



# Urban Growth in the Coast of Puerto Madryn (Chubut, Argentina): Impacts on Coastal Dune Field and Implications for Coastal Planning

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**Abstract.** Human activities, predominantly developed in dense urbanized coastal areas, are mostly responsible for the modification of natural landscape. The intense use of coastal resources has favored erosion processes by destabilizing the dynamic balance of sediments in beach-foredune systems and coastal dune fields.

Puerto Madryn is a touristic center of Patagonia Argentina which has been deeply modified by urbanization and industry development since 1970. The aim of this contribution is to analyze the urban growth and its direct impact on the original coastal dune field and foredunes. It was estimated a dune destruction rate of 5 hectares per year, decreasing from 700 m wide to only 30 and 60 m, between 1942 and 2012. This type of retrospective study, by means of the use of historical records, is essential to understand natural coastal dynamics and the importance of landscape preservation.

Previous conservation policies are discussed and new basic strategies are proposed to minimize negative impacts in the near future and to achieve an integrated coastal planning of natural resources.

**Keywords:** Urbanization · Coastal dynamics · Dunes · Beach · Human alterations · Patagonia · Argentina

## 1 Introduction

It has been estimated that more than 44% of the world's population lives within 150 km of a coastline (Syvitski et al. 2005). Even worse, according to a technical report published by United Nations (2010), in 2009, 67% of the megacities (those with more than 10 million inhabitants) were located at the coast and 80% had coastal influence. These urban centers have increased in population and occupation enhancing the demand of infrastructure, services and natural resources. This expansion has not been gradually planned but has responded to socio-economic growth pulses, especially during the second half of the 20th

century, and has not considered the capacity of the natural environment to support it. Even more, most of these cities depend economically on tourism, concentrated in the summer season. This problematic has been broadly studied along the coast of Buenos Aires province by López and Marcomini (2014), Bértola (2016) and Merlotto et al. (2016). In Patagonia, the impacts of coastal urban growth have been analyzed by Monti and Escofet (2008), Ferrari and Monti (2015), Monti et al. (2016), Bunicontro (2017), Bunicontro and Marcomini (2018) and Bunicontro (2018). However, government policies have not been efficient enough at reaching to a sustainable use of coastal resources and the lack of urban planning is causing almost irreversible consequences.

Coastal and beach erosion, flooding, biological invasions (Bunicontro et al. 2019), beach sand mining and seawater pollution are some of the most serious environmental impacts that need to be attended along the coast of the Golfo Nuevo, northern Patagonia. Generally, in coastal dune models like this, the urban growth alters the geomorphological and ecological processes in a significant way, causing deterioration of resources (for example, in foredunes and beaches) and modifications in littoral sedimentary balance.

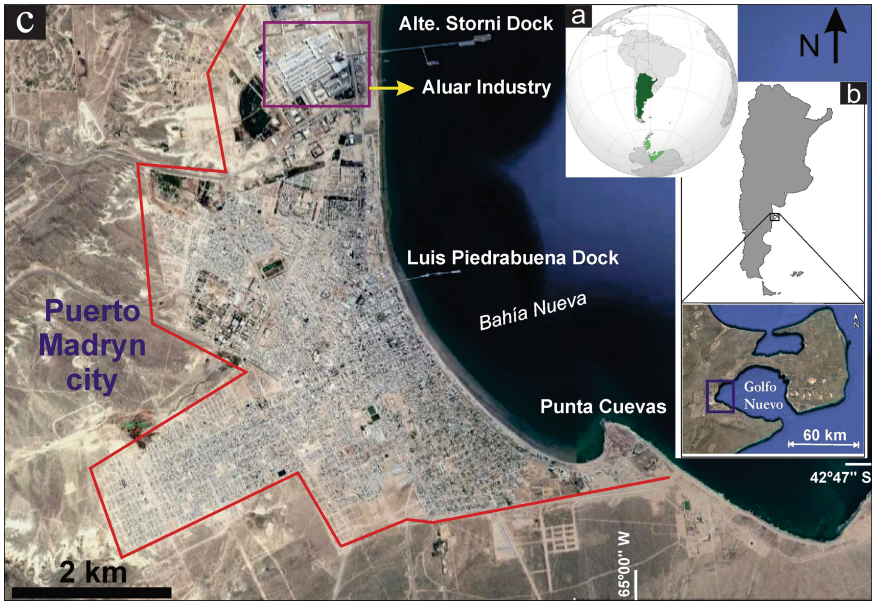
All these negative alterations due to urban development are not exclusive of Puerto Madryn and the Patagonian coasts (Weiler and Gómez Simes 2005; Monti and Escofet 2009; Monti 2011; Bunicontro 2015, 2017; Bunicontro and Marcomini 2018) but there have already been studied all along the Argentine littoral zone, especially in Buenos Aires province. Some examples of this human intervention in natural dune environment have been also analyzed in: Mar del Tuyú (López and Marcomini 2013), Monte Hermoso (Marcos et al. 2010); Pehuén C6 (Marcomini et al. 2009); Cabo San Antonio (López 2010) and Villa Gesell (Marcomini and López 1997; Isla et al. 1998; Marcomini and López 1999).

Historical information was collected to understand the morphodynamic effects that have derived from the rapid urban expansion of the Patagonian city of Puerto Madryn since the '70s. This contribution will focus in analyzing the development of this city as one of the most important industrial and touristic centers in the Patagonia coast. Also, it will study how that growth alters the natural landscape, especially the coastal sand dunes.

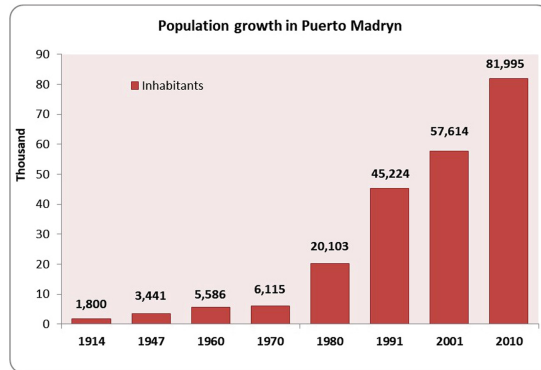
## 2 Study Area

The city of Puerto Madryn (42°46' S-65°02' W) is located in Bahía Nueva, at the western coast of Golfo Nuevo in Chubut province, Argentine Patagonia (Fig. 1). It was founded in 1865 and, during the 20th century, it has slowly become an important harbor for commercial activities and passenger transportation. Since 1970, Puerto Madryn went through a social, economic and physical transformation process. The installation of the Aluminum Production Plant (ALUAR S.A.), completed in 1974, was the key in the economic and social development of the city. The demand for employment was accompanied by the construction of housing and a large movement of people directly or indirectly linked to the industry (Kaminker 2016). Consequently, the population of Puerto Madryn tripled in just one decade, transforming not only its demographics but also the demand for infrastructure and services, and the urban design of the coastal zone. Between national and international immigrants the city multiplied its population

by thirteen in the period 1970–2010, growing from 6,100 inhabitants to more than 80,000 (INDEC 2010) (Fig. 1 and 2).



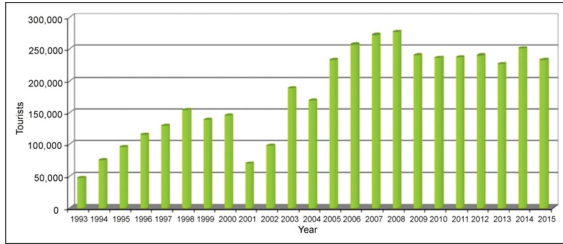
**Fig. 1.** Map location of the city of Puerto Madryn in Chubut province, Argentina. The area in red shows the present distribution of the urbanization.



**Fig. 2.** Population growth in the city of Puerto Madryn between 1914 and 2010 (taken and modified from Bunicontró 2018). Source: INDEC (2010).

Puerto Madryn is also a very important destination for tourism. There are two main touristic seasons during the year: (a) the summer season (between December and March) and (b) the “Right whales” season (between June and December). Every year the population doubles during each high season reaching between 200,000 and 250,000 tourists

on average (data from the Secretary of Tourism and Sports of Puerto Madryn) (Fig. 3). This situation increases the demand for basic services and some problems appear such as coastal pollution and an increase in sewage discharge to the beaches.



**Fig. 3.** Number of tourists per year that arrived in Puerto Madryn during the last decades. (Source: Secretary of tourism and sports of Puerto Madryn. Taken and modified from Bunicontro 2018).

## 2.1 Geology and Geomorphology

Puerto Madryn is located along Bahía Nueva, bounded at its ends by headlands and surrounded to the west by a plain relief. This one is cut by stepped scarps forming several terraces of altitude from 130 to 0 m a.s.l. The structural terrace is represented by an erosive scarp of steep slope that can reach between  $25^\circ$  to  $30^\circ$  and gradually decreases towards the sea. The outcrops correspond to the Puerto Madryn and Gaiman Formations (Miocene marine sedimentary rocks), which also extend on the cliffs of Golfo Nuevo (Haller et al. 2005; Haller 2017). At the top, there are different levels of sandy gravel deposits assigned to Quaternary fluvial terraces and defined as “Rodados Patagónicos” (the Patagonian Shingle Formation; Fidalgo and Riggi 1970). Also, low slope pediments and bajadas develop seawards. From a hydrographic point of view, the city is crossed by ephemeral streams that flow towards the sea. Most of them end in the bajada or are interrupted by Holocene marine terraces, infiltrating before reaching the sea. The marine terraces correspond to the San Miguel Formation (Haller et al. 2005), that are constituted by beach ridges (composed of sand, gravel and biogenic material) which were formed during a middle Holocene sea level highstand.

Analyzing the historical aerial photographs of 1942 and 1957, it can be seen that an ancient marine terrace used to be in the same place where Puerto Madryn city is settled nowadays and that a large aeolian mantle covered the coastal landscape. In the marine terrace, beach ridges aligned with the present coastline can be identified (See Sect. 3.2). Nowadays, the coastline is delimited partially by a seawall and by foredunes. The beach is composed by fine sandy sediments. It has a low slope with long-shore bars and channels and represents a dissipative beach model (Fig. 4).

## 3 Materials and Methods

Field trip surveys were carried out between December 2013 and March 2014. A representative dataset of different attributes (coastline morphologies and beach features)





**Fig. 4.** The Puerto Madryn beach during low tide (a) and during high tide (b).

along the studied coast was generated. Morphological data was collected along different cross-shore profiles with Total Station equipment (Kolida KTS400L Series) and GSP for global positioning (Garmin 60CSx, precision of 3–5 m). Beach profiles were used to determine morphometric parameters, such as beach width and gradient, both in backshore and foreshore.

The characterization of the environment and the recent geomorphologic evolution were analyzed with satellite images (from Google Earth) and vertical aerial photographs of 1942, 1957, 1971, 1988, 1999, and 2011 (provided by Base Aeronaval, Punta Indio, Argentina; 1:20,000 scale). The oldest records are from 1940, so an evolution for 70 years has been reconstructed. The urban growth rate was quantified through the use of Global Mapper GIS software. Also, to determine human intervention, field observational data was collected as a checklist with the aim of detecting the main alterations along the coast.

## 4 Results

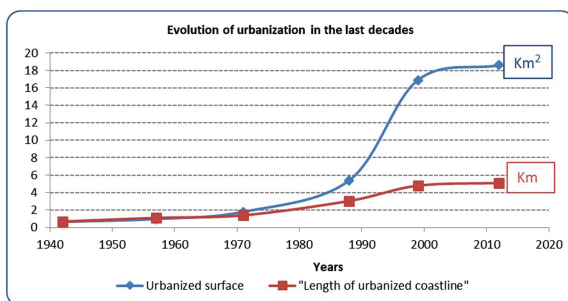
### 4.1 Human Impacts: Coastal Dune Field Reduction

The alterations recognized in the natural coastal system are mostly consequence of anthropic activity (Monti 2011; Bunicontro et al. 2015; Bunicontro and Marcomini 2018). These actions generate direct and indirect negative effects on the physical environment such as: degradation and segmentation of foredunes, dune vegetation with non-native species, dune destruction, beach width reduction and erosion, increase in wastewater discharge to the sea, increase in the surface runoff, changes in the terrain topography, coastline modification (such as the design of seaside avenues), construction of seawalls on the backshore, sedimentary balance deficit, beach profile changes and increase in the floods events.

One of the most impressive changes in the landscape was the reduction of the coastal dune field due to the expansion of housing construction, soil waterproofing, asphalted streets and coastal buildings. The analysis of these modifications through the last decades allows making a historical evolution of the study area in order to understand the importance of preserving the original natural landscape in coastal areas.

## 4.2 Urban Growth

Since 1942, the city of Puerto Madryn has been in continuous development and has not stopped expanding both transversally and longitudinally to the coast, registering a maximum growth in the '70s. According to the Code of Urban Planning of Puerto Madryn (municipal regulation N° 7555/10), “the present urban situation of the city is characterized by the impact of an accelerated growth, a perspective of dynamic growth, an excessive dispersion in the urban land occupation and a spontaneous distribution of uses in a disarticulated way”. Figure 5 shows the increase of that urbanization from the Piedrabuena Dock to Punta Cuevas, between 1942 (oldest recorded database) and 2012.

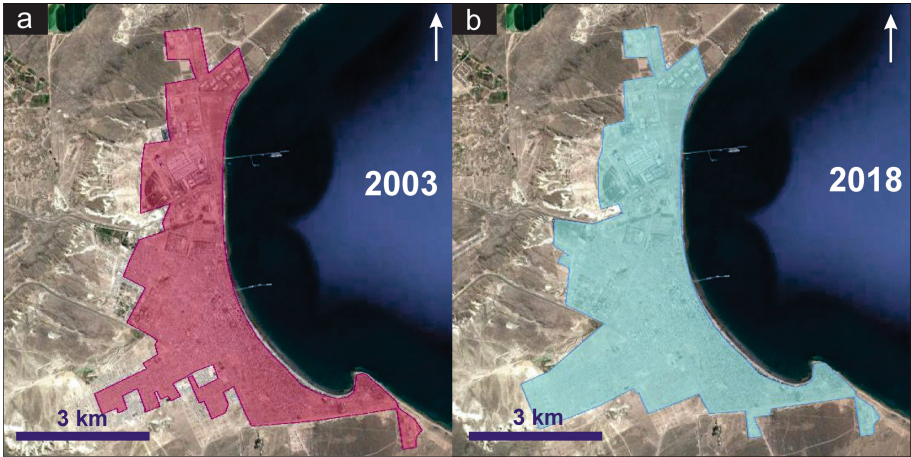


**Fig. 5.** Evolution of urbanized surface (in km<sup>2</sup>) and its length along coastline (in km) measured from the Piedrabuena Dock to Punta Cuevas, between 1942 and 2012 (taken and modified from Bunicontro 2018).

In a recent analysis, the urbanized surface has increased 25% only between 2003 and 2018, from 18.1 km<sup>2</sup> to 22.7 km<sup>2</sup> (Fig. 6). This urban expansion has been done firstly from north to south along the coastline, and then, from east to west. In this way, the coastline occupied by building and housing construction has increased from 0.8 km in 1942 to 11.2 km in 2014 (Bunicontro 2018).

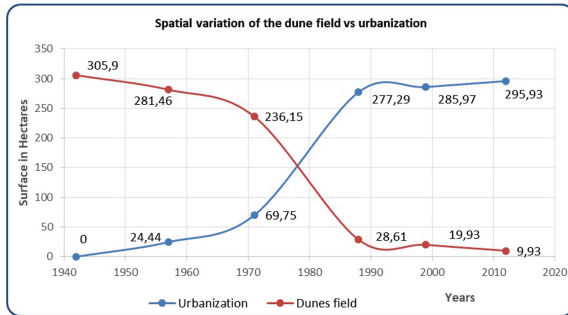
## 4.3 Degradation and Reduction of Coastal Dune Field

The original littoral dune field reached up to 700 m wide and extended along 3,100 km from north to south in 1942, from Sarmiento Street to Punta Cuevas (Fig. 7). It was composed by foredunes along the coast and an active aeolian mantle developed over the marine terrace. Both deposits have been drastically altered through the years. The elimination of most of the aeolian mantle to give rise to urban development has derived in a much degraded deposit. Figure 7 shows that spatial variation, which was intensified during '70s decade, when the local population tripled in only 10 years. Weiler and Gómez Simes (2005) mentioned that by 1980 the coastal zone was covered by dunes of 3 m high that extended inland about 300–400 m. Currently, the dunes field extension has reduced by 30% in length and 90% in width, reaching up to 60 m in those sites where it is still preserved. In this way, considering the database of historical aerial photographs and satellite images, a reduction rate of 9 m per year was estimated in a cross shore



**Fig. 6.** Evolution of urban development in Puerto Madryn between 2003 (a) and 2018 (b).

direction between 1942 and 2012. The Figs. 8 and 9 show the evolution of the urban development through the years. Bunicontro (2018) determined a destruction rate of the aeolian coastal field of 5 hectares per year, between 1942 and 2012.

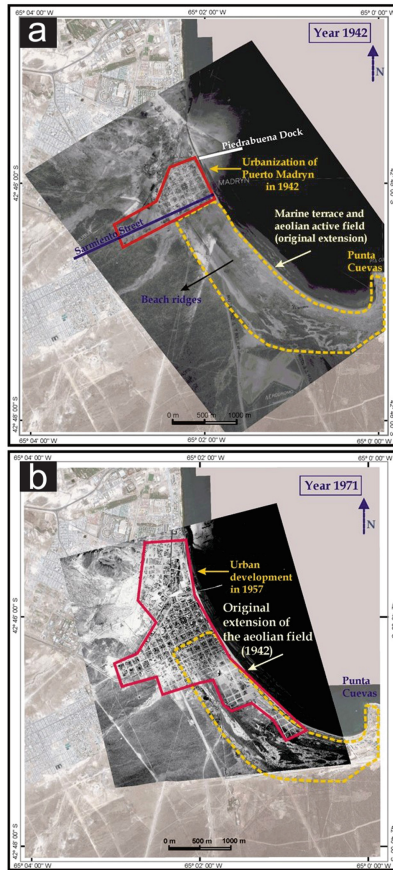


**Fig. 7.** Comparison through time of the urban growth of Puerto Madryn and the reduction of the original coastal dunes field measured from Sarmiento Street to Punta Cuevas. Taken and modified from Bunicontro (2018).

#### 4.4 Present State of Foredunes

Despite the destruction of aeolian landforms during the last decades, a narrow foredune ridge parallel to the shore is still preserved. Based on beach profiles done in the southern coast of Puerto Madryn, foredunes can reach between 30 and 60 m wide and 1 to 2.5 m high (Fig. 10). They are composed by fine and well sorted sandy sediments and, according to Bunicontro (2018), they are the main source of sediments to the beach.

As it can be seen in Fig. 10, most part of the profile is dominated by foreshore (at least 300 m wide) while backshore is almost 25 m wide and the storm high tide level



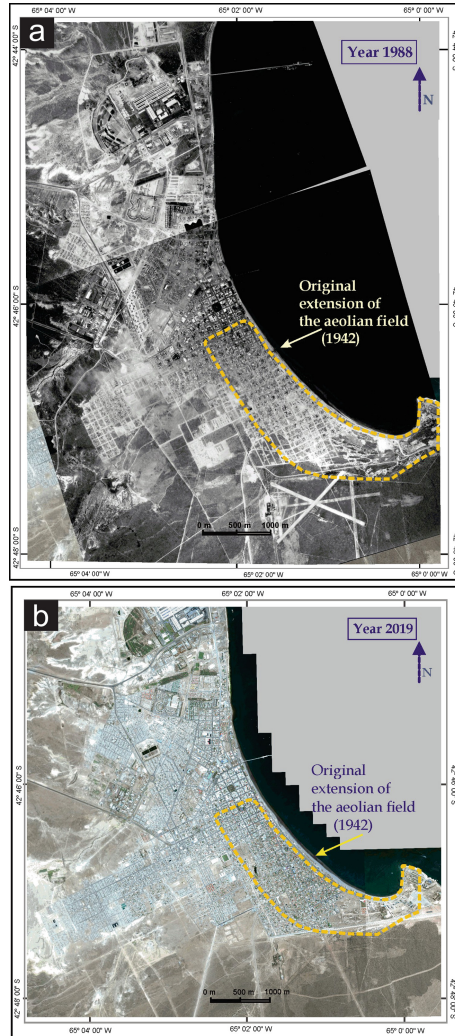
**Fig. 8.** Urban expansion between 1942 (a) and 1971 (b) of Puerto Madryn. The aerial photograph of 1942 shows a small village and the original landscape while that of 1971 evidences urban expansion over the original coastal dune field (in yellow) and the marine terrace.

(SHT) is at the base of foredunes. This situation generates a great pressure over foredunes because they could be easily affected by marine erosion during storms, favoring a deficit in sedimentary balance.

Moreover, foredunes are stabilized as consequence of exotic species vegetation and they show segmentation due to pedestrian accesses to beaches or to storm drains (Fig. 11 and 12). They are also affected by the building of beach restaurants and coastal avenues (Fig. 11 and 12). This continuous degradation increases the foredune vulnerability to be eroded by wind deflation, flooding, storms or wave action, and reduces its capacity as a source of sediment for beaches.

## 5 Final Considerations and Recommendations

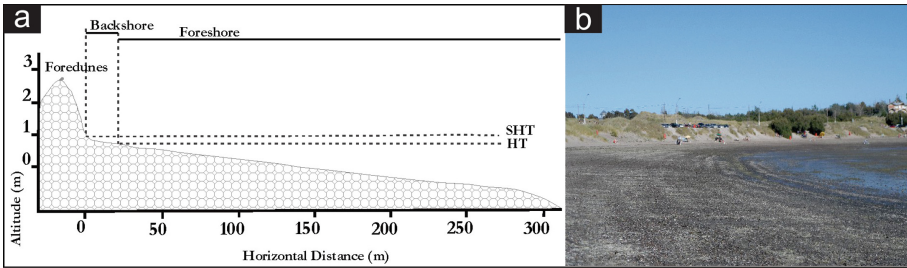
Considering the rapid growth of population and urban development in coastal areas, especially during the last years, it is very important to preserve the natural landscape



**Fig. 9.** Urban expansion between 1988 (a) and 2019 (b) of Puerto Madryn. The aerial photograph of 1988 shows an incipient urban development while the satellite image of 2019 (Google Earth) evidences the present state of urbanization. It can be seen how the dunes field has been reduced to a narrow foredune. The yellow line indicates the original extension of the dunes field by 1942.

and to regulate the use of the coastal resources. In Puerto Madryn, the conservation and restoration of foredunes is essential to minimize impacts such as beach erosion. Locally, the municipal regulation N° 1658/96 (modified then by N°6428/07 and N°6947/08) is the only one that promotes the preservation of the coastal dunes field. It declares: “the aeolian ridge that extends from the highest tide level to the coastal avenue in all the urban area, as a protected natural area, prohibiting the sand extraction, the destruction of the





**Fig. 10.** Beach profile in the southern coast of Puerto Madryn (a). SHT: Storm high tide; HT: High tide. Field photograph (b).



**Fig. 11.** Present state of foredune in the southern coast of Puerto Madryn. It can be seen their segmentation due to pedestrian paths (a and b) and their stabilization as consequence of exotic vegetation (c and d).

natural and native vegetation and the circulation of all type of vehicles on beaches and dunes” (free translation by the authors).

However, this kind of normative does not seem to be enough to preserve the present landscape in the surroundings of Puerto Madryn city. In fact, new urbanizations are developing southward and northward the center of the town and new regulations and management strategies are needed. In this way, it is important to mention that during the ‘90s, some protective actions began in order to generate recommendations for coastal





**Fig. 12.** Alterations of the natural foredune: beach access stairs (a), buildings and coastal resorts (b) and wooden walkways (c).

managements and dunes conservation (Monti 2014, 2017). Most recently, in 2007, educational workshops were organized to share this environmental problem with the local community and to discuss different coastal management proposals. In 2013, a coastal dunes recovery program was driven by local authorities, scientists and non-governmental organizations. The aim of the program was to restore the foredunes located in the southern coast of Puerto Madryn through the installation of aeolian barriers. However, this program was partially active only until 2015 (Monti 2017).

To face this situation some recommendations for an integrated coastal management are:

- To reconsider the generation of a land use policy and to create a coastal plan for the future urbanizations in order to preserve natural dunes field. This can be achieved by setting restricted areas for construction along the sea front space.
- To promote a temporary monitoring study of cross-shore beach profiles in different sites along the city to estimate beach erosion and coastal retreat.
- To reactivate the dune and beach conservation programs. Also, it is necessary to consider that the restoring processes imply medium to long term actions and they require maintenance over time.

Finally, to preserve foredunes it is necessary to put into practice dunes restoration strategies, such as the use of aeolian barriers as it has been done before. These barriers, according to its position in the field, would increase the height and width of foredunes and would close those areas where segmentation favors wind erosion. Also, restoring foredunes would minimize beach erosion process, preserving the main source of sand and favoring the balance of sediments in a cross-shore direction. This type of management strategy has been applied in Buenos Aires coast with good results for many years (López and Marcomini 2006), so it could be taken into account as a successful example of dunes restoration. However, another type of strategies are needed such as community and authorities collaboration and communication, awareness about the importance of natural landscape conservation and diffusion campaigns of these environmental problems to people (for example, through open workshops in public institutions).

The study of urbanized coastal cities like Puerto Madryn and the analysis of their landscape transformation are two essential things to understand the natural dynamics of

the coastal systems. These studies should be taken as a base for future urban planning in order to achieve a sustainable use of resources.

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