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SHORT COMMUNICATION - Silviculture

Use of Nucleation Technique in the Recovery of Degraded Insular Environment in Rio de Janeiro

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Abstract

The study evaluated the use of the nucleation method to plant native species on the Cagarras Islands (RJ), affected by invasive grasses such as crabgrass. Four native species (two pioneers and two late-successional species) were tested together with *Muellera virgilioides* (Vogel) M.J.Silva & A.M.G.Azevedo, which had been previously planted. After 18 months of monitoring, *Schinus terebinthifolia* Raddi was the most resistant species, with the highest survival and growth rates. *Monteverdia obtusifolia* Mart. (Biral) and *Allopyllus puberullus* (Cambess.) Radlk., on the other hand, showed poor performance. The study concludes that the method is viable, but in demanding environments it is better to use species with more vigorous growth to ensure restoration success.

Keywords: Islands, Restoration Ecology, Invasive Plant Species, Cagarras.

The text discusses the threats that biological invasions pose to native biodiversity and the stability of ecosystems, especially on islands, which are ecologically fragile. Exotic species, such as African grasses, take advantage of the absence of natural competitors and grow rapidly, as is the case with crabgrass (*Megathyrsus maximus* (Jacq.) B.K.Simon & S.W.L.Jacobs), one of the most aggressive grasses in Brazil. To control these invaders, restoration techniques such as nucleation — the concentrated planting of native seedlings — are effective, especially in areas that are difficult to access. Nucleation facilitates ecological succession, promotes biodiversity, and helps suppress invasive grasses through shading.

We report a case study evaluating the efficiency of nucleation on the Cagarras Islands Natural Monument (CINM), composed of four islands off Rio de Janeiro. The study tested nucleation to control the invasive grass *Megathyrsus maximus*. The CINM, an integral protection unit of the Coastal Marine system, covers 91 hectares and is located 5 km from Ipanema (Bovini et al., 2014).

Comprida Island, the second largest (19.2 ha, 0–40 m elevation), was selected due to its easy access and degradation by fishermen and tourists (Moraes & Seone, 2013). Its vegetation resembles restinga, with shrub formations and adaptations to high light, salinity, and water scarcity (Bovini et al., 2013).

A crabgrass-invaded site (30 × 30 m; ~900 m²) on the island's northwest side was selected for nucleation. The initial restoration in 2014 involved grass removal and planting 300 individuals of *Muellera virgilioides* (MV), a native restinga species. Monitoring lasted two years, but funding ended and management halted until 2018. Lessons from this failed attempt informed improved strategies (Table 1).

Table 1. Comparison between the techniques used in planting and initial management of the 2014 and 2018 restoration projects at CINM of the Cagarras Islands, RJ, Brazil.

Year	Grass control	Type of planting	Choice of species	Seedling size
2014	Controlled burn + glyphosate + canvas	Monospecific planting in rows	Native species, without considering the successional group	30 cm
2018	Monthly manual weeding	Planting in cores of four species	Distinct successional groups	40 - 150 cm

Of the 49 surviving MV, 10 were selected as nucleation centers. Around each, one individual of *Schinus terebinthifolia* (ST), *Monteverdia obtusifolia* (MO), *Allophylus puberulus* (AP), and *Inga maritima* (IM) was planted using the Anderson model

(Reis et al., 2014), spaced 50 cm apart, and 3 meters each nuclei. In December 2018, 46 seedlings were planted: 13 AP, 12 IM, 8 MO, and 13 ST. Each hole received hydrogel and irrigation; maintenance included monthly weeding and biannual mowing.

Monitoring from January 2019 to July 2021 (31 months) recorded ground-level diameter, height, and health. MV were classified as isolated or within a nucleus, with survival, flowering, fruiting, and regenerant counts (1 m² per seedling) documented.

Statistical analyses were conducted in R (R Core Team, 2023). Survival rates were modeled using generalized additive models (GAMs), both overall and for *Muellera virgilioides* (MV) grouped by presence or absence of nuclei. Growth in height and diameter (final minus initial) assessed species performance. Normality was tested with Shapiro-Wilk; comparisons used the Kruskal-Wallis test with Dunn's post hoc ($\alpha = 0.05$). Visualizations were created with "ggplot2" (Wickham, 2024) and "ggpubr" (Kassambra, 2023).

Of the 95 seedlings, 53 (55.8%) survived by the end of monitoring. *Schinus terebinthifolia* (ST) had the highest survival (77%), followed by *Inga maritima* Benth. (33.3%) and *Allophylus puberulus* (23.1%) (Table 2). *Monteverdia obtusifolia* (MO) had 0% survival and was excluded. MV individuals had a 74% survival rate from 2018 to 2022.

Table 2. Survival of seedlings in restoration Project at CINM Cagarras Islands, RJ, Brazil. Species; Initial - number of individuals planted in December 2018; Final – number of living individuals in June 2022; Survival rate of each species.

Species	Initial	Final	Survival
M. virgilioides	49	36	73.%
A. puberulus	13	3	23.1%
I. marítima	12	4	33.3%
M. obtusifolia	8	0	0.0%
S. terebenthifolius	13	10	76.9%
Total	**95**	**53**	**55.79%**

Inga maritima and *Allophylus puberulus* showed the highest early mortality, especially in the first months (Figure 1). After seven months, survival rates stabilized. MV individuals within nuclei had higher survival than isolated ones (Figure 2).

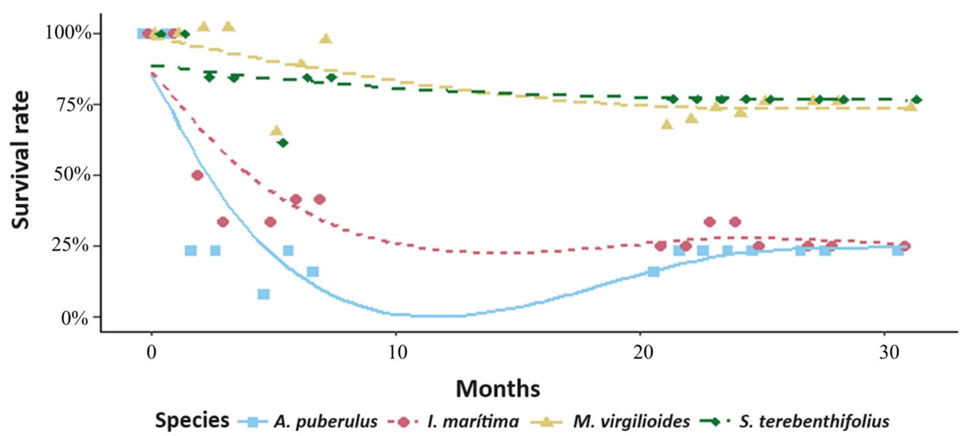

Figure 1. Survival rate of species monitored in the ecological restoration Project of CINM Cagarras Islands.

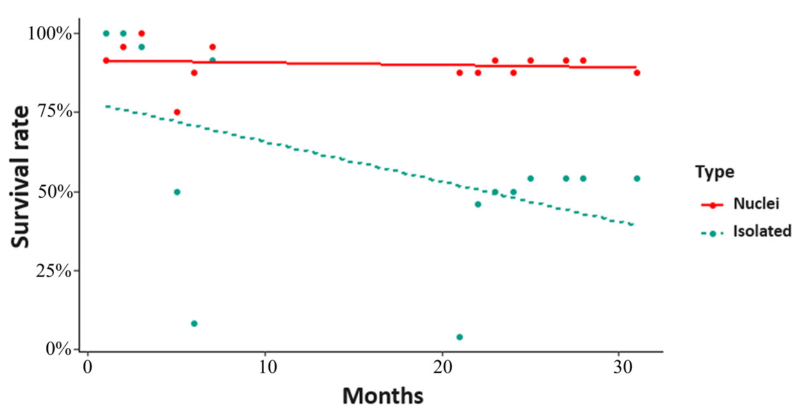

Figure 2. Survival rate of *M. virgilioides* over the months of monitoring after planting in cores. Nuclei = individuals with densely planted seedlings nearby; Isolated = individuals isolated in crabgrass.

Allophylus puberulus and *Inga maritima* exhibited negative growth due to breakage and death of larger individuals, while *Schinus terebinthifolia* and *Muellera virgilioides* showed positive growth in height and diameter, indicating establishment (Table 3). Four ST individuals stood out for accelerated growth, canopy formation, and reproductive activity, while no other species reproduced during monitoring.

Table 3. Growth in height and diameter at ground height - DAS (cm) of four species in 31 months of monitoring of the Cagarras Islands MoNa restoration project. The Kruskal-Wallis analysis was used (alpha=0.05), where equal letters in the same column represent no significant difference.

Species	Height		Diâmeter	
Allophylus puberulus	135	a	1.1	a
Inga maritima	35.5	b	0.6	a
Muellera virgilioides	67.5	c	0.95	b
Schinus terebinthifolia	62.4	bc	1.8	b

* The values represent the average growth of the species in centimeters.

The five most developed nuclei showed significant natural regeneration, with high abundance of native woody recruits. These nuclei had dense canopies and zoochorous species in reproductive phase. Regenerants included *S. terebinthifolia*, *Eugenia uniflora* L., and *Ficus luschnatiana* (Miq.) Miq., though only ST had been planted. No woody regenerants were found around isolated MV individuals in crabgrass.

This case study implemented seedling-based nucleation on CINM, an innovative effort given the limited restoration on coastal islands. Challenges such as restricted access and high costs hinder interventions, but nucleation showed promise as a low-cost, low-effort method that leverages natural regeneration. Monitoring focused on simple, predictive indicators like survival and growth (Cole et al., 2024). The nucleation method is especially important in restoration areas dominated by grasses, as it creates small nuclei of vegetation capable of reducing competition with invasive grasses, improving microenvironmental conditions and facilitating the entry of other native species (Reis et al. 2010).

As expected in early restoration, mortality was highest in the first three months, likely due to seedling stress (Gonçalves & Fonseca, 2023; Groves & Brudvig, 2019). A key issue was the lack of crabgrass crowning, an effective control method (Weidlich et al., 2020), which was logistically unfeasible.

Crabgrass also increased mortality by overgrowing seedlings—especially isolated ones—making them harder to locate and manage. In contrast, nuclei facilitated seedling visibility and maintenance, improving survival. Additionally, nuclei shaded crabgrass and promoted native species regrowth, outcompeting grass for light and space. Zoochoric species like ST attracted dispersers, enhancing regeneration. Isolated individuals failed to do so, limiting their ecological role.

Species selection was key to success. This explains the difference between the first planting (16% survival with one unsuitable species) and the second (55.8%) with taxonomically and functionally diverse species. The inclusion of the resilient *S. terebinthifolia* also contributed to improved outcomes. Moreover, planting tree species with regeneration potential likely supported natural regeneration, a critical factor for long-term restoration success (König et al., 2022).

Pioneer species have a higher survival rate in restoration centers, but their exclusive use is not recommended, as it can lead to the formation of a homogeneous canopy. The recommendation is to plant non-pioneer species in the center of the centers after the initial development of the pioneers, creating a favorable microclimate. The species *S. terebinthifolia* had the best performance in the study and is recommended for ecological restoration projects in the region, due to its ability to quickly cover the soil and provide resources for fauna, contributing to the reestablishment of ecological processes.

Limiting factors must be considered, such as environmental conditions of an island, which are atypical of most restoration environments. The use of individuals from an old plantation may have influenced the ideal number of seedlings to be inserted, and finally, the island environment demonstrated complex logistical and abiotic difficulties such that techniques with less need for management would likely increase the success of insular restoration projects.

Finally, limiting factors such as the specific environmental conditions of the islands must be considered in restoration projects, and the logistical and abiotic difficulties of the island environment indicate that techniques with less management requirements tend to be more effective.

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DATA AVAILABILITY
All data supporting the findings of this study are available upon request from the corresponding author, Dr. Massimo G. Bovini.

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