

RESTORATION TECHNIQUES FOR COASTAL DUNES AND RESTINGAS DEGRADED BY PINUS ELLIOTTII ENG., IN SOUTHERN BRAZIL**TÉCNICAS DE RESTAURAÇÃO DE DUNAS COSTEIRAS E RESTINGAS DEGRADADAS POR PINUS ELLIOTTII ENG., NO SUL DO BRASIL****TÉCNICAS DE RESTAURACIÓN DE DUNAS COSTERAS Y RESTINGAS DEGRADADAS POR PINUS ELLIOTTII ENG., EN EL SUR DE BRASIL**

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Tiago Pereira dos Santos¹, Marcelo Maisonette Duarte²**ABSTRACT**

The forestry of *Pinus elliottii* reached a commercial scale in the mid-1980s in the municipality of São José do Norte, RS, Brazil. With the aid of tax incentives, producers sought income from resin extraction, and the plantations expanded significantly, forming large blocks in the district of Bojuru. This study aimed to evaluate the natural regeneration of pioneer native species following the removal of *P. elliottii* in a dune area; assess the implementation of vegetative barriers using native species for area restoration and dune protection; and test different techniques for dune stabilization using physical barriers and clustered native plantings. The results of natural regeneration were favorable at the experimental site, unlike the seedling survival rates, which were below the levels considered ideal for restoration purposes. The dune stabilization technique using physical barriers (containment fences) proved effective on the dune crest but did not yield the same results in wet areas or those with pre-established vegetation. Dune areas adjacent to commercial plantations and lacking established vegetation are particularly vulnerable to the spread of *P. elliottii* seeds.

Keywords: Ecological Restoration. Forestry. Dune Stabilization.**RESUMO**

A silvicultura de *Pinus elliottii* atingiu escala comercial em meados da década de 1980 no município de São José do Norte, RS, Brasil. Com a ajuda de incentivos fiscais, os produtores buscavam renda da extração de resina, e as plantações se expandiram significativamente, formando grandes lotes no distrito de Bojuru. Este estudo teve como objetivo avaliar a regeneração natural das espécies nativas pioneiras após a remoção de *P. elliottii* em uma área de dunas; avaliar a implementação de barreiras vegetativas usando espécies nativas para restauração de áreas e proteção de dunas; e testar diferentes técnicas para estabilização de dunas usando barreiras físicas e plantios de espécies arbóreas nativas. Os resultados da regeneração natural foram favoráveis no local experimental, ao contrário das taxas de sobrevivência das mudas, que ficaram abaixo dos

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níveis considerados ideais para fins de restauração. A técnica de estabilização das dunas usando barreiras físicas (cercas de contenção) mostrou-se eficaz na crista da duna, mas não produziu os mesmos resultados em áreas úmidas ou com vegetação pré-estabelecida. Áreas de dunas adjacentes a plantações comerciais e sem vegetação estabelecida são particularmente vulneráveis à disseminação das sementes de *P. elliottii*.

Palavras-chave: Restauração Ecológica. Silvicultura. Estabilização de Dunas Costeiras.

RESUMEN

La silvicultura de *Pinus elliottii* alcanzó escala comercial a mediados de la década de 1980 en el municipio de São José do Norte, RS, Brasil, con el apoyo de incentivos fiscales que incentivaron a los productores a obtener ingresos mediante la extracción de resina, lo que resultó en una expansión significativa de las plantaciones y la formación de grandes extensiones en el distrito de Bojuru. Este estudio tuvo como objetivo evaluar la regeneración natural de especies nativas pioneras tras la remoción de *P. elliottii* en un área de dunas, analizar la implementación de barreras vegetativas con especies nativas para la restauración ambiental y la protección de dunas, y probar diferentes técnicas de estabilización mediante barreras físicas y la plantación de especies arbóreas nativas. Los resultados indicaron una regeneración natural favorable en el sitio experimental; sin embargo, las tasas de supervivencia de las plántulas permanecieron por debajo de los niveles considerados ideales para fines de restauración. La estabilización de dunas mediante barreras físicas (cercas de contención) fue eficaz en la cresta de la duna, pero no presentó los mismos resultados en áreas húmedas o con vegetación previamente establecida. Las áreas de dunas adyacentes a plantaciones comerciales y sin cobertura vegetal establecida demostraron mayor vulnerabilidad a la dispersión de semillas de *P. elliottii*.

Palabras clave: Restauración Ecológica. Silvicultura. Estabilización de Dunas Costeras.



1 INTRODUCTION

As described by Villwock (1987), the coastal strip stretching from Torres to Chuí (Rio Grande do Sul, Brazil) is composed of low, sandy lands with lagoons, marshes, forests and gentle topography. This strip spans approximately 660 km of uninterrupted exposed beaches (TOMAZELLI & VILLWOCK, 1992). Along this strip there are fragments of forest interspersed with wetlands and dune ridges that serve as habitat for a diverse fauna, including several endemic species (BELLOLI et al., 2024; BENCKE, 2009; DUARTE & BENCKE, 2007; SEELIGER et al., 2004; WAECHTER, 1985, 1990). These factors make the region a unique environment and a biologically diverse ecosystem (SCUR et al., 2013).

According to Cordazzo and Seeliger (1998), the topographic features formed by aeolian processes result in distinct biotopographic units which, combined with abiotic factors, create varied environmental conditions. From a temporal analysis, it is possible to state that these ecosystems are particularly susceptible to environmental change and conversion to other land cover and uses (Belloli et al., 2024).

Despite the economic benefits of this crop, the silvicultural activity involving *Pinus elliottii* causes aggressive environmental impacts on native vegetation. Miashike (2015) notes that certain strategies — such as seed dormancy and rapid seedling growth — may facilitate the invasion of *Pinus* species in natural environments. Characterized as an invasive species in southern Brazil, *P. elliottii* has a high seed production capacity. These seeds are dispersed by the wind and often germinate outside the intended planting areas.

Areas with native vegetation become vulnerable when located adjacent to exotic species plantations (like *P. elliottii*). In the case of areas designated for the conservation of natural vegetation, such as permanent preservation areas (APPs) and legal reserves (RLs), this vulnerability is even more pronounced. According to Ziller and Galvão (2002), when such areas receive propagules of exotic species, their primary function — preservation and biodiversity protection — is compromised, and legal requirements are not met.

In the present study, several techniques for restoring coastal environments have been implemented and tested in areas where commercial plantations of *P. elliottii* had been removed. In addition to these interventions, natural regeneration was also assessed, in order to observe the resilience and development capacity of the native vegetation throughout the year.



2 METHODOLOGY

2.1 STUDY AREA DESCRIPTION

The study area designated for testing is located in the district of Bojuru, municipality of São José do Norte, situated between the Atlantic Ocean and the Patos Lagoon on the mid-coast of the state of Rio Grande do Sul, Brazil (Figure 1). The delineated experimental polygon covers 18 hectares and borders productive plots of *P. elliottii* to the west. On the eastern side, it borders a sandy field that extends to the foredunes and the ocean, approximately 1,500 meters away.

This polygon was selected due to its easy access, allowing for the establishment of sampling plots and subsequent data collection. The area was also prioritized for presenting a variety of environmental conditions ideal for testing: dune areas without vegetation, vegetated dunes, and wetland fields. This diversity ensured a representative sampling aligned with the local ecosystem.

Figure 1

Municipality of São José do Norte, Rio Grande do Sul, Brazil



Source: Santos (2022).

2.2 SITE PREPARATION

At the beginning of the project, the area underwent initial management activities. Due to the presence of advanced *P. elliottii* plantations in the dune system, the first action taken was the clear-cutting of adult specimens (Figure 2), thereby retreating the commercial plantation boundary from the dunes and reducing the impact on the APP's.



Figure 2

Pine trees (Pinus elliottii) in coastal sand dunes



Source: Santos (2022).

Following this initial treatment in 2018, the area was left fallow for 12 months. During this fallow period, fences were installed to isolate the site and reduce cattle intrusion. Once the fallow period ended and the residual material in the field had decomposed, the first stage of *P. elliottii* sprouting control began. After clear-cutting, seeds remaining in the soil began to germinate, and the first control intervention occurred prior to the establishment of sample plots.

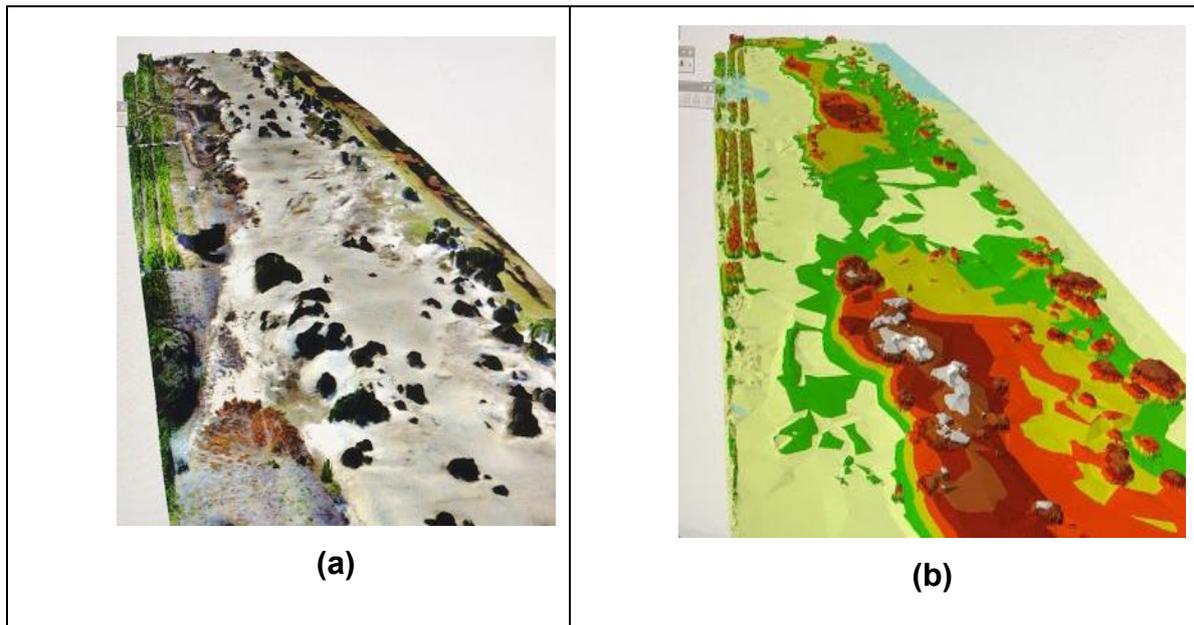
The tree species used in the experiment were pre-selected based on a phytosociological survey conducted in a reference area within the same property. It is a fragment of Atlantic Forest restinga located near the dune ridge where the experiment was conducted. The selected species were *Myrsine coriacea* (Capororoca), *Psidium cattleianum* (Araçá), *Schinus terebinthifolius* (Brazilian Pepper Tree), *Allophylus edulis* (Chal-Chal), and *Myrciaria tenella* (Camboim). All five pioneer species are indicated for restoration of degraded areas (Backes e Irgang, 2002).

Aerial images captured by drone mapping and topographic contour data were used to identify suitable areas (elevated zones, lowland areas, and vegetated zones) for plot placement (Figure 3), also taking into account logistical feasibility for field installation.



Figure 3

Aerial images captured by drone mapping (a) and topography (b)



Source: Santos (2022).

a) Nuclei Planting of Native Species

This experiment involved the implementation of nucleation technique (REIS et al., 2014), aiming to create vegetative barriers for the protection and stabilization of dunes. Nuclei planting seeks to enhance the chances of ecological succession by leveraging the area's natural regeneration potential through the formation of biodiversity nuclei that promote and accelerate the recovery process of degraded areas. This technique allows for the creation of nuclei of varying sizes and shapes. In this study, each cluster consisted of five seedlings, with a spacing of 1 meter between seedlings and 5 meters between nuclei. The methodology was applied along the dune ridge, with replications both on the windward and leeward sides. The test included 176 replications, 84 nuclei on the leeward side and 92 on the windward side, totaling 880 seedlings planted. The lower number of replications on the leeward side was due to the presence of waterlogged areas. All nuclei were georeferenced for future tracking. The planting of this experiment and the others that followed was carried out in December 2019.

b) Evaluation of Dune Stabilization Techniques

Initially, nine plots measuring 15m x 30m were established for the application of these techniques. The areas were chosen based on dune sediment elevation and vegetation presence. As such, four plots were installed in a low and humid dune section, four in a vegetated dune area, and one in a high dune area encompassing all tested techniques. In each plot 20 nuclei were implemented. The techniques used included: a) Sand retention



fences and seedling protection . This technique aimed to retain sand and protect native seedlings from strong winds. The fences also served as perching structures for migratory birds using the area as a flight path. The fences were built using *P. elliotii* wood planks and measured 1.30 meters in height (Figure 4); b) Coconut fiber biomat for sand containment and moisture retention. Made from coconut fiber, this material has a relatively short lifespan when exposed to the natural environment. The biomat has standard factory dimensions and was adapted on-site for this project. It is commonly used in bioengineering to retain sediment and moisture, facilitating seed germination and seedling development (Figure5); c) Nuclei planting of native seedlings without fencing and biomat. The same methodology as the first experiment was used, but with 3-meter spacing between nuclei. The same five species were used. All plots were marked using locally available materials, including wood residues from previous harvesting. The plots were delineated using *Pinus* stakes. In the dune crest, only one plot was installed, consisting of nuclei planting with 20 replications using both sand retention fencing and biomat.

These experiments aimed to assess seedling survival under each technique and evaluate the effectiveness of sand containment using fences and coconut fiber biomats. The results were assessed after one year.

Figure 4

Sand retention fences



Source: Santos (2022).

Figure 5

Coconut fiber biomat



Source: Santos (2022).

c) Natural Regeneration Management

The natural regeneration assessment was conducted in areas where *Pinus* was removed, but no additional techniques from the previous experiments were applied. Only basic cleaning was performed to eliminate or control the development of undesirable plant species, while promoting the growth of species of ecological interest. Management was carried out through periodic weeding and clearing around regenerating individuals (seedlings and juveniles), and/or by controlling grasses and invasive exotic tree species. This method was monitored for one year, as the area demonstrated good resilience and natural regeneration capacity. The area was prepared to be free from degradation factors that could inhibit regeneration. The actions taken included the removal of livestock and installation (and maintenance) of fencing; installation of warning signs; environmental awareness activities for operational teams and enforcement actions involving the forest asset security team, aiming to reduce environmental incidents that could harm vegetation.

3 RESULTS AND DISCUSSION

3.1 NUCLEI PLANTING OF NATIVE SPECIES

From December 2019 to November 2020, it was observed that the nuclei planted on the leeward side had a higher survival rate (41,0%) compared to those planted on the windward side (12,8%). Each nuclei was monitored, and the number of surviving seedlings was recorded to evaluate survival rates by species. The results showed a high mortality for



all species. Among the species used, *Pisidium cattleyanum* had the highest survival percentage (46,9%), followed by *Schinus terebinthifolius* (28,4%), *Mirsine coriacea* and *Myrciaria tenella* (18,18%), *Allophilus edulis* (17.61%).

3.2 EVALUATION OF DUNE STABILIZATION TECHNIQUES

The survival rate, considering the total planting for evaluation of dune stabilization was very low (18.29%). The number of survivors of each species using the various techniques is presented in Table 1. The species that obtained the highest survival, considering all methodologies, was the *S. terebinthifolius* (30.7%), followed by *A. edulis* (21.4%), *P. cattleyanum* (20.7%), *Myrciaria tenella* (10%) and *Myrcine coriacea* (8.6%).

The methodology that was most successful in planting was planting in the vegetated area with fences (A3), with 36% survival of the seedlings in the period of 12 months. The plots implanted as controls did not change over the 12 months, indicating the need for intervention to recover the area.

Table 1

Number of survivors after one year. A1: High area with biomat and fence; A2: Vegetated area with biomat; A3: Vegetated area with fence; A4: Vegetated area without interference; A5: Wet area with biomat; A6: Wet area with fence; A7: Wet area whitout interference. S1: Myrsine coriacea; S2: Allophylus edulis; S3: Myrciaria tenella; S4: Psidium cattleyanum; S5: Schinus terebinthifolius

Species/Technique	S1	S2	S3	S4	S5	%
A1	0	0	0	0	0	0
A2	0	0	0	0	2	2
A3	7	8	3	7	11	36
A4	0	0	0	1	4	5
A5	3	8	4	11	8	34
A6	0	6	1	2	8	17
A7	2	8	6	8	10	34
TOTAL	12	30	14	29	43	
%	8,6	21,4	10,0	20,7	30,7	



3.3 QUALITATIVE EVALUATION

The sand containment fences proved efficient at the dune crest by containing sand in unvegetated areas and improving seedling survival in vegetated plots, as they reduced wind impact. Accumulated sediment hindered seedling development at the crest but helped stabilize the dune and prevent encroachment into commercial planting areas.

Coconut fiber biomat performed best in the low dune area, likely due to moisture retention and lack of sand movement. In the high dune area, the biomat was ineffective, buried by sand accumulation.

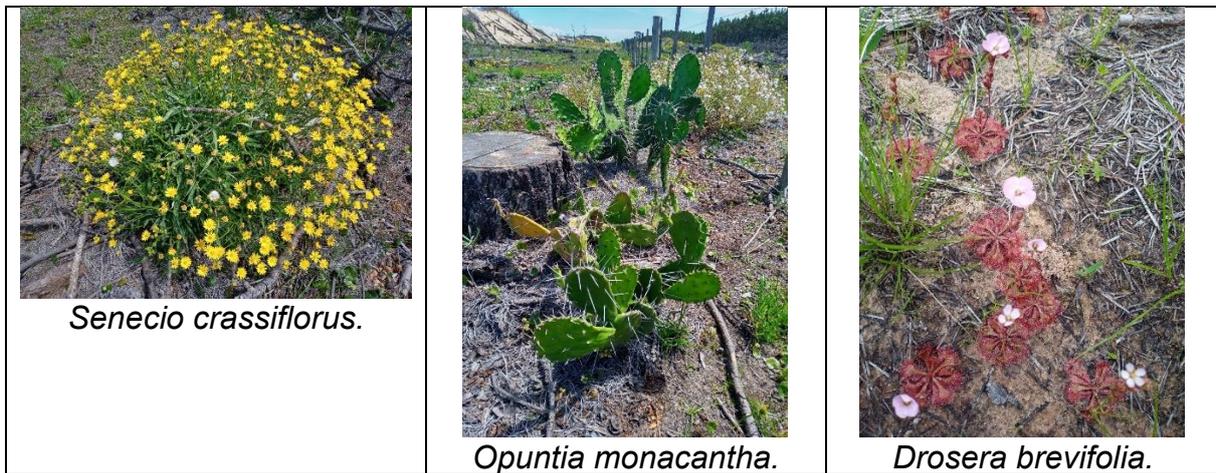
Test 3 – Natural Regeneration

Over one year, natural regeneration showed strong potential. After fencing and removing Pinus trees, the ecosystem demonstrated resilience. After 6 months, early successional species like *Hydrocotyle bonariensis* and *Senecio crassiflorus* appeared (Figure 6). By the end of the year, the area was nearly fully covered with native groundcover species. Native species such as *Opuntia monacantha* and *Drosera brevifolia* were observed during the experiment (Figura 6).

Figure 6

Some species in the area without intervention for a year





Source: Santos (2022).

4 FINAL CONSIDERATIONS

Field surveys revealed that planting native seedlings in the coastal region of Rio Grande do Sul is a major challenge. Harsh weather, salinity, wind, cattle presence, and exotic seed dispersal hinder recovery. Leeward plantings fared better than windward ones, benefiting from dune shelter. Yet, even leeward survival was unsatisfactory. These results highlight the need to consider wind and salinity in restoration planning. Dunes should serve as natural barriers for native planting. In Test 2, the Red Pepper Tree had the best survival. Still, this was below expectations for area recovery.

The most successful technique was planting with fences in vegetated areas. The worst was planting at the dune crest using biomat and fences. Still, fencing was effective at sand containment, preventing sediment movement toward productive areas. Fencing appears ideal for dune crests, creating sediment barriers. In vegetated areas, this method shows promise but needs improvements (e.g., selecting other species, ant control, hydrogel use). Coconut fiber biomat proved unviable due to high cost and low effectiveness. Natural regeneration is the most promising technique. After Pinus removal, native pioneer species established successfully. This low-cost method is recommended to continue monitoring for five years and consider enrichment planting to help restore local biodiversity, as well as controlling new invasive pine seedlings.

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