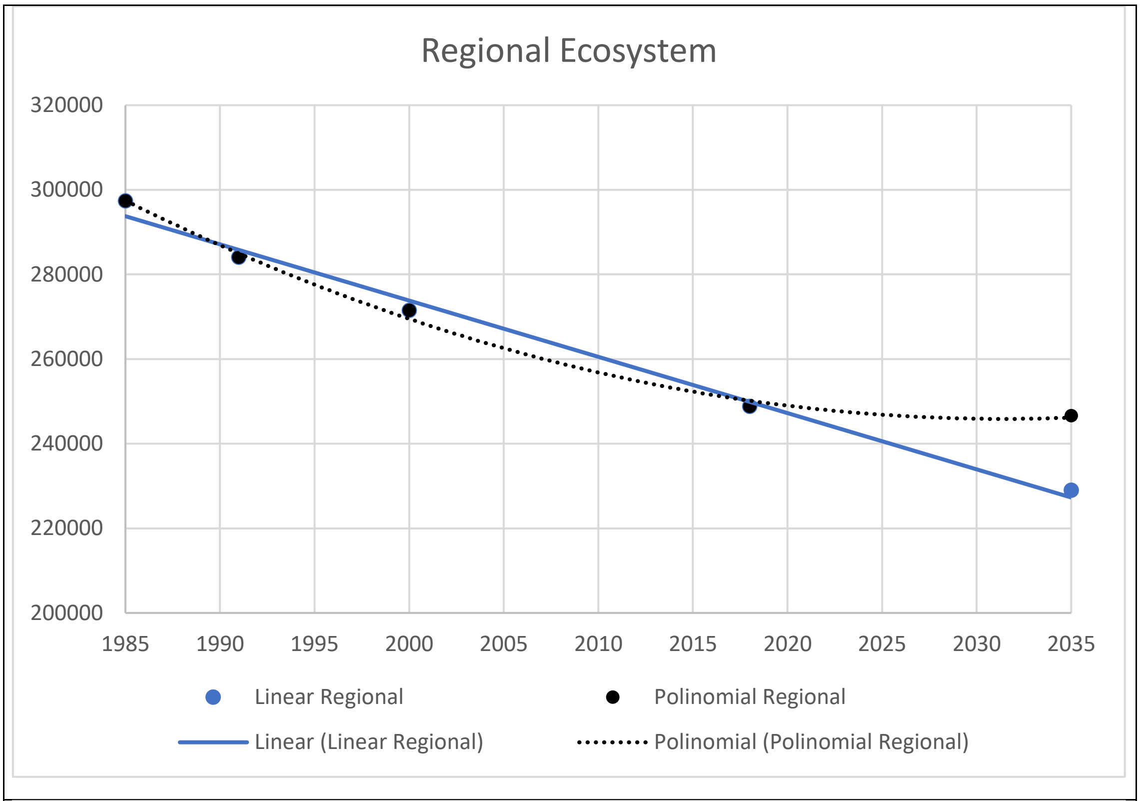
Figure 4. Change in distribution of sand dunes ecosystem between 1985 and 2008 on the four sectors analyzed.

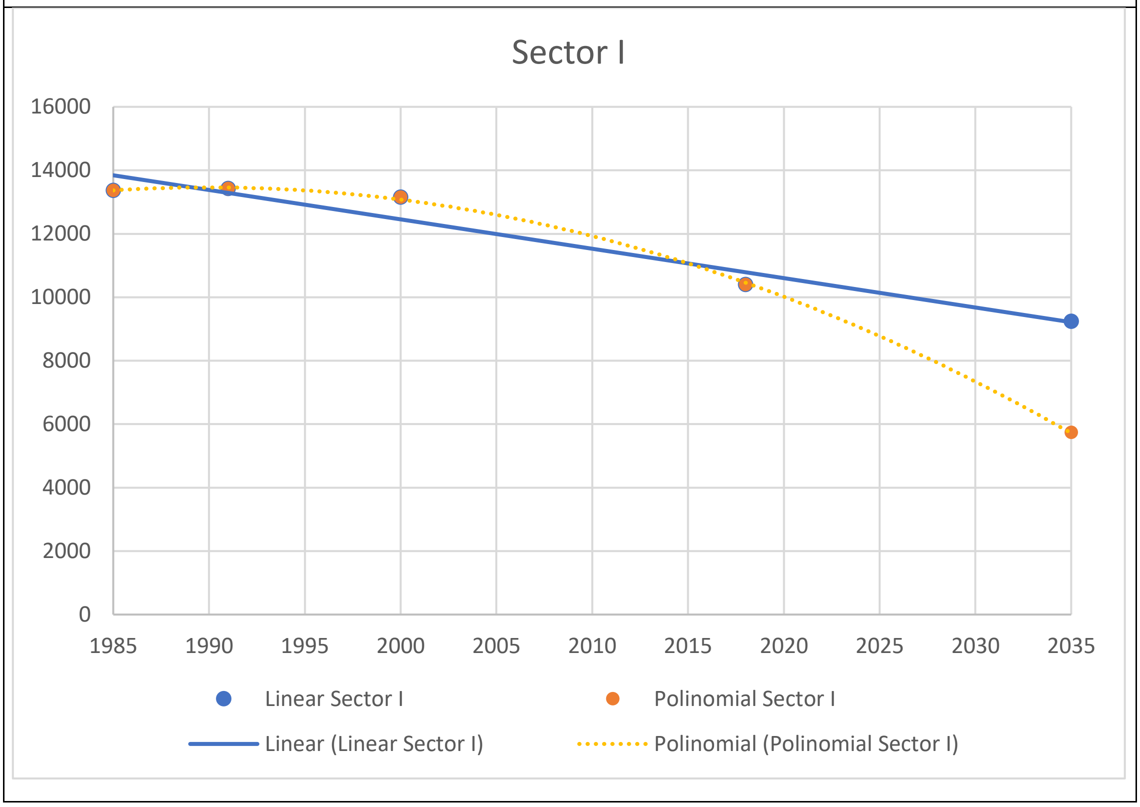
Future decline: Based on the trends of decline on ecosystem distribution we estimated rates of decline until 2035 (50-year period) for each sector (Table 2). We analyzed two different scenarios – (1) linear decline; and a (2) polynomial decline in distribution. Linear decline c

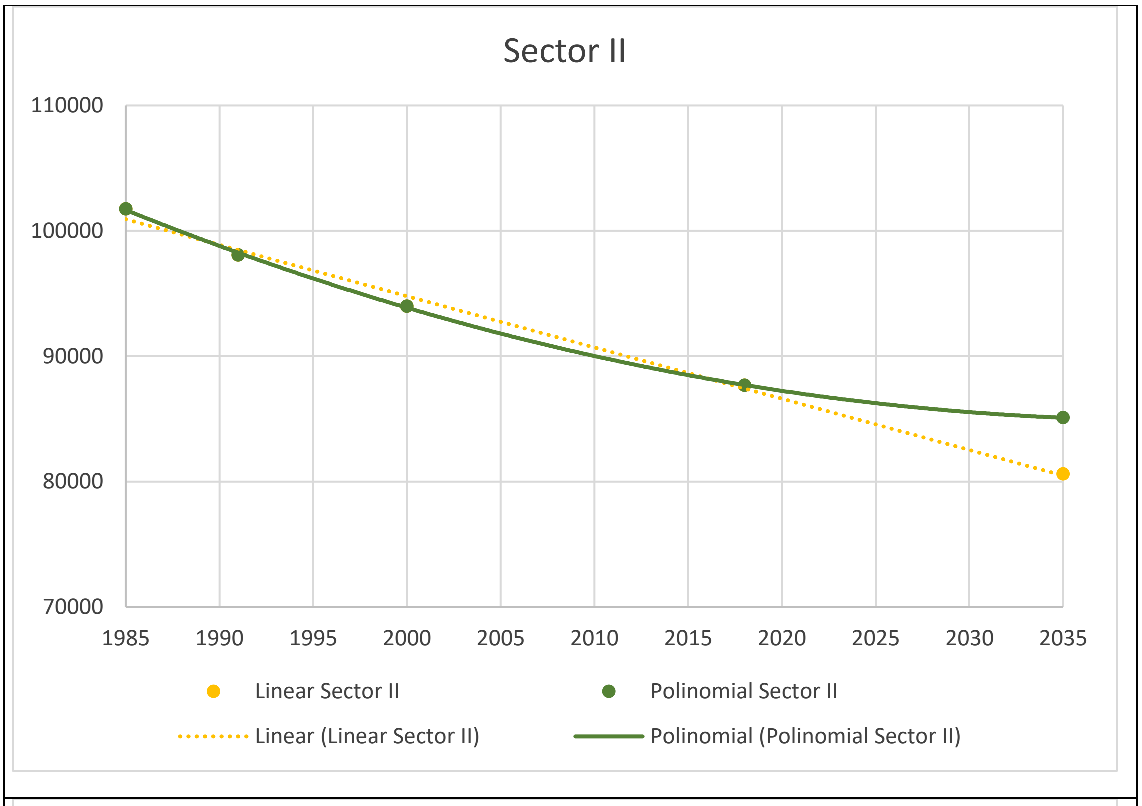
Results show that Sector I is projected to decline 30.85% in scenario 1 and 57.07% in scenario 2 until 2035. Based on the projections, Sector II is likely to decline from 16.36% (scenario 2) to 20.78% (scenario 1). Sector III is projected to decline 21.76 - 50.9%, according to the scenarios, and Sector IV is likely to decline 13.37 – 19.38%. Overall, the regional dune system is projected to decline from 17.05% (scenario 2) to 22.99% (scenario 1) in a 50-year period, from 1985 to 2035 (Figure 5).

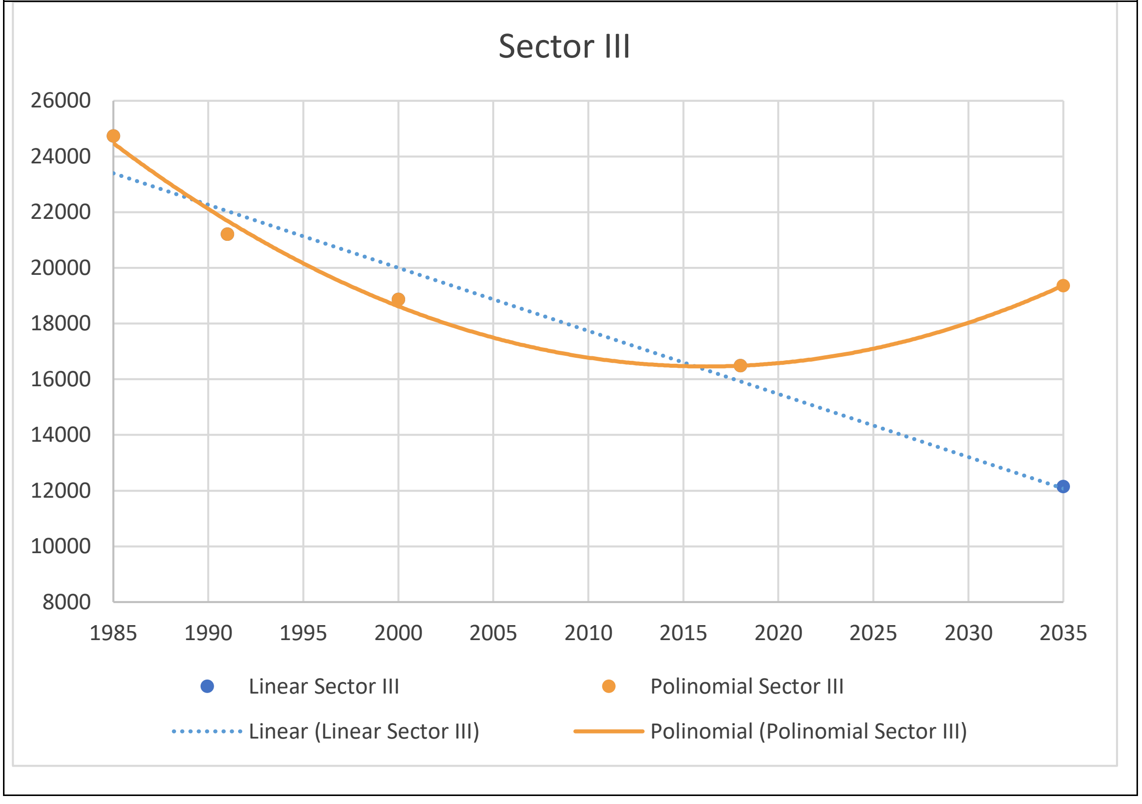
Table 2. Projections of ecosystem distribution by sectors and total, from 1985 to 2035. Projections based on linear (Scenario 1) or polynomial (Scenario 2) calculations.

	1985 (ha)	**Scenario 1 - 2035**	**Decline**	**Scenario 2 - 2035**	**Decline**
Regional Ecosystem	297,348	228,958	22.99%	246,624	17.05%
Sector I	13,364	9,241	30.85%	5,736	57.07%
Sector II	101,753	80,605	20.78%	85,101	16.36%
Sector III	24,734	12,143	50.90%	19,352	21.76%
Sector IV	157,498	126,969	19.38%	136,435	13.37%


Regional Ecosystem
320000
300000
280000
260000
240000
220000
200000
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
Linear Regional
Polinomial Regional
Linear (Linear Regional)
Polinomial (Polinomial Regional)


Sector I
16000
14000
12000
10000
8000
6000
4000
2000
0
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
Linear Sector I
Polinomial Sector I
Linear (Linear Sector I)
Polinomial (Polinomial Sector I)


Sector II
110000
100000
90000
80000
70000
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
Linear Sector II
Polinomial Sector II
Linear (Linear Sector II)
Polinomial (Polinomial Sector II)


Sector III
26000
24000
22000
20000
18000
16000
14000
12000
10000
8000
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
Linear Sector III
Polinomial Sector III
Linear (Linear Sector III)
Polinomial (Polinomial Sector III)

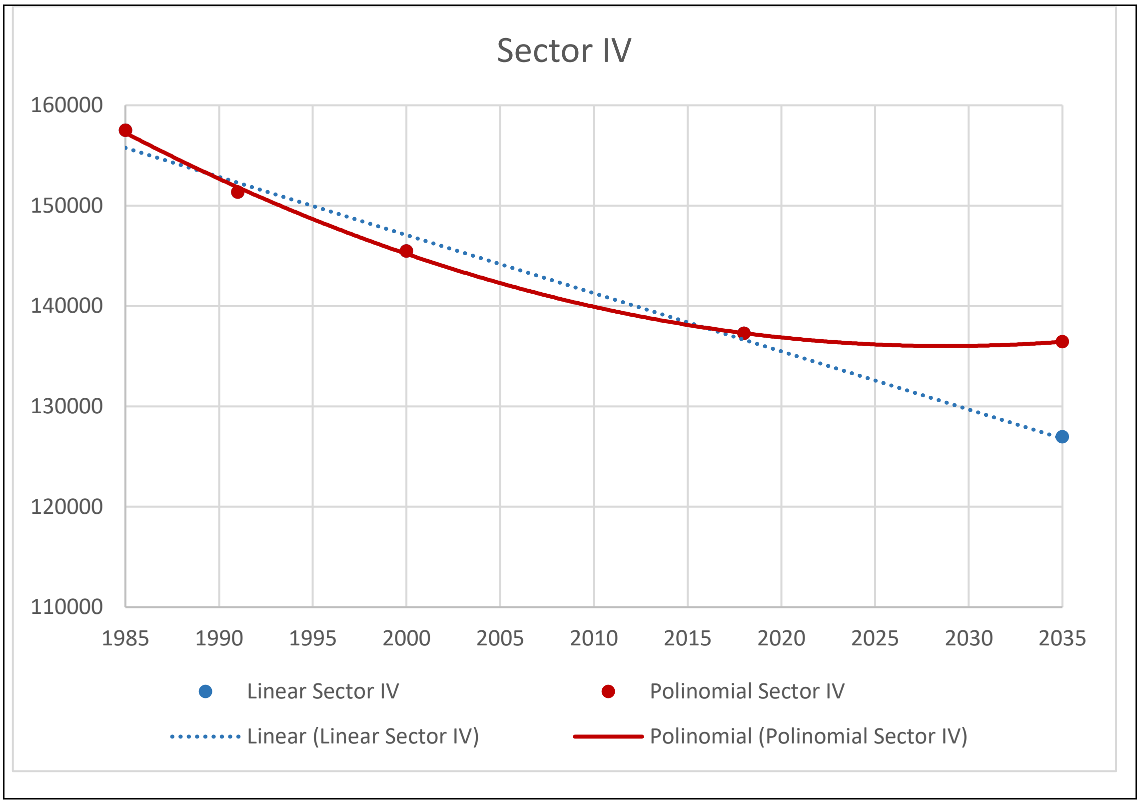


Figure 5. Projections of ecosystem decline between 1985 and 2008 of the regional ecosystem and by sectors, according to linear and polynomial calculations.

It is important to highlight that, linear projections are more conservative, since it is based on the actual trend observed on current analyzed data; whereas polynomial projections are influenced by larger variations and, therefore, reflect more severe alterations in the ecosystem. Overall, the polynomial projection (scenario 2) has demonstrated to be closer to the observed transformations over the analyzed period, except for Sector I. This sector has shown a large decrease over the period between the years of 2000 and 2018 (44.53%), which have deeply influenced the projection for 2035. In this context, although the category assignment should be based on the "precautionary principle" (Keith *et al.*, 2013), scenario 1 should be considered as the most likely scenario according to the data analyzed. Therefore, Sector I was classified as Vulnerable under criterion A2b. Sector II was classified as Least Concern, for both scenario 1 and scenario 2.

According to the analysis performed, Sector III demonstrated a high level of uncertainty between the two scenarios. Scenario 1 is likely to be influenced by the high levels of decline in the first period (1985 -1991), although it had shown a decrease in the observed decline percentage on the most recent periods. On the other hand, scenario 2 suggests a small recovery of the ecosystem within next years, influenced by the decrease on decline rates. In this sense, Sector III was classified as Endangered under criterion A2b.

Finally, Sector IV as Least Concern and the regional ecosystem was classified as Least Concern under criterion A2a.

Historical decline: No estimate of a long-term reduction in spatial extent exists for the Southern South America dunes since 1750. The status of the ecosystem is Data Deficient under criterion A3.

Criterion B

Extent of occurrence (B1)

B1 subcriterion measures the spread of risk over a contiguous area that encloses all occurrences using a minimum convex polygon. The minimum convex polygon (MCP) draws the smallest polygon around a certain distribution of points with all interior angles less than 180 degrees (Figure 6). First, all areas previously classified as dune fields in 2018 were selected. In this selection, the “minimum bounding geometry” tool in the Esri’s ArcGIS software was applied, considering a CONEX HULL geometry, which guarantees that the internal angles of the formed polygon will have less than 180º. The tool was applied to the entire length of the dune field ecosystem and to each sector assessed.

According to the results, Sector I was classified as Critically Endangered by criterion B1.b, since threats in this sector – such as urbanization and climate change – are likely to affect ecosystem distribution in the next 20 years. Sectors II and III were considered as Endangered, and likely to decline due to the major threats (afforestation and urbanization) in the next 20 years. Sector IV was classified as Vulnerable due to the extent occupied (48,255 km^2) and the current decline rate within the next 15 years (13.37 – 19.38%). Still, the regional ecosystem was classified as Least Concern.

Table 3. *Area occupied by the regional ecosystem and each sector on the minimum convex polygon.*

Sector	**Area (km²)**
Regional Ecosystem	180,425
Sector I	924
Sector II	18,738
Sector III	11,332
Sector IV	48,255

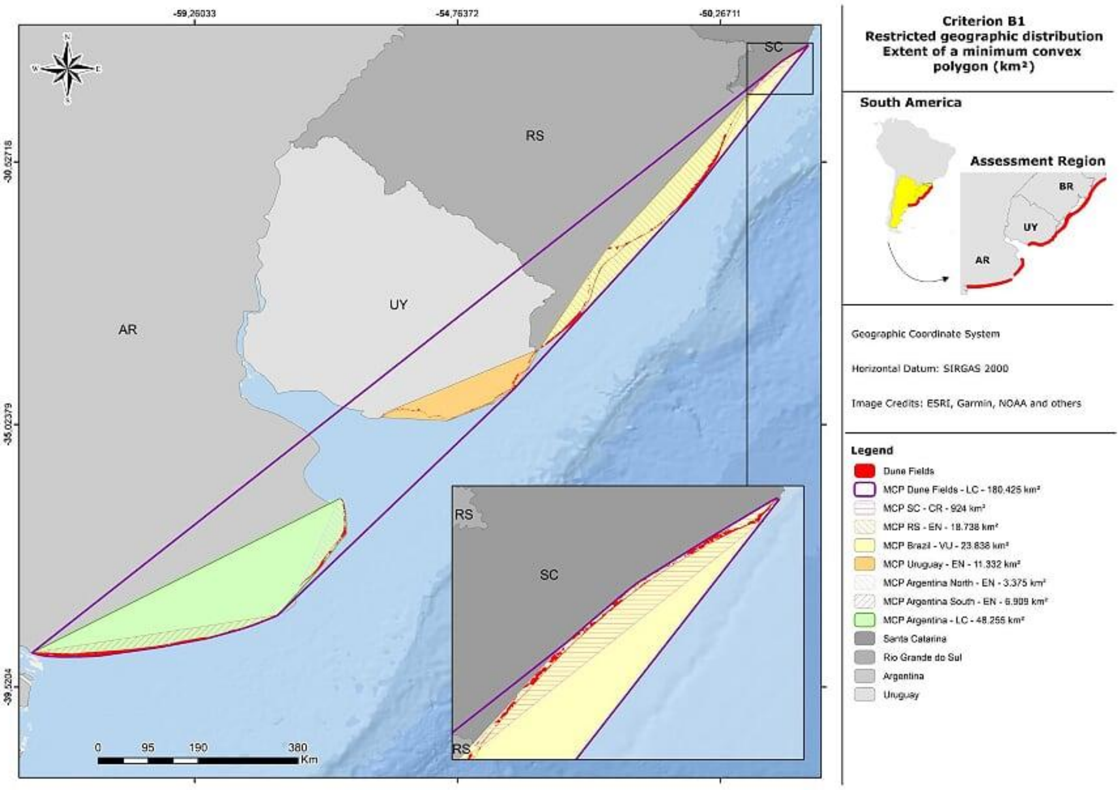


Figure 6. Minimum convex polygon for the study area.

Area of Occurrence (B2)

The Area of Occupancy - AOO (subcriterion B2) of an ecosystem defined in the RLE is determined by counting the number of 10×10 km grid cells that contain the ecosystem (Bland *et al*., 2017). First the study region was divided into 10 x 10 km cells and then cells containing dune fields were counted using the Esri ArcGIS software "select by location" tool (Figure 7). Very small patches of dune fields contribute almost nothing to minimize the risk of loss of spatial distribution, so only cells with more than 1 km² of dunes have been counted, as recommended by the IUCN methodology.

Results demonstrated that Sector I was classified as Endangered by criterion B2.b, due to the observed threatening processes identified on this sector. In addition, Sector III was classified as Vulnerable by the same criterion, with threatening processes directly affecting the sector, as demonstrated above. Sectors II, IV and the regional ecosystem were classified as Least Concern under the B2 criterion (Table 4).

Table 4. Number of grid cells occupied by the regional ecosystem and each sector.

Sector	**Number of 10×10 km grid cells occupied**
Regional Ecosystem	201
Sector I	16
Sector II	79
Sector III	32
Sector IV	74

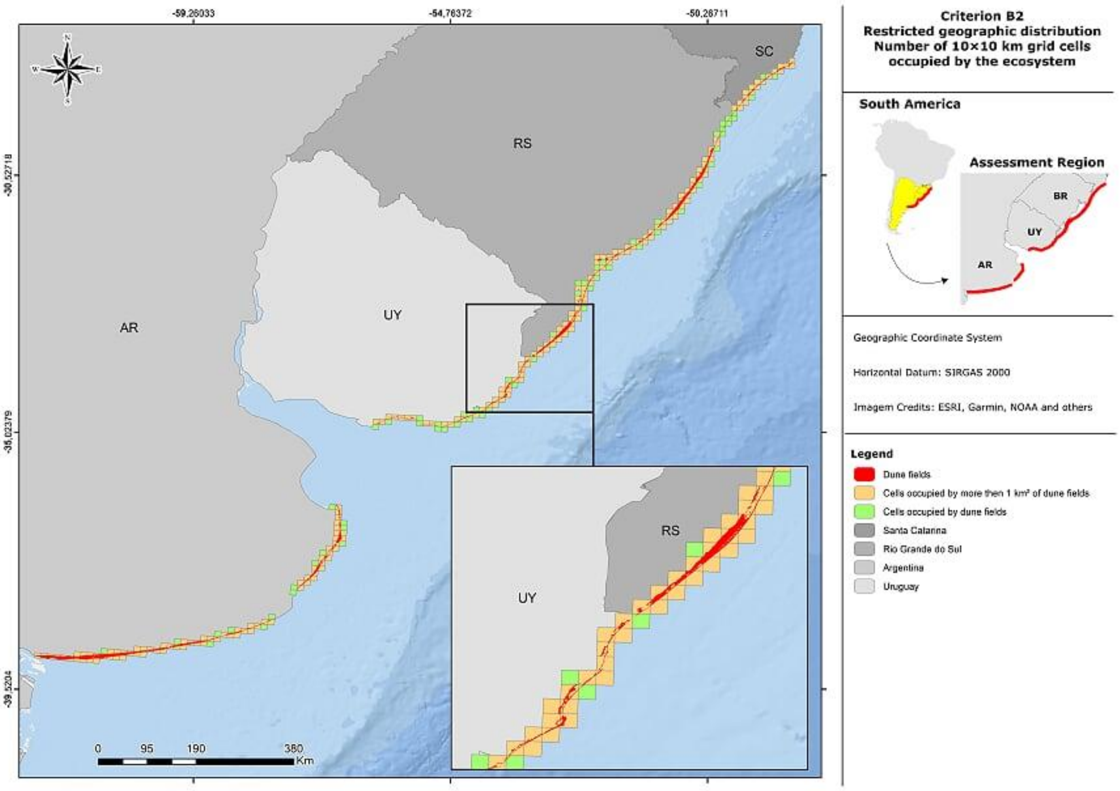


Figure 7. Number of 10x10 km grid cells occupied by the ecosystem

It is important to highlight that the sectorization performed in this study aimed at comprising different management strategies across three countries and threats over each sector. However, the regional ecosystem is formed by a continuum of sand dune fields and should be assessed as single feature under criterion B. Therefore, the results demonstrated for each sector was not accounted in the overall category assignment.

In addition, criterion B3 was not applied on this study case, since it was not possible to define a small number of threat-defined locations across the entire ecosystem.

Criterion C

Dune formation is conditioned to three main aspects: (i) sediment availability, (ii) aeolian movement with sufficient energy to transport available sediment, and (iii) adequate topographic and climate characteristics for a long-term accumulation of sediments (Pye & Tsoar, 2008).

For the first aspect, the assessment would be performed through the estimation of input and output of sediment availability into the system. In order to quantitatively estimate the volume of sediment throughout time, a geological temporal series of data is needed. However, this dataset is not available nor estimated in the scientific literature for the entire study region.

For the second aspect, there is a need for a continuous temporal wind dataset for the region. Still, the distribution of anemographs and meteorological stations along the study area is sparse and the use of the respective information is often associated to the interpolation and modelling of discrete data. In addition, downscaling of global models is uncertain, especially regarding the impacts of climate change in local dynamics and processes. Therefore, it was not possible to use wind data as a proxy for modelling sediment balance throughout the ecosystem.

Finally, the third aspect could not be accessed due to the highly dynamic nature of the ecosystem. Dune topography can be influenced by extreme events (such as storms surges) and/or by long-term climate changes (such as global warming). Still, as outlined above, global climate change impacts on local and regional dynamics is highly uncertain, particularly on wave, current and wind patterns. In addition, dune topography may be affected by inland dynamics, such as the growth of urbanization towards the dune. In combination with coastal erosion it creates an effect named "coastal squeeze" (Pontee, 2013) which is still hard to quantify.

In this context, an environmental degradation analysis could not be performed in this study. Therefore, the status of the ecosystem is Data Deficient under criterion C.

Criterion D

Colonization of ruderals and other invasive vegetation species is one of the main outcomes of biological degradation processes in the ecosystem. Changes in plant species abundance and richness would therefore be suitable proxies for biotic degradation. Quantitative analysis of changes in species composition were performed regionally (Seeliger *et al.*, 2000; Seeliger, 2003; Fontana, 2004; Monserrat *et al.*, 2012), but such data was insufficient to assess species richness and abundance within the entire ecosystem.

In addition, faunal species that occurs along the entire ecosystem are scarce. Population assessment of cosmopolitan bird species such as the American Oystercatcher (*Haematopus palliatus*) would be an adequate proxy for biotic disruption. However, regional assessments of this species concentrate on the northern hemisphere (Kushlan *et al.*, 2011; Hayes *et al.*, 2006; Nol *et al.*, 2012; Palacios *et al.*, 2017), with no studies found for the study area.

Therefore, disruption of biotic processes and interactions was not accessed for this ecosystem. Thus, the ecosystem is classified as Data Deficient under criterion D.

Criterion E

Criterion E was not assessed in this evaluation and, therefore, is classified as Not Evaluated.

References

Aguilar, C. G., Mesa, V., & del Carmen Alvez, M. (2011). Sinopsis geológico-ambiental de la costa platense y atlántica de Uruguay. *Problemática de los ambientes costeros*, 59.

Andrés, M. D., & Barragán Muñoz, J. M. (2016). Desarrollo urbano en el litoral a escala mundial. Método de estudio para su cuantificación. Revista de Estudios Andaluces, 33 (1), 64-83.

Ardö, P. A. E. (1957). Studies in the Marine Shore Dune Ecosystem with Special Reference to the Dipterous Fauna: By Paul Ardö. Nya litografen.

Bakker, T. W. M. (1990). The geohydrology of coastal dunes. In Dunes of the European Coasts, ed. T. W. M. Bakker, P. D. Jungerius & J. Klijn. Catena, lg (supplement), 109-19.

Barboza, E. G., Rosa, M. L. C. C., Hesp, P. A., Dillenburg, S. R., Tomazelli, L. J., & Ayup-Zouain, R. N. (2011). Evolution of the Holocene Coastal Barrier of Pelotas Basin (Southern Brazil)-a new approach with GPR data. *Journal of Coastal Research*, 646-650.

Barnes, R. D. (1953). The ecological distribution of spiders in non-forest maritime communities at Beaufort, North Carolina. Ecological Monographs, 23(4), 316-337.

Barragán, J. M., Dadon, J. R., MatteuccI, S. D., Morello, J. H., Baxendale, C., & Rodriguez, A. (2003). Preliminary basis for an integrated management program for the coastal zone of Argentina. *Coastal Management*, *31*(1), 55-77.

Bird, E. (Ed.). (2010). *Encyclopedia of the world's coastal landforms*. Springer Science & Business Media.

Boyce, S. G. (1954). The salt spray community. *Ecological monographs*, *24*(1), 29-67.

Bracco, R., García-Rodríguez, F., Inda, H., Del Puerto, L., Castiñeira, C., & Panario, D. (2011). Niveles relativos del mar durante el Pleistoceno final-Holoceno en la costa de Uruguay. *Holoceno en la zona costera de Uruguay*, 65-91.

Bujes, C. S., & Verrastro, L. (2008). Annual activity of the lizard Liolaemus occipitalis (Squamata, Liolaemidae) in the coastal sand dunes of southern Brazil. Iheringia. Série Zoologia, 98(1), 156-160.

Castiñeira, E.; Fagúndez, C.; D A Costa, E.; Canavero, A.. Composition and vegetation structure in a system of coastal dunes of the "de la Plata" River, Uruguay: a comparison with Legrand ́s descriptions (1959). Brazilian Journal of Botany, v.36, n.1, p.9-23, 2013.

Capítulo, L. R., Carretero, S. C., & Kruse, E. E. (2018). Impact of afforestation on coastal aquifer recharge. Case study: eastern coast of the Province of Buenos Aires, Argentina. Environmental earth sciences, 77(3), 74.

Codignotto, R.O., Isla, R.R., Monserrat, A. L. (2012). Manejo del Sistema Playa-Dunas en las Costas de la Provincia de Buenos Aires (Argentina). En: Rodríguez-Perea, A., Pons, G.x., Roig-Munar, l.X., Martín-Prieto, l.Á., Mir-Gual, M. y Cabrera, l.A. (eds.). La gestión integrada de playas y dunas: experiencias en Latinoamérica y Europa: Mon. Soc. Hist. Nat. Balears, 19: 271-287. ISBN: 978-84-616-2240-5. Palma de Mallorca.

Cordazzo, C. V., & Seeliger, U. (1993). Zoned habitats of southern Brazilian coastal foredunes. *Journal of Coastal Research*, 317-323.

Cortizo, L. C., & Isla, F. (2007). Evolución y dinámica de la barrera medanosa entre los arroyos Zabala y Claromecó, partidos de San Cayetano y Tres Arroyos, Buenos Aires. *Revista de la Asociación Geológica Argentina*, *62*.

Dadon, J. R. (1999). Gestión de sistemas con baja biodiversidad: Las playas arenosas del Noreste de la Provincia de Buenos Aires. *Biodiversidad y uso de la tierra. Conceptos y ejemplos de Latinoamérica*, 529-548.

Dillenburg, S.R.; Roy, P.S., Cowell, P.J.; Tomazelli, L.J. (2000). Influence of antecedent topography on coastal evolution as tested by the Shoreface Translation Barrier Model (STM). Journal of Coastal Reserch, 16(1):71–81.

Dillenburg, S. R., Barboza, E. G., Tomazelli, L. J., Ayup-Zouain, R. N., Hesp, P. A., & Clerot, L. C. (2009). The Holocene Coastal Barriers of Rio Grande do Sul. In *Geology and Geomorphology of Holocene Coastal Barriers of Brazil* (pp. 53-91). Springer, Berlin, Heidelberg.

Doing, H. (1981). A comparative scheme of dry coastal sand dune habitats, with examples from the eastern United States and some other temperate regions. Veroffentlichungen Geobotanisches Institut ETH, Stiftung Riibel, 77, 41-72.

Doing, H. (1985). Coastal foredune zonation and succession in various parts of the world. Vegetatio, 61, 65-75.

Esteves, L. S. (2004). Shoreline changes and coastal evolution as parameters to identify priority areas for management in Rio Grande do Sul, Brazil. *Pesquisas em Geociências*, *31*(2), 15-30.

Ferreira, J. C., Silva, L., & Polette, M. (2009). The coastal artificialization process. Impacts and challenges for the sustainable management of the coastal cities of Santa Catarina (Brazil). *Journal of Coastal Research*, 1209-1213.

Fontana, S. L. (2004). *Present and past coastal dune environments of South Buenos Aires Province, Argentina* (Doctoral dissertation, Acta Universitatis Upsaliensis).

Forster, S. M., & Nicolson, T. H. (1981). Microbial aggregation of sand in a maritime dune succession. Soil Biology and Biochemistry, 13(3), 205-208.

Foster, S. S. D., Morris, B. L., & Lawrence, A. R. (1994). Effects of urbanization on groundwater recharge. In *Groundwater problems in urban areas: Proceedings of the International Conference organized by the Institution of Civil Engineers and held in London, 2–3 June 1993* (pp. 43-63). Thomas Telford Publishing.

Gautreau, P. (2010). Rethinking the dynamics of woody vegetation in Uruguayan campos, 1800–2000. Journal of Historical Geography, 36(2), 194-204.

Geary, T. F. (2001). Afforestation in Uruguay: Study of a changing landscape. Journal of

Forestry, 99(7), 35-39.

Hayes, F. E., Paice, M. R., Blunden, T., Smith, P. W., Smith, S. A., White, G., & Frost, M. D. (2006). Status of the American Oystercatcher (Haematopus palliatus) in St. Vincent and the Grenadines. Journal of Caribbean Ornithology, 19(1), 48-51.

Hill, M. O. & Wallace, H. L. (1989). Vegetation and environment in afforested sand dunes at Newborough, Anglesey. Forestry, 62, 249-67.

Hesp, P. A., Giannini, P. C., Martinho, C. T., Da Silva, G. M., & Neto, N. E. A. (2009). The Holocene barrier systems of the Santa Catarina coast, southern Brazil. In *Geology and geomorphology of Holocene coastal barriers of Brazil* (pp. 93-133). Springer, Berlin, Heidelberg.

Hugenholtz, C. H.*, and* S. A. Wolfe *(*2005*),* Biogeomorphic model of dunefield activation and stabilization on the northern Great Plains*. Geomorphology,* 70*,* 53–70*.*
Isla, F. I. (2017). Coastal barriers from Argentina: Buenos Aires, Patagonia and Tierra del Fuego. *Quaternary and Environmental Geosciences*, *8*(1).

Isla, F. I., Cortizo, L. C., & Schnack, E. J. (1996). Pleistocene and Holocene beaches and estuaries along the Southern Barrier of Buenos Aires, Argentina. *Quaternary Science Reviews*, *15*(8-9), 833-841.

Isla, F. I. (2017). Coastal barriers from Argentina: Buenos Aires, Patagonia and Tierra del Fuego. Quaternary and Environmental Geosciences, 8(1).

Keith, D. A., Rodríguez, J. P., Rodríguez-Clark, K. M., Nicholson, E., Aapala, K., Alonso, A., ... & Benson, J. S. (2013). Scientific foundations for an IUCN Red List of Ecosystems. *PLOS one*, *8*(5).

Kushlan, J. A., Hickey, C., & White, A. W. (2011). The American Oystercatcher (Haematopus palliatus) in the Northern Bahamas. Journal of Caribbean Ornithology, 24(2), 48-55.

Lasta, Carlos; González, Emiliano; Verón, Eleonora; Ortale, Manuel y Camiolo, Martina. (2019). Evaluación de la Vulnerabilidad a la Erosión del Frente Costero de la provincia de Buenos Aires. Informe Anual General 2019. OPDS. 170pp.

Latorre, E. C., & Canavero, A. (2014). Coastal Dunes changes from 1966 to 2001 in the de La Plata River, Uruguay. Revista Ibero-Americana de Ciências Ambientais, *5*(1), 27-37.

Marcomini, S. C., & López, R. A. (1997). Influencia de la urbanización en la dinámica costera, Villa Gesell, provincia de Buenos Aires, República Argentina. *Revista de la Asociación Argentina de Sedimentología*.

Marcomini, S. C., & López, R. A. (2013). Erosion and management in coastal dunes. In *Coastal hazards* (pp. 511-553). Springer, Dordrecht.

Maun, M.A. (2009). The biology of coastal sand dunes. Oxford University press, New York, p 265.

McLachlan, A., Ascaray, C., & Du Toit, P. (1987). Sand movement vegetation succession and biomass spectrum in a coastal dune slack in Algoa Bay, South Africa. Journal of arid environments, 12(1), 9-25.

McLachlan, A. (1991). Ecology of coastal dune fauna. Journal of Arid Environments, 21(2), 229-243.

Monserrat, A. L., Celsi, C. E., & Fontana, S. L. (2012). Coastal dune vegetation of the southern Pampas (Buenos Aires, Argentina) and its value for conservation. Journal of Coastal Research, 28(1), 23-35.

Morton, R. A. (1977). Historical shoreline changes and their causes, Texas Gulf Coast (1).

Morton, R. A. (2003). An overview of coastal land loss: with emphasis on the Southeastern United States (p. 28). US Geological Survey, Center for Coastal and Watershed Studies.

Nol, E., Murphy, S. P., & Cadman, M. D. (2012). A historical estimate of apparent survival of American Oystercatcher (Haematopus palliatus) in Virginia. Waterbirds, 35(4), 631-635.

Palacios, E., Castillo-Guerrero, J. A., Galindo-Espinosa, D., Alfaro, L., Amador, E., Fernández, G., ... & Vega, X. (2017). Population status of American Oystercatchers (Haematopus palliatus frazari) breeding in northwest Mexico. Waterbirds, 40(sp1), 72-78.

Panario, D., & Gutiérrez, O. (2005). La vegetación en la evolución de playas arenosas. El caso de la costa uruguaya. Revista Ecosistemas, 14(2).

Pontee, N. (2013). Defining coastal squeeze: A discussion. Ocean & coastal management, 84, 204-207.

Projeto MapBiomas. (2020). Coleção 4 da Série Anual de Mapas de Cobertura e Uso de Solo do Brasil, accessed January 7, 2020, at URL: https://mapbiomas.org/

Pye, K., & Tsoar, H. (2008). Aeolian sand and sand dunes. Springer Science & Business Media.

Roberts, J. D. (1984). Terrestrial Egg Deposition and Direct Development in Arenophyrne rotunda Tyler, a Myobatrachid Frog from Coastal Sand Dunes at Shark Bay, W. A. Wildlife Research, 11(1), 191-200.

Seeliger, U.; Cordazzo, C. V.; Oliveira, C. P. L. & Seeliger, M. (2000). Long-term changes of coastal foredunes in the Southwest Atlantic. *Journal of Coastal Research*, 16(4): 1068-1072.

Seeliger, U. (2003). Response of southern Brazilian coastal foredunes to natural and human-induced disturbance. Journal of Coastal Research, 51-55.

Sturgess, P., & Atkinson, D. (1993). The clear-felling of sand-dune plantations: soil and vegetational processes in habitat restoration. *Biological Conservation*, *66*(3), 171-183.

U.S. Geological Survey. (2020). Landsat Science Products, accessed January 7, 2020, at URL https://www.usgs.gov/land-resources/nli/landsat/

Villwock, J. A., Tomazelli, L. J. (1995). Geologia costeira do Rio Grande do sul. *Notas técnicas*, *8*, 1-45.

Webley, D. M., Eastwood, D. J., & Gimingham, C. H. (1952). Development of a Soil Microflora in Relation to Plant Succession on Sand-Dunes, Including the Rhizosphere Flora Associated with Colonizing Species. *The Journal of Ecology*, 168-178.

Wells, B. W., & Shunk, I. V. (1938). Salt spray: an important factor in coastal ecology. Bulletin of the Torrey Botanical Club, 485-492.