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Natural enrichment and regeneration in clearings of a heavily exploited forest in the humid Parque Chaqueñoco

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Abstract

The behavior of five forest species and natural regeneration through the strip enrichment method in clearings, was evaluated in a logged forest in southeastern Formosa. For this purpose, one hectare of forest was selected and subdivided into 25 parcels of 400 m^2, where clearings of 6m by 20m were opened. In each plot, 21 seedlings per species were planted, with five replications. The plantation carried out in 2000 was evaluated at 22 years of age. Results showed that *Peltophorum dubium* had the largest diameter (9.19 cm ± 5.31 cm), while *Handroanthus heptaphyllus* had the smallest (3.58 cm ± 2.33 cm). *P. dubium* also reached the greatest stem height (4.34 m ± 1.53 m), while *H. heptaphyllus* had the shortest (2.97 m ± 1.10 m). *Cordia americana* had the highest survival rate (67% ± 10), and *H. heptaphyllus* the lowest (14.2% ± 5.8). The highest percentage of quality stem was found in *Gleditsia amorphoides* (69,6%) and *C. americana* (57,8). Natural regeneration showed predominance of species whit low commercial value, which made up 75% of the total, *Phyllostylon rahmnoides*, was the most dominant species, with 8% *P. dubium* proved to be the most suitable species for this type of silvicultural practice, followed by *G. amorphoides*.

Keywoords: Methods; Regeneration; Rehabilitation; Forestry.

Introduction

The degradation and declining productivity of native forests in the Chaco Park region are a matter of serious concern, mainly due to inadequate forest harvesting regulations and the use of outdated technologies in their exploitation. This situation is evidenced by the fragmentation of the resource, as well as by the expansion of the agricultural frontier, which makes its continuity unsustainable unless management-oriented actions are implemented (Brassiolo et al., 2013).

In southeastern Formosa, within the eastern Chaco Park region, the few remaining native forests are severely overexploited and undergoing a marked decline as a result of inadequate extraction regulations and growing land-use pressures. These two factors have resulted in both the degradation and fragmentation of the resource (Sirka & Acosta, 2021).

One of the alternatives for the recovery or rehabilitation of these logged forests is enrichment with commercially valuable species and the management of regeneration of valuable species. These practices could generate highly positive social, economic, and environmental impacts by incorporating low-productivity forest areas currently threatened by land-use conversion (Brassiolo & Grulke, 2013).

Rehabilitation involves restoring the capacity of previously logged forests or degraded areas to produce forest goods and services, thereby improving the productivity of these environments (FAO, 2009). These actions will enable different management approaches, depending on the degree of resource degradation and management objectives, while considering the particular characteristics of the area (Grance & Maiocco, 1995).

Enrichment is defined as the introduction of valuable tree species into degraded or secondary forests, commonly referred to as underplanting, and it can be implemented in clearings, lines, or strips for improvement and/or conversion purposes. These practices offer comparative advantages in ecological and environmental terms compared with open-field planting, although their potential disadvantages include the high technical and economic requirements during the initial years of establishment (Weaver, 1987; Lamprecht, 1990).

Due to their management complexity, enrichment plantations with different planting densities are considered viable alternatives at small and medium scales (Ramos & Del Amo, 1992).

Valentini and Schaeffer (1978) conducted enrichment trials with *M. azedarach var. gigantea*, *Tipuana tipu*, and other native species in strips and clearings within the forest, achieving productivity levels three times higher than those of the adjacent native forest. Enrichment also proved to be a promising option in forests where the natural regeneration of valuable species was insufficient and the standing volume did not justify an economic exploitation of the resource (Pérez et al., 1993).

Other studies in the region estimated the minimum area to be enriched at 100 ha to ensure the sustainability of an average family (Pérez et al., 2011). On the other hand, Sirka et al. (2019) studied the performance of two native forest species under different strip widths, estimating the planting and maintenance costs, as well as the effect of strip width on natural regeneration.

The decrease in survival recorded in this trial during the first three years after the species were established in clearings ranged from 30 % to 60 %, mainly attributed to prolonged droughts and heat stress caused by high summer temperatures during that period, and to a lesser extent, to insect attacks, particularly in *Handroanthus heptaphyllus* (Oviedo et al., 2007). The same study also reported that in exotic species such as *Toona ciliata* M. Roem (Toona) and *Cordia trichotoma* Arráb. ex Steud. (Peteribí), mortality reached 100 %.

The objective of this study was to determine the performance of five native forest species — *Cordia americana* (L.) Gottschling & J.S. Mill. (Guayaibí blanco), *Handroanthus heptaphyllus* (Vell.) Mattos (Lapacho negro), *Peltophorum dubium* (Spreng.) Taub. (Ibirá pitá guazú), *Pterogyne nitens* Tul. (Tipa colorada or Vira-ó), and *Gleditsia amorphoides* (Griseb.) Taub. (Espina corona) — as well as the natural regeneration of commercially valuable species under enrichment planting in clearings within a logged forest.

Materials and Methods

Study Area

The study was conducted at the Institute of Silviculture (F.R.N.–U.Na.F.), located in Villa Dos Trece, Formosa, Argentina (26°09'26.61'' S, 59°20'53.56'' W). The site is located in an area classified as Category III under the Land-Use Planning Program (POT, Programa de Ordenamiento Territorial), which allows the conversion of up to 60% of its forested area to other land uses. Therefore, the few remaining forests must be enhanced to avoid competition for land with other productive activities. The proposal to rehabilitate the logged forests through the strip enrichment method is framed within the Act No. 26331 on Minimum Standards for Environmental Protection of Native Forests (2007).

According to the Köppen climate classification (McKnight et al., 2000), the eastern portion of Formosa Province has a humid subtropical climate, without dry season, characterized by very hot summers, with winter temperatures ranging from 0°C to 18°C. The warmest months record average temperatures above 25°C. Maximum annual rainfall ranges between 1,000 and 1,200 mm, with a high potential evapotranspiration reaching up to 1,408.4 mm. Both variables show very high values in December and January, decreasing during the winter months (Figure 1).

Climatic Map of The Province of Formosa

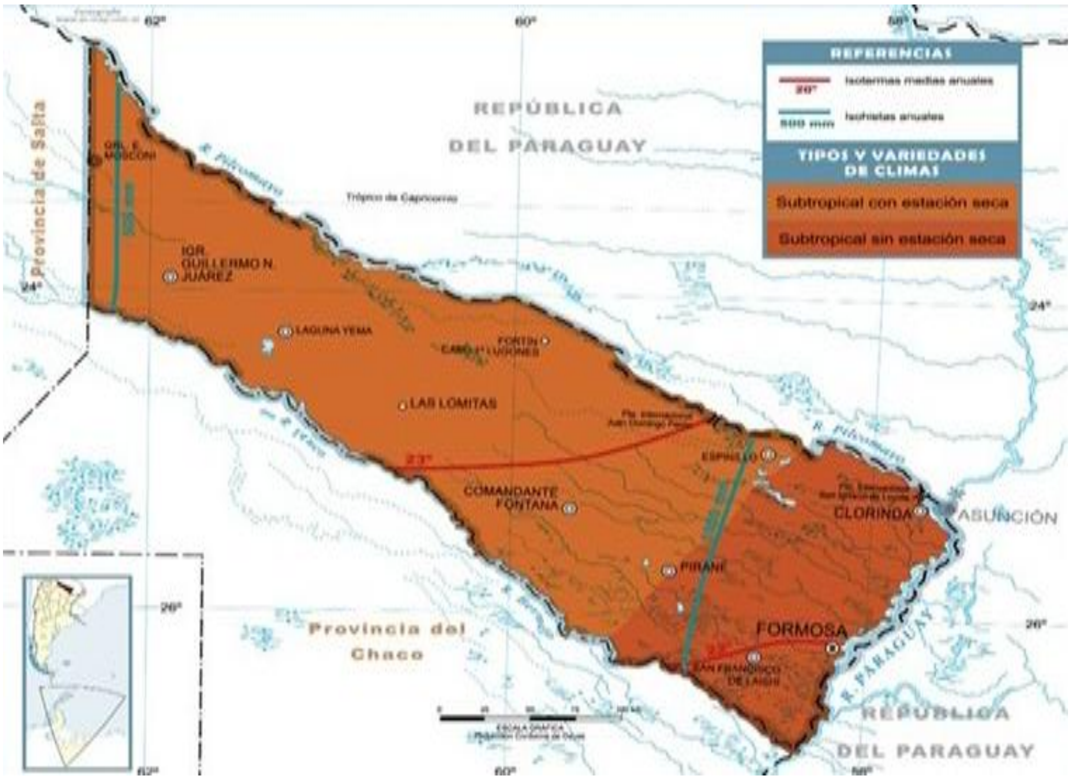

Figure 1. Climatic map of Formosa source
https://www.formosa.gob.ar/miprovincia/aspectosgenerales

The preliminary assessment of the logged forest recorded a basal area of 12.34 m^2 $ha^{-1}$and a density of fewer than 90 commercially valuable trees per hectare, each with diameters below 30 cm. Approximately 25% of trees with harvestable diameters exhibited poor sanitary status, and three vertical strata were distinguished. The upper stratum comprised commercially valuable species such as *H. heptaphyllus, C. americana, Phyllostylon rhamnoides* (J. Poiss.) Taub. (Palo lanza), *G. amorphoides* y *Diplokeleba floribunda* N.E.Br. (palo piedra); the intermediate stratum, of low commercial value, included *Myrcianthes pungens* (O. Berg) D. Legrand (guabiyú), *Trichilia catigua* A. Juss. (catigua), *Holocalyx balansae* Micheli (alecrín), *Eugenia bergii* Nied. (ñangapirí), and *Achatocarpus praecox* Griseb. (palo tinta); and the herbaceous stratum was composed mainly of Bromeliaceae species.

Experimental Design

One hectare of logged forest was selected and subdivided into 25 plots of 400 m^2 each. In every plot, rectangular clearings measuring 6 m in width and 20 m in length were opened, oriented at 45° to the north, with an effective opening area corresponding to 30% and 70% canopy cover.

A randomized complete block design was used for species introduction, since the site has an east–west slope that could affect the response variables. Five species were planted: 1. *P. dubium* 2. *H. heptaphyllus,* 3. *G. Amorphoides;* 4. *P. nitens* y 5. *C. americana*. 21 seedlings were established per clearing, with five replications per species (Figure 2).

To assess abundance, the clearings were opened by manually felling trees in poor sanitary status and selectively removing species from the arboreal and shrub strata. The herbaceous layer was also removed, except for naturally regenerated individuals of higher commercial value and specimens with outstanding phenotypic characteristics.

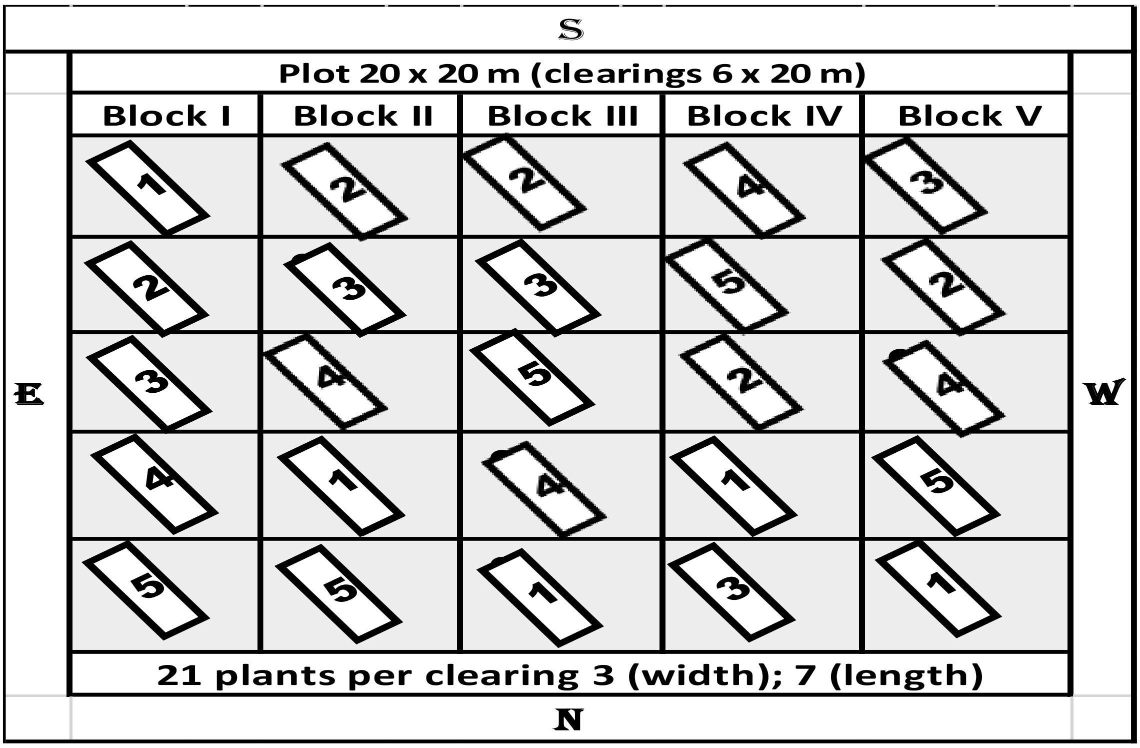

Figure 2. Distribution of species in plots according to block and orientation of the 6 x 20 m clearings

Initial Planting Conditions

The plantation was carried out in September 2000. Three rows were established across and seven along the strips, at 2 × 3 m spacing, using 20-cm-tall nursery-grown seedlings produced in plastic containers in an in-house nursery. Periodic maintenance was carried out during the first three years, including weed and ant control. In the third year, liberation pruning was conducted on the lateral side of the remaining forest, and formative pruning was performed on the planted trees.

The following variables were measured and evaluated for the planted trees in 2022: diameter at 1.30 m height (DBH; cm), clear stem height (HF; m), total height (TH;

m), survival, and stem shape. The survival percentage was calculated as the ratio of the current number of plants of each species to their initial number, multiplied by 100. For stem shape, the following categories were defined: 1) a stem straight without bifurcations (division into two branches at a height of less than 2 m), with a well-defined apex; 2) a stem with a dead or missing dominant apex; and 3) a stem with bifurcations into more than two dominant branches (three main branches at a height of less than 2 m). The abundance and frequency of natural regeneration were also assessed for two categories: "small-pole stage" with diameters between 1.5 and 4.9 cm and "large-pole stage" with diameters from 5 to less than 10 cm.

After measuring the DBH and HF of the planted trees, the mean annual increment for each variable was calculated, defined as the value measured in 2022 divided by 22 growth periods. MAI-DBH (cm $year^{-1}$) = (DBH / 22); MAI-HF (m $year^{-1}$) = (HF / 22). Subsequently, the basal area was calculated using the following formula: ($BA = DBH^2 \times \pi / 4$) in each clearing of every plot ($m^2 \cdot plot^{-1}$). The sum of all species in the different clearings of the plots was expressed in square meters (m^2). From this, the value per hectare ($m^2 \cdot ha^{-1}$) was estimated, allowing the assessment of each species' participation and its contribution to the composition of the logged forest. To estimate the volume with bark ($m^3 \cdot plot^{-1}$ and $m^3 \cdot ha^{-1}$), the basal area of each species was multiplied by the clear stem height, with estimations made per plot and per hectare. To assess the abundance of natural regeneration in the clearings, a complete survey of each clearing was conducted, considering only two regeneration stages: small pole stage (individuals exceeding 1.5 m tall and with a DBH UP TO 4.9 cm), and large pole stage (individuals with DBH between 5 and 10 cm). These pole stage categories were surveyed throughout the entire area of each clearing in 2022.

Data processing and analysis

Analysis of variance (ANOVA) and Tukey's test were used for the post hoc comparison of DBH and clear stem height. To analyze the stem shape of the planted trees, a non-parametric Kruskal–Wallis test was performed. All analyses were carried out at a 95% significance level using the free version of INFOSTAT software.

Results and Discussion

The survival rate of the species introduced in the clearings was 67.62 ± 10.90 for *C. americana,* 46.66 ± 14.82 for *G. amorphoides*, 35.22 ± 10.99 for *P. dubium,* 33.34 ± 4.75 for *P. nitens*, and 14.28 ± 5.84 for *H. heptaphyllus* (Figure 3). This parameter was statistically significant (Kruskal-Wallis, $p = 0.003$), with greater values observed in *C.*

americana compared to the other species, except for *G. amorphoides*. The latter, in turn, showed higher values than *H. heptaphyllus*. These figures are lower than those previously reported for *C. americana* (97%), *P. dubium* (95%), *H. heptaphyllus* (70%), and *P. nitens* (88%) in 6m-wide strips exceeding 100m-in length at the same site (Oviedo et al., 2007)

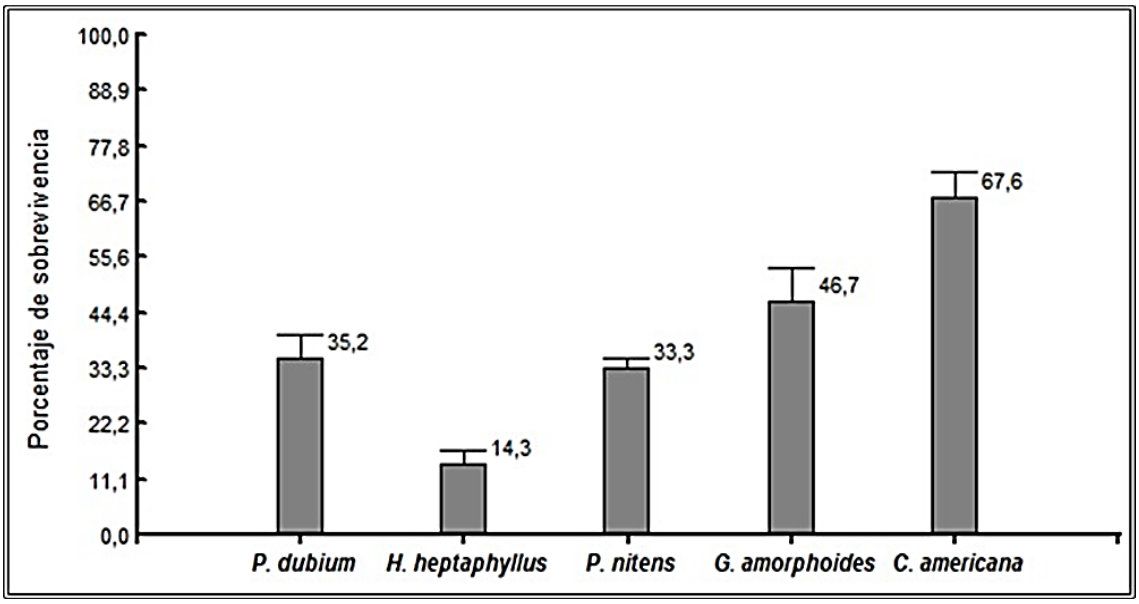

Figure 3. Survival percentage of forest species in enrichment clearings

Mean diameters and stem height, together with their corresponding standard deviations for the t species tested are shown in Table 1. The largest diameter was recorded for *P. dubium*, showing statistically significant differences compared with the other species tested. The diameter of *G. amorphoides* was also significantly greater than that of *H. heptaphyllus*, while no significant differences were found among the remaining species (p = 0.0001). Stem height was statistically more significant in P. dubium than in *H. heptaphyllus* and *C. americana* (p = 0.0038), but not significant differences were found when compared with the other species, nor between those two. In addition, total height was greater in P. dubium than in the other species (p = 0.0041). The diameter increment was higher in *P. dubium*, showing statistically significant differences compared with the other species (p = 0.0001). The increment in stem height was also significant in relation to *H. heptaphyllus* (p = 0.0041).

On the other hand, *P. dubium* the highest proportion of individuals with diameters greater than 5 cm (72.9%), followed by *C. americana* (63.6%), whereas *H. heptaphyllus* showed the lowest proportion (53.8%). The remaining two species fell within the range of these latter values. This value is considered the threshold above which the plants are regarded as established (Brassiolo et al., 2015).

The species tested in the area in 6 x 200 m strips showed higher diameter growth rates ten years after establishment, recording values of 0.61 cm year^{-1} for *P. dubium*, 0.81 cm year^{-1} for *P. nitens*, 0.50 cm year^{-1} for *H. heptaphyllus*, and 0.30 cm year^{-1} for C. americana (Oviedo et al., 2007).

Table 1. DBH, HF, HT and increments (DBH) and HF) in species in enrichment clearings

Species	DBH (cm) ± SD	HF (m) ± SD	HT (m) ± SD	Incr. DBH (cm yr^{-1}) ± SD	Incr. HF (m yr^{-1}) ± SD
P. dubium	9,19 ± 5,82**	4,34 ± 1,53**	8,44 ± 3,63**	0,42 ± 0,26	0,20 ± 0,07
G. amorphoides	6,67 ± 3,39 *	3,84 ± 1,50	6,94 ± 3,05	0,30 ± 0,15	0,17 ± 0,07
C. americana	5,40 ± 2,66	3,36 ± 1,11	5,84 ± 2,16	0,42 ± 0,26	0,20 ± 0,07
P. nitens	4,59 ± 2,36	3,64 ± 1,60	5,86 ± 3,20	0,20 ± 0,11	0,16 ± 0,08
H. heptaphyllus	3,58 ± 2,33	2,97 ± 1,10	4,64 ± 2,50	0,16 ± 0,11	0,13 ± 0,05

Basal Area and Volume of the Planted Species

After 22 years of establishment, the five introduced species in 3,000 m² of enrichment clearings attained a basal area of 0.8234 m², representing 6.67% of the total basal area of this forest type (12.345 m² ha^{-1}). Table 2 shows the basal area per plot and per hectare for each species, as well as their contribution to the total. *P. dubium* accounted for 41.11 % of the total basal area, followed by *G. amorphoides* with 24.8 %, whereas *H. heptaphyllus* had the lowest contribution, with 2.20 %. The total estimated volume for all species was 2.8774m³. *P. dubium* recorded the highest volume at 1.332 m³, representing 46.18% of the total. It was followed by *G. amorphoides* with 0.723 m³ and *C. americana* with 0.5445 m³, while *H. heptaphyllus* had the lowest value, 0.0544 m³.

Table 2. Basal area per plot and per hectare for each species and its relative contribution

Species	Basal area (m²) in clearings (600 m²)	Estimated basal area per hectare (m² ha^{-1})	Species contribution (%)
P. dubium	0,3385 ± 0,010	5,64	41,11
G. amorphoides	0,2042 ± 0,043	3,40	24,80
C. americana	0,1861 ± 0,033	3,10	22,60
P. nitens	0,0761 ± 0,021	1,28	9,30
H heptaphyllus	0,0181 ± 0,018	0,30	2,20
Total	**0,8234**	**13,72**	**100**

Stem shape

Stem shape distribution, expressed as percentages, was as follows: The highest-quality stems (Form 1) were observed in *G. amorphoides* 74.48%, *C.*

americana 59.52%, *P. dubium* 55.18%, *P. nitens* 49.88%, and *H. heptaphyllus* 46.66%. No statistically significant differences were found according to the Kruskal–Wallis test (p = 0.226). Inferior-quality stems (Form 3), were recorded in *G. amorphoides* 10.06%, *C. americana* 10.18%, *P. dubium* 18.02%, *P. nitens* 29.46%, and *H. heptaphyllus* 23.32%. The proportions for *P. nitens* and *H. heptaphyllus* were 27% and 28%, respectively. Differences were not statistically significant according to the Kruskal–Wallis test, p = 0.6865 (Figure 4). The values for this parameter in *P. dubium* and *P. nitens* were lower than those recorded in strip trials four meters wide and 100 m long, with 69.8% and 59.8%, respectively (Sirka et al., 2019).

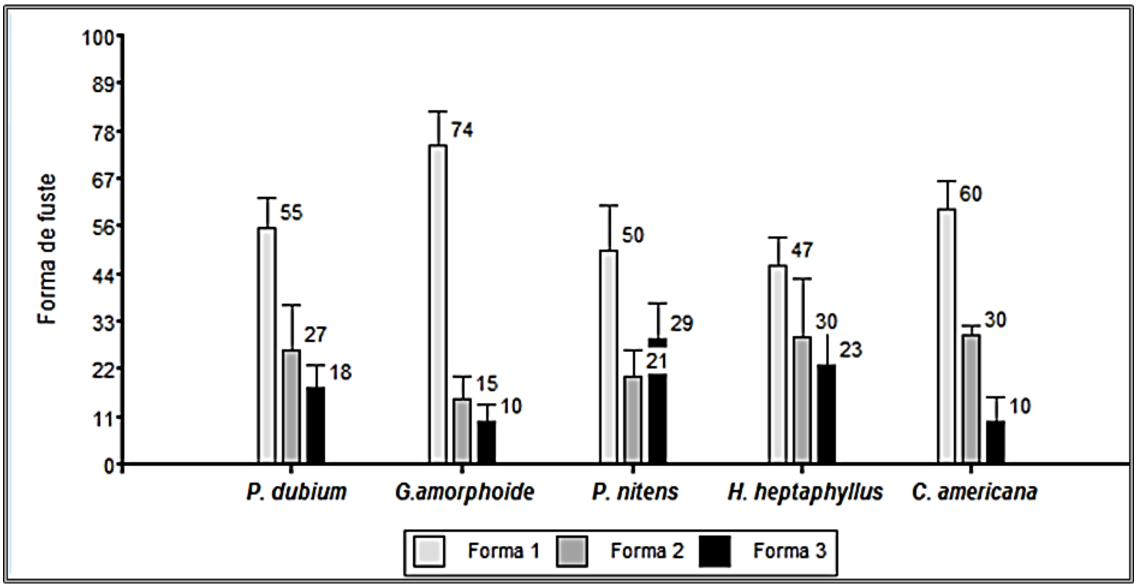

Figure 4. Percentage of stem shapes of forest species in enrichment clearings

Natural Regeneration

A total of 385 individuals were recorded, 319 corresponding to the small pole stage and 66 to the large pole stage. In both categories, species with low commercial value predominated over those of higher value, accounting for 75% of all individuals in the small pole stage. *Holocalyx balansae* (Alecrín) accounted for 37.9% and *Myrcianthes pungens* (Catigua) for 13.5%. Among the commercially valuable species, the most representative were *P. rahmnoides* with8.5% and *C. americana* with 6.1%. In the large pole stage, low-value species represented 66.67% of the total. The dominant species were *Holocalyx balansae* with 33.3% and *Myrcianthes pungens* with 15.2%. Among those of higher commercial value, *P. rahmnoides* comprised 10.5%, followed by *C. americana* and *G. amorphoides*, each with 6.1% (Figures 5 and 6).

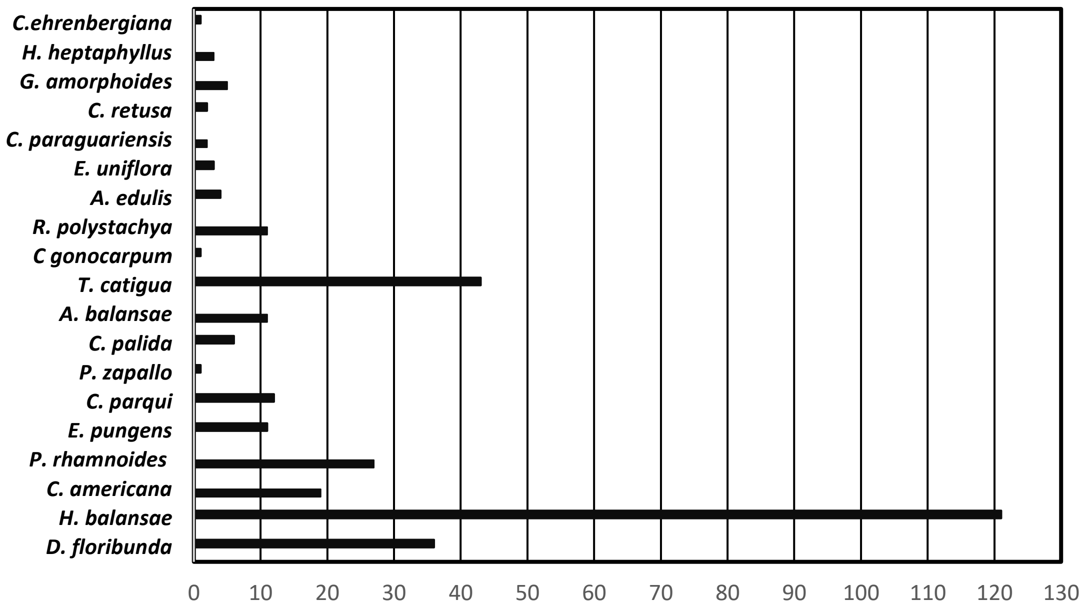

Figure 5. Number of regenerated species (small pole stage) in enrichment gaps

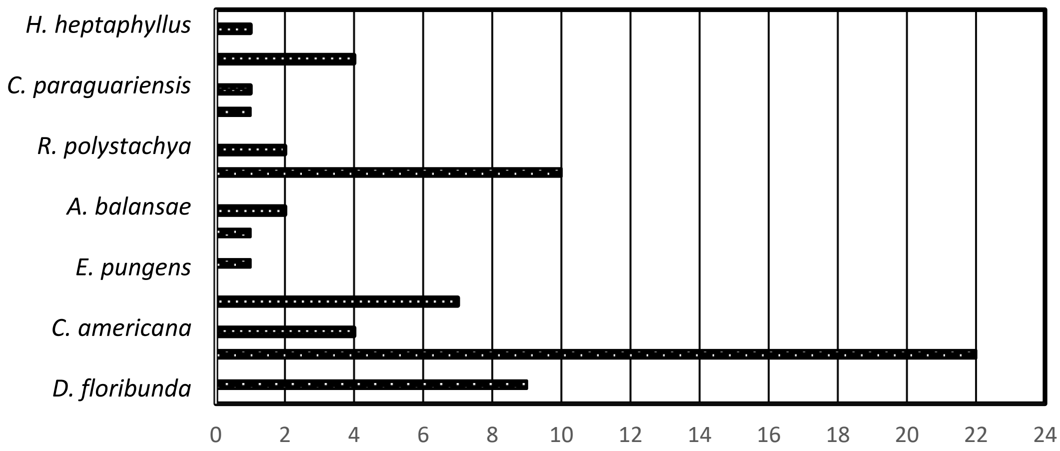

Figure 6. Number of regenerated species (large pole stage) in enrichment gaps

Conclusions and Recommendations

The species that showed the best performance under this enrichment method, in terms of both dendrometric and growth variables, was *P. dubium*, followed by *G. amorphoides* and *C. americana*. The latter also exhibited a significantly higher survival rate than the other species tested. Regarding the stem quality, higher quality stems were observed in *G. amorphoides*, followed in order of importance by *C. americana* and *P. dubium*.

As for natural regeneration, species of low commercial value tend to predominate and establish rapidly after forest clearings, whereas species of higher commercial value are much less represented. Among the latter, *P. rahmnoides* and *C.*

americana were the most representative species, although their density and spatial distribution in the forest clearings were deficient.

It is recommended to test forest species with the best possible morphological and physiological attributes in order to achieve greater development and growth, thereby reducing maintenance time and cost. Finally, with respect to natural regeneration, it is advisable to remove low-commercial-value species as they tend to occupy the available space, thereby reducing the chances of establishment of higher-commercial-value species.

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