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Native regenerant rescue

Short Communication

Early survival of native woody regenerants after simplified bare-root rescue in the Brazilian semi-arid region

Cleyton dos Santos Souza [a]*, Poliana Coqueiro Dias Araujo [b]

[a] Federal Rural University of Pernambuco, Department of Forestry Science, Postgraduate Program in Forest Sciences, Recife, Pernambuco, Brazil.
[b] Federal Rural University of the Semi-Arid Region, Mossoró, Rio Grande do Norte, Brazil.

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Corresponding author: klaytonsantossouzaprivado@gmail.com

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Abstract

The rescue of native regenerants is increasingly required in areas subjected to vegetation suppression, yet its implementation is often constrained by the costs and logistical demands of conventional protocols. Here, we assessed the effectiveness of a simplified bare-root rescue procedure applied to native woody species of the Brazilian Caatinga under real operational conditions. A total of 122 individuals of *Amburana cearensis*, *Anadenanthera colubrina*, *Luetzelburgia auriculata*, and *Pseudobombax marginatum* were rescued during the rainy season. After uprooting, regenerants were kept under shade for approximately 24 h and subsequently transplanted into nursery bags containing subsoil. Survival, height, and stem collar diameter were assessed 78 days after transplanting. Overall survival reached 87.7%, ranging from 76.7% in A. colubrina to 100% in A. cearensis. Penalized binomial regression revealed a significant negative effect of stem collar diameter on survival, whereas plant height was not associated with mortality. The high survival rates observed indicate that simplified bare-root rescue can be successfully applied under real operational conditions in the Caatinga when performed during the rainy season and combined with measures that minimize dehydration. These findings provide practical guidance for flora rescue programs and ecological restoration initiatives in seasonally dry tropical forests.

Keywords: Caatinga, transplanting, plant translocation, natural regeneration, environmental licensing.

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Introduction

Vegetation suppression associated with infrastructure expansion, mining, transmission lines, wind farms, dams, and other enterprises often removes naturally regenerating individuals before they reach reproductive stages. In seasonally dry tropical forests, this removal may intensify environmental degradation because natural regeneration is already constrained by irregular water availability, seed limitation, herbivory, fire, and other environmental disturbances (Bhadouria et al., 2016; Ceccon et al., 2006). These limitations are particularly relevant in the Brazilian Caatinga, where rainfall seasonality and chronic anthropogenic disturbances strongly influence the recruitment and establishment of woody species (Vanderlei et al., 2022; Noutcheu et al., 2024).

Flora rescue and plant translocation programs are part of mitigation strategies aimed at reducing vegetation losses during suppression activities. In Brazil, environmental licensing, regulated by CONAMA Resolution No. 237/1997 (Brasil, 1997), often includes mitigation measures in enterprises with significant potential environmental impact. However, information on the effective survival of rescued and transplanted regenerants under real operational conditions remains limited.

Most available studies address long-term conservation translocations, genetic management, or controlled ecological restoration protocols (Van Rossum et al., 2020; Rutherford et al., 2022). However, rescue operations carried out in professional practice often occur under limitations of time, labor, resources, and environmental conditions. In this context, simplified procedures are widely adopted, even without ideal transplanting, irrigation, or acclimatization protocols.

Simplified rescue strategies may represent an important alternative in ecosystems where natural regeneration is limited. In tropical dry environments, low seed availability, propagule predation, herbivory, fire, and environmental degradation may further restrict the recruitment of native woody species (Ceccon et al., 2006; Gunaratne et al., 2014). Thus, rescuing already established regenerants may conserve individuals that would otherwise be eliminated during vegetation suppression while increasing the use of local biological resources for ecological restoration.

Morphological traits, such as height and stem collar diameter, may also influence post-transplant survival in restoration and plant translocation programs (Ivetić et al., 2016; Andivia et al., 2021). However, these responses vary among species, developmental stages, and operational conditions. Therefore, rapid and applied studies are necessary to support decision-making in flora rescue activities carried out under field conditions.

This study was based on the hypothesis that native woody regenerants subjected to a simplified bare-root rescue procedure would show satisfactory early survival under operational field conditions. Accordingly, the objective of this study was to evaluate the early survival of native woody regenerants subjected to a simplified bare-root rescue procedure in the Brazilian semi-arid region under conditions representative of real operational rescue activities.

Methodology

Study area. The study was conducted in the municipality of Rafael Fernandes, Rio Grande do Norte, Brazil, in an area with native regenerants at an early developmental stage (Figure 1). The region is located within the Brazilian semi-arid zone and is characterized by marked climatic seasonality, limited water availability, and high temporal variability in rainfall, which is concentrated mainly during a relatively short rainy season (Sparacino et al., 2021). According to the Köppen climate classification adapted for Brazil, much of the northeastern semi-arid region has a BSh climate, corresponding to a hot semi-arid climate (Alvares et al., 2013).

Operation al rescue. The procedure simulated real operational conditions of flora rescue during vegetation suppression activities. The method represented situations in which available time, labor, resources, and environmental conditions limited the use of more refined techniques for removal, acclimatization, and transplanting.

We selected four native species under natural regeneration: cumaru (*Amburana cearensis* (Allem.) A.C.Sm., Fabaceae), angico (*Anadenanthera colubrina* (Vell.) Brenan, Fabaceae), pau-mocó (*Luetzelburgia auriculata* (Allemão) Ducke, Fabaceae), and embiratanha (*Pseudobombax marginatum* (A.St.-Hil., Juss. & Cambess.) A.Robyns, Malvaceae). We collected individuals without strict standardization of initial plant size to represent the morphological variation commonly found in real field rescue operations.

Rescue of individual. We carried out the rescue during the rainy season, when the soil was moist. The rescued individuals ranged from 10 cm to 1.5 m in height. They were later grouped into 50-cm height classes only to describe the collected material, without specifically testing the effect of these classes on survival.

Initially, we attempted to remove each plant manually by gently pulling it from the stem base. When manual removal was not possible, we used a hand tool regionally known as a pick mattock, to loosen the soil around the individual.

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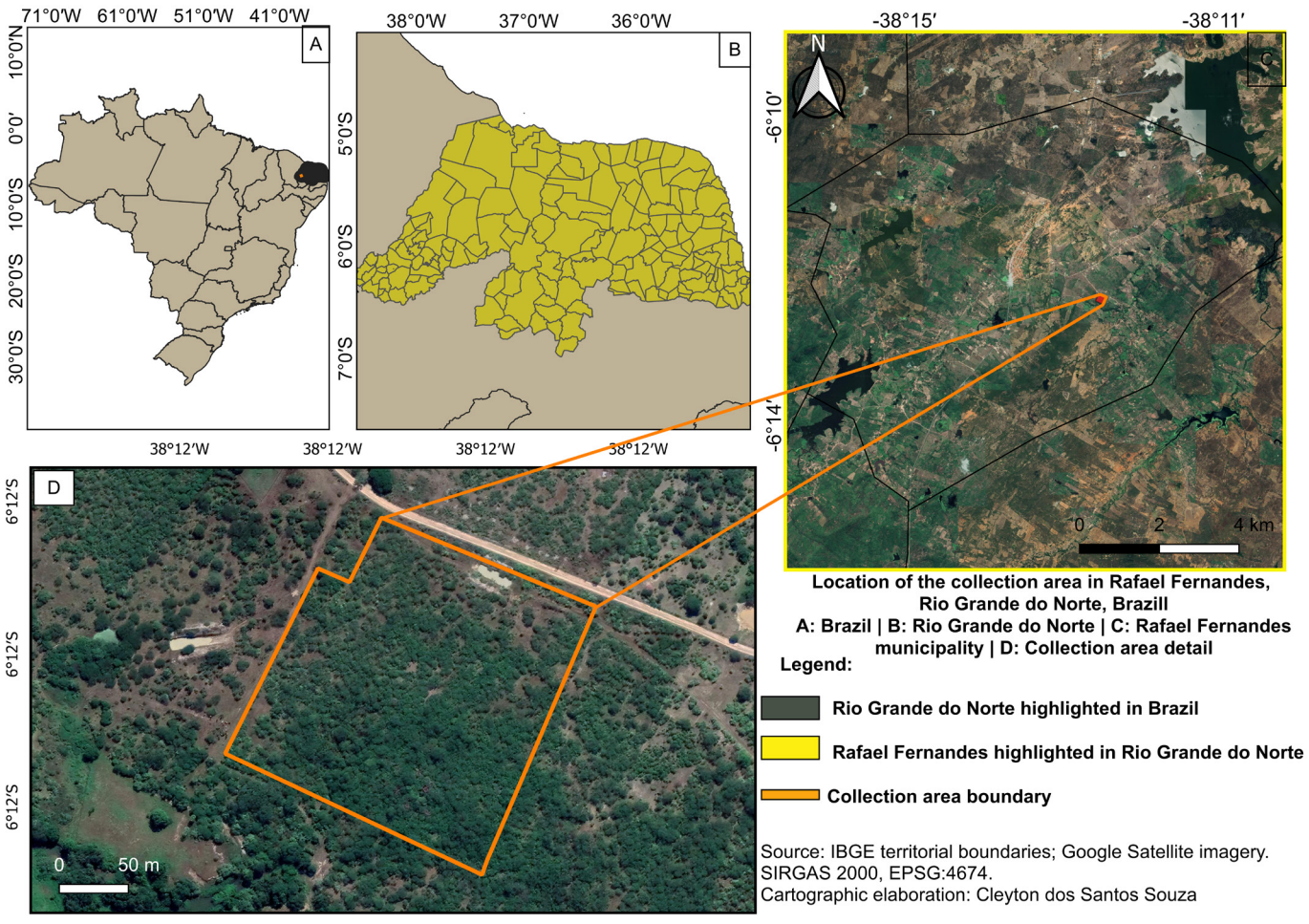

Figure 1. Location of the study area in Rafael Fernandes, Rio Grande do Norte, northeastern Brazil. (A) Location of the state of Rio Grande do Norte within Brazil. (B) Location of the municipality of Rafael Fernandes within Rio Grande do Norte. (C) Satellite image showing the study area within the municipality. (D) Detailed view of the sampling area where native woody regenerants were rescued. Source: Authors.

For plants with deeper root systems or underground storage structures, we opened a circular trench approximately 10 cm from the stem base to release the roots from the surrounding soil and attempt to remove the root system as intact as possible. However, in some individuals, this distance was not sufficient to avoid damage at greater soil depths, and part of the root system or underground structure was sectioned by the tool during removal.

Most individuals were removed with the root system exposed, under a condition similar to bare-root rescue (Figure 2). After removal, we kept the regenerants in a shaded place to reduce dehydration until transplanting.

Planting and initial management. Approximately 24 hours after removal, we transplanted the regenerants into 18 × 30 cm nursery bags filled with subsoil available in the region. During the first three days after planting, we irrigated the plants three times a day to maintain tissue turgor and reduce initial water stress. After this period, we irrigated the plants once a day until sprouting occurred.

After initial establishment, we removed some individuals from the containers for visual verification of new root emission. The remaining individuals continued under management for later transplanting to the target area.

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Figure 2. Native regenerants removed under simplified flora rescue conditions. The figure shows variation in size, morphology, and root system exposure immediately after removal. A–E) *Anadenanthera colubrina* individuals with different lengths and root conditions after uprooting; F–H) *Luetzelburgia auriculata* individuals; I) *Amburana cearensis* regenerants with different sizes and exposed root systems; J) *Pseudobombax marginatum* individuals showing exposed underground reserve structures after removal. Measuring tapes were used as an approximate scale reference.

Evaluated traits. We rescued the individuals on February 14, 2026, and evaluated early survival on May 3, 2026, 78 days after uprooting. For each individual, we recorded early survival, classified as alive or dead; plant height; and stem collar diameter.

We considered survival as the main response trait. We considered height and stem collar diameter as morphological traits predicting transplant response.

Statistical analysis. We calculated early survival for the total set of individuals and for each species. Because survival was a binary response, with 1 for live individuals and 0 for dead individuals, we fitted a generalized linear model with binomial distribution and logit link function.

The model evaluated the effect of species, height, and stem collar diameter on the probability of early survival. Because one species showed 100% survival, we also fitted a bias-reduced penalized binomial model using the brglm2 package to reduce problems associated with complete data separation.

We checked model fit using an overdispersion test. We also calculated odds ratios, AIC values, and predicted survival probabilities as a function of stem collar diameter. We performed all analyses in R software.

Results

We evaluated 122 regenerants belonging to four native species, of which 107 remained alive after 78 days of monitoring. Overall early survival was 87.7%. Survival varied among species, reaching 100% in *Amburana cearensis*, 90.0% in *Pseudobombax marginatum*, 83.3% in *Luetzelburgia auriculata*, and 76.7% in *Anadenanthera colubrina* (Figure 3).

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The distribution of surviving individuals differed among species according to Fisher's exact test (P = 0.019), indicating distinct responses to the simplified rescue procedure. The penalized binomial model indicated a negative effect of stem collar diameter on the probability of early survival (β = -0.196; Z = -2.230; P = 0.0257). Height had no significant effect (β = 0.021; Z = 0.973; P = 0.3306). Thus, the predicted probability of survival decreased as stem collar diameter increased (Figure 4).

In *Anadenanthera colubrina* and *Luetzelburgia auriculata*, dead individuals were concentrated mainly among those with larger stem collar diameters. In *Pseudobombax marginatum*, despite the high overall survival, some individuals with larger underground structures also died. In *Amburana cearensis*, no mortality occurred during the evaluation period. The complete coefficients of the penalized binomial model are presented in Table 1.

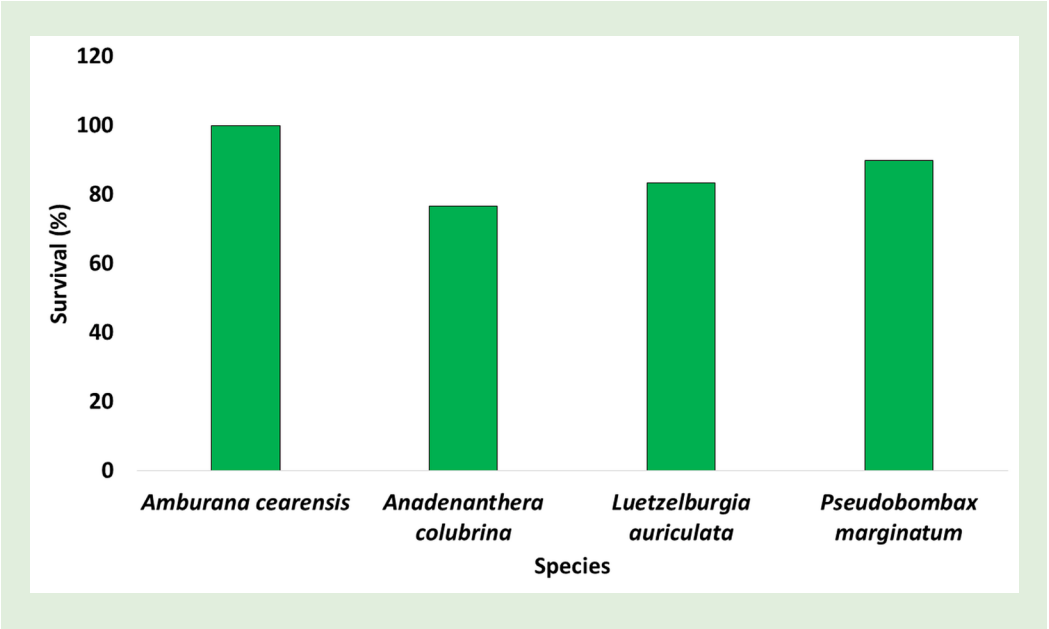

Figure 3. Early survival (%) of native regenerants subjected to simplified rescue after 78 days of monitoring. Values represent the proportion of surviving individuals of *Amburana cearensis*, *Anadenanthera colubrina*, *Luetzelburgia auriculata*, and *Pseudobombax marginatum* after removal under a condition similar to bare-root rescue and transplanting into containers filled with subsoil. Source: Authors.

Table 1. Results of the penalized binomial model for early survival of native regenerants after simplified rescue.

Predictor	Estimate	Standard error	Z value	*P* value
Intercept	5.093	1.621	3.142	0.0017
Anadenanthera colubrina	-3.891	1.521	-2.558	0.0105
Luetzelburgia auriculata	-2.948	1.486	-1.984	0.0472
Pseudobombax marginatum	0.602	2.084	0.289	0.7728
Height	0.021	0.021	0.973	0.3306
Stem collar diameter	-0.196	0.088	-2.230	0.0257

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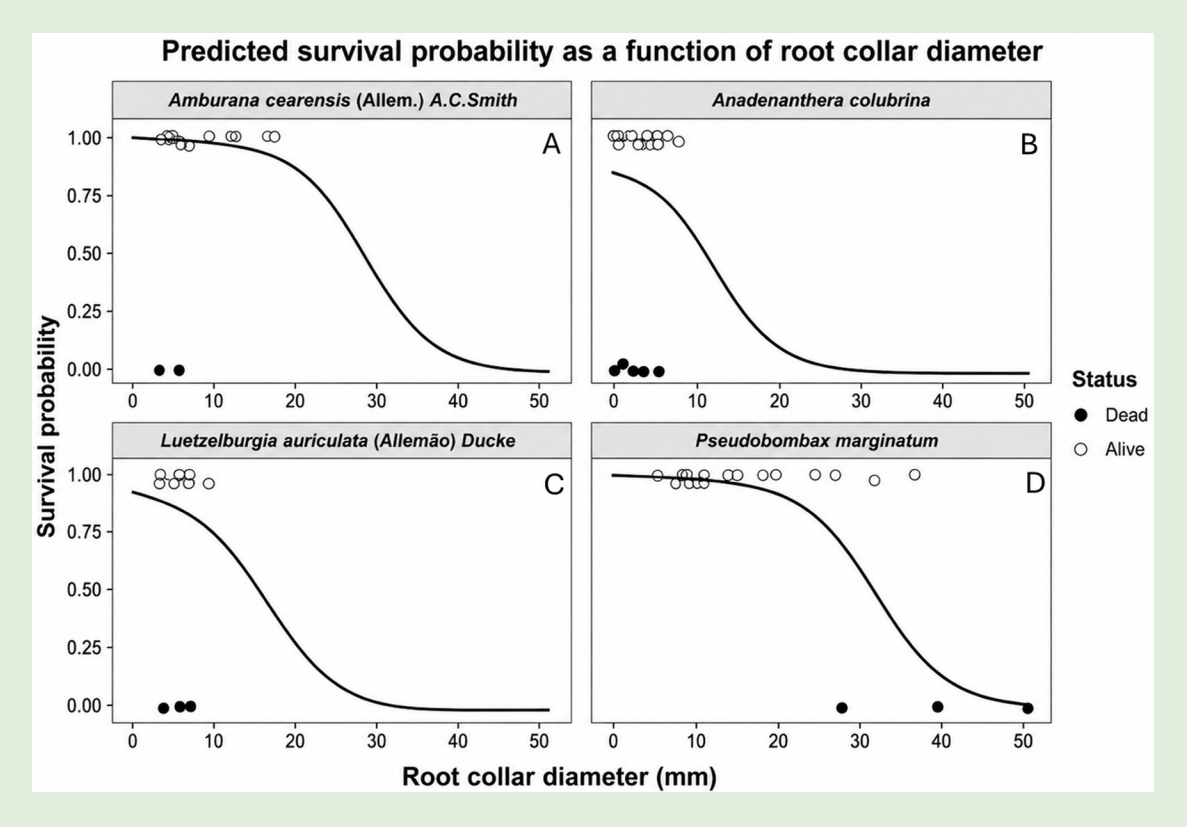

Figure 4. Predicted survival probability as a function of root collar diameter in native regenerants subjected to simplified rescue after 78 days of monitoring: (A) *Amburana cearensis* (Allem.) A.C.Sm.; (B) *Anadenanthera colubrina*; (C) *Luetzelburgia auriculata* (Allemão) Ducke; and (D) *Pseudobombax marginatum*. The lines represent the fitted values from the penalized binomial model with logit link function. Source: Authors.

In addition to early survival, the regenerants showed new root emission and vegetative recovery after transplanting (Figure 5). In *Anadenanthera colubrina*, some individuals showed damage to underground structures during uprooting, but some surviving regenerants emitted new roots along the remaining structures. In *Luetzelburgia auriculata*, even individuals with low initial root volume formed new roots. In *Pseudobombax marginatum*, root emission occurred mainly from thickened underground structures. In *Amburana cearensis*, all evaluated individuals maintained survival.

Discussion

The observed early survival indicates that simplified bare-root rescue of regenerants can reduce losses of native individuals during vegetation suppression activities. This result is relevant because the procedure simulates a common operational situation in the field, involving rapid removal, a short waiting period before planting, and the use of local soil in containers. Thus, simple practices can maintain the initial viability of native regenerants when rescue occurs during the rainy season and includes minimal protection against dehydration, consistent with evidence that water availability and the mitigation of dry conditions can favor seedling survival in tropical dry forests (Derroire et al., 2016).

The negative effect of stem collar diameter on survival suggests that larger individuals are more sensitive to the procedure. This response may be related to an imbalance between the shoot and the functional root system after uprooting. The loss of fine roots reduces water absorption, while the shoot maintains transpiratory demand, favoring transplant shock, which involves loss of turgor, reduced water potential, and post-planting mortality (Yin et al., 2014). Desiccation before planting may also reduce new root formation and increase seedling mortality (Brønnum, 2005).

This pattern helps explain the higher proportional mortality observed in *Anadenanthera colubrina*. Larger individuals are more

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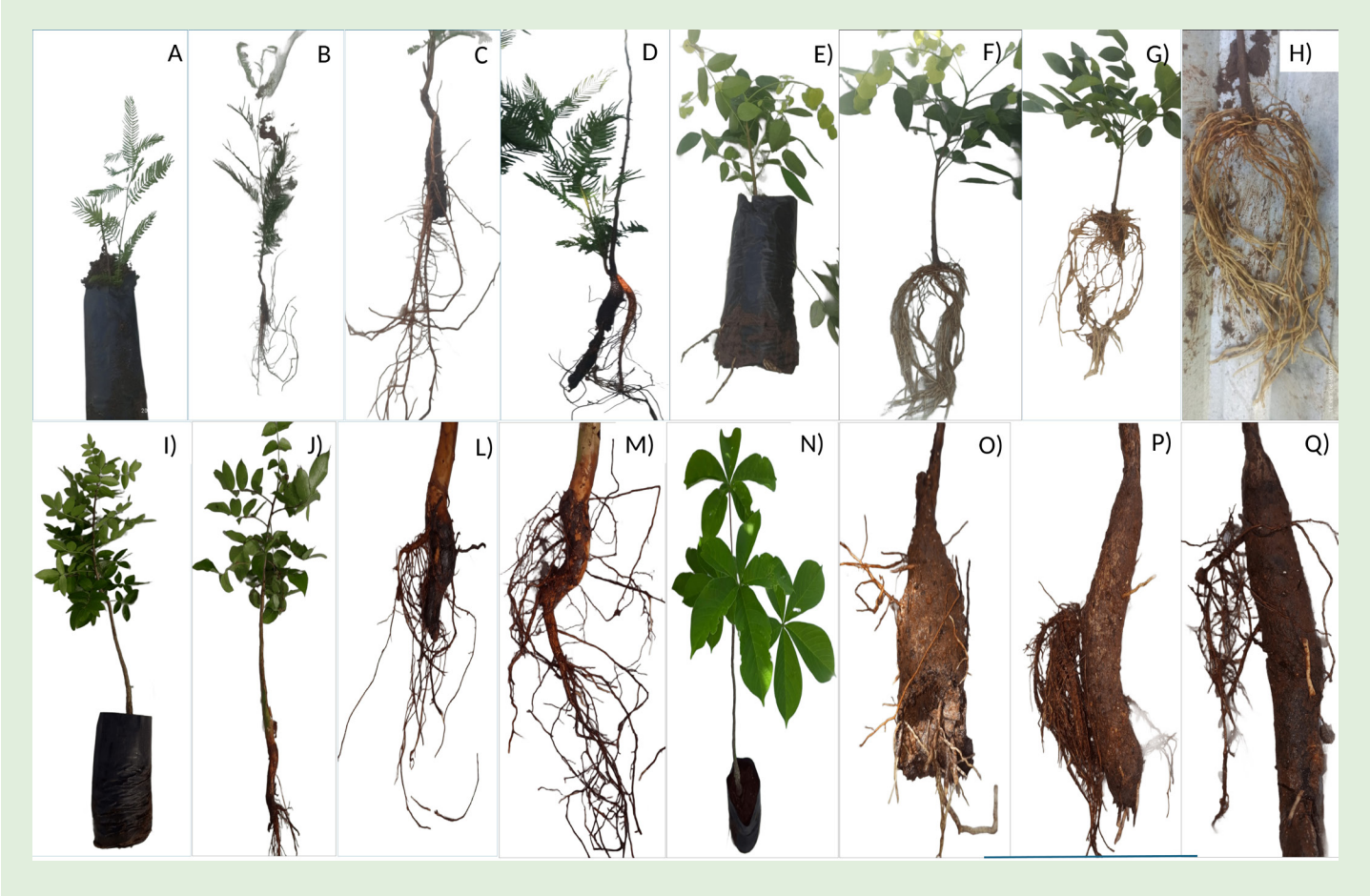

Figure 5. Native regenerants subjected to simplified rescue, showing new root emission and vegetative recovery after 78 days of monitoring. A–D) *Anadenanthera colubrina*; E–H) *Luetzelburgia auriculata*; I–M) *Amburana cearensis*; N–Q) *Pseudobombax marginatum*. Source: Authors.

likely to suffer mechanical damage to underground structures during uprooting, especially when removal occurs rapidly and with hand tools. In *Anadenanthera* species, thickened underground structures, such as xylopodia, store reserves and support resprouting after disturbances (Cunha et al., 2020). Therefore, rescuing smaller individuals or reducing the shoot before transplanting may increase operational success in this species.

The absence of mortality in *Amburana cearensis* indicates high initial tolerance to the simplified rescue procedure. This response may be related to the species' capacity to maintain biomass production and water-use efficiency under moderate water deficit, although high salinity levels can negatively affect its early growth (Santos et al., 2024). In addition, studies on vegetative propagation indicate that the species can maintain viability after stresses associated with propagule management, although rooting success varies according to experimental conditions (Silva et al., 2024).

In *Luetzelburgia auriculata*, new root emission after transplanting suggests recovery capacity even when individuals show low initial root volume. This response may favor early establishment after simplified rescue, especially when transplanting occurs during a period of greater water availability. Studies with seeds of this species indicate tolerance to water deficit during early development, especially in individuals originating from heavier seeds (Lopes et al., 2022).

In *Pseudobombax marginatum*, thickened underground structures seem to contribute to survival maintenance and new root emission after rescue. Underground reserve organs store resources and buds capable of sustaining resprouting after fire, drought, or mechanical damage (Pausas et al., 2018). However, the size of these structures does not guarantee greater tolerance when severe damage occurs during removal or when physiological demand after transplanting is high, as observed in studies with geophytes (Mocko & Jones, 2021).

Overall, the results support the hypothesis proposed in the Introduction, demonstrating that native woody regenerants subjected to a simplified bare-root rescue procedure can achieve satisfactory early survival under operational field conditions. Although survival varied among species, the consistently high overall survival indicates that simplified rescue represents a feasible strategy for mitigating vegetation losses during suppression activities in the Brazilian semi-arid region.

Despite the promising results, this study has limitations. The monitoring period evaluates only early survival and does not confirm the definitive establishment of individuals in the field. In addition, the study does not include a control group, experimental irrigation, physiological evaluation, or continuous monitoring of root growth. The sampling also reflects a real operational condition, with an unequal number of individuals among species. Therefore, the results represent initial evidence of the feasibility of simplified rescue, rather than definitive proof of restoration success.

Simplified bare-root rescue supports satisfactory early survival of the studied species under operational field conditions, especially when performed during the rainy season and with care to avoid dehydration and preserve underground structures.

Conclusions

Simplified bare-root rescue has potential to reduce losses of native regenerants during vegetation suppression activities in the Brazilian semi-arid region. Satisfactory early survival indicates that the procedure can be useful under real operational conditions, especially when carried out during the rainy season and with protection against dehydration.

Stem collar diameter negatively influences survival, indicating that larger individuals tend to be more sensitive to mechanical damage and post-transplant stress. Thus, rescue success tends to increase when removal prioritizes smaller individuals and preserves underground structures.

Future studies should evaluate field establishment, longer-term performance, and the response of a greater number of native species subjected to different levels of post-rescue management.

Author contributions

Cleyton dos Santos Souza and Poliana Coqueiro Dias Araujo conceived the study, interpreted the results, and revised the manuscript. Cleyton dos Santos Souza collected the data, conducted the experiment, performed the statistical analyses, and wrote the first draft. Both authors approved the final version.

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AI use declaration

The authors used ChatGPT, developed by OpenAI, with the GPT-5.6 Sol model, exclusively as a support tool for the translation and linguistic revision of portions of the manuscript and for technical adjustments to the quality and resolution of images intended for publication. The artificial intelligence tool was not used to generate data, perform statistical analyses, interpret results, formulate conclusions, or produce the scientific content of the study. All content translated or revised with the assistance of the tool, as well as the figures subjected to technical adjustments, was subsequently reviewed and verified by the author Poliana Coqueiro Dias Araújo, who supervised and conducted the editorial review of the material. The authors retained full control over the scientific and editorial content of the manuscript and assume full responsibility for the accuracy, integrity, and content of the final version.

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