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ENVIRONMENTAL EVOLUTION OF COASTAL AFFORESTATIONS: MANAGEMENT STRATEGIES FOR DUNE FIXATION IN THE SANDY BARRIERS OF BUENOS AIRES, ARGENTINA

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ABSTRACT: Tourism in the southern sandy temperate barriers has historically been one of the drivers of coastal development in Buenos Aires, Argentina. This process, which has been accompanied by dune fixation and a subsequent urbanization, began in the 1930s and occurred in the absence of coastal management policies causing several environmental problems. This work aims to analyze the historical development of two dune afforestation projects with the objective of characterizing their main environmental issues. These projects, which started almost simultaneously, are currently at completely different levels of development. For this purpose, a literature and relevant legislation review was carried out, allowing us to characterize them and generate comparisons. At the same time, it is intended to propose new strategies for dune fixation. One of the peculiarities of these afforestation projects is that two brothers carried them out: Carlos and Ernesto Gesell. Carlos initiated an afforestation that led to the sprawl of Villa Gesell. This city reached historical records of urban growth and it is actually one of the most popular bathing resorts of Argentina. Ernesto founded Dunamar on a more restricted dune field and it is currently at a significantly lower stage of development than Villa Gesell. Coastal erosion, surface runoff increase, decrease of foredune areas and replacement of native dune vegetation are some of the reported problems. Currently, there are projects for the expansion of the urban area of these villages under different strategies for dune stabilization. Although their effects have been extensively documented, they propose fixations with fast-growing exotic species. This work proposes the revegetation by means of native species corresponding to the original landscape of the dunes of about a century ago. To this end, certain aspects must be taken into account within the framework of integrated coastal management.

Keywords: urban development; coastal tourism; native dune vegetation; dune fixation.

RESUMO: *O turismo nas barreiras arenosas do Sul em Buenos Aires, Argentina, tem sido um dos motores históricos de expansão costeira local. O seu desenvolvimento iniciou-se na década de 1930, na ausência de políticas de gestão costeira, sendo acompanhado por mecanismos de fixação dunar e uma subsequente urbanização, que causaram vários problemas ambientais. Este trabalho pretende analisar o desenvolvimento histórico de dois projetos locais de florestação dunar, por forma a enquadrar o seu contexto ambiental. Os projetos, que começaram quase simultaneamente, encontram-se atualmente em níveis de desenvolvimento técnico completamente diferentes. Foi realizada uma revisão bibliográfica e de legislação relevante, que nos permitiu caracterizá-los e compará-los. Ao mesmo tempo, foram propostas novas estratégias para a fixação das dunas. Uma das peculiaridades destes projetos de florestação é que foram levados a cabo por dois irmãos: Carlos e Ernesto Gesell. Carlos iniciou a reflorestação que levou à expansão de Villa Gesell. Esta cidade atingiu recordes históricos de crescimento urbano e é na realidade uma das estâncias balneares mais populares da Argentina. Ernesto fundou a cidade Dunamar num campo de dunas mais restrito e o projeto encontra-se atualmente numa fase de desenvolvimento significativamente inferior à de Villa Gesell. Fenómenos de erosão costeira, aumento do escoamento superficial, diminuição da área natural de dunas e substituição da vegetação nativa das dunas, são alguns dos problemas relatados para estes locais. Atualmente, existem projetos para a expansão da área urbana destas cidades assumindo diferentes estratégias para a estabilização das dunas. Embora os seus efeitos tenham sido amplamente documentados, estes projetos propõem fixações com espécies exóticas de crescimento rápido. Este trabalho propõe a revegetação de espécies nativas correspondentes à paisagem original das dunas há cerca de um século atrás. Para o efeito, certos aspetos técnicos deverão ser tidos em conta no âmbito da gestão costeira integrada do troço litoral.*

Palavras-chave: *desenvolvimento urbano; turismo costeiro; vegetação nativa das dunas; fixação de dunas.*

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1. INTRODUCTION

Sand barriers caused by a Holocene fluctuation of the sea level dominate temperate Southern Hemisphere. The sand availability at the maximum sea level high stand permitted that onshore winds help accumulated sand to establish barriers of about 3 km width (Isla, 2017). The afforestation of these barriers could be performed where the wind-blown sand can be dominated into fixed dunes. For success, it was necessary that the roots of the introduced trees could reach the depth of the water table (Rodrigues-Capítulo *et al*., 2018).

One of the main drivers of coastal development has been and continues to be tourism (Da Silva and Schwingel, 2019). This process is accompanied by the location of infrastructures and services that promote diverse land use and land cover (LULC) changes over coastal areas (Roig-Munar, 2018). Several authors place coastal urbanization and dune afforestation among the most relevant LULC changes resulting from tourism development over dune systems (Mollema *et al*., 2015; Okello *et al*., 2015).

In the Buenos Aires Province, Argentina (Figure 1), several resort villages were developed in relation to anthropogenic forests that were later managed into parks (Juarez and Isla, 1999; Isla, 2013). In some of these coastal areas, the process of tourism development occurred with poor planning strategies and in the absence of coastal management policies, resulting in environmental problems (Dadon, 2011).

This work aims to analyze the historical development of two dune afforestation projects carried out in the province of Buenos Aires, Argentina, which have become important coastal tourist villages, with the objective of analyzing their main environmental problems. Although they are almost contemporaneous, these projects are currently at completely different levels of development. A review was based on previously bibliography and relevant legislation or regulations over the study sites, allowing a characterization and comparison of these two projects.

At the same time, taking into account the existence of current projects for the expansion of these developments on dune areas, this work aims to generate proposals for new dune fixation processes within the framework of Integrated Coastal Management.

One of the particularities of these projects is that they were carried out by two brothers. Carlos Idaho Gesell initiated the Villa Gesell project in 1931. His brother Ernesto Gesell forested Dunamar a few years later. Although both towns were settled on a coastal barrier of dunes, their beginnings and later development were different.

2. THE SANDY BARRIERS OF BUENOS AIRES

Villa Gesell, on the one hand, is located on the Eastern Barrier of Buenos Aires in the homonymous county; Dunamar, on the other hand, is located on the Southern Barrier and in the Tres Arroyos County (Figure 1). Both sites were developed over barriers dominated by transverse dunes. In Villa Gesell, winds from the north dominate slightly; however, the asymmetry of the transverse dunes indicates that the sand transport is towards the NNE. In Dunamar, westerly winds prevail causing an asymmetry of the transverse dunes (Cortizo and Isla, 2007; Cortizo, 2010). Annual precipitations are higher in Villa Gesell (844 mm) than in Tres Arroyos (766 mm).

Since the origin of these touristic projects, groundwater availability for the inhabitants and for the afforestation purposes were completely different in both barriers. On the one hand, in Villa Gesell the water table has a lenticular shape and the aquifer comprises the 3 km of the sand barrier (Bértola *et al*., 2002). Another aquifer was discovered below the Villa Gesell sand barrier within sandy silts of Upper Pleistocene age (Violante *et al*., 2001). In detail, at the neighboring Pinamar County, three aquifers were discriminated: one comprising Pleistocene rocks, while two aquifers within the Holocene sediments (Rodrigues-Capítulo and Kruse, 2017). On the other hand, at Dunamar, the sand barrier is on top of cliffs, 7 m above mean sea level (Cesare, 2016).

3. HISTORICAL DEVELOPMENT AND ACTUAL ENVIRONMENTAL PROBLEMS

3.1. The Villa Gesell of Carlos Gesell

In 1930, estimates of federal property indicated that there were 3089 ha to be incorporated into the Argentine heritage; 1648 of these ha were bought by Carlos Idaho Gesell in 1931 (Juarez and Mantobani, 2006; Benseny, 2011). In 1946, he bought more fields to Astengo Morando, who kept the ownership of the southern sand-dune field of the current Villa Gesell County. The Morando's property today comprises the localities of Mar de las Pampas, Las Gaviotas and Mar Azul (Figure2).

Carlos Gesell works were very difficult as the sand-dune fields were very dynamic and the plants specimens did not adapt easily. Despite this, by the early 1940s, he successfully stabilized the dunes by means of wooden sand fences followed by artificial afforestation with rapid-growth exotic species (Figure 3). The city grew in three stages. During 1931-1940, the main purpose was the fixation of the dunes. In the second stage (1941-1970) the

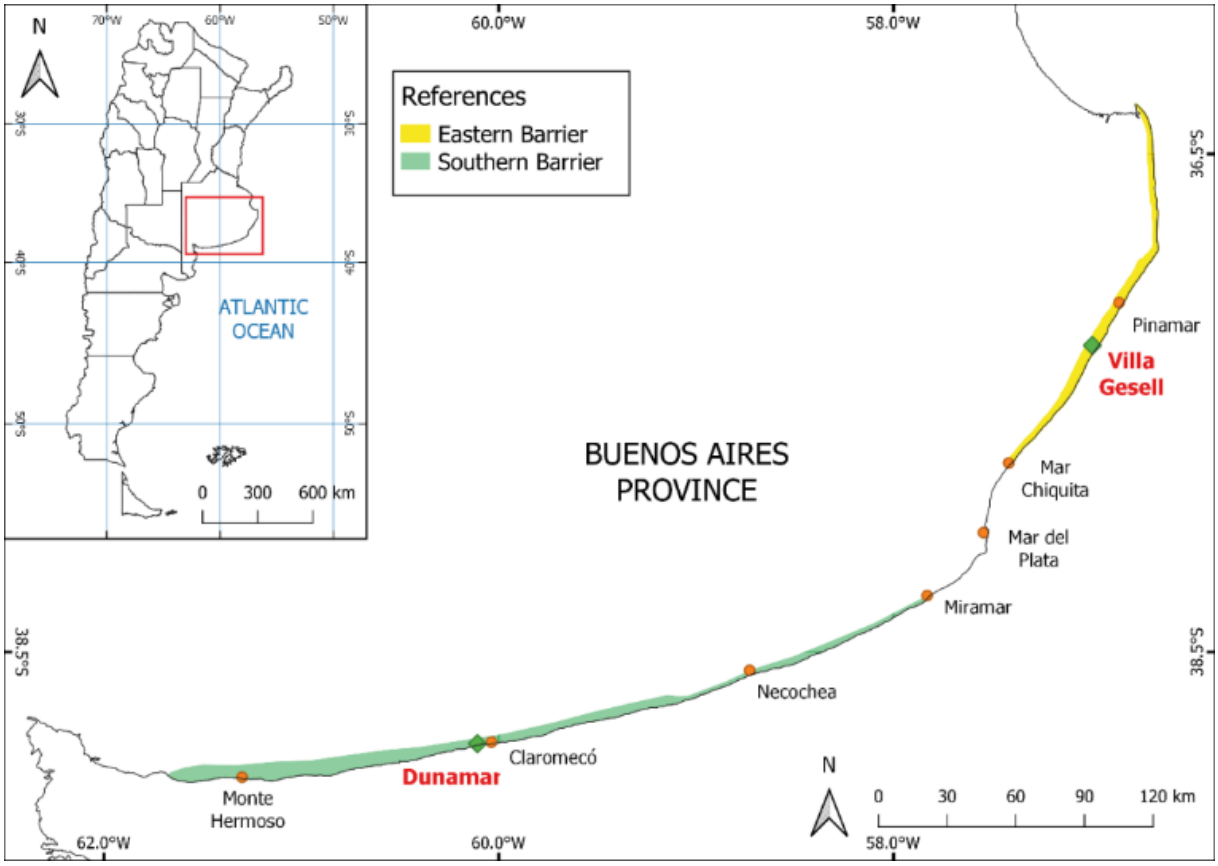

Figure 1. Location of Villa Gesell (Eastern Barrier) and Dunamar (Southern Barrier), in the Buenos Aires Province, Argentina. [Modified after Isla *et al.* (2001)].

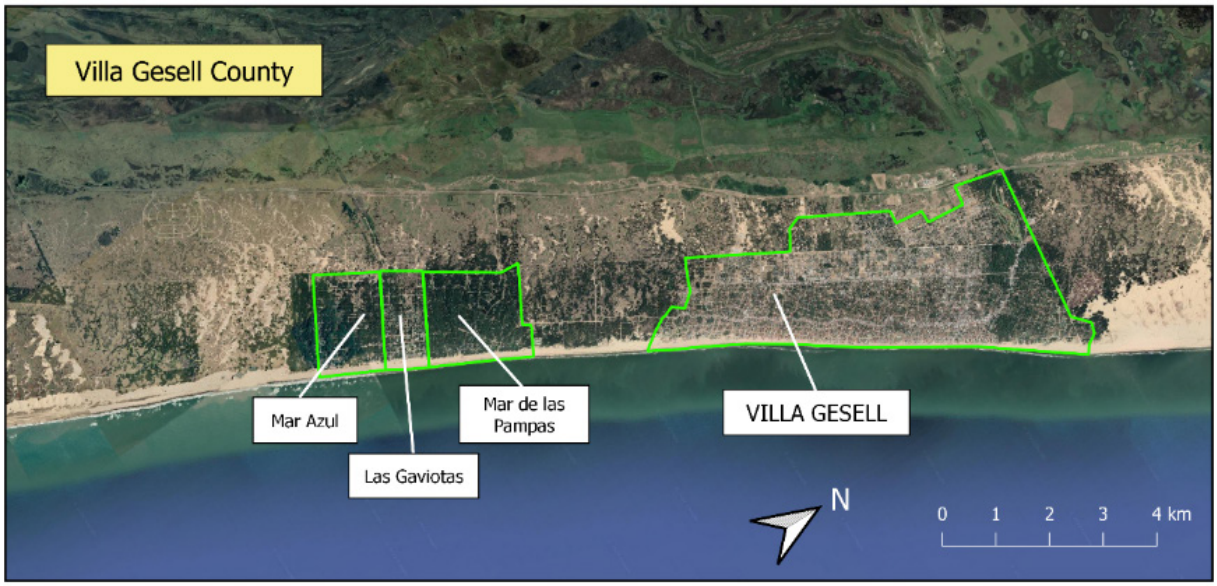

Figure 2. Coastal villages of the Villa Gesell County: Mar Azul, Las Gaviotas, Mar de las Pampas and Villa Gesell.

consolidation of the village occurred, with avenues parallel to the beach and streets (called "paseos") normal to the coast but oriented preferentially to the inter-dune depressions and respecting the original morphology of the dunes. During the third stage (1971 to present), the village became a city restricted to the width of the sand barrier. Due to the promotion of access to land and construction, during 1974 and 1975 Villa Gesell reached the highest urban growth rate in Argentina (Juarez and Isla, 1999). In this way and due to conflicting interests, the urban county became independent from General Madariaga, its historical rural municipality. Some characteristics inherited from the resort village evolved into the problems of a densely populated city (Isla, 2013; Isla and Isla, 2020).

In spite of the enormous work done to fix and forest the dunes and the advantages that this brought for the urban expansion, the northern sector of Villa Gesell has been deforested in the last decades (Figure 4). A reduction in the forested area in the first 300 m closer to the beach has been observed at the expense of an increase in the density of urban surfaces (building, asphalted streets, parks and gardens). One of the few areas where dense woods are still preserved are the neighborhood of the Carlos Gesell's foundational house, known as "Pinar Del Norte". In both cases, urbanized and densely forested sectors, the width of the beach diminish drastically. However, in the first of these the setback was greater than in the second.

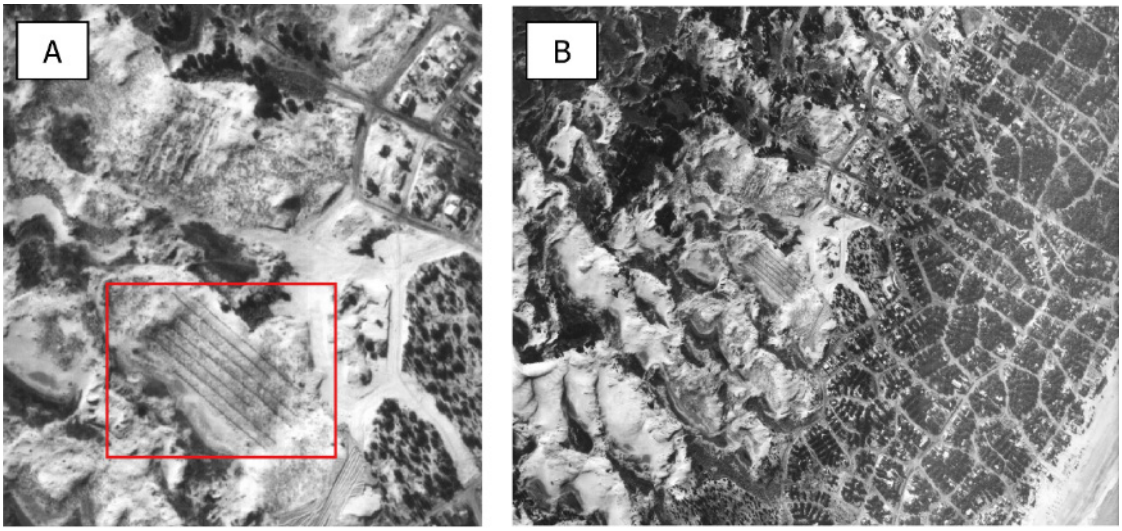

Figure 3. Aerial photographs from Villa Gesell in the 1960s. Sand fences in the transverse dune fields before tree establishment (A). Urbanization of the dune fields after fixation with sand fences and afforestation. Streets respecting the original morphology of the dunes (B).

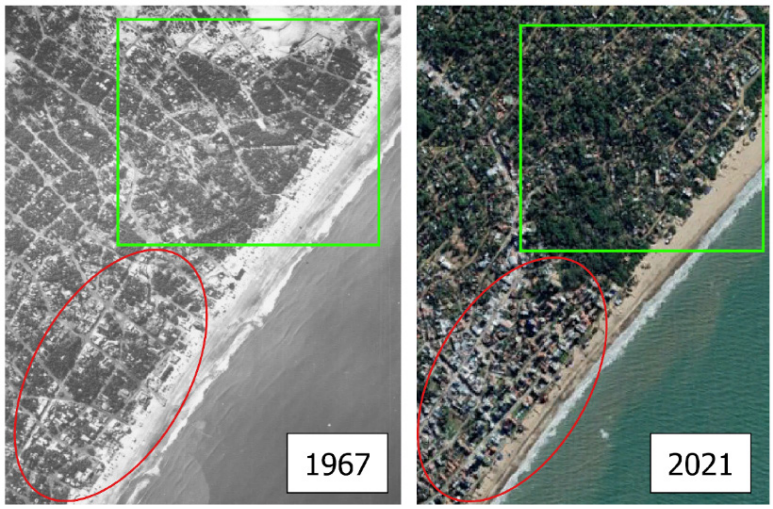

Figure 4. Land use/land cover comparison in northern Villa Gesell between 1967 and 2021. It is observed a decrease in the afforestation in the first 300 m from the beach (circle). In Pinar Del Norte (square) the tree cover grew but beach widths diminished. Lots are approximately 100 x 100 m.

Foredunes are retreating faster at the city center (located in the north sector) mostly due to the episodic impact of storms arriving from the SSE (Isla *et al*., 1998 and 2018). This erosion has increased due to the pluvial runoff induced by the pavement of the streets normal to the coast (Figure 5). The channeling of stormflows towards the beaches generates scarps and canals. To the south of the county, in Mar de las Pampas, Las Gaviotas and Mar Azul, the retreat is less than 0.5 m/yr. but may certainly increase if the forecasted sea-level rise (Oppenheimer *et al*., 2019).

Comparing oblique photographs from the sixties to recent ones, it is evident the decrease of the foredune areas. The areas with shrubs (mainly *Tamariscus*) were replaced by bathing-resort facilities (Figure 6).

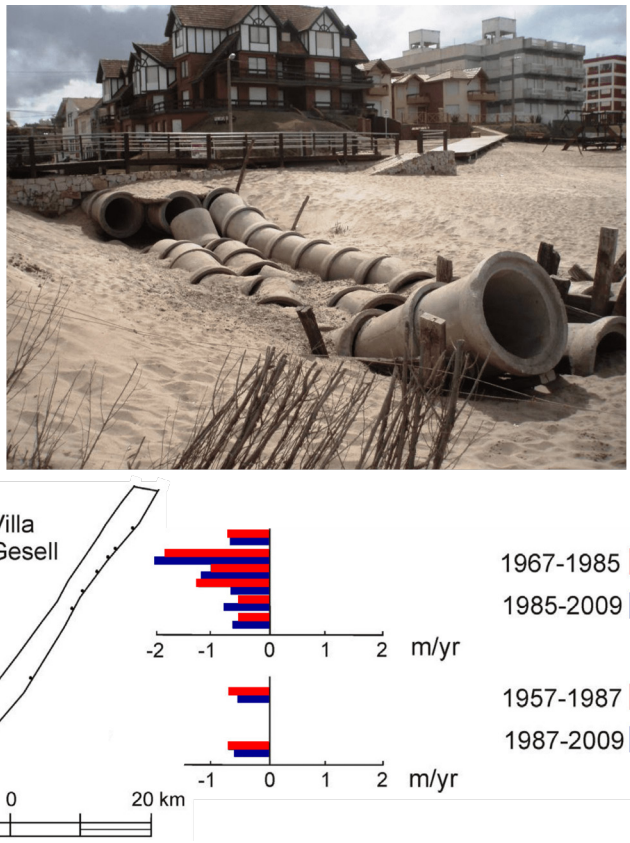

Figure 5. Up: storm flows discharge over beaches in Villa Gesell city centre. Down: Retreat of the Villa Gesell County coastline between 1967-1985 and 1985-2009 [Modified after Isla *et al.* (2018)].

Figure 6. The original village grew to be transformed in a coastal city with tall buildings. Left photo: Mid '70s, right photo: 2010 [Modified after Isla (2013)].

The urban growth of Villa Gesell has generated a systematic replacement of the dune fields with their native vegetation by urban areas and exotic forests (Faggi and Dadon, 2010). This urbanization parallel to the coast had its maximum development in the second half of the century (Figure 7). However, in the last 20 years the urban surface of Villa Gesell has not expanded. Instead, there has been a densification of buildings, increasing the establishment of impermeable covers over the sandy substratum (Figure 7). This led to an increase of runoff processes causing beach erosion.

3.2. The Dunamar village

The Dunamar bathing resort grew associated to the Claromecó village. This village was originated by a proposal of the Bellocq family to the Federal authorities (Juarez and Mantobani, 2006). In 1945, Ernesto Gesell bought 1600 ha of the dune fields immediately to the west of the Claromecó creek (Figure 8). The first problem was the access to these dunes. Bridges across the creek were constructed twice and destroyed by floods. Since 1980, a bridge assure the access of cars. Although precipitation in this region was significantly less, Ernesto Gesell's experience gained from working with his brother was applied to an improved strategy. At the same time, the terrace below the dunes were an easy access of the trees to the water table.

The sand fence and afforestation of Dunamar generated three subsequent urban subdivisions between 1947 and 1949, defining 753 lots. Subsequently, in 2002, two grandchildren of

Figure 7. Urban development of Villa Gesell, mainly parallel to the coast (1957-2021) (A). Densification of buildings between 2003 (B) and 2021 (C). [Modified from Juarez and Isla (1999); Isla (2017); Isla and Isla (2020)].

Eduardo Gesell promoted the inclusion of 80 new lots, raising to the actual number of 832 lots (Cesare, 2016). As in Villa Gesell, the urban area of Dunamar has not increased in the last 20 years. However, buildings have densified and the forest cover has expanded towards the west (Figure 9).

The afforestation and subsequent stabilization of the dunes has generated changes in the morphological characteristics because of the decrease in the availability of sand. At Médano Verde, next to Dunamar, transverse dunes migrated at rates of 5-6 m/yr. between 2003 and 2013. These migration rates diminished drastically to 1.5 m/yr. in the last years (Isla *et al*., 2021). This has generated that, today, the main problem in Dunamar continues to be the sedimentary excess and the dune mobility.

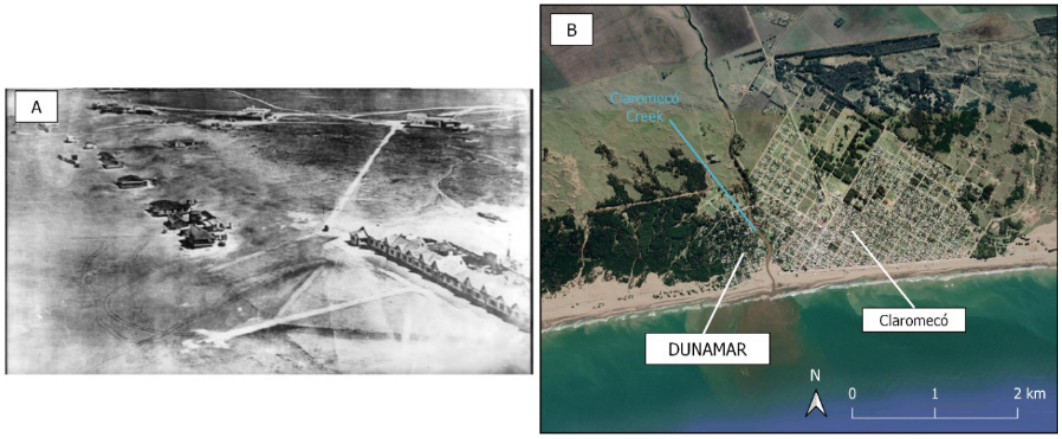

Figure 8. From the beginnings, the Claromecó village was urbanized on a terrace where the dunes were eliminated (Photo of the '40s decade) (A). In contrast, Dunamar dunes were afforested and the village is expanding to the west (B).

Figure 9. Dunamar densification and advance of afforestation (2003-2021).

4. CURRENT PROJECTS FOR URBAN DEVELOPMENT

In the whole territory of the Buenos Aires Province, according to Decree No. 3202/06 the foredunes cannot be removed, forested or urbanized. At the same time, according to Decree No. 8912/77, in order to develop new urbanization in dune areas, the dunes must be previously fixed and forested and the density of urbanization will be that which allows the permanence of fixation and afforestation works. The Decree No. 10081/1983 establishes that the Federal Government is able to expropriate public and private properties in dune areas in order to fix them. Taking into account the provincial decrees together with other normative that regulate the action at municipal level, there are current projects for the expansion of the urban area and the vegetation of new dune sectors in Villa Gesell and Dunamar.

4.1. The Villa Gesell City Assessment Plan

Villa Gesell grew at rates without antecedents in Argentina that led to several unsolved growing problems (water provision, coastal-dune retreat, beach erosion, runoff episodes, and domestic-sewage disposal). Nowadays it is one of the main destinations of domestic tourism in Argentina with more than 1.15 million tourists registered in Villa Gesell during January 2022 (Source: Villa Gesell Touristic Office). The complexity of the different areas of the Villa Gesell city led to propose an Assessment Plan for coastal urbanization (*Plan de Ordenamiento Municipal*; Decree No. 13621/21) discriminating at least 6 sectors of the county. The city has 13,257 lots of which 18% are vacant, only taking into account authorized and declared constructions. Its stable population was 29,600 inhabitants by 2010 but with a high growth rate; 40,800 inhabitants were projected to 2025. At the same time, the potential tourist population of the city taking into account its hotel vacancies is 180,000 inhabitants, meaning 600% of its stable population at times of maximum occupancy.

The municipal plan proposes reaching a potential tourist population of 300,000 inhabitants by 2030 and 590,000 inhabitants by 2045. To this end, it is proposed to extend the linear extension of the waterfront that can be urbanized from 8.05 km to 17.36 km. This means restructuring in six stages about 870 of the 1170 ha of the city center to reach an urban density of 400 inhabit/ha; and expanding urban development linked to tourism by approximately 1,300 ha divided into the south ("Colonia Marina") and the north of the city center and with an average urban density of 30 inhabit/ha (Source: *Plan de Ordenamiento Municipal*; Decree No. 13621/21) (Figure 10).

The same plan proposes a "reconversion" of urban forests due to the age of the existing trees since the initial forestation of Carlos Idaho Gesell, which occurred almost a century ago. To this end, reseeding strategies are planned. At the same time, new dune fixation and forestations are planned in those areas where the urban area will be expanded. For this purpose, the municipality

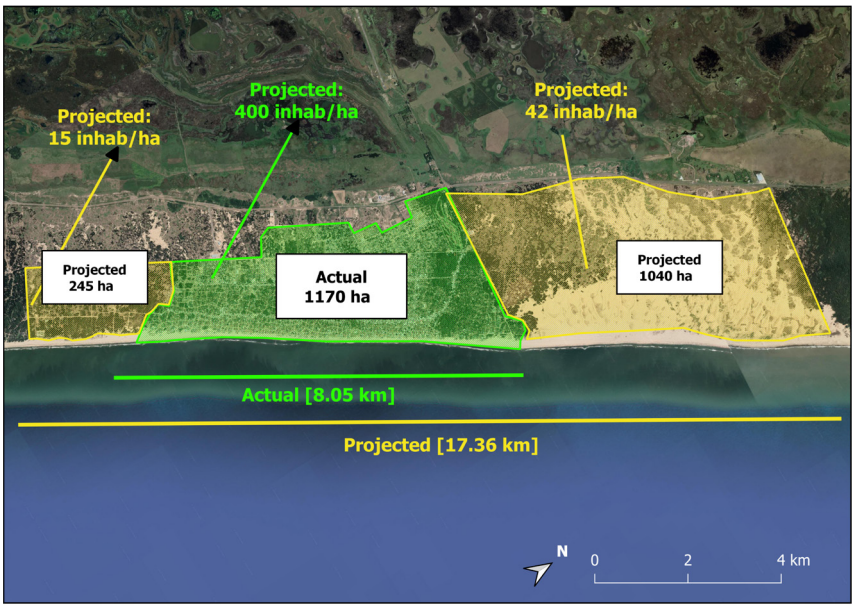

Figure 10. Actual and projected urban surface, population density and alongshore urban waterfront coverage in Villa Gesell.

plans to fix the dunes with grasses and low shrub species, avoiding landscaping with lawn and fixing with large species that consume a lot of water.

4.2. The Dunamar forest urbanization

Ernesto Gesell's descendants are proposing the urbanization of the afforestation towards the west of Dunamar taking care about the new procedures and rules stated by the environmental authorities of the Buenos Aires Province (Figure 12). For this purpose, 120 ha will be urbanized in a first stage, keeping a remaining 40 ha for future expansions. 610 lots will be assigned to low-density family housing and only 3 lots will be destined to hotels, projecting a density of 40 inhabit/ha (Cesare, 2016). This means and urban waterfront increase from 670 m to 2320 m. The project anticipates new fixation and afforestation of dunes, consolidating the areas without forests. In this way, the project intends to guarantee a reserve zone of 56.9 ha covering the first 250 m inland from the shoreline, granting 39.6 ha to the public domain and keeping 17.3 ha of the private domain undeveloped (Cesare, 2016) (Figure 11).

5. CONTEMPORARY AFFORESTATIONS

In order to compare the afforestation strategies employed and the historical development of Villa Gesell and Dunamar, Table 1 summarizes the characterization and data collected through the literature and legislation review.

According to the Decree No. 3202/06, Dunamar has 670 m of urbanized coastline, while Villa Gesell has 8,050 m. This shows that the project initiated by Ernesto Gesell is currently at a significantly lower stage of development than the one initiated by his brother Carlos. The afforestation process in Dunamar was carried out following the guidelines developed in Villa Gesell, however, the current projections and forestation policies of Dunamar do not seem to take in account the subsequent experience of the urbanization process in the project of Carlos Gesell. Villa Gesell is currently facing several environmental issues due to the lack of management. The importance of approaching the future urbanization of Dunamar under integrated coastal management strategies and environmentally efficient management of coastal resources is reinforced. In Villa Gesell, it is important not to continue with the mistakes of the past and the lack of planning that led to serious environmental problems and coastal erosion. In Dunamar, being in a less advanced stage of urban development and planning, it is important to take the failed experience of Villa Gesell as a lesson to avoid repeating this paradigm of uncontrolled urbanization.

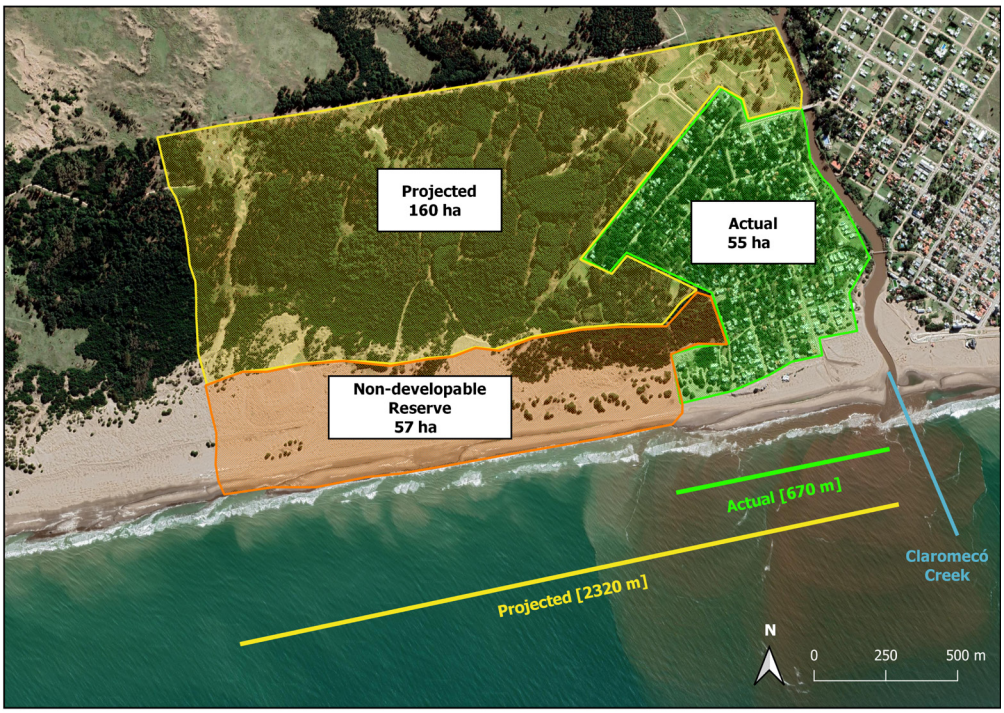

Figure 11. Actual and projected urban surface and alongshore urban waterfront coverage in Dunamar.

Table 1. Comparison between Villa Gesell and Dunamar. Historical development, dune afforestation strategies and future planning.

Criteria/Coastal Village	**VILLA GESELL**	**DUNAMAR**
Start of afforestation works	1931. Successful from 1942 onwards.	1945
Dune stabilization strategy	Wooden sand fences	
Nature of vegetation used for dune fixation	Rapid-growth exotic species	
Main species used for dune fixation	*Carpobrotus chilensis* <Uña de gato> *Acacia melanoxylon* <Acacia Negra> *Tamarix gallica* <Tamarisco> *Myoporum laetum* <Siempre Verde> *Yuca spp.* *Pinus spp.*	
Pre-planning for dune fixation	Trial and error approach (1931-1942)	Based on previous experience in Villa Gesell
Original dune landscape	Respected in the original conception of the urban development plan and in the dune founding forestations	Restricted by the morphology of the Claromecó Creek that made access to Dunamar difficult
Development of the subsequent urbanization	Reached the highest urban growth rate in Argentina between 1975 and 1975. Currently is one of the most popular bathing resort places of the whole country	The current urbanization covers only 55 ha, which means a stable population of less than 2000 people. It presents an incipient degree of development.
Main current environmental problems derived from dune fixation	- Coastal erosion - Sedimentary imbalance - Surface runoff increase - Diminish of foredune areas - Replacement of native dune vegetation - Spread of invasive exotic species	- Changes in dune morphology - Dune mobility - Diminish of foredune areas - Replacement of native dune vegetation - Spread of invasive exotic species
Current regulations associated with dune fixation	Decree No. 8912/1977 Decree No. 10081/1983 Decree No. 3202/2006	
Future planning of dune fixation and urban development	Assessment Plan for Coastal Urbanization Decree No. 13621/2021	Private initiatives carried by the grandchildren of Ernesto Gesell
Projected extension of the waterfront that can be urbanized	From 8.05 km to 17.36 km (115.7% increase)	From 0.67 km to 2.32 km (246.3% increase)
New urbanized area	1285 ha	160 ha
Nature of the proposed fixation	Native dune vegetation	Rapid-growth exotic species
Proposal for reforestation of historic forests	Yes	No

6. DISCUSSION

Forested coastal settlements progress in relation to the availability and quality of freshwater resources. Drought periods can change the mineralization of the groundwater when evaporation dominates over precipitation. At the same time, vegetation diversity can also change depending on the ground water quality. Significant changes linked to anthropogenic threats (afforestation, farming, intensive grazing, tourist urbanization and military activities, among others) were reported between the Belgian and Netherlands coastal dunes (Martens *et al*., 2013).

Several authors have identified afforestation in coastal areas as having a major impact on the local hydrological balance. These fast-growing exotic species evaporate and transpire large amounts of water from infiltrating rain, increasing the concentration of solutes in groundwater and modifying water table levels (Cozzolino *et al*., 2017). These variations have been recognized in the Mediterranean coast of Italy (Mollema *et al*., 2013), the Netherlands (Stuyfzand, 2016) and even in Pinamar County, neighboring Villa Gesell (Rodrigues-Capitulo *et al*., 2018). In a similar way, urbanization processes induce significant decrease in evaporation due to the reduction of green areas and the development of artificial stormwater infiltration (Locatelli *et al*., 2017).

One of the main doubts regarding the forested sand barriers is the transpiration effects in the water budget. Comparing forested and non-forested segments of the Pinamar barrier, the water table is 3 m lower at the forested sector (Rodrigues-Capítulo *et al*., 2018). Another issue to consider is whether the urban growth in altitude at coastal cities can alter the wind dynamics and annual temperature differences within the dune field (Isla, 2010a).

At the same time, coastal problems resulting from dune stabilization have been extensively documented. Dolan and Lins (1987) have identified large-scale fixation of the Outer Banks, United States, sandy barrier as the main cause of coastal erosion. Illenberger (1993) has recognized similar patterns in Port Elizabeth, South Africa. In Denmark, the impacts of afforestation in coastal areas have led to the evaluation of deforestation for the recovery of natural areas with landscape value (Jensen, 1994). In Rio Grande do Sul, Brazil, preservation areas were deliberate occupied by fast dispersion Pinus afforestation, acting as a physical barrier against winds and affecting the sedimentary imbalance. Actually, is recommended to eradicate pine trees in these dune systems in order to preserve the original landscape (Lipp-Nissinen *et al*., 2018). In Costa da Caparica, Portugal, the dune stabilization by mean of tree species turned worthless fields into profitable lands for tourist urbanization but promoting further coastal erosion processes (Palma *et al*., 2021).

According to documented afforestation in 50 years, these forests can sequester 400 tons of C/ha (Turno-Orellano and Isla, 2004). At the same time, some authors identified that afforestation processes promote thermal comfort in public areas of Itapirá, San Pablo, Brazil (Martelli and Santos, 2015) and can improve the local microclimate significantly (Leal *et al*., 2015).

Although the dune afforestation has allowed the subsequent process of tourist urbanization and economic development of these villages, some authors have identified a systematic replacement of native dune vegetation during the process of dune fixation (Faggi and Dadon, 2010; Marcomini *et al*., 2017). These dunes were originally dominated by sparse vegetation of the Panicum genus resistant to the conditions of the environment (Cabrera, 1941). The implantation of fast-growing exotic species and the production of gardens and green spaces in residential areas generated a decrease in the availability of sand. This altered the original morphology and the beach-dune sedimentary exchange, inducing coastal erosion problems (Isla *et al*., 1998).

At the same time, the strategies for dune fixation are intimately connected to perceptions. Historically, dunes were considered a danger for human property and housing. Carlos Gesell has even been widely recognized and awarded as “the dune tamer” for his afforestation works (Benseny, 2011). Nowadays, dunes have an intrinsic value for their ecosystem services, which are to be preserved through new integrated management strategies (Palma *et al*., 2021). In Torres, Rio Grande do Sul, Brazil, the Itapeva State Park was exclusively created in order to protect the dune fields and its native vegetation from the encroachment and impacts of tourist development, being dune fixation one of the most relevant (Rockett *et al*., 2018).

Dune afforestation can have both benefits and disadvantages. Although it is recommended for arid and semi-arid zones where the aim is to increase species richness and improve soil fertility, there is evidence that the introduction of exotic species has caused irreversible damage to the environment at the local level. For this reason, dune stabilization with forestation has been discontinued in some countries such as England, Wales and Denmark (Defra, 2007). In spite of their documented environmental impacts, in some localities such as Villa Gesell,

coastal forests are valued as community heritage and are part of the local cultural identity (Dadon, 2002).

There is abundant evidence of urbanization as a driver of vegetation dispersion. This process can be accompanied by the extinction of native species and the spread of highly invasive exotic species (Faggi and Dadon, 2010). Tourist activities gradually spread from the urban environments towards the more remote and preserved beaches, including conservation areas. This generates a gradient of anthropogenic impact and a process of vegetation dispersion, such as that observed towards the western sector of Dunamar (Figure 9). Thus, the impacts of artificial afforestation are not strictly restricted to the boundaries of touristic coastal urbanizations (Garzo and Dadon, 2021).

Numerous studies identify urbanization and tourism as two of the main factors that alter and destroy coastal dune systems (Nordstrom, 2000). The economy of coastal tourist villages is strongly based on urban development, but is highly dependent on the preservation of coastal landscapes and the bathing quality of their beaches (Klein and Osleeb, 2010). In this way, it is highlighted that coastal development and tourism promotes environmental changes but are also vulnerable to these changes (Li *et al*., 2016).

These initiatives are only two examples of several coastal urbanization plans that are evolving in relation to anthropogenic modifications of the coastal dune fields with different restrictive issues. Gesell and other foresters initiated a touristic "industry" that comprises stages of tree thinning, parking strategies and urban plans (Isla, 2013; Isla and Isla, 2020). Buenos Aires Province has stated new models for the growth of urban settlements: field clubs ("clubes de campo"; Decree No. 9404/86), and neighborhoods of restricted accesses ("barrios cerrados"; Decree No. 27/98). These urbanization models flowered during the nineties although they were criticized for giving more initiatives for the private owners, coastal barriers included (Vidal-Koppmann, 2015).

The Gesell brothers promoted the afforestation of sand barriers in Buenos Aires Province. Carlos Gesell imagined transforming those high-altitude dunes into a touristic city. His brother Ernesto faced lately a similar task afforesting the dunes west of the Claromecó. The current dune fixation plans for these bathing resorts differ significantly from those originally proposed almost a century ago by Carlos Gesell and his brother. Not only thanks to the regulations that govern these projects and the activities related to dune afforestation and coastal urban development; but also thanks to the knowledge of the environmental processes that these fixations with fast-growing exotic species have promoted over time.

The future dune-fixation plans for Villa Gesell and Dunamar present important differences with different approaches: forests re-conversion, meaning de-forestation and afforestation, and dune fixation with both native and exotic dune species. For Villa Gesell, on the one hand, a forest re-conversion is proposed meaning the replacement of almost centennial trees for new individuals in those sectors where forests are already established. This approach is primarily intended to reduce the hazard related with frequent tree falls during extreme climate events. Although the environmental impacts of coastal afforestation were extensively documented (Yang *et al*., 2006; Ratas and Rivis, 2008; Weston, 2014; Luo *et al*., 2015), the de-forestation and introduction of new trees will not led to a significant change in coastal dynamics. Some authors have also identified de-forestation as a useful strategy for coastal dune restoration (Lithgow *et al*., 2013).

On the other hand, new dune fixation areas with native dune species are proposed. However, Novoa *et al*. (2013) identified the impacts of exotic species over the re-vegetation of costal dunes with native species and difficulties on its re-introduction. Zaloumis and Bond (2011) showed that forest restoration over coastal dunes follows a linear increase in woody species over time but restoring native grasslands may represent efforts that are more considerable.

In contrast, new dune fixation areas with exotic rapid-growth tree species are projected for Dunamar. As mentioned previously, this strategy promotes several impacts over coastal dynamics and beach equilibrium. Although it promotes an increase in species richness, the introduction of exotic species means several problems for dune conservation (Castillo and Moreno-Casasola, 1996). Malavasi *et al*. (2013) proposed to strictly regulate the afforestation's area in order to preserve natural dune fields. Avis (1989) recommended to only stabilizing those areas when it is absolutely necessary but only by using native species.

Strategies for future dune fixation

As mentioned above, LULCs resulting from urban and tourism development associated with afforestation projects are usually recognized as the main driver force behind impacts on hydrology, sediment balance and biodiversity change in dune areas (Lemauviel and Rozé, 2003). The stability of the dunes is greatly threatened when changes in land use occur, such as forestation

with exotic trees and shrubs (Curr *et al*., 2000). These species can generate favorable conditions to the new establishment of exotic vegetation from other sources of dispersal.

One of the consequences of the urbanization of fixed dune sectors is the introduction of ornamental species and the production of gardens and urban green spaces. This generates a change in the species assemblages from the residual natural vegetation that may remain standing, also generating the introduction of exotic shrub and grass species related to gardening (Pauchard *et al*., 2006).

Historically, the vegetation of the sandy barriers of the Buenos Aires province was an open grassland composed of about 70 species, dominated by *Panicum racemosum* and other grasses that withstand being buried with sand and dispersed by seawater (Faggi and Dadon, 2011). Cabrera (1941) described this grassland community in detail. This can be considered as the typical plant community prior to the arrival of massive sea-and-sun tourism.

Faggi and Dadon (2010) compared the species assemblages between urban and non-urban dune areas. They found that the number of exotics increased substantially towards the urban centers. At the same time, the areas located 10 km away from urban centers presented a high similarity with pristine original communities obtained from the plant inventories made in the 1940s (Cabrera, 1941).

The plant associations described in the early 20th century are still present today, although some species have disappeared and the percentage cover of many species has changed (Faggi and Dadon, 2011). The spread of exotics, either introduced into the surroundings from pastures or as weeds from the rural environment (*Dactylis glomerata*, *Festuca arundinacea*) together with ornamentals escaped from gardens (*Gazania longiflora*, *Lagurus ovatus*) changed the composition of the original vegetation.

Based on this, the fixation of native species with high colonization power of dune environments is proposed as a management strategy. This would avoid the new introduction of exotic species with their subsequent changes in coastal morphodynamics, as well as the impact on coastal aquifers and changes in local biodiversity. To this end, certain relevant aspects must be taken into account:

1. The species to be used should tend to reestablish the original dune system or at least an environment with a high percentage of floristic similarity. For this purpose, surveys from the 1940s are available (Cabrera, 1941) (Table 2, Figure 12).
2. It should be taken into account that not all plant species colonize all the spaces present in dune environments. In active dunes, vegetation will tend to establish in the shallows, being the most humid sectors. On the continental side of the foredunes, establishment will be more successful than on the seaward sides. Likewise, the vegetation may differ with respect to the semi-fixed and fixed dunes, as well as their dune faces and crests (Table 2).
3. The use of properly constructed and installed sand fences would allow the sediment retention necessary for the establishment of incipient vegetation. Adequate sand management is a key aspect for revegetation of the dunes.
4. Dune revegetation zones should be protected from being affected by tourist traffic, off-road vehicles and other urban-tourist activities that may affect the development of plant species.
5. To this end, it is important to have signage and delimitation to alert and to make people aware of the process carried out, its relevance and the care that must be taken into account.
6. A monitoring plan should be established to evaluate the fixation strategies used from the point of view of the success of plant species establishment, as well as various environmental variables related to the sediment balance and coastal aquifers.
7. The proposed management plan should foresee permanent evaluations in order to be able to adapt the next steps according to the results obtained throughout the dune fixation process.
8. It is necessary to work with adequate planning to ensure the establishment of native vegetation in the dunes. Under this premise, the Integrated Coastal Management tools that guarantee an adequate execution of the plan become relevant. Therefore, it is proposed and promoted that all the aforementioned aspects be framed in a constant process of public participation, contemplating the opinions and interests of civil society, academia, coastal managers and private actors.

Table 2. Dominant native species for each of the dune sub-environments and level of dune coverage. Status of each species: ntv = native; ntz = naturalized; end = endemic [Adapted and modified from Faggi and Dadon, 2010; Faggi and Dadon, 2011; Marcomini *et al.*, 2017]

Dune type	Sub-environment	Dominant species and status	Level of dune coverage
Active dune fields	Crests	*Panicum racemosum* [ntv] *Cortaderia selloana* [ntv]	Low
	Lows	*Panicum racemosum* [ntv] *Calycera crassifolia* [ntv] *Cakile maritima* [ntz] *Sporobolus coarctatus* [ntv]	Low
	Incipient dunes	*Panicum racemosum* [ntv] *Cakile maritima* [ntz] *Sporobolus coarctatus* [ntv]	Low
	Continental faces	*Baccharis genistifolia* [ntv] *Tessaria absinthoides* [ntv] *Androtrichum trigynum* [ntv] *Cortaderia selloana* [ntv] *Solidago chilensis* [ntv] *Cyperus prolixus* [ntv] *Achyrocline satureioides* [ntv]	Intermediate - High
	Seaward faces	*Panicum racemosum* [ntv] *Calycera crassifolia* [ntv] *Cakile maritima* [ntz] *Sporobolus coarctatus* [ntv]	Low
Semi-active dune fields	Crests	*Panicum racemosum* [ntv] *Calycera crassifolia* [ntv] *Hydrocotyle bonariensis* [ntv]	Low
	Lows	*Adesmia incana* [ntv] *Tessaria absinthoides* [ntv] *Cortaderia selloana* [ntv] *Panicum racemosum* [ntv] *Androtrichum trigynum* [ntv]	Intermediate - High
	Slip faces	*Senecio crassifolius* [ntv] *Panicum racemosum* [ntv]	Intermediate
	Stoss faces	*Panicum racemosum* [ntv] *Calycera crassifolia* [ntv] *Hydrocotyle bonariensis* [ntv]	Low
Stable dune fields	Crests	*Achyrocline satureioides* [ntv] *Panicum racemosum* [ntv] *Ambrosia tenuifolia* [ntv] *Cortaderia selloana* [ntv] *Hydrocotyle bonariensis* [ntv] *Adesmia incana* [ntv] *Schoenoplectus californicus* [ntv]	Intermediate - High
	Faces	*Achyrocline satureioides* [ntv] *Tessaria absinthoides* [ntv] *Cortaderia selloana* [ntv]	Intermediate
	Lows	*Hydrocotyle bonariensis* [ntv] *Cortaderia selloana* [ntv] *Ambrosia tenuifolia* [ntv] *Conyza blakei* [ntv] *Typha sp.* [ntv] *Mikania parodii* [end] *Eleocharis viridans* [ntv]	Very High
	Dune margins	*Ambrosia tenuifolia* [ntv] *Cortaderia selloana* [ntv] *Melilotus albus* [ntz] *Hydrocotyle bonariensis* [ntv] *Equisetum giganteum* [ntv] *Melilotus indicus* [ntz] *Eleocharis viridans* [ntv]	Very High

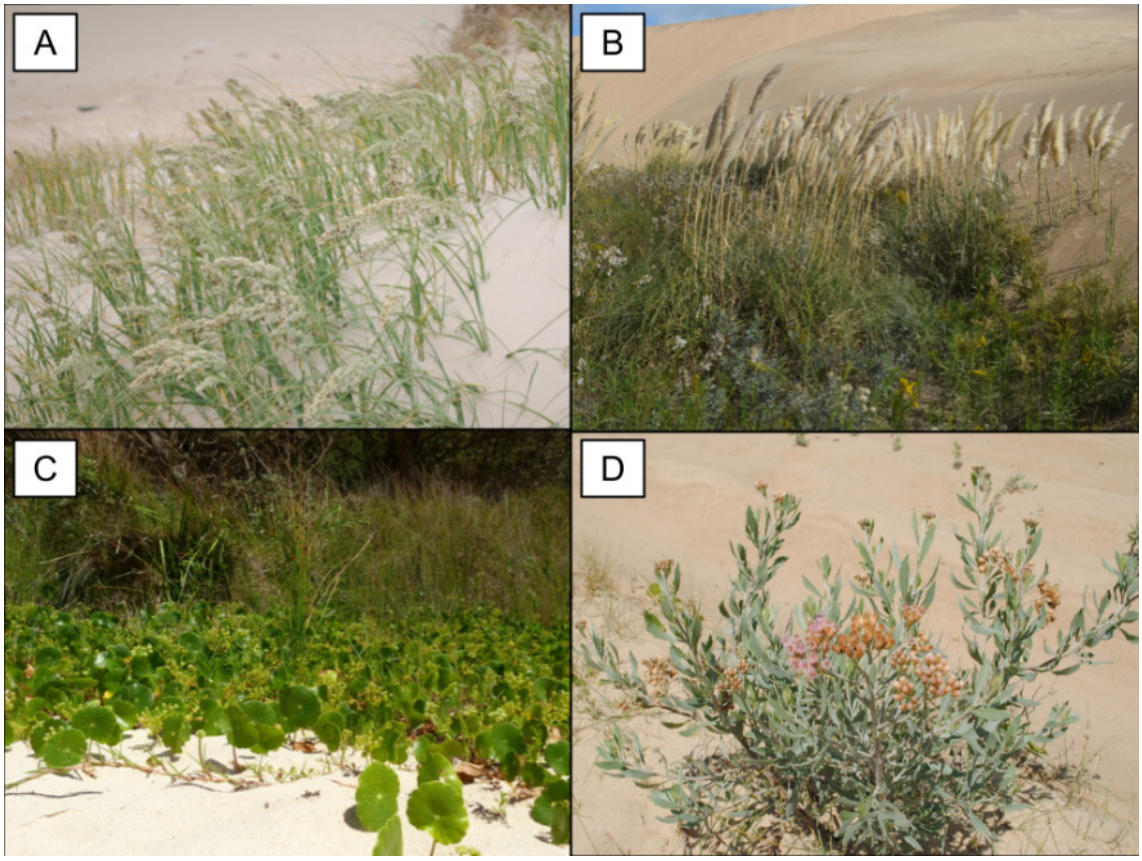

Figure 12. Native species proposed for dune fixation. *Panicum racemosum* (A), *Cortaderia selloana* (B); *Hydrocotyle bonariensis* (C); *Tessaria absinthoides* (D).

7. CONCLUSIONS

The Gesell brothers faced similar afforestation challenges, but with different physical conditions inherited from the spatial intervals and the environmental conditions of two different sand barriers. Although the dune afforestation has allowed the tourist and economic development of Villa Gesell and Dunamar, the systematic replacement of native vegetation by fast-growing exotic species has induced several environmental problems. Coastal erosion, surface runoff increase, diminish of foredune areas and spread of exotic plant species are some of these impacts. In this way, afforestation projects over coastal areas could have a major impact on the local hydrological balance. At the same time, the fixation of dunes generates a sedimentary imbalance that induces coastal erosion processes, among other impacts.

The urban development of the studied villages was substantially different. Villa Gesell grew at rates without precedent in Argentina that led to several unsolved growing problems (water provision, coastal-dune retreat, beach widths, runoff episodes, domestic sewages). Dunamar is still being planned in stages and present incipient problems due to the abundance of sand. Recent plans propose the urban development of Dunamar and Villa Gesell, taking into account the increase in the urbanized surface and the tourist capacity of these villages, as well as different strategies linked to dune fixation. Re-conversion (de-forestation and afforestation) and dune vegetation with native species are proposed for Villa Gesell; afforestation with exotic woody species is proposed for Dunamar.

These strategies present different levels of complexity for their implementation as well as diverse environmental impacts. Re-conversion may not signify several changes over coastal sedimentary imbalance; despite of that de-forestation is recommended in order to restore natural dynamics over dune areas. New dune fixations with woody exotic species is not recommended, especially taking into account negative

experiences in the region. Dune stabilization with native species is strongly recommended, even representing more effort in order to reach a success in the implementation of the strategy.

This review propose a series of measures as a guideline for the implementation of the future dune fixation strategies. Besides the plant species to use, the implementation of sand fences and other specific measures proposed in this work, it is important to face the future development of coastal villages over dune areas under the orbit of an Integrated Coastal Management.

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AUTHORS CONTRIBUTION

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