Viability of three native tree species for reforestation in riparian areas within the Panama Canal Watershed, Republic of Panama:

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P R O R E N A

The Native Species Reforestation Project (Proyecto de Reforestación con Especies Nativas - PRORENA) is a collaborative research, education, and outreach project led by the Center for Tropical Forest Science at the Smithsonian Tropical Research Institute and the Tropical Resources Institute at the Yale School of Forestry and Environmental Studies, in partnership with public (The National Environmental Authority, the Panama Canal Authority), private (Ecoforest-Panama S.A., Futuro Forestal S.A.), and non-profit entities (Association of Independent Producers of Darién, Inter-American Tropical Tuna Commission), academic institutions (the University of Panama, National Technological University), and private individuals.

PRORENA's mission is the development of strategies for the reforestation of degraded landscapes in Panama using native species of tree, and the development of resource management professionals with the capacity to utilize and expand upon such efforts.

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SUMMARY

Municipalities, governments, and researchers around the world are coming to recognize the relationships between the health of upland ecosystems and the quality of downstream services. Though little information presently exists for Panama, research in other parts of the world, particularly the Pacific Northwest, U.S.A., has indicated that riparian areas (streamside areas of high water availability and vegetative diversity) can be particularly important in determining wildlife habitat, stream structure, and water quality, and may be very important to streambank stability and limiting bank erosion. To test the viability of three native species of tree for riparian restoration (*Anacardium excelsum*, *Dalbergia retusa*, and *Tabebuia rosea*), we planted seedlings along 3 stream segments near the Barro Colorado Nature Monument in central Panama, in areas presently occupied by the exotic grass species *Saccharum spontaneum* L.

Two years after planting significant differences in mean height and diameter were detected among species. *T. rosea* continues to outperform the other species, with a mean height at 24 months of 2.75-m and a diameter at breast height (DBH) of 3.1-cm, though all species have averaged greater than 1-m annual height growth. Mortality is high among all species, ranging from 33% - 39%. Significant differences in mortality were detected among plots, likely due to initial differences in site conditions and subsequent variation in plot maintenance. No significant species / plot interaction effects were identified, suggesting that relative species responses are consistent across the range of conditions encountered. Continued monitoring will be necessary to determine whether these differences will persist over time.

INTRODUCTION

Municipalities, governments, and researchers around the world are coming to recognize the relationships between the health of upland ecosystems and the quality of downstream services such as water quantity and quality, flood control, and fish and wildlife habitat (Gregory 1997, Waterloo et al. 1999). Though little information presently exists for Central America, research in other parts of the world, particularly the Pacific Northwest, U.S.A., has indicated that riparian areas (streamside areas of high water availability and vegetative diversity) can be particularly important in determining wildlife habitat, stream structure, and water quality (Gregory 1991, Berg 1995, Peterken and Hughes 1995, Gregory 1997, Hagar 1999). Riparian vegetation can also be very important for stream bank stability and limiting bank erosion (Rosgen and Silvey 1996).

Research from temperate regions indicates that the maintenance of buffer strips of varying widths that protect riparian vegetation may ameliorate the delivery of sediments and agrochemicals to streams (Hewitt 1990, Burt et al. 1999). The maintenance of such buffers may be sufficient to protect many ecological values, while allowing for agricultural production or other uses further up-slope (Burt et al. 1999).

There is growing interest in the role of riparian systems within the Panama Canal Watershed. Recent research conducted by the Panamanian National Environmental Authority's Panama Canal Watershed Monitoring Project and the Center for Tropical Forest Science have attempted to characterize riparian vegetation communities within the

Watershed. The Panama Canal Authority is in the process of initiating a community based riparian reforestation program. However, to date there have been no experimental studies of the viability of native species of tree for riparian reforestation.

Ecoforest-Panama, S.A., is a Panamanian forestry company with lease rights to approximately 7000 ha of "reverted areas" (regions of the Panama Canal Watershed previously controlled by the government of the United States) immediately adjacent to the Barro Colorado Nature Monument. Ecoforest-Panama is establishing 18-25 year rotation teak plantations in the upland portions of the lease areas, and is planting native species along stream courses, on steep slopes, and in inundated areas. This research is an effort to make use of the ongoing reforestation efforts of Ecoforest-Panama to investigate the viability of three native species, *Anacardium excelsum* (Bertero & Balb. ex Kunth), *Dalbergia retusa* Hemsl., and *Tabebuia rosea* (Bertol.) DC, for use in riparian reforestation projects.

METHODOLOGY

Site description -- Study plots were established along 3 streams located in the Ecoforest-Panama lease area, near Santa Clara, Panama (9°02' N, 79°45' W) (Figure 1). The study plots are surrounded by large expanses of abandoned pasture previously occupied by the exotic Asian grass *Saccharum spontaneum* (L.) (common name paja blanca). Ecoforest-Panama is in the process of re-planting these grasslands with *Tectona grandis* (L.F.) (common name teak), and is employing an aggressive chemical and mechanical *S.*

spontaneum control program until seedlings are able to grow free of weed and grass competition.

The terrain is characterized by undulating and occasionally steep hills, dissected by frequent, small streams. Soils of the area are predominantly Humults and Aquic Haplustalfs derived from andesites and basalts. Soils are relatively deep and well-drained, with well developed A (8 -10 cm) and B horizons (104 - >150 cm), and are of moderately low fertility (Vásquez Morera 1999). Soils within the study plots are frequently inundated.

The study area is approximately 10 km from Barro Colorado Island, home to the Smithsonian Tropical Research Institute field station, for which meteorological records have been kept since 1925. The average temperature on Barro Colorado Island is 27º C with a 9º C average diurnal variation (Dietrich et al. 1996). Average precipitation is 2600 mm per year, with 90% of this precipitation occurring between May and December (Dietrich et al. 1996).

Species selection -- Two of the three species were selected by Ecoforest-Panama on the basis of economic value and the availability of sufficient numbers of seed. *Dalbergia retusa* (common name cocobolo) is a moderately sized tree growing to 20 m in height and 80 cm in diameter (Santander and Waldemar 1974) and has demonstrated extremely high survival rates when planted on acidic soils (Tilki and Fisher 1998). Its heavy, oily wood is highly valued for carving, turnery, and craft objects. *Tabebuia rosea* (common name roble) is common throughout much of the Panama Canal Watershed. *T. rosea* grows to 35 m in height and 1 m in diameter (Croat 1978). In addition to these two species, wildlings of *Anacardium excelsum* (common name espavé) were collected from the Parque Metropolitano, Panama, for use in these experiments. *A. excelsum* is one of the largest tree species native to panama, growing as tall as 50 m and as much as 3 m in diameter, and its wood is frequently used for construction (Hartshorn and Gentry 1991).

Seedling production -- Seedlings were produced from seed or collected as wildlings. Seed of *T. rosea* was collected from trees in and around the study area. Seed of *D. retusa* was purchased from Cooperativa Aguadefor in Costa Rica, and is of the Hoja Ancha provenance. Seed of *D. retusa* and *T. rosea* were germinated in seed beds at the Ecoforest-Panama nurseries at Las Pavas, Panamá, in July, 2000. Seedlings of *A. excelsum* were collected as wildlings in the Parque Metropolitano, Panama, approximately 30 km from the study site, and transported to the Ecoforest nurseries. All germinants and wildlings were planted into 4 cm wide x 12 cm deep, round plastic containers filled with a mixture of approximately equal parts chicken manure, wood chips, and soil, with a small component of wood charcoal. Proportions of these components were varied slightly to adjust soil pH to a target of 6.0. Seedlings were then grown within a greenhouse at the Ecoforest facilities until planting in September.

Study design -- Three research plots were located along stream segments that had been designated for native species plantings by Ecoforest-Panama staff. Only segments that were wide enough to include three or more planting lines to either side of a stream were selected. Species were arranged randomly within each plot, with a roughly proportional representation of each species at each plot (Table 1).

Site preparation and subsequent maintenance -- Prior to planting, the study plots were hand-cleared with machetes of all *S. spontaneum* and other standing vegetation, burned, and treated with 3-5 gallons of Roundup™ per hectare. Subsequent maintenance was unevenly applied to the plots. Each received a single ring clearing, in which all vegetation was removed down to bare soil in a radius of 60-80-cm around each seedling, in September 2001. Plot #3 had also received a moderate clearing in March 2001.

Plantings -- Planting holes were arranged on a 3-m x 3-m spacing. Seedlings were planted on September 9, 2000. Approximately 20 seedlings were replaced with additional seedlings on October 16, 2000, to even the proportional representation of each species within each plot.

Measurements -- The height to shoot apical meristem (in cm) and basal diameter (in mm) were measured for each seedling at the time of planting, and once every 6 months therafter for the first 24 months. The diameter at breast height (1.3 m) was measured for all individuals with a total height of 1.5-m or greater. Basal diameter was not measured on individuals greater than 2-m in height. Height to live crown and crown diameter were measured, and degree of competition for growing space and for light were estimated, at 18 and 24 months.

Analysis – Mean height, basal diameter, and mortality were calculated for each species within each plot, for each plot, and for each species across all plots. An analysis of variance using least square means for unbalanced sample sizes (SAS 2001) was conducted to check for species and plot effects and for species/plot interactions. Tukey-Kramer pairwise comparisons (SAS Institute 2001) were used to test for differences between the means ($\alpha = 0.05$).

RESULTS

The analysis of variance (ANOVA) found that at 24 months only survivorship varied significantly by plot ($P < 0.0001$) (Table 2), with Plot 2 continuing to show higher survivorship than Plots 1 and 3 (Figure 2). These differences were also detected as significant by Tukey-Kramer pairwise comparisons. The ANOVA did not detect significant plot effects for height ($P = 0.4138$), basal diameter ($P = 0.5125$), or DBH ($P = 0.1065$). Differences in basal diameter among plots detected at 12 months appear to have evened out. Height, basal diameter, and DBH at 24 months were all found to vary significantly with species ($P < 0.005$ in all cases). The ANOVA did not find mortality to vary significantly by species ($P = 0.6553$). No significant plot / species interactions were detected. Tukey-Kramer Pairwise comparisons found significant differences among species at 24 months for all measured variables, with the exception of mortality which was similar for all species. *T. rosea* (2.75-m) was found to be significantly taller than both *D.retusa* and *A. excelsum* (2.06-m and 2.21-m respectively), which were not significantly different from each other (Figure 3). Pairwise comparisons found significant differences in mean basal diameter among species, with *A. exclesum* significantly larger than *D. retusa* (3.01-cm versus 1.68-cm), though no information was available for *T. rosea* as all individuals had already grown taller than 2-m (Figure 4). At 24 months *T.*

rosea has the greatest DBH (3.1-cm), which is significantly greater than both *A. excelsum* and *D. retusa* (2.4-cm and 2.1-cm respectively), which are not significantly different from each other.

Discussion

Differences among plots detected among plots at 12 months appear largely to have evened out, with only survivorship varying significantly among plots. High mortality at Plot 1 in the first 6 months after planting was largely responsible for differences in survival among plots detected at 12 months. In the following 12-month period mortality in both Plots 1 and 2 appears to have stabilized, with an annual mortality rates of 5% and 6% respectively. However, Plot 3, which is the most isolated and most sporadically maintained of the plots, suffered extremely high mortality (> 40%) in the most recent 12 month period, most likely due to extreme competition with *S. spontaneum* and other vegetation. Species differences in survivorship have now evened, with all species experiencing 33% - 39% mortality at 24 months.

Because basal diameter is measured only on individuals less than 2-m in height, and DBH is measured only on individuals greater than 1.5-m in height, comparisons of the diameters of species at 24 months are difficult as some individuals are too large for basal diameter measurement, while others are too small for DBH measurement. However, *T. rosea* continues to perform the best of all the species in all growth measures. Though both *A. excelsum* and *D. retusa* are significantly smaller than *T. rosea*, there are no longer significant differences between these species in terms of height or basal diameter. It is notable that all three species have more than doubled in height in the most recent 12-month period, and all now average greater than 1-m in annual height growth.

CONCLUSIONS

Differences in mean values among plots in survivorship persist, though differences at 24 months appear to be due largely to plot maintenance, while differences at 12 months appeared to be due to initial differences in site conditions. Two years after planting clear differences in species performance are apparent. *T. rosea* continues to perform best, showing the greatest overall height and diameter growth, though all species now demonstrate greater than 1-m annual height growth, and earlier differences between *A. excelsum* and *D. retusa* are no longer detectable. Continued measurements are necessary to determine whether differences among species and among plots will persist over time.

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TABLE 1. Size of study plots (ha) and proportional representation of each species.

	Plot 1		Plot 2		Plot 3	
Species	n	Proportion	N	Proportion	n	Proportion
Anacardium excelsum	30	34%	43	34%	17	37%
Dalbergia retusa	29	33%	43	34%	14	30%
Tabebuia rosea	30	34%	42	33%	15	33%
Total	**89**		**128**		**46**	
Area (ha)	**0.08**		**0.12**		**0.04**	

TABLE 2. P-values of F-tests conducted in an analysis of variance (ANOVA) of plot, species, and plot x species effects on measured variables at 24 months and 12 months. P-values less than 0.05 (highlighted in bold text) are considered significant.

24 MONTHS

	Plot		Species		Plot x Species	
	F	Pr > F	F	Pr > F	F	Pr > F
Basal diameter (cm)	0.68	0.5125	**6.69**	**0.004**	1.83	0.1633
DBH (CM)	2.28	0.1065	**8.51**	**0.0003**	0.38	0.8245
Height (m)	0.89	0.4138	**5.65**	**0.0042**	1.74	0.1429
Survivorship	**22.38**	**<0.0001**	0.42	0.6553	0.42	0.7917

12 MONTHS

	Plot		Species		Plot x Species	
	F	Pr > F	F	Pr > F	F	Pr > F
Basal Diameter (cm)	**8.21**	**0.0004**	**21.14**	**<0.0001**	1.07	0.3742
Height (m)	1.57	0.2106	**8.32**	**0.0003**	0.64	0.6343
Survivorship	**19.51**	**<0.0001**	2.99	0.052	0.77	0.5436

FIGURE 1. Map of the Republic of Panama with the area of the Panama Canal and the location of study plots highlighted.

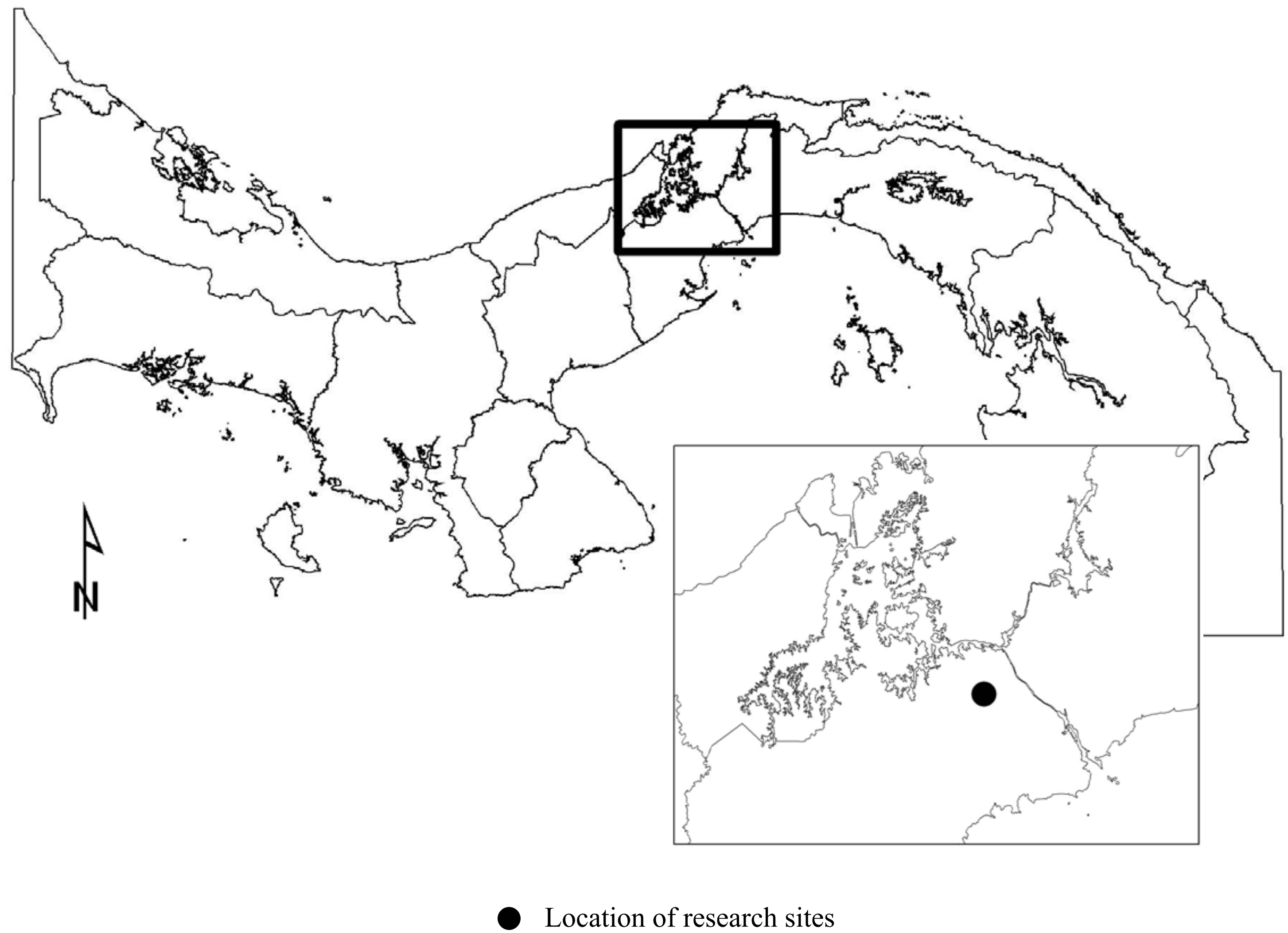

FIGURE 2. Mortality at 12 months and 24 months by species (ANACEX = *Anacardium excelsum,* DALBRE = *Dalbergia* retusa, TABERO = *Tabebuia rosea*) and by plot. Values with the same letter are not significantly different at $\alpha = 0.05$.

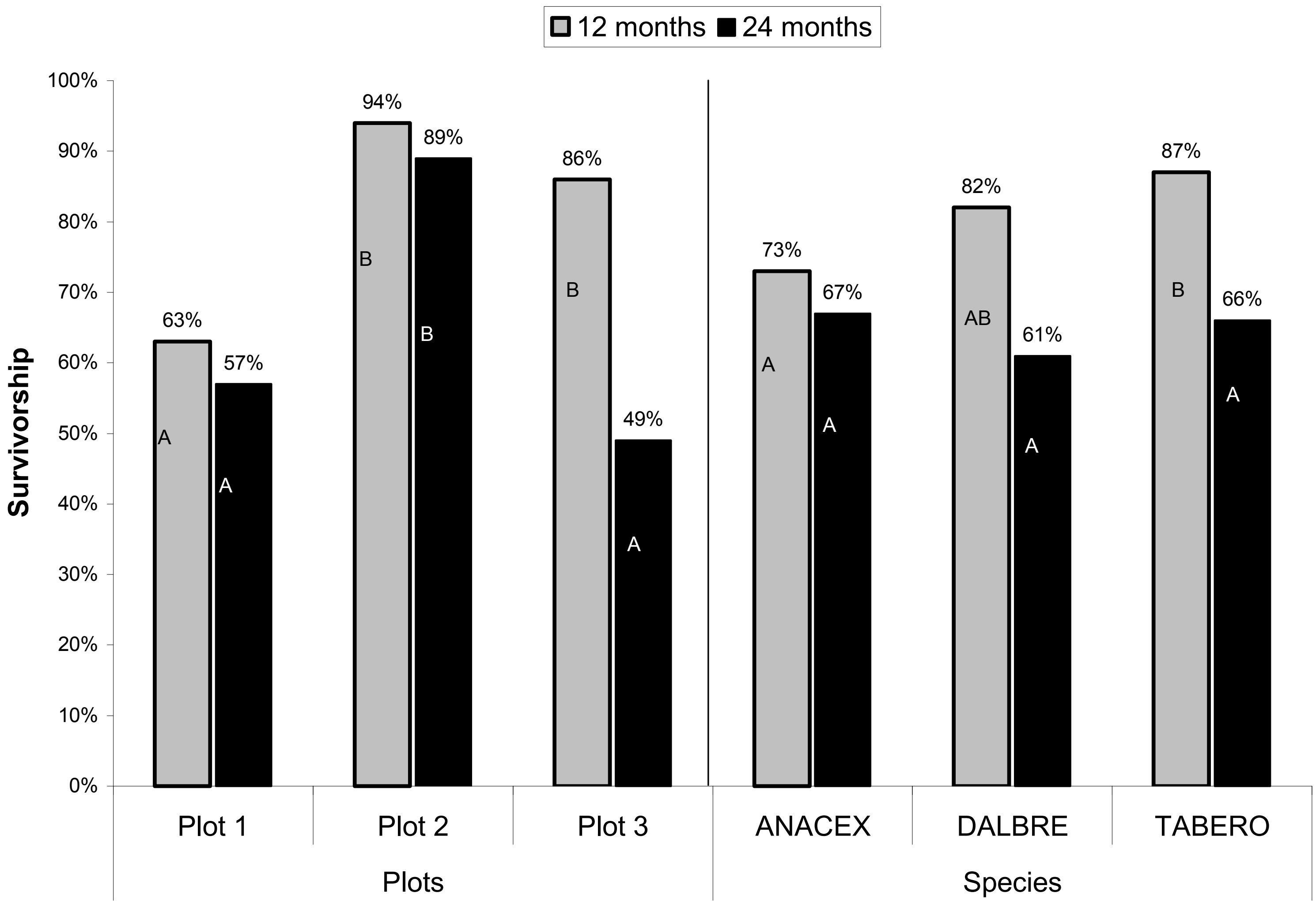

FIGURE 3. Height in meters at 12 months and 24 months by species (ANACEX = *Anacardium excelsum,* DALBRE = *Dalbergia* retusa, TABERO = *Tabebuia rosea*) and by Plot. Values with the same letter are not significantly different at $\alpha = 0.05$.

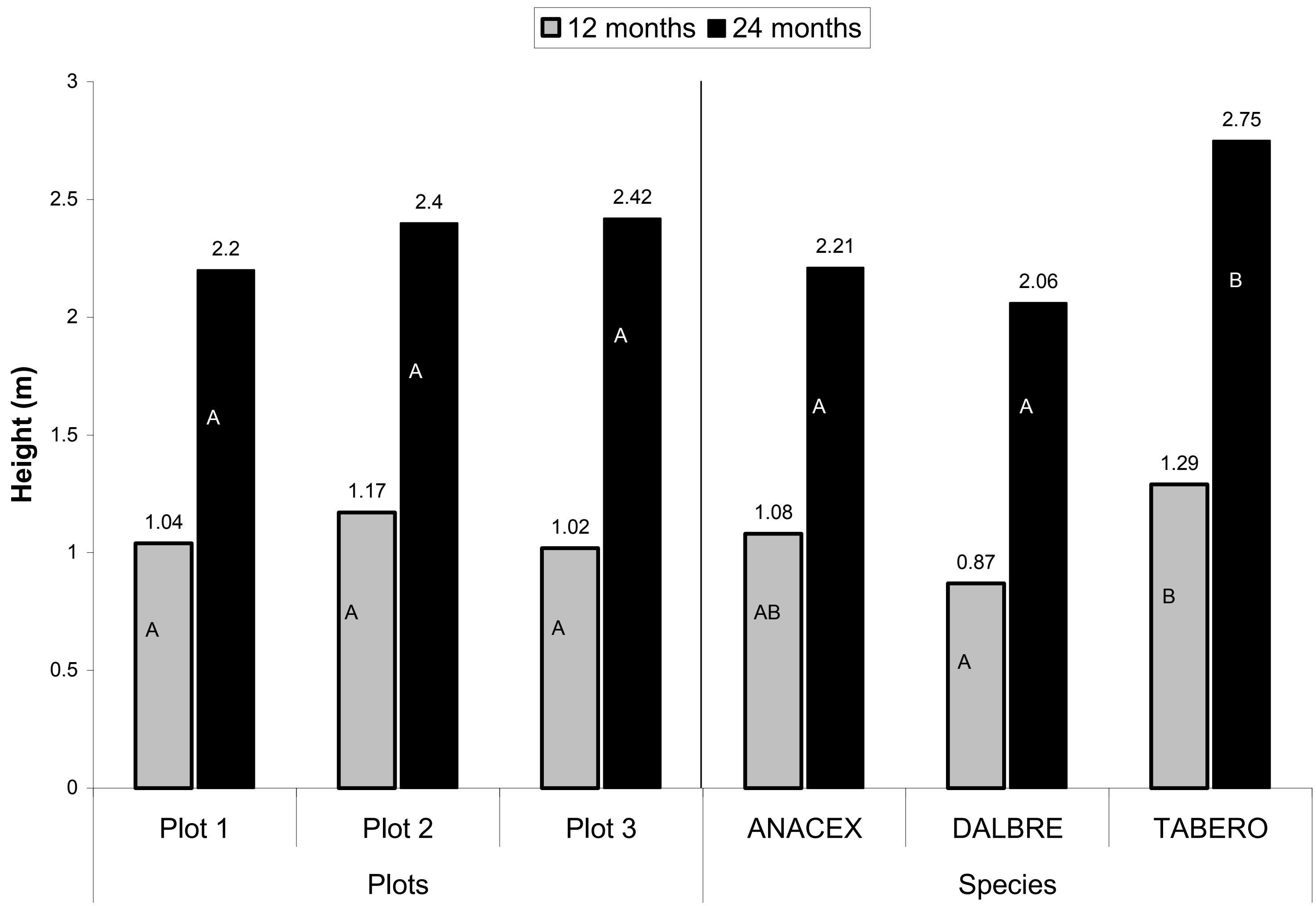

FIGURE 4. Basal diameter in centimeters at 12 months and 24 months by species (ANACEX = *Anacardium excelsum,* DALBRE = *Dalbergia* retusa, TABERO = *Tabebuia rosea*) and by plot. Values with the same letter are not significantly different at α = 0.05.

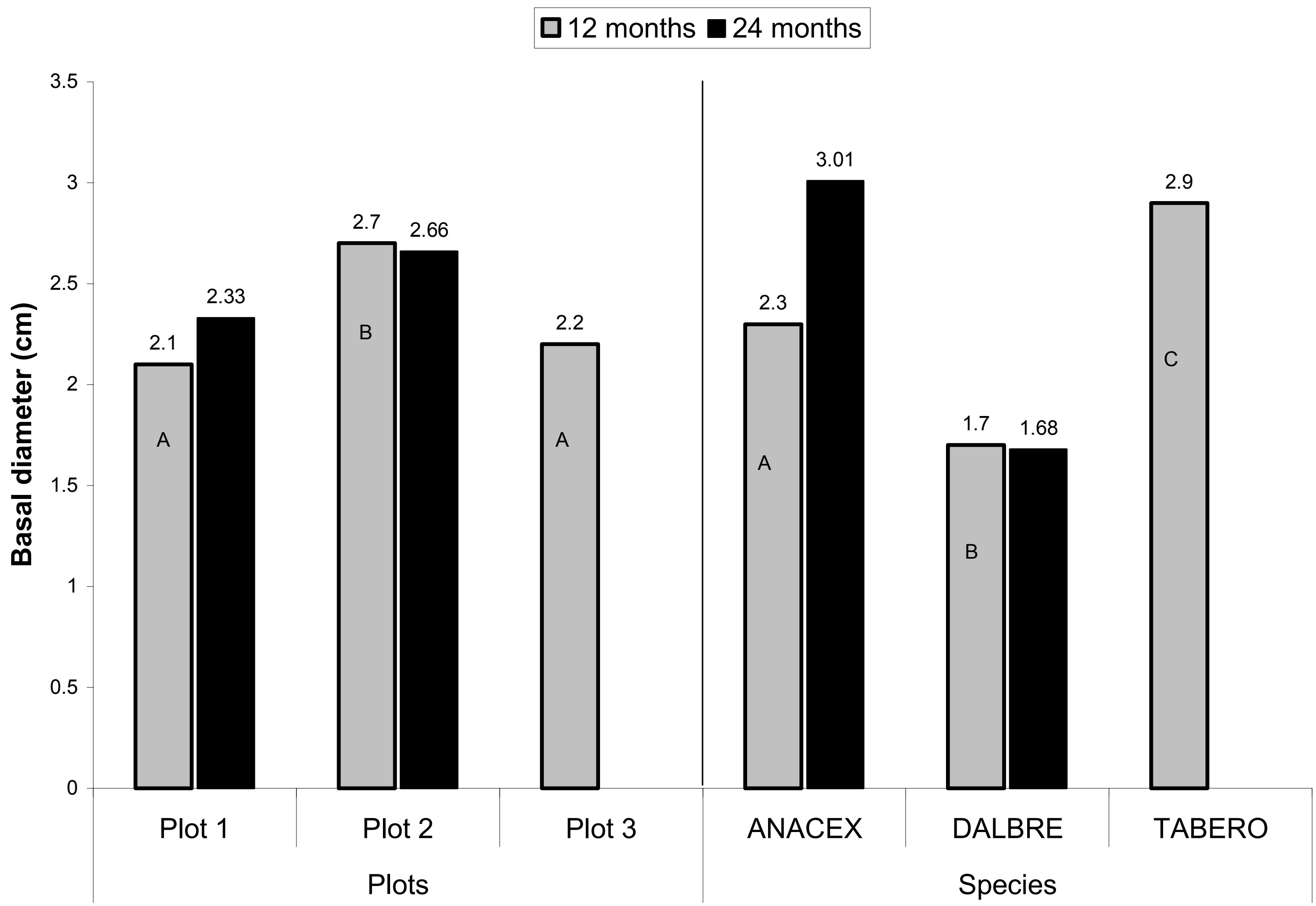

FIGURE 5. Diameter at breast height (1.3-m) in meters at 24 months, by species (ANACEX = *Anacardium excelsum,* DALBRE = *Dalbergia* retusa, TABERO = *Tabebuia rosea*) and by plot. Values with the same letter are not significantly different at $\alpha = 0.05$.