United States Department of Agriculture

Forest Service

Southern Forest Experiment Station

Research Note

SO-358
December 1989

The Luquillo Experimental Forest Arboretum

John K. Francis

SUMMARY

Since 1960, various tree species, mostly exotics with productive potential, have been planted in small blocks within a tract of subsistence farmland. The site, located on the lower western slope of the Luquillo Experimental Forest in Puerto Rico, has become a unique arboretum. The plantings were weeded and maintained for several years, but later were neglected. A complete inventory and measurements have been made now that some of the species have reached harvest size. Sixty-eight species, some represented by multiple subspecies or provenances, still survive. Fourteen species have died out completely. Promising species are identified for timber production or for ornamental use in high rainfall areas of Puerto Rico. Statistics given for plots of each species are: average height and diameter for trees on the plot, height and diameter of the tallest tree, percent survival, and seed and seedling production.

INTRODUCTION AND METHODS

Many native Puerto Rican trees, while producing wood of superior quality, often grow slowly. Some species lack sufficient populations to justify development of markets and management methods. For these reasons, many useful exotic species have been imported and tested for adaptability and growth potential. A number of adaptability tests were established in Puerto Rico. One site of such tests is the Luquillo Experimental Forest arboretum, which is the source of the data in this study. In addition to comparing a large number of species in a single area, the arboretum is used for ecological research, seed collection, demonstration, and instruction.

The arboretum is about 625 m above sea level and lies on the western flank of El Toro Peak. Rainfall is approximately 3000 mm per year. Of 10 soil samples removed from the upper 10 cm of mineral soil, all were clays with a mean pH of 4.7 and an organic matter content of 8.6 percent. The area was cleared for subsistence farming in the 1920's and later was partially replanted with trees and allowed to grow up in brush. In the pristine state, the area probably straddled the transition between the Tabonuco *(Dacryodes excelsa)* Forest and Palo Colorado *(Cyrilla racemiflora)* Forest.

Although a small test plantation established in 1959 was incorporated into the arboretum, the main planting project commenced in 1960 and continued through 1963. Since then, several plots have been planted with seeds from novel species. Incomplete records have not permitted the sources (provenances) of the seeds to be identified in all cases. The seeds were germinated in trays, and the resulting seedlings were transplanted into plastic nursery bags where they grew until large enough for planting in the field. Sites were prepared by slashing trees and brush, and "coronas" (areas 1 meter in diameter that were scalped and tilled) were prepared at the plantation spacing of 3 by 3 m. Plots consisted of 49 trees (7 by 7 trees) when sufficient seedlings were available. After seedlings were planted in the coronas, weeds were controlled by a combination of hoeing, chemical spraying, and lopping until the seedlings grew above the competition, 2 to 6 years later. Replacements for the seedlings that failed were planted during the first year for a few of the plots when extra seedlings were available. A map of the area with the plot positions indicated is presented in figure 1. Early measurements were performed on some of the plots, but no complete inventory and measurement work was done until 1987. At that

Southern Forest Experiment Station/T-10210 U.S. Postal Services Bldg., 701 Loyola Avenue, New Orleans, La. 70113
Forest Service, U.S. Department of Agriculture.
Serving Alabama, Arkansas, Louisiana, Mississippi, E. Oklahoma, Tennessee, E. Texas, Puerto Rico, U.S. Virgin Islands

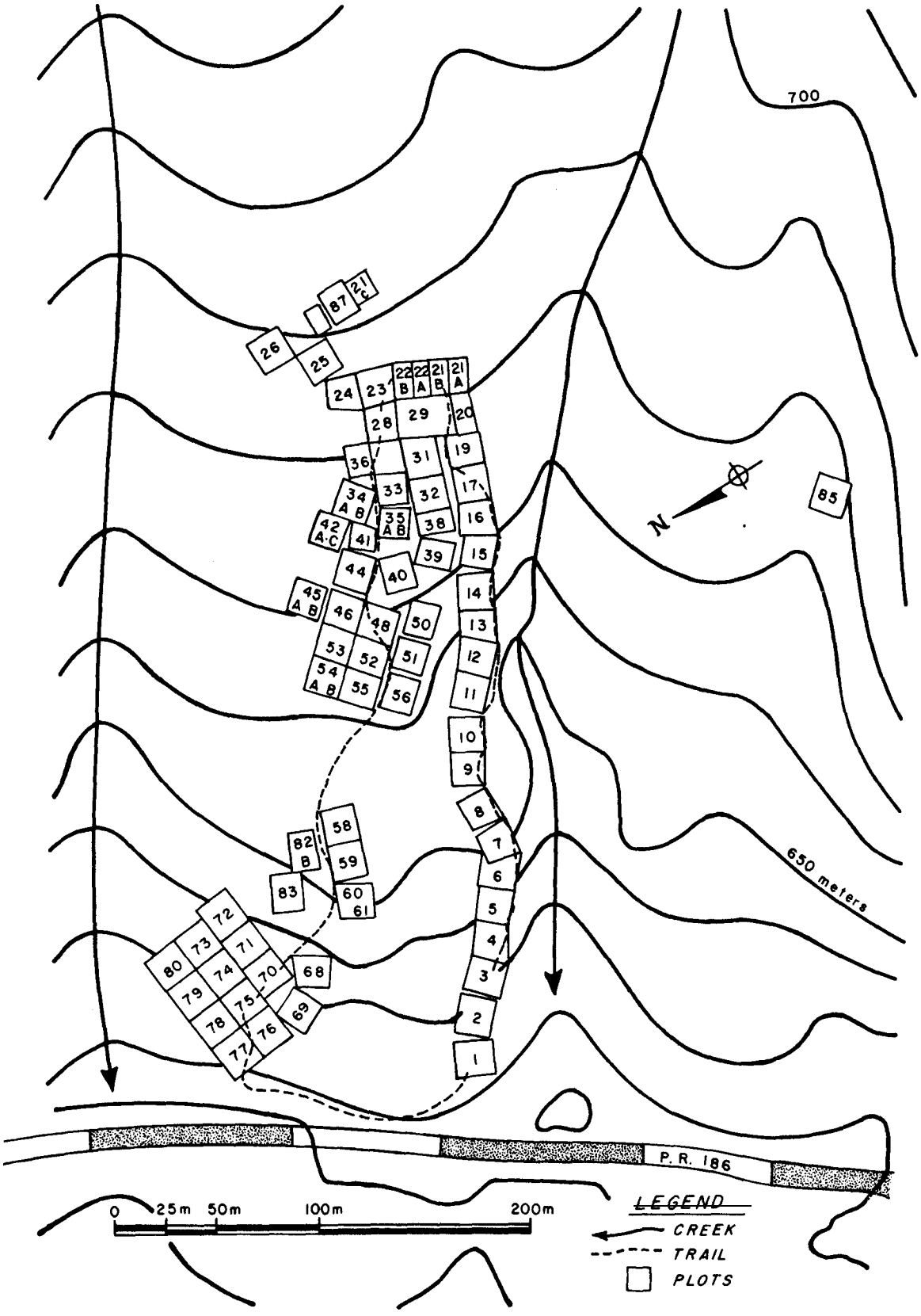

Figure 1.—*Map of* ***plot*** *locations in the* ***Luquillo*** *Experimental Forest arboretum, Cianaga* ***Alta,*** *Puerto Rico.*

John K. Francis is research forester at the Institute of Tropical Forestry, Southern Forest Experiment Station, USDA Forest Service, Rio Piedras, Puerto Rico, in cooperation with the University of Puerto Rico, Rio Piedras, PR.

time, tree height was measured with an altimeter and diameter at breast height (d.b.h.) was measured with a diameter tape. Clear bole length (the distance between the groundline and the first branch) was also measured. Survival, seed production, and presence of natural reproduction in the understory were noted.

RESULTS AND DISCUSSION

The surviving species with their respective provenances are listed in alphabetical order in table 1, which also shows age, height, d. b. h., survival, and presence of reproduction for each species. Some results tended to support planting preferences already evident in Puerto Rico. One of the best performers, *Pinus caribaea* var. *hondurensis,* is also one of the most widely used species for forest plantations. *Swietenia macrophylla* and *Hibiscus elatus* performed reasonably well in the arboretum and are both widely planted in Puerto Rican forests. *Agathis robusta*, a valuable softwood planted to a limited extent in Puerto Rican forests, has shown steady diameter growth.

Several other species have shown enough promise to be recommended for planting or further testing. Two African species that are recommended for pilot plantations are *Maesopsis eminii* and *Terminalia ivorensis.* Both species grow rapidly, are self-pruning, and reproduce naturally both in the arboretum and on other test sites across Puerto Rico. In fact, one individual that regenerated naturally from the *Maesopsis* plot is now approaching a 40-cm d.b.h. Both species produce a medium-density wood suitable for construction, paneling, furniture parts, and pulp. The wood of *Maesopsis* is light brown and that of *Terminalia* is a lustrous yellow.

Pinus caribaea var. *caribaea* is not presently used in planting operations in Puerto Rico, but could be used as a substitute for *P. caribaea* var. *hondurensis,* especially on dry and alkaline soils. It has better form and wood quality than *P. caribaea* var. *hondurensis. Pinus oocarpa* performed well in the arboretum and in other tests and compares favorably with *P. caribaea* var. *hondurensis.* So far this species has not been consistently better and probably will not replace *P. caribaea* var. *hondurensis.* The low altitude seed source of *P. chiapensis* grew well in the arboretum, but has not performed well at lower elevations. It might find limited use as a windbreak or shade tree at higher elevations in Puerto Rico.

All three of the *Khaya* (African mahogany) species compared well with *Swietenia macrophylla. Khaya grandifolia* grew the fastest, had the best form, and has produced seeds. Seeds from both *K. nyasica* and *K. senegalensis* are available from other Puerto Rican sources. *Cordia alliodora* is a widely occurring native species that performed fairly well in the arboretum plot. Although widely planted in Central America, this *Cordia* has not been used to any great extent in Puerto Rican plantations. *Fraxinus uhdei* has shown respectable growth in the arboretum plot, although the commercial bole section in somewhat short. Seeds can be obtained from other Puerto Rican sites. *Fraxinus* wood is valuable for furniture, trim, and tool handles.

Eucalyptus grandis and *E. saligna* in these plots are the tallest trees currently known in Puerto Rico. These species and *E. robusta* have great wood-producing potential. Unfortunately, except for limited use as treated posts, building poles, and rough lumber, the wood of *Eucalyptus* is little used in Puerto Rico. If future markets for fuel or other biomass develop, one or more of these species would be an excellent choice for planting on mountain sites. Three fast-growing species with low-density wood are *Anthocephalus chinensis, Aleuritis moluccana* (fig. 2), and *Hernandia sonora.* All produce seeds, but conditions have favored reproduction of only the latter two. None of the three are currently marketable in Puerto Rico. The 22 timber species mentioned so far are compared in box plots (fig. 3) using the index: d.b.h. squared multiplied by height-which normally is highly correlated with tree volume.

Several of the planted species demonstrated potential as ornamentals and shade trees. *Pterocarpus indicus* forma *echinatus* (fig. 4) grows faster than both *P. macrocarpus* and *P. indicus,* which are currently popular shade trees in urban areas. It has the same deep green foliage and pleasing form. Abundant reproduction was observed nearby. *Clitoria racimosa* is a small- to medium-sized tree with pleasing form, color, and attractive violet blossoms; it has also produced many seedlings. *Callitris glauca* and *C. intertropica* are similar conifers with blue-green foliage; these trees both have potential as ornamentals.

Fourteen species suffered loo-percent mortality. They are listed in table 2. The specific causes of mortality were not known or recorded. Because the plots were weeded for up to 6 years, it seems reasonable to assume that the primary cause of failure was poor adaptation to the soil or local climate and not competition. It should not be concluded that plantings of the same seed sources on different sites in Puerto Rico would also fail. *Eucalyptus deglupta, Swietenia mahagoni,* and *Tectona grandis* are growing successfully on other (drier) sites in Puerto Rico. One additional species, *Cecropia peltata,* was planted but not evaluated. This short-lived species is ubiquitous in openings and low-basal area plots in the area. It could not be determined whether the few *Cecropia peltata* trees present were the original planted trees or volunteers.

Since the measurements for this document were made, a thinning to remove suppressed, deseased, and malformed trees was conducted, and the entire area was weeded. Seven new species have been planted recently (table 3) and others will be established as time and resources permit. One of those recently planted, *Goetzia elegous*, is endangered and has disappeared entirely from the Luquillo Mountains. The arboretum should be considered as an excellent site to plant rare species that need preservation and protection.

Table 1 .--Species survival, growth, and reproduction in the Luquillo Experimental Forest arboretum, located in Puerto Rico

Plot no.	Species (seed source)	Age	Plot average ± standard error'			Tallest tree		Survival	Seeds and reproduction present	
			Height	D.b.h.	CBL	Height	D.b.h			
		Yr	m	cm	m	m	cm	No./percent	Yes	No
85	Agathis robusta (Queensland, Australia)	29	13.8±1.9[2]	21.6±1.2	5.2±0.4	22.5	36.9	55 / 75	No	No
25B	Aleurites moluccana (Queensland, Australia)	23	23.3±0.5	43.6kO.8	11.8±0.8	24.0	51.7	13 / 93	Yes	Yes
16	Anthocephalus chinensis (. .)†	26	17.2±0.8	27.8a2.3	11.5±0.7	29.0	58.0	35 / 71	Yes	No
22A	Araucaria angustifolia (Comanducaia, Mines Gerais, Brazil)	25	11.2k1.7	23.5±5.4	4.4±1.0	17.0	40.7	5 / 20	No	No
22B	Araucaria angustifolia (Misiones, Argentina)	25	12.3±0.8	19.6±0.6	3.0±1.0	13.0	20.2	2 / 7	No	No
23	Araucaria angustifolia Argentina	25	9.5a1.3	17.4±3.4	3.8±0.4	14.0	33.5	10 / 18	No	No
82	Araucaria cunninghamii (Papua, New Guinea)	5	3.3±0.2	3.6-cO.3	<.5	5.5	7.5	39 / –‡	No	No
70	Callitris glauca (New South Wales, Australia)	23	13.8±1.8	26.5±3.4	2.9±0.3	23.5	39.3	9 / 18	Yes	No
26	Callitris intratropica (Northern Territory, Australia)	23	9.8±0.9	26.2±2.1	1.3±0.1	13.0	27.2	14 / 29	No	No
14	Carapa guianensis (Coastal Plain, Surinam)	26	18.1±1.2	24.7±2.6	3.6a0.3	22.0	38.7	9 I 18	No	No
11	Casuarina equisetifolia (locally collected)	26	11.6±1.5	13.8±2.4	3.0±0.5	17.5	18.8	9 I 18	No	No
34A	Cedrela toona (Umtali, Rhodesia)	23	15.8±1.8	18.8k2.6	3.5±0.5	17.5	16.2	2 / 6	No	No
34B	Cedrela toona (Umtali, Rhodesia)	23	11.5t1.5	20.7±6.0	3.0±0.4	13.0	32.5	3 I 21	No	No
71	Crickrassia tabularis (Colombo, Ceylon)	23	8.2±0.7	9.3±0.9	2.2±0.6	9.5	10.2	3 / 6	No	No
75A	Clitoria racemosa (Belen, Brazil)	17	11.3±1.9	15.3±4.0	0.5±0.1	18.0	30.2	9 I 82	Yes	Yes
31	Cordia alliodora (Turrialba, Costa Rica)	24	14.7±1.2	19.8±2.6	9.5±0.5	22.5	32.5	13 / 26	Yes	Yes
35D	Cryptomera japonica (Ali-san, Taiwan)	23	8.0	15.7	0.5	8.0	15.7	1 / 50	No	No
21A	Cunninghamia laceolata (Dehra Dun, India)	25	12.5±0.6	18.7±1.3	1.2±0.1	17.5	25.8	29 I –	Yes	No
15	Cupressus lusitanica (Tecpamo, Guatemala)	26	16.0	37.0	2.5	16.0	37.0	1 / 2	No	No
25A	Entandophragma angolensis (Sapoba Forest, Nigeria)	23	11.7k1.5	13.2±1.3	9.1±1.2	16.0	14.8	8 I 27	No	No
32	Eucalyptus grandis (. . . .)	24	30.9±1.8	41.7±4.3	13.6k1.7	46.5	75.2	25 I 51	Yes	No
38	Eucalyptus citriodora (. . . .)	23	29.4k2.2	38.3k4.2	17.1±1.5	39.0	50.4	9 I 26	Yes	No
60	Eucalyptus maidenii (. . . . . .)	24	11.9t1.7	16.5±2.3	7.0±1.5	14.5	15.6	4 I 20	No	No
46	Eucalyptus X mysore-bangalore (India)	25	21.3±0.9	29.3k2.3	7.8±0.5	29.0	48.9	26 I 53	Yes	No
59	Eucalyptus crebra (. . . .)	24	13.6'1.4	19.6±3.1	4.2±0.8	20.0	33.4	9 I 20	Yes	No
5	Eucalyptus robusta (. . .)	26	20.7±0.8	34.0k1.8	8.5±0.5	31 .0	58.8	41 I 84	Yes	No
61	Eucalyptus robusta (. .)	24	18.7±1.4	37.6±3.5	6.0±0.8	31.3	71.0	22 I 79	Yes	No
17	Eucalyptus saligna (. . . . .)	25	28.5-c 1.5	38.6±3.8	13.3±1.1	43.0	58.0	32 I 56	Yes	No
81	Fraxinus uhdei (Oaxaca, Mexico)	23	16.1 ±0.9	21.5±1.6	4.5-co.4	23.5	41.9	42 / 86	No	No
83	Gmelina arborea (. . . . . .)	14	13.5±0.6	19.5±1.4	4.5rto.4	24.0	47.0	46 I 94	Yes	No

Table 1 .-*Species survival, growth, and reproduction in the Luquillo Experimental Forest arboretum, located in Puerto Rico-Continued*

Plot no.	Species (seed source)	Age	Plot average ± standard error'			Tallest tree		Survival	Seeds and reproduction present
			Height	D.b.h.	CBL	Height	D.b.h		
		Yr	m	cm	m	m	cm	No/percent	Yes / No
12	*Hernandia sonora* (locally collected)	26	18.3±0.6	25.7±1.4	7.5±0.5	24.0	47.0	46 / 94	Yes Yes
2	*Hibiscus elatus* (Jamaica)	26	20.4±0.5	31.2±1.5	3.9±0.5	26.0	34.5	43 / 88	Yes Yes
29	*Inga vera* (locally collected)	24	14.0±0.9	11.2±0.6	4.1 ±0.4	16.0	20.3	38 / 78	Yes Yes
45A	*Khaya grandifoliola* (Ife Forest, Nigeria)	23	20.1±0.6	22.9-co.9	12.0±0.6	24.5	24.1	28 / 80	Yes No
9	*Khaya nyasica* (. . . . . .)	26	16.0±0.8	23.5±1.3	5.9±0.4	25.0	37.7	49 /100	No No
50	*Khaya senegalensis* (Wad Medani, Sudan)	25	19.5±0.6	25.0± 1.4	8.1±0.5	27.0	48.8	44 / 90	No No
40	*Maesopsis eminii* (Uganda)	24	19.1±0.6	28.6±1.9	8.6±0.7	26.0	56.8	28 I 57	Yes Yes
a4	*Olea* sp. (. . . .)	?	10.8±0.9	12.5±1.3	2.1±0.4	13.8	16.6	7 / -	No No
77	*Pinus bahamensis* (. . . . .)	23	19.6±0.8	25.5± 1.8	12.1±0.5	27.0	23.3	*29 I 59*	Yes No
10	*Pinus caribaea* var. *caribaea* (Cuba)	26	21.6±0.7	29.32 1.4	10.2±0.5	29.5	49.3	41 *I 64*	Yes No
1	*Pinus caribaea* var. *hondurensis* (Belize)	26	23.8±0.9	35.2±1.8	11.8±0.7	31 .0	45.6	*39* / 80	Yes No
58	*Pinus caribaea* var. *hondurensis* (Honduras)	24	25.6±1.O	45.5±2.5	10.2±0.6	33.0	51.1	24 *I 53*	Yes No
28	*Pinus chiapensis* (Solistahuacan, Chiapas, Mexico, 540 m elevation)	24	19.8±1.3	32.7±3.6	3.1 ±0.4	27.0	34.8	18 / 36	Yes No
76	*Pinus chiapensis* (Oaxaca, Mexico, 820 m elevation)	23	19.0±0.5	43.6±1.5	3.2-cO.2	19.5	42.1	2 / *4*	No No
75	*Pinus chiapensis* (Oaxaca, Mexico, 1,340 m elevation)	23	11.0	23.3	4.5	11.0	23.3	1 / *2*	No No
51	*Pinus echinata* (Florida, USA)	25	7.2±1.O	15.0±1.6	3.2±0.3	9.5	18.9	5 *I* 10	No No
3	*Pinus elliotti* var. *densa* (Florida, USA)	26	18.0±0.5	25.3± 1.3	10.0±0.5	24.0	29.7	41 *I a4*	Yes No
52	*Pinus elliotti* var. *elliotti* (Florida, USA)	25	10.2±0.5	13.8±0.8	3.9±0.3	15.0	19.7	33 *I* 67	No No
69	*Pinus insularis* (Baguio, Mt. Province, Philippines)	23	20.2±1.1	35.0±2.2	5.5±0.7	26.5	44.1	22 / 45	Yes No
7	*Pinus massoniana* (Nanking, Huansi, China)	26	12.8±0.5	22.4±1.3	4.1±0.3	17.6	38.0	22 / 45	No No
56	*Pinus michoacana* (Uruapan, Michoacan, Mexico)	25	11.6±1.8	22.9±4.0	2.9±0.9	16.5	37.2	7 / *9*	No No
68	*Pinus montezuma* (Chimaltenango, Guatemala)	23	16.6±0.6	39.5±2.8	2.4±0.8	17.5	37.1	3 / *6*	No No
55	*Pinus oocarpa* (Guatemala)	25	23.8±1.3	36.5±2.7	9.1 ±0.9	33.0	50.2	22 *I 45*	Yes No
30	*Pinus oocarpa* (Mexico)	25	17.5±2.0	26.5±5.0	4.5±0.5	19.5	31.5	2 / *4*	No No
42A	*Pinus patula* (. . . . .)	23	14.0±0.9	30.6±2.5	2.2±0.4	17.5	43.3	8 *I 42*	No No
48	*Pinus pseudostrobus* (Puebla, Mexico)	25	16.8±0.8	32.8±4.3	1.7±0.4	19.5	38.6	8 *I* 16	No No
13	*Pinus taeda* (Florida, USA)	25	11.8±0.3	18.8±0.8	2.9±0.2	14.0	21.8	18 / 37	No No
44	*Pinus taeda* (Mississippi, USA)	26	12.2±0.4	18.3-cO.6	3.6a0.4	16.5	20.4	27 *I 56*	No No
79	*Pterocarpus indicus* (Philippines)	23	10.4±1.5	11.4±2.2	4.0±0.6	13.5	16.4	4 *I* 11	No No
74B	*Pterocarpus indicus* forma *echinatus* (Philippines)	23	17.9±1.5	31.3±4.2	2.9±0.3	26.0	52.2	20 *I 95*	Yes Yes

Table 1 .--Species *survival, growth, and reproduction in the Luquillo Experimental forest arboretum, located in Puerto Rico-Continued*

Plot no.	Species (seed source)	Age	Plot average ± standard error*			Tallest tree		Survival	Seeds and reproduction present
			Height	D.b.h.	CBL	Height	D.b.h		
		Yr	*m*	*cm*	*m*	*m*	*cm*	*No/percent*	Yes / No
33	*Pterocarpus macrocarpus* (locally collected)	25	14.4±1.1	19.1±2.0	4.2a0.3	24.0	36.9	22 / 45	Yes No
6	*Schizolobium parahybum* (Guatemala)	25	17.3±1.0	31.1±2.8	9.9a0.8	24.0.	47.9	19 / 39	Yes Yes
19	*Swietenia macrophyla* (locally collected)	26	17.1±0.9	23.8±1.9	6.3±0.5	26.0	35.5	29 / 59	Yes Yes
73	*Swietenia macrophyla* (Quintana Roo, Mexico)	23	17.6±0.8	21.8±1.5	7.8±0.5	20.5	34.3	23 I 82	No No
72	*Swietenia macrophylla* (Belize)	23	16.6±0.8	22.5±1.6	6.6±0.4	22.5	34.9	24 / 69	No No
80	*Swietenia macrophylla* (Quintana Roo, Mexico)	23	17.2±0.9	21.6±2.0	6.9kO.5	22.0	31.0	18 I 51	No No
18	*Tabebuia donnell-smithii* (Mexico)	26	9.5±0.5	8.9±0.9	7.2±0.2	9.5	9.8	2 / 49	No No
8	*Tabebuia heterophylla* (St. Croix, U.S. Virgin Islands)	26	12.0±0.8	18.6±1.9	5.1±0.3	20.0	37.4	15 / 31	Yes No
39	*Taxodium mucronatum* (Guatemala)	26	4.4±0.5	15.5±2.4	1.8±0.2	9.0	34.1	18 I 37	No No
78	*Terminalia catappa* (Manokwari, Iran Jira)	23	17.5±1.9	21.5±1.2	5.3±0.7	28.1	25.9	8 / 17	Yes No
53	*Terminalia ivorensis* (Nigeria)	23	22.6±0.7	31.5±1.7	13.2±0.7	27.0	54.0	25 / 62	Yes Yes
84	*Toona ciliata* (India)	23	15.4-r-0.7	25.7±1.8	3.7±0.5	19.0	27.2	12 / •	No No
35A	*Toona surenia* (Monokawave, Iran Jira)	23	16.5±1.0	26.2±2.4	7.8±0.8	21.0	32.4	13 / 62	No No

'Abbreviations: d.b.h.=diameter at breast height; CBL=clear bole length.

†Information on source is not available.

*Percent cannot be calculated because number planted is not known.

Table *2. -Species suffering 100-percent mortality on old farmland in the Luquillo Experimental Forest arboretum, located in Puerto Rico*

Species	Seed source	Number planted
Acacia koa	Hawaii	16
Acrocarpus fraxinifolius	Kenya	10
Afromosa elata	Nigeria	49
Cedrela odorata	Mexico, Guatemala	140
Chlorophora excelsa	Ghana	10
Eucalyptus deglupta	New Guinea	Unknown
Entandophragma utile	Nigeria	3
Pinus ayacahuite	Puebla, Mexico	2
Sequoia sempervirens	California, USA	17
Simaruba amara	Grenada	8
Swietenia humilis	Guatemala	Unknown
Swietenia mahagoni	Unknown	28
Terminalia superba	Nigeria	31
Tectona grandis	India	21
Widdringtonia whytei	Malawi	49

Table *3. -Species recently planted in the Luquillo Forest Arboretum in Puerto Rico'*

Species (seed source)	Number planted	Year
Alstonia macrophylla (Unknown)	49	1989
Annona squamosa (Local)	3	1987
Castanospermum australe (Queensland, Australia)	49	1988
Goetzia elegans (Local)	2	1987
Gyranthera caribensis (Venezuela)	49	1989
Myroxylon balsamum (El Salvador)	44	1988
Parkia timoriana (Unknown)	44	1988

*These plots do not appear in the map (fig. 1).

Figure 2.—*Arboretum* plot of Aleurites moluccana.

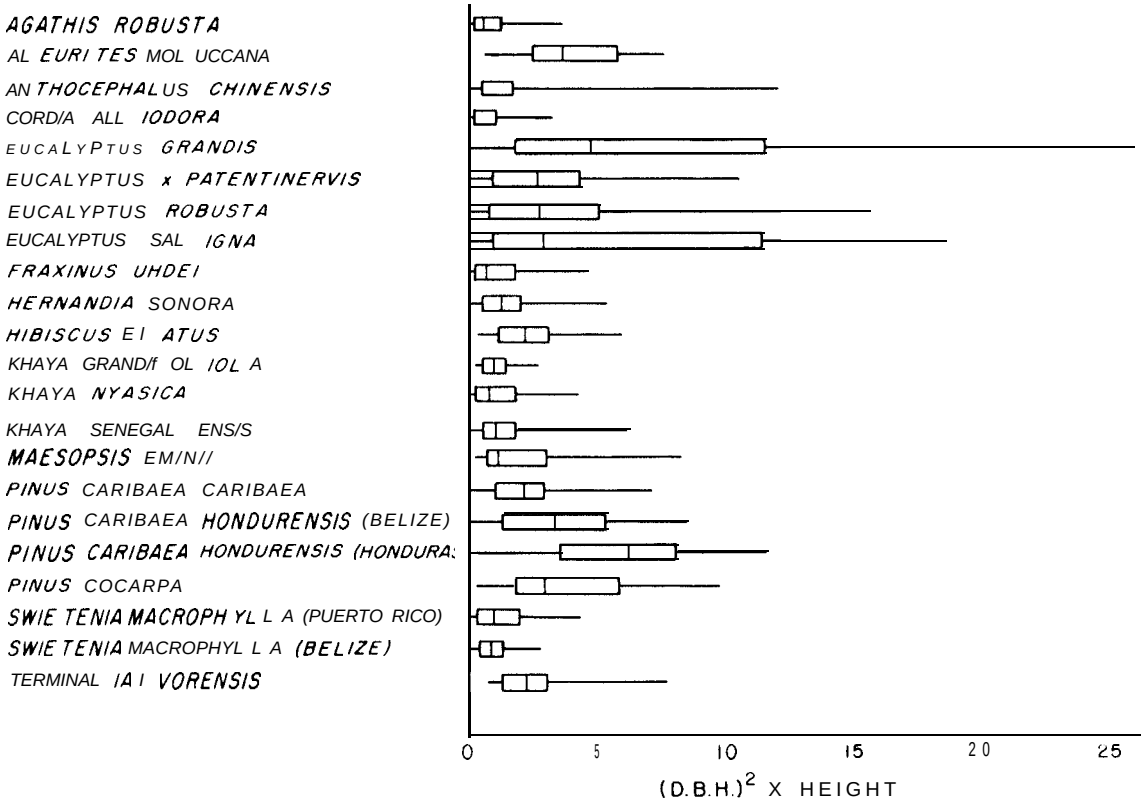

Figure 3.—*Box plot of volume index [(d.b.h.)2 x height]. Extremes of horizontal bars are low and high values; vertical bars indicate 25th percentile, median, and 75th percentile.*

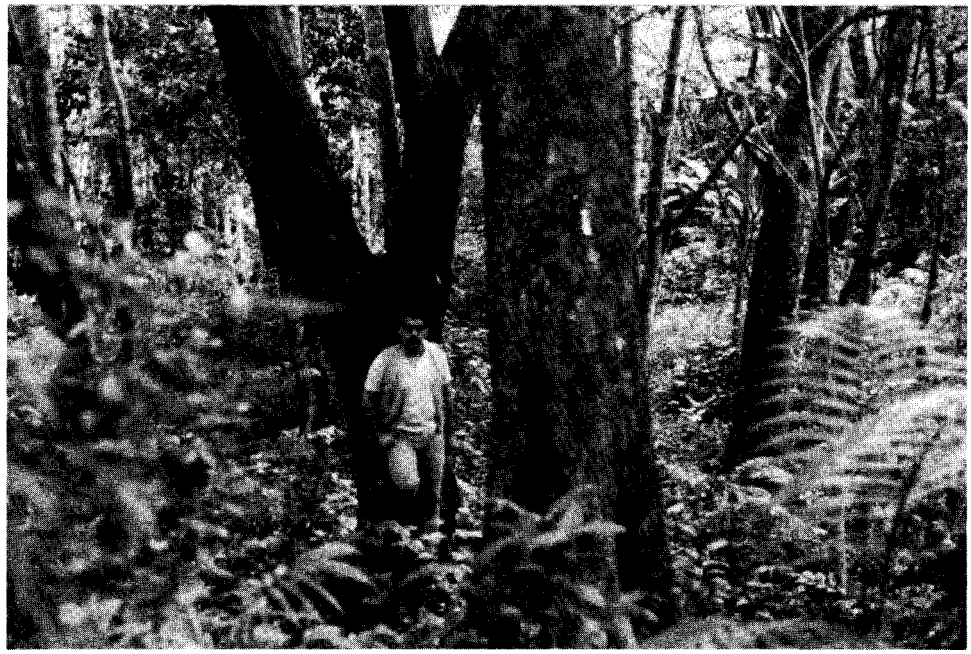

Figure ***4.-Arboretum plot of*** Pterocarpus **indicus** ***forma*** echinatus.