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The Impact of Hardwood Line-Planting on Tree and Amphibian Diversity in a Secondary Subtropical Wet Forest of Southeast Puerto Rico

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The impact on tree and amphibian diversity of line-planting of tropical hardwoods—mahogany (Swietenia macrophylla × S. mahagoni) and mahoe (Hibiscus elatus)—was studied in a secondary subtropical wet forest of Puerto Rico. Common coqui (Eleutherodactylus coqui) and melodious coqui (E. wightmanae) are the most frequent frog species; forest coqui (E. portoricensis) is less abundant. Although relative abundance means were slightly greater in the undisturbed forest and during the wet season, differences were not statistically significant suggesting that line-planting did not significantly affect amphibian diversity.

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The line-planted areas had a slightly higher, but not statistically significant diversity, richness, and evenness of tree species than the unplanted forest. Multi-response permutation procedure (MRPP) showed statistically significant community composition differences between line-planting and control plot trees ($T = -5.89$, $A = .86$; $p < .001$). But mean similarity among plots in both the line-planted and control plots was relatively low at less than 50% of shared species, indicating high diversity of vegetation in the overall forest area. Canopy cover by tree species greater than 3 cm in dbh was much higher in the undisturbed forest but this difference may be reduced as the young line-planted hardwoods mature. Forest enrichment through line-planting of valuable timber species in secondary subtropical wet forest does not significantly affect tree diversity.

KEYWORDS amphibian, coqui, diversity, equitability, forest enrichment, frog, hardwood plantation, Hibiscus elatus, line-planting, mahoe, mahogany, Puerto Rico, secondary, species richness, subtropical wet forest, sustainable forestry, Swietenia spp

INTRODUCTION

Overall, the rate of deforestation is still increasing worldwide. In 1992, the Food and Agriculture Organization of the United Nations (FAO) estimated that 8.3 million ha of secondary forest were lost per year in Latin America alone (FAO, 1992). It was estimated in 1990 that at least 5 million ha of tropical forests are cut per year for timber, paper pulp, and other wood products; 2 million ha/yr for cattle ranching; and 8 million ha/yr for cultivation—much of it slash and burn agriculture (Corson, 1990). The purpose of the present study was to assess whether the method of line-planting, with minimal disturbance of the forest in between the lines, results in fewer negative impacts on the surrounding forest as measured by some broad-based metrics of forest diversity such as species diversity, species equitability, species richness, light capture, and canopy closure. This work is reflective of an increase of attention on forestry methods that result in lower impact on wildlife and forest structure than traditional clear-cutting. In the context of the worldwide decline in forestry cover, especially that of subtropical and tropical wet forest area, demonstrating long-term methods for economic utilization of previously disturbed, secondary forests may also be valuable for giving alternatives other than forest clear-cutting or conversion to grazing or cropping use. If such methods are viable, it may also help reduce pressure on the economic exploitation of pristine wet forest areas. Our hypothesis was that the program of line-planting, since overall forest conditions are minimally disturbed, would result in only small changes in both forestry parameters and in faunal populations.

The experimental project is located on mountain subtropical wet forest, which is old secondary tabonuco forest, much of the area having been planted to coffee trees and the site of a number of small grazing and fruit production endeavors before the land was abandoned to forest regrowth. Thus, the project is of value in addressing conservation and utilization issues for secondary subtropical wet forest areas. Human intervention has extensively disturbed most of the mature subtropical wet forests in Puerto Rico during the last few centuries—including the use of subtropical wet forests for agriculture, coffee plantations, and pastures. The increased standard of living on the island has led to a decline in agricultural land use and in the use of wood or charcoal for burning. The most marginal of these lands have reverted to secondary forests and they are left untended until it proves profitable to use them again for timber, fuel, or agriculture.

In 1984, Tropic Ventures started a program of line-planting valuable hardwood timber trees within the existing secondary forest at the Las Casas project site. Approximately 40,000 trees were planted, primarily between 1985 and 1989, on 87 ha (215 ac), with a spacing of 3 m (10 ft) between trees in the rows and 10 m (32 ft) between the rows. The planting density for the mahogany was approximately 365 trees/ha (148 trees/ac). Final stocking with approximately 33% of the planted crop trees being carried through to maturity was projected to be 120/ha (50/ac). The line-planting was done by clearing 2-m (6-ft) planting lines through the forest using hand tools, which minimizes damage to the soils that are easily eroded when disturbed. In general, 10 m (32 ft) of subtropical wet forest is left undisturbed between tree lines. The plantings utilized economically valuable tree saplings, primarily mahogany (*Swietenia macrophylla* × *S. mahagoni*), chosen because of its availability and proven success in previous plantings on the island (Weaver & Bauer, 1983). Mahoe (*Hibiscus elatus*), pine (*Pinus caribaea*), and other native species—e.g., *Prunus occidentalis* (western cherry laurel) and *Magnolia portoricencis* (Puerto Rican magnolia)—were planted in smaller numbers, accounting for around 10% of the planted trees, and are being evaluated for future plantings. Mahogany is a relatively shade intolerant (light demanding) species representative of an early to intermediate stage of natural succession (Wadsworth, 1992). It is known to grow well in natural or created gaps in the forest matrix. The trees grow up rapidly with the combination of protection and competition afforded by the surrounding forest. It is also comparatively resistant to hurricane damage (Mayhew & Newton, 1998).

Research into the sound ecological management of timber production in tropical and subtropical secondary subtropical wet forest areas could make a valuable contribution to the future preservation of subtropical wet forestland and subtropical wet forest species by providing a method of sustainable utilization of the land for profit without adverse changes to local forest conditions. In the case of Puerto Rico, it could also make a considerable contribution to the island economy. It is estimated that in 1828 half of the lands previously owned by the Spanish Crown in Puerto Rico had been ceded to settlers whose main occupation was agriculture. At this time approximately 72% of the island was still covered by forest. By the end of the 19th century, nine-tenths of the land had been ceded to settlers and only 25% was still forested. Four percent of this forestland was government owned and 21% privately owned. By 1935, 17% of the island was privately owned forestland and this percentage increased after World War II when much of the land that had been cleared for sugar cane became unproductive and was abandoned (Pico, 1974). In general, the economically valuable species found in the secondary forest areas are fruit trees in the old plantation areas and shade trees in the old coffee growing regions. Valuable timber is generally only found in government reserves and the less accessible parts of some farms. Puerto Rico currently imports nearly all of its timber from the continental United States and Canada.

Las Casas de la Selva, a 409-ha tabonuco forest experimental enrichment project in Puerto Rico, was established in 1983. This forest project is located on steep slopes (ranging from 10–40 degrees) in the mountains of southeastern Puerto Rico. The Las Casas de la Selva project has tested strategies for utilizing a subtropical wet forest environment for long-term economic utilization without diminishing its species richness, biological diversity, or total biomass. The forest has an average elevation of 600 m and an average temperature of 22°C (71.7°F). With the prevailing Easterly trade winds delivering an average annual rainfall of 3000 mm (120 in), the year-round humidity is high.

Amphibians are abundant, integral components of many diverse ecosystems (Wake, 1991; Woolbright, 1991; Blaustein, Wake, & Sousa, 1994). These animals are considered bioindicators because their biomass constitutes an appreciable fraction of many terrestrial ecosystems (Stewart & Woolbright, 1996), they have complex life cycles and their skin is permeable to gases and liquids (Wake & Morowitz, 1991). As such, amphibians are especially useful as biological monitors of environmental health (Wake, 1991). Since in Puerto Rico frogs are the most important vertebrate nocturnal carnivores, a change in their population dynamics could have an important effect on the forest food web (Joglar, 1998). Thus, monitoring amphibians at the Las Casas de la Selva was an important way to assess the impact of a line-planting forestry approach to tropical forest ecosystems.

METHODS

Overall Purpose of the Research

As part of an ongoing study of the impact of line-planting of tropical hardwoods in a secondary subtropical wet forest area of Puerto Rico, eight plots were randomly selected for study of diversity and dominance patterns in the planted areas and in the undisturbed forest. The plots were each 10 m × 10 m and chosen to examine comparable aspect and elevation. In addition, the composition and abundance of amphibian species, an important component of Puerto Rican ecosystems, were studied over two seasons in transects located in the line-planted and undisturbed forest at similar elevations.

Amphibians' Methodology

The amphibian research, examining the diversity and abundance of amphibians, provided an opportunity to establish baseline data on amphibian populations on the property. In addition, other factors were investigated to assess potential stressors to amphibian populations at a time when amphibians are declining worldwide (Burrowes, Joglar, & Green, 2004; Stewart & Woolbright, 1996).

Two 50 m × 3 m transects were established in both line-planted and undisturbed forested areas, in order to compare amphibian diversity and relative abundance. These transects were sampled for four nights during the wet season and four nights during the dry season for 2 consecutive years (2004 and 2005). Data were collected on (a) number of frog species calling; (b) relative abundance of frogs for each species = (number of frogs observed/150 m^2); (c) age distribution per species; (d) size of male and female adults per species, (e) climatic conditions for the night: temperature, relative humidity, and wind speed; and (f) general notes on microhabitat utilization. Data for the 2 yr were analyzed using Analysis of Variance (ANOVA; Minitab–Release 14)—a statistical test for heterogeneity of means by analysis of group variances (Miller, 1997)—to determine if forest practices had any effect on anuran species composition or abundance.

Tree Methodology

Study plots

Tree diversity was determined by comparison of data from sixteen 10 m × 10 m plots. Half the plots were in areas that were line-planted and half were control plots in areas of secondary forest that have not been used for line-planting. The plots were chosen in line-planted and control plots so that they had comparable topography, slope aspect, and location on ridge top or on valley slope. Within the 100 m^2 plots, all plants with a stem diameter at breast height (dbh) greater than 3 cm were identified and tagged, with measurements of dbh, height, and canopy cover.

Richness, evenness and diversity comparisons

Summary statistics for each treatment (i.e., line-planted and control plots) included richness (R), evenness (E), Shannon diversity (H), and Simpson's index (S) calculated at the species level. Richness was defined as the total number of distinct taxa encountered within each sample plot. Evenness was calculated as the Shannon diversity value divided by the natural log of richness (McCune & Grace 2002; Equation 1):

$$E = H/\log(R).$$

Evenness has been described as the fraction of maximum possible ecosystem diversity. The Shannon diversity index (H) has been described as measuring the "information content" of a sample unit where maximum diversity yields maximum uncertainty (McCune & Grace; Equations 2 and 3):

$$H = -\Sigma\, p_i * \log(p_i),$$

$$p_i = n_i/N,$$

where n_i was the number of occurrences of species i, and N was the total number of occurrences of all species within a plot. Simpson's index (S) was calculated as (Equation 4):

$$S = 1 - S\,(p_i * p_i),$$

where p was defined in Equation 3.

Gamma diversity was calculated as the overall number of species encountered in a treatment (i.e., line-planting or control). A higher gamma diversity would suggest a greater difference among the species composition of plots within a given treatment. Beta diversity was calculated as treatment category gamma diversity divided by mean plot species richness. Summary statistics were compared using the non-parametric Mann-Whitney U-Test ($\alpha < .05$) in Analyse-It (Version 2.03 Analyse-It Software, Ltd., Leeds, England, UK), which requires two independent samples measured on an ordinal or continuous scale that have similar shape distributions, though they need not be normal.

Multi-Response Permutation Procedure (MRPP) to test for similarity

The Multi-Response Permutation Procedure (MRPP) was used to test the similarity of vegetation community composition between line-planting and control plots using stem counts of all taxa. MRPP is a non-parametric technique which tests for no difference between groups (the null hypothesis) and is available in PCORD (Version 5 from MJM Software, Gleneden Beach, Oregon, USA). It was an appropriate procedure for ecological community data as it does not require distributional assumptions of normality and homogeneity of variances. The Sørensen distance measure was used to calculate the average weighted within-group distance. MRPP provides a test statistic (T), p-value, and chance-corrected within-group agreement (A), which describes within-group similarity. When A equals 1, all items are identical within groups, and when A equals 0, differences within-groups equal that expected by chance. Most values of A are less than .1 in community ecology (McCune & Grace 2002).

Frequency

Plant species' frequency in the line-planted and control areas of secondary forest was determined as each individual plant stem counted as an observation in the site.

Plant cover

Plant cover for each species was evaluated by measuring canopy cover of the most prevalent species (among those with a dbh > 3 cm) in the line-planted and undisturbed plots.

Importance values

Importance values were calculated by combining frequency and cover data and dividing by 2, so that the sum of all importance values for each system equals 1. The graph of these data, called a dominance-density curve or species importance curve, was plotted on a log/arithmetic scale against rank order (Brower, Zar, & von Ende, 1991).

Canopy closure

Canopy closure in line-planted and undisturbed plots was evaluated using a spherical crown densitometer (Forestry Suppliers, Inc., Jackson, MS, USA, 24-quarter-inch crosshairs). Data was recorded and is expressed in this article as the number of crosshairs where open sky was observed.

RESULTS

Amphibians

There was no statistically significant difference in frog species composition between the two areas studied. *Eleutherodactylus coqui* and *E. wightmanae* are the two most common species in both forests, with occasional sightings of *E. portoricensis*. In the line-planted forest, a mean of 38.7 (σ = 21.3) *Eleutherodactylus coqui* frogs were observed per transect, per night compared to a mean of 55.2 (σ = 27.6) in the undisturbed forest. For *E. wightmanae*, observations in the line-planted forest had a mean of 137.33 (σ = 51.3) while in the undisturbed forest, a mean of 155.1 (σ = 52.42) frogs per transect, per night. ANOVA test for independence of relative abundance of frogs and forest type was non significant, ($P > 0.05$), suggesting that the line-planting forestry practice at Las Casas did not have an effect on amphibian diversity.

Trees

Richness (R), evenness (E), Shannon diversity (H), and Simpson's index (S) were calculated for each plot. Species richness ranged from 9 species at line-planting plot BD6 to 18 species at line-planting plot BD8. Species evenness ranged from .722 at control plot CBD2, to .927 at line-planting plot BD5, where 1.000 represents equal representation by all species. Shannon diversity ranged from 1.679 at control plot CBD8 to 2.550 at control plot CBD6, suggesting that individual control plots had both lowest and highest Shannon diversity. Simpson's index was also highest and lowest at control plots CBD6 (S = .90) and CBD2 (S = .711), respectively. Beta and gamma diversity were similar among treatments. Richness, evenness, Shannon diversity, and Simpson's index were not significantly different between treatments (Table 1).

TABLE 1 Comparison of Vegetation Species Richness, Evenness, and Diversity Between Treatments (Values Are Mean ± Standard Deviation)

	Line-planting	Control
Species richness (R)	13 ± 3^{a}	11 ± 3^{a}
Species evenness (E)	0.892 ± 0.026^{a}	0.852 ± 0.066^{a}
Shannon diversity (H)	2.259 ± 0.187^{a}	2.035 ± 0.317^{a}
Simpson's index (S)	0.864 ± 0.027^{a}	0.815 ± 0.065^{a}
Beta diversity	2.0	2.2
Gamma diversity	38	36

Note. Categories with similar letters were not significantly different (Mann-Whitney U test, $\alpha = 0.05$).

The Multi-Response Permutation Procedure MRPP test for similarity of vegetation community composition between line-planting and control plots suggested a difference in community vegetation ($T = -5.89$; A = .86; $p < .001$). Comparison of values within the Sørensen distance matrix show a mean similarity among line-planting plots of .47 ($\sigma = .11$), among control plots of 0.41 ($\sigma = .11$), and between line-planting and control plots of .35 ($\sigma = .11$).

The undisturbed forest areas had very slightly greater canopy closure as measured by crown densitometer measurements (Tables 2 and 3). The plots in the undisturbed forest averaged light capture of 92.1% (σ = 1.2%) compared to 90.9% (σ = 1.6%) in the line-planted plots. However, canopy cover by tree species greater than 3 cm in dbh was on average 19% higher in the undisturbed forest than the line-planted plots. Mean canopy coverage

TABLE 2 Tree Diversity Plots Within Line-Planted Area, Showing Number of Individuals, Number of Species, Light Capture, and Canopy Cover

	Aspect	Elevation (m)	# of individuals	# of species	Light capture (%)	Canopy (m^2)
PLOT BD1	Southwest	580	37	15	87	247
PLOT BD2	Southwest	589	39	15	94	121
PLOT BD3	Southwest	595	30	14	86	171
PLOT BD4	Ridgetop	605	47	18	97	236
PLOT BD5	Southeast	527	27	15	95	181
PLOT BD6	Southeast	517	23	10	85	237
PLOT BD7	Southeast	516	31	14	94	401
PLOT BD8	Southeast	526	44	22	89	293
Mean ± Std. error			34.75 ± 3.0	15.4 ± 1.22	90.9 ± 1.6	235.9 ± 30.2

TABLE 3 Tree Diversity Plots in Undisturbed Secondary Rain Forest Showing Number of Individuals, Species, Light Capture, and Canopy Cover

	Aspect	Elevation (m)	# of individuals	# of species	Light capture (%)	Canopy (m^2)
Control 1	Ridgetop	600	28	13	85	189
Control 2	Southwest	524	34	14	95	390
Control 3	Southwest	590	48	11	95	274
Control 4	Southeast	509	33	10	91	332
Control 5	Southeast	523	43	13	95	181
Control 6	Southwest	533	63	18	92	294
Control 7	Southeast	507	35	16	91	387
Control 8	Southeast	N/A	27	8	93	208
Mean ± Std. error			38.9 ± 4.3	12.8 ± 1.1	92.1 ± 1.2	289.3 ± 27

was 289.3 ± 26 m^2 in the control plots, considerably greater than the 235.9 ± 30.2 m^2 in the planted plots. The number of individual trees was also about 10% higher, with a mean value of 38.9 ± 4.3 in the control plots contrasted with 34.75 ± 3.0 in the line-planted plots.

Examination of the patterns of dominance (Tables 4 and 5) showed some differences between the undisturbed and line-planted forest plots. Most obviously, the planted mahogany trees *Swietenia macrophylla* × *S. mahagoni* were the most important species in one of the eight planted plots and third most important in two of the others. However, the results showed that a number of species were dominant in both the undisturbed and line-planted areas with *Prestoea montana* being the most important species in three of the undisturbed and two of the line-planted plots. *Micropholis guyanensis* was the most important species in two of the line-planted plots and among the top six in all of the other six. In the undisturbed forest, *Micropholis guyanensis* was less prominent, ranking third in two of the eight plots. *Casearia arborea* was among the six most important species in six of the eight planted plots but in only three of the eight control plots, although in one it was the most important species.

Schefflera morototoni was the most important species in one of the line-planted plots and ranked third and fourth in two of the undisturbed forest plots. *Ardisia* spp. was a more important species in the undisturbed plots with *Ardisia* spp. being twice the most dominant species in undisturbed plots while never being among the top six species in the line-planted plots. *Byrsonima spicata* was the top species in another of the line-planted plots, although not in the top six otherwise. It was not in the top six in any of the undisturbed plots. Other species were more important in just the line-planted areas, such as *Dacryodes excelsa* (in four of the eight line- planted plots, and in none of the undisturbed plots). *Miconia prasina* was among the six most important species in two of the line-planted and none of the undisturbed plots; *Sloanea berteriana* was among the six most important species in two of the line-planted and none of the undisturbed; and *Bucida buceras*, *Chionanthus domingensis*, and *Alchorneopsis floribunda* all were in the top six in one line-planted and in no undisturbed plots.

Species which were more important in the undisturbed than in the line-planted areas include *Miconia tetrandra* (in two of the control plots and one of the line-planted); *Guatteria caribaea* (three times in the controls compared to none of the line-planted); *Alchornea latifolia* and *Hirtella rugosa* (each twice in controls and not in the line-planted); *Matayba domingensis*, *Guarea guidonia*, *Myrcia deflexa*, *Dendropanax arboreus*, *Coffea arabica*, and *Cecropia schreberiana* (all of which are among the top six species once in controls, and did not rank among the top six species in line-planted plots).

TABLE 4 Most Important (Dominant) Species in Frequency and Canopy Cover Within Line-Planted Plots

	1st in importance	2nd	3rd	4th	5th	**6th**
PLOT BD1	*Micropholis guyanensis*	*Dacryodes excelsa*	*Swietenia macrophylla* × *S.mahagoni*	*Casearia arborea*	*Homalium racemosum*	*Tabebuia heterophylla*
PLOT BD2	*Prestoea montana*	*Casearia arborea*	*Sloanea berteriana*	*Ocotea leucoxylon*	Unidentified	*Micropholis guyanensis*
PLOT BD3	*Swietenia macrophylla* × *S. mahagoni*	*Prestoea montana*	*Casearia arborea*	*Micropholis guyanensis*	*Ocotea leucoxylon*	*Miconia prasina*
PLOT BD4	*Schefflera morototoni*	*Miconia prasina*	*Micropholis guyanensis*	*Tabebuia heterophylla*	*Casearia arborea*	*Chionanthus domingensis*
PLOT BD5	*Buchenavia tetraphylla*	*Micropholis guyanensis*	*Miconia* spp.	*Casearia arborea*	*Alchomeopsis floribunda*	*Sweietenia macrophylla* × *S. mahagoni*
PLOT BD6	*Byrsonima spicata*	*Dacryodes excelsa*	*Micropholis guyanensis*	*Swietenia macrophylla* × *S.mahagoni*	*Miconia tetrandra*	*Miconia* spp.
PLOT BD7	*Prestoea montana*	*Micropholis guyanensis*	*Manilkara bidentata*	*Dacryodes excelsa*	*Swietenia macrophylla* × *S.mahagoni*	*Inga laurina*
PLOT BD8	*Micropholis guyanensis*	*Casearia arborea*	*Dacryodes excelsa*	*Bucida buceras*	*Buchenavia tetraphylla*	*Sloanea berteriana*

TABLE 5 Most Important (Dominant) Species in Frequency and Canopy Cover Within Undisturbed Forest

	1st in importance	2nd	3rd	4th	5th	6th
Control 1	*Tabebuia schumanniana*	*Casearia arborea*	*Unidentified*	*Guatteria caribaea*	*Miconia tetrandra*	*Prestoea montana*
Control 2	*Prestoea montana*	*Manifera indica*	*Guarea guidonia*	*Inga laurina*	*Dendropanax arboreus*	*Alchornea latifolia*
Control 3	*Prestoea montana*	*Tabebuia heterophylla*	*Schefflera morototoni*	*Ocotea leucoxylon*	*Alchornea latifolia*	*Casearia arborea*
Control 4	*Prestoea montana*	*Coffea arabica*	*Ocotea leucoxylon*	*Schefflera morototoni*	*Cecropia schreberiana*	*Guarea guidonia*
Control 5	*Ardisia* spp.	*Miconia tetrandra*	*Micropholis guyanensis*	*Matayba domingensis*	*Casearia arborea*	*Micropholis* spp.
Control 6	*Ardisia* spp.	*Micropholis* spp.	*Micropholis guyanensis*	*Miconia tetranda*	*Buchenavia tetraphylla*	*Guatteria caribaea*
Control 7	*Micropholis* spp.	*Manilkara bidentata*	*Hirtella rugosa*	*Matayba domingensis*	*Drypetes glauca*	*Cordia borinquensis*
Control 8	*Casearia arborea*	*Micropholis* spp.	*Hirtella rugosa*	*Prestoea montana*	*Myrcia deflexa*	*Ocotea leucoxylon*

A total of 49 species was found in the eight line-planted plots (including seven unidentified species). In the undisturbed plots a total of 46 species was found (including 4 unidentified species).

DISCUSSION

The fact that neither amphibian diversity nor relative abundance was altered by line-planting economically valuable trees in the forest, suggests that the effect of this forestry practice is not adverse to these animals. Because amphibians are good indicators of environmental conditions, and play such an important role in tropical forest food webs (Joglar, 2005), the results of this work shed light toward management practices compatible with sustainable development. At a time when the consequences of anthropogenic activities on amphibian populations are being evaluated, it is important to show that the type of forestry enrichment practiced at Las Casas de La Selva did not have a negative impact on frog populations.

The vegetation community composition was significantly different between line-planting and control plots. Interestingly, the mean similarity among plots within either the line-planting treatment or control group was relatively low at less than 50% of shared species. It is interesting that these differences seen at the community vegetation composition structure level are not reflected in the broader and commonly used indices of richness, diversity, and evenness.

Although there are significant differences in vegetative composition between undisturbed forest and the line-planted areas, this may just be indicative of the high overall diversity of vegetation in the forest, since there is not great similarity among either control or line-planted plots. The present study has shown that no statistically significant changes have occurred in either amphibian diversity nor in tree species as measured by richness, evenness, and diversity indicating that line-planting of valuable timber species in secondary wet subtropical forest may indeed be a viable ecological alternative for productive long-term use of this kind of forest.

As is frequently the case, the clearing of secondary subtropical wet forest in the local area around the project, has been done mostly to accommodate agriculture and livestock grazing. As much of the land in this area is on very steep slopes, this results in severe erosion and crop production is poor without heavy use of chemical fertilizer. Silvicultural techniques developed and applied at Las Casas de la Selva over the last two decades (and since 2004 selective thinning and harvesting of trees, with subsequent sale of valuable timber and products) demonstrate, that on a small scale in Puerto Rico, secondary forests can be ecologically and economically suitable for sustainable timber production. The line-planting ecotechnology at Las Casas de la Selva was implemented to encourage similar practice as a contribution to economic development that encourages protection and sustainable management of secondary tropical forests.

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