Growth of Secondary Forest in Puerto Rico Between 1980 and 1985 [1]

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ABSTRACT

Successive inventories in Puerto Rico provided the first estimates of secondary forest growth on a regional basis. The volume of growing stock trees increased by 32%, and timber volume by nearly 36%, on all classes of forest land between 1980 and 198.5. Timber volume growth rates (in $m^3 ha^{-1} yr^{-1}$) varied by forest class and averaged 2.0 in young secondary forest, 6.9 in advanced secondary forest, 7.1 in abandoned coffee shade forest, and 1.2 in active coffee shade forest. Tree diameter growth rates were weakly correlated with initial tree diameter (r^2 = 0.16, n = 1090). A slight increase of valuable timber species and human intervention in more than half the forests were other trends recorded between surveys.

COMPENDIO

lnventarios sucesivos en Puerto Rico suministraron los primeros estimados de crecimiento en bosques secundarios a nivel regional. El volumen de árboles clasificados como existencias (growing stock) aumentó en 32%, y el volumen de pies maderables (madera de aserrío) en 36%, para todas las clases de terreno designado como forestal en 1980 y 1985. Las tasas de crecimiento de volumen (en m^3 ha-' $año^{-1}$) variaron por clase de bosque y promediaron 2.0 en bosque secundario joven, 6.9 en bosque secundario, 7.1 en sombra para café abandonada, y 1.2 en sombra para café activa. Se correlacionó levemente el crecimiento en diámetro con el diámetro inicial. Un leve aumento de especies madereras valiosas y de la intervención humana en mis de la mitad de los bosques fueron otras tendencias observadas entre los inventarios.

INTRODUCTION

Migratory agriculture, logging, pasture conversion, and fuelwood harvests have caused notable reductions of tropical forests in recent years (3, 13, 19). Furthermore, the problem is most aggravated in areas of greatest need. Deforestation causes the loss of timber and its increment (16) and, depending upon its scale, the decline of flora and fauna and accelerated soil erosion. In the Amazon Basin, concern has been expressed about potential changes in the water regimen and quality (6) and possible decreases in rainfall (18) associated with deforestation. At the same time that global deforestation is underway, world use of wood and its derivatives is projected to rise 134% between 1974 and the year 2000 (17). The need to reverse trends in deforestation is evident (9, 13, 19) so that future requirements for domestic and industrial wood supplies may be met.

One factor that counteracts deforestation is the regeneration of secondary forests on marginal and abandoned lands. Some 3 1 million ha in Mexico, Central America, and the Caribbean are in distinct stages of recovery after agricultural abandonment (10). This represents 40% of the forested area of the region. Moreover, 78 million ha in South America have been classified as "forest fallow" according to a regional inventory (14). This category includes the regeneration of woody vegetation after shifting cultivation in areas previously covered with closed broadleaf forest. It is probable that much of this area would be amenable to silvicultural techniques to improve species composition and growth. The forest fallow area where silviculture could be practiced is about 50 times as large as the area that was proposed for plantations in Latin America between 1980 and 1985.

Of Puerto Rico's 890 000 ha of land surface, about 96% was forested at the time of the island's discovery (20). Subsequent clearing for settlement and agriculture reduced the forested areas to 13% in the mid-1940s, half of which was actually coffee shade forests (8). At that time, < 1% of Puerto Rico's original forests remained in pristine condition (20). Beginning in the late 1940s, the growth of industry caused the

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abandonment of marginal agricultural lands. Migration from rural to urban areas followed, allowing the development of secondary forests.

Projections indicated that Puerto Rico's demand for timber products would increase five times in volume and 14 times in commercial value between 1970 and the year 2000 (22). An inventory devised to assess the island's timber resources was conducted in 1980; it showed that over 30% of the land surface was again forested, largely in coffee shade and secondary forests (1). About 130 000 ha were classified as timberland and were characterized by low volumes, poor form, and a high proportion of trees previously used in agriculture. By 1985. an update of aerial estimates showed that forest cover had further increased to 34% of the island's surface (2).

The purpose of this study was to summarize stand changes and growth that occurred in secondary and coffee shade forests between inventories. This information is required as baseline data for assessing the effectiveness of future silvicultural treatments in secondary stands.

METHODS

In the 1980 survey (1), the island was geographically partitioned to focus the inventory in regions with commercial forestry potential. Two life zones (7) of the six in Puerto Rico (5) were used along with four broad groupings of soils, based on their geological origin and depth, to stratify the island. Excluded from the field sample were the agricultural lands of the north coast and interior valleys, all of the dry south coast, and the steepest mountainous regions with excessive rainfall. The sample area was concentrated in the mountainous interior of the island.

Forest cover estimates were made by dot count on aerial photographs. Field sample plots were located at the intersections of a grid of lines spaced at 3 km intervals. These were first located on topographic maps and later transferred to the photographs. The estimated areas derived from the dot count were adjusted according to actual land, use after verifying the cover on each of the plots in the field. Of the 437 ground locations that were visited, 134 were classed as forest.

Each forested location was described and permanently marked so that growth, recruitment of new trees, mortality, and tree harvest could be estimated in the future. On each plot, trees < 12.5 cm in diameter at breast height (dbh) were recorded in a circle of 40 m^2. Larger trees were sampled by using a basal area prism with a factor of 2.5 $m^2 ha^{-1}$. Detailed measurements, including height, diameter, and defective portions, were made for each sample tree to determine wood volume and wood quality.

Coffee shade plots (refer to glossary for definitions) were classified as active or abandoned, and secondary forest plots were grouped as young or advanced, based on tree size and/or information provided by persons living in the vicinity. All trees were identified to species (11, 12). Fruit and fuelwood tree species usually not included in forest inventories were also measured.

The inventory update of 1985 again used aerial photographs to determine the total forested area of the island. A subsample of 52 of the original 134 forested plots, stratified by forest class, was used to estimate stand changes and growth. These plots consisted of secondary and abandoned coffee shade forests randomly selected within each group. Plots originally sampled within the limestone region were not m-measured because of logistical considerations and because they were of less interest silviculturally than plots located on the rest of the island. The 1980 field measurements were repeated, but total and commercial tree heights were measured with an optical rangefinder, whereas in 1980 they had been estimated by experienced cruisers. The 1985 plots were further partitioned into those that had been disturbed between 1980 and 1985 and those that had not. These data sets were treated separately using the same analytical techniques.

Diameter growth rates of timber species were compared among species, and by crown class within species, using Duncan's new multiple range test at the 5% probability level. The computation of mean diameter increment involved weighting to account for the variable probability of selecting trees > 12.5 cm. Volume growth of individual trees was determined according to several categories by calculating the differences in total growing stock and timber volumes between inventories. Gross volume growth of sample plots included growth and ongrowth of survivor trees, ingrowth of new trees, and growth on trees that were cut or died between surveys (annual growth by species until the estimated time of cut or mortality). Mortality and cull increment were subtracted from gross growth to obtain net growth.

RESULTS

Area surveyed

Of the 108 900 ha of timberland re-surveyed in 1985, 47.9% was active or abandoned coffee shade forest, 41.5% was secondary forest, and 10.5% had been cleared (Table 1). Fifty-seven percent of the timberland sampled was disturbed between surveys, including 36% of the secondary forest, 45% of the abandoned coffee shade forest, and all of the active coffee shade forest and landcleared areas. Removal of trees for fenceposts and cleaning of coffee plantations in response to fluctuations in coffee market prices may explain some of the removals.

Table 1. Areas by forest class and disturbance class for re-sampled timberland in Puerto Rico, 1980-85.

Forest class	Disturbance class: Undisturbed		Disturbance class: Disturbed		Total	
	Hectares	No. of plots	Hectares	No. of plots	Hectares	No. of plots
Secondary						
Young	10 829	6	8231	4	18 520	10
Advanced	18 519	9	8231	4	26750	13
Coffee shade						
Abandoned	17 700	11	14 482	9	32182	20
Active	0	0	20000	3	20000	3
Landclearing	0	0	11 449	6	11449	6
Totals	47048	26	62393	26	108901	52

Table 2. Stem changes in undisturbed secondary forests for major timber species.

Tree species[1]	Number of trees ha^{-1}: 1980 stand	Ingrowth	Ongrowth	Mortality	Removals	1985 stand
Andira inermis	142.9	39.3	2.0	20.5	0.0	163.7
Cordia alliodora	46.6	20.5	0.0	27.3	0.0	39.8
Dacryodes excelsa	14.1	0.0	2.5	0.0	0.0	16.6
Didymopanax morototoni	54.7	13.7	0.0	6.8	0.0	61.6
Guarea guidonia	93.1	53.3	3.2	6.8	6.8	136.0
Micropholis chrysophylloides	55.7	21.3	0.0	0.0	0.0	83.0
Ormosia krugii	27.4	0.0	4.2	0.0	0.0	31.6
Spondias mombin	5.4	0.0	4.6	0.0	0.0	10.0
Tabebuia heterophylla	191.3	70.8	8.8	41.0	0.0	229.9
Sapium laurocerasus	22.1	0.0	0.0	6.8	0.0	15.3
Subtotal	653.3	224.9	25.3	109.2	6.8	787.5
Other species	2 188.6	976.1	48.5	492.0	0.0	2 721.1
Grand total	2 841.9	1 201.0	73.8	601.2	6.8	3 508.6

1 Timber species listed in Wadsworth and Birdsey (23), plus addition to their list.

Changes in stem numbers

The total number of stems increased in undisturbed stands and decreased in disturbed stands between 1980 and 1985 (Tables 2-S). The proportion of timber species, however, remained the same or increased slightly in all forest classes between surveys. In undisturbed secondary forest, the total number of stems increased by 24% (Table 2), whereas in disturbed secondary forest they declined by 1% (Table 3). Timber trees averaged about 23% of the total in both surveys in the undisturbed secondary stands, but they in-

Table 3. Stem changes in disturbed secondary forests for major timber species.

Tree species[1]	Number of trees ha-’					
	1980 stand	Ingrowth	Ongrowth	Mortality	Removals	1985 stand
Andira inermis	36.3	40.9	0.0	0.0	10.2	67.0
Buchenavia capitata	6.3	0.0	2.5	0.0	0.0	8.8
Byrsonima coriaceae	8.6	0.0	0.0	0.0	0.0	8.6
Didymopanax morototoni	50.9	20.5	3.6	10.2	0.0	64.8
Guarea guidonia	89.3	26.5	7.8	2.9	0.0	120.7
Inga fagifolia	66.0	0.0	0.0	10.2	0.0	55.8
Ormosia krugii	47.8	0.0	0.0	0.0	40.9	6.9
Pouteria multiflora	a.4	0.0	0.0	0.0	0.0	8.4
Eugenia stahlii	8.3	10.2	0.0	0.0	0.0	18.5
Magnolia portoricensis	1.3	0.0	0.0	0.0	0.8	0.5
Manilkara bidentata	21.7	0.0	4.5	0.0	10.2	16.0
Subtotal	344.9	98.1	18.4	23.3	62.1	376.0
Other species	2 094.3	604.1	23.2	361.7	317.4	2 042.4
Grand total	2 439.2	702.2	41.6	385.0	379.5	2 418.4

1 Timber species listed in Wadsuorth and Birdsey (23), plus addition to their list.

creased from 14 to 16% of the total in the disturbed secondary stands (Table 3).

In undisturbed coffee shade stands, the number of trees increased by 9%, while the proportion of timber trees increased from 2.5 to 29% of the total between surveys (Table 4). In disturbed coffee shade stands, the total number of trees declined by 19%, whereas the proportion of timber trees increased from 26 to 28% of the total between surveys (Table 5).

Diameter growth rates

When the mean annual increments in diameter (MAI) for all trees, regardless of species, were partitioned according to several forest classes, differences were apparent. MAI in abandoned coffee shade stands was significantly greater than for the remaining groups, which averaged only half to one-third as great (Table 6). When MAI was regressed on the initial stem dbh's determined in the first inventory, the relationship

Table 4. Stem changes in undisturbed coffee shade forests for major timber species.

Tree species	Number of trees ha^{-1}					
	1980 stand	Ingrowth	Ongrowth	Mortality	Removals	1985 stand
Andira inermis	46.1	0.0	3.8	0.0	0.0	49.9
Cordia alliodora	10.1	0.0	7.5	0.0	0.0	17.6
Didymopanax morototoni	2.1	14.9	0.0	0.0	0.0	17.0
Guarea guidonia	216.9	67.0	18.5	14.9	0.0	287.5
Inga fagifolia	86.2	7.4	9.0	10.9	0.0	91.7
Petitia dominguensis	5.9	0.0	0.0	0.0	0.0	5.9
Tabebuia heterophylla	8.9	0.0	0.0	0.0	0.0	8.9
Subtotal’	316.2	89.3	38.8	25.8	0.0	478.5
Other species	1 124.2	284.1	32.9	275.7	7.4	1 158.0
Grand total	1 500.4	373.4	71.7	301.5	7.4	1 636.5

1 Timber species listed in Wadsworth and Birdsey (23).

Table 5. Stem changes in disturbed coffee shade forests for major timber species.

Tree species	Number of trees ha⁻¹					
	1980 stand	Ingrowth	Ongrowth	Mortality	Removals	1985 stand
Andira inermis	33.7	19.5	5.1	3.9	0.0	55.0
Calophyllum calaba	2.5	0.0	0.0	0.0	0.0	2.5
Didymopanax morototoni	36.1	15.6	6.4	3.9	7.8	46.4
Cuarea guidonia	165.7	37.9	13.8	3.9	61.5	152.0
Inga fagifolia	41.9	0.0	2.3	15.6	14.0	14.6
Nectandra sintenisii	42.8	7.8	0.0	0.0	38.9	11.7
Subtotal[1]	322.7	X0.8	28.2	27.3	122.2	282.2
Other species	910.0	293.8	31.4	221.6	303.1	716.6
Grand total	1 232.1	314.6	65.6	248.9	425.3	998.8

1 Timber species Listed in Wadsworth and Birdsey (23).

$MAI = 0.086 + 0.0164\ d - 0.000107\ d^2$ was derived. The coefficient of determination (R^2) was 0.16 (Table 7).

Comparison of MAI by crown class was restricted by sample sizes and was complicated by the field procedure which did not designate classes for trees < 12.5 cm in dbh (Table 8). Most of these trees were probably in the intermediate or suppressed classes. ***Guarea guidonia*** grew significantly faster in the dominant class than either the intermediate or non-designated class. The remaining species did not have enough replications for meaningful comparisons.

Table 6. Comparison of mean annual diameter growth (MAI) on surviving trees, by forest class without regard to species.[1]

Forest class	MAI (diameter)[2] (cm yr⁻¹ ± SE)[3]	Sample size (No. trees)
Secondary		
Young	0.21 ± 0.02[b]	229
Advanced	0.19 ± 0.01[b]	423
Coffee shade		
Active	0.21 ± 0.02[b]	421
Abandoned	0.52 ± 0.17[a]	22
Mean all classes[4]	0.21 ± 0.01	1095

1 Minimum tree size was 2.5 cm in dbh.
2 Analysis of variance showed the means to be different (P = 0.0002). Means followed by the same letter are not significantly different by Duncan's multiple range test.
3 SE = standard error of mean.
4 Mean is weighted by sample size.

Table 7. Analysis of variance of mean annual diameter growth, by tree size class.[1]

Source	DF	Sum of squares	Mean square	F value	P > F
Past diameter	1	24.31	24.31	168.6	0.0001
Square of past diameter	1	5.53	5.53	38.4	**0.0001**
Error	1088	156.91	0.14		
Total	1 090	186.75			

1 Growth $= 0.086 + 0.164\ d - 0.000107\ d^2$, where d = initial diameter. The coefficient of determination (R^2) is 0.16.

When commercially valuable timber species were compared without regard to crown class, considerable overlap in MA1 was apparent (Table 9). ***Didymopanax morototoni*** grew most rapidly and *Andira inermis* grew the slowest.

Volume growth rates

The volume of growing stock increased by an average of 32% for all forest classes and disturbance classes combined between 1980 and 1985 (Table 10). The increases in young secondary forest and both classes of coffee shade forest ranged from 50 to 56%, whereas advanced secondary forest increased by only 18%. The proportion of change in disturbed forests was-greater than that in undisturbed forests.

Timber volumes increased by an average of nearly 36% on all classes of timberland combined between

Tabie 8. Mean annual diameter growth (MAI) of timber species with ⩾ 20 trees, by crown class.

Species	MAI (diameter) by crown class[1,2]			
	D	C	I	0
	cm yr^{-1} (n)[3]			
	0.11(2)	0.18(9)	0.18(8)	0.15(24)
Didymopanax morototoni	0.58(15)	0.60(8)	0.11(2)	0.23(7)
Guarea guidonia	0.88(46)[a]	0.73(47)[ab]	0.37(16)[bc]	0.18(46)[c]
Inga fagifolia	0.36(7)	0.68(11)	0.03(4)	0.26(14)
Tabebuia heterophylla	0.63(1 I)	0.29(3)	0.05(4)	0.33(13)

1 Crown classes: D = dominant, C = codominant, I = Intermediate, and 0 = all trees < 12.5 cm in dbh that were not classified to crown class.
2 An analysis of variance to test the effects of crown class showed differences for *Guarea guidonia* (P = 0.0001). Row means followed hy the same letter are not different by Duncan's multiple range test (P = 0.05).
3 n = number of individuals measured.

1980 and 1985 (Table 10). Secondary forests ranged from 31 to 37% and coffee shade forests from 19 to 53%. When the lands were partitioned according to disturbance classes, the proportion of change in undisturbed forests was more than twice that in disturbed forests. Excluding the landcleared areas, the Undisturbed advanced secondary forest had the highest volume per hectare of growing stock and timber at the beginning of the study, and the disturbed Young secondary forests had the lowest volume per hectare (Table 10).

Mean annual volume growth rates for growing stock and timber are shown in Table 11. Landcleared

Table 9. Comparison of mean annual diameter growth (MAI) on surviving timber species and other groupings with ⩾ 20 trees.'

Species or grouping	MAI (diameter)* (cm yr^{-1} ± SE)"	Sample size (No. trees)
Didymopanax morototoni	**0.42** ± 0.09[a]	32
Tabebuia heterophylla	0.35 ± 0.06[ab]	31
Inga fagifolia	0.32 ± 0.10[abc]	36
Guarea guidonia	0.30 ± 0.03[abcd]	121
Other timber species	0.25 ± 0.04[bcd]	99
Non-timber dicots	0.19 ± 0.01[cd]	590
Andira inermis	0.16 ± 0.05[d]	43
Total		952

1 Open grown trees and overtopped trees were excluded from the analysis. The crown classes of all trees were dominant, codominant, or intermediate.
2 Analysis of variance showed the means to be different (P = 0.0001). Means followed by the same letter are not different by Duncan's multiple range test (P = 0.05).
3 SE = Standard error.

areas had negative values in both categories. Advanced secondary forest in the disturbed category and abandoned coffee shade forest in the undisturbed category showed the most rapid increases in growing stock volumes, averaging 5.0 and 4.2 $m^3 ha^{-1} yr^{-1}$, respectively. When undisturbed and disturbed categories were combined by forest class, the growing stock of abandoned coffee shade forest increased most rapidly at 3.6 $m^3 ha^{-1} yr^{-1}$. The most rapid timber volume increases were for abandoned coffee shade forest in the undisturbed category and advanced secondary forest in the disturbed category, which averaged 9.2 and 7.9 $m^3 ha^{-1} hr^{-1}$, respectively. When undisturbed and disturbed categories were combined by forest class, the timber volume in abandoned coffee shade forest increased most rapidly at 7.1 $m^3 ha^{-1} yr^{-1}$.

Tables 12 and 13 show the components of annual change in timber volumes according to forest classes in undisturbed and disturbed timberland, respectively. In undisturbed forests, growth of survivors in young secondary forest, advanced secondary forest, and abandoned coffee shade forest was 56, 87, and 90%, respectively, of the gross volume growth (Table 12). These percentage changes were in the same order as the original stand volumes. Ingrowth, in turn at 1.5, 12, and 4%, respectively, was in reverse order of the initial stand volumes. In disturbed forest, increment on survivors ranged from 67 to 88%, and ingrowth ranged from 6 to 21% for all forest classes. Neither was related to initial stand volumes.

Four tree species accounted for 52% of the average net annual timber growth in volume: ***Cecropia peltata***, 19.3%; ***Guarea guidonia*** 13.8%; ***Ormosia krugii***, 9.9%; and ***Erythrina poeppigiana***, **9.0%.** An

Table 10. Growing stock and timber voiumes, by forest class and disturbance class, in Puerto Rico's timberland for both surveys.

Forest class	Volume (m^3 ha^{-1}) by disturbance class						
	Undisturbed		Disturbed		Mean[1]		Percent change
	1980	1985	1980	1985	1980	1985	
				Growing Stock -- All Species			
Secondary							
Young	11.9	17.0	5.4	9.2	9.4	14.0	48.9
Advanced	59.2	63.3	49.1	74.2	56.1	66.0	17.6
Coffee shade							
Abandoned	37.1	58.7	27.8	42.1	33.3	51.2	53.7
Active	0	0	15.3	24.0	15.3	24.0	56.4
Land clearing	0	0	8.3	0.8	8.3	0.8	-90.4
Mean[1]	40.2	51.1	20.1	28.6	28.9	38.2	32.2
Percent change	27.1		42.3		32.2		
				Timber Species			
Secondary							
Young	40.1	51.8	18.5	25.4	31.7	41.6	31.2
Advanced	92.8	132.4	91.9	114.8	92.5	127.0	37.3
Coffee shade							
Abandoned	76.X	122.9	54.4	77.4	66.7	102.4	53.4
Active	0	0	33.0	39.3	33.0	39.3	18.9
Land clearing	0	0	18.5	1.2	1 x.5	1.2	-93.5
Mean[1]	75.5	111.6	41.2	49.3	55.8	75.9	35.8
Percent change	47.8		19.6		35.8		

1 Means are weighted by land areas.

additional 17% of growth was fairly evenly distributed among *Inga laurina*, *Didymopanax morototoni*, and *Tabebuia heterophylla*. *Cecropia*, *Didymopanax*, and *Tabebuia* are early secondary species, and *Guarea*, *Erythrina*, and *Inga* are coffee shade species. *Ormosia* is a more frequent component of secondary forests than undisturbed forests.

Three species accounted for 80.6% of the average net annual mortality: *Inga vera*, 60.2%; *Cecropia peltata* 13.6%; and *Guareaguidonia*, 6.8%. More than 60% of the mortality was attributed to disease and nearly 10% to human disturbance. The cause of the remaining mortality was less evident but appeared largely due to suppression by competing trees and growth of vines.

DISCUSSION

This study constitutes the first regional assessment of secondary forest growth rates in Puerto Rico. Several trends that might be expected in other areas where agricultural abandonment is followed by the growth of secondary forests were previewed in this study. The first was continual human intervention in more than half of the forests surveyed, presumably to satisfy local needs for wood or to continue subsistence cropping (Table 1). Another trend was that commercially valuable timber species, which comprised 14 to 26% of the stems on all classes of forest land in the initial survey, increased slightly between surveys (Tables 2-S). This may be due to the fact that the commercially valuable trees are larger and longer lived and tend to replace other species over time. The last trend was that growth rates were satisfactory for many species and forest classes.

Diameter growth for abandoned coffee shade forest (Table 6) and for many timber species in the dominant and codominant crown classes (Table 8) was in the upper range of values reported elsewhere in Puerto Rico. Diameter growth rates for many of the timber species included in this study had been previously determined in logged-over secondary forest

Table 11. Mean annual growth in volume of growing stock and timber, by forest class and disturbance class, in Puerto Rico's timberland between surveys, 1980-85.[1]

Forest class	Volume growth (m^3 ha^{-1} yr^{-1}) by disturbance class: Undisturbed	Disturbed	Mean[1]
	Growing Stock		
Secondary			
Young	1.0	0.7	0.9
Advanced	0.6	5.0	2.0
Coffee shade			
Abandoned	4.2	2.8	3.6
Active	0	1.7	1.7
Land clearing	0	-1.5	-1.5
Mean[1]	2.1	1.7	1.9
	Timber		
Secondary			
Young	2.3	1.4	2.0
Advanced	7.9	4.6	6.9
Coffee shade			
Abandoned	9.2	4.6	7.1
Active	0	1.2	1.2
Land clearing	0	-3.5	-3.5
Mean[1]	7.2	1.6	4.0

[1] Means are weighted by land areas.

of the Luquillo Mountains in northeastern Puerto Rico (4), an area not included in the inventory. In that study, ***Guarea guidonia*** averaged 0.80 cm/yr, *Inga fagifolia* ranged from 0.40 to 0.60 cm/yr, and ***Tabebuia heterophylla*** and ***Didymopanax morototoni*** grew from 0.30 to 0.35 cm/yr, depending on locale.

Our estimates of timber volume growth are shown in Table 11. Apparently, volume growth is satisfactory in the advanced secondary and abandoned coffee shade stands and certainly is favorable when compared to volume growth in Puerto Rico's primary forests (12, 25). Direct comparisons with secondary forest studies elsewhere are difficult, however, because of differences in sampling designs and measurements.

Numerous tree species in Puerto Rico's secondary forests have timber potential (27). The forests, however, are dominated by early secondary species of limited utility and those previously used in subsistence agriculture (26). Furthermore, they are characterized by poor tree form and low timber volumes.

A "new look" at Puerto Rico's timberland (23), using information from the 1980 inventory, indicated that there were more than 20 timber species on about 50 000 ha of forest that were adequately stocked in the poletimber and sapling size classes. The study also posed research questions related to Puerto Rico's secondary forests. One of them -"how well can secondary forests redeem investments in their production?"- is critical to future work. In adequately stocked stands, existing regeneration would preclude

Table 12. **Components** of annual **change** in volume of timber, by forest class, in Puerto Rico's undisturbed timberland, **1980-85.**

Component	Landclearing	Secondary forest: Young	Advanced	Coffee shade: Abandoned	Active	Total
	1 000 m^3 yr^{-1}					
Growth:						
Survivor growth	0.0	33.6	134.2	168.4	0.0	336.2
Ingrowth	0.0	8.7	18.0	7.4	0.0	34.0
Growth on cut	0.0	0.0	0.0	0.0	0.0	0.0
Growth on mortality	0.0	17.3	2.2	10.9	0.0	30.4
Gross growth	0.0	59.6	154.4	186.7	0.0	400.6
Mortality	0.0	-34.6	-5.5	-22.3	0.0	-62.4
Net growth	0.0	25.0	148.9	164.4	0.0	338.2
Removals	0.0	0.0	0.0	0.0	0.0	0.0
Net change	0.0	25.0	148.9	164.4	0.0	338.2

Table 13. Components of annual change in volume of timber, by forest class, in Puerto Rico's disturbed timberland, 1980-85.

Component	Landclearing	Secondary forest: Young	Secondary forest: Advanced	Coffee shade: Abandoned	Coffee shade: Active	Total
	1 000 m³ yr⁻¹					
Growth:						
Survivor growth	-0.5	11.2	40.0	74.1	65.0	189.9
Ingrowth	0.0	2.1	2.8	22.8	8.9	31.3
Growth on cut	0.0	0.2	0.0	7.4	0.0	1.6
Growth on mortality	-1.1	0.0	2.9	4.9	21.7	28.4
Gross growth	-1.6	14.1	45.7	109.2	95.6	263.2
Mortality	0.0	0.0	-8.8	-14.4	-67.0	-90.2
Net growth	--1.6	14.1	36.9	94.8	28.6	173.0
Removals	-39.0	-2.1	0.0	-17.7	0.0	-58.9
Net change	-40.6	12.0	36.9	77.1	28.6	114.1

the need for costly nursery facilities and planting efforts but would require management of the regeneration. Although the silvicultural techniques required to stimulate growth (26) have not been widely tested, previous studies in Puerto Rico's secondary forests provide insights for future management. Tree diameter growth on abandoned agricultural lands without silvicultural treatment was correlated with crown size (28). Another study comparing diameter growth of timber trees in thinned secondary forest with the same species in undisturbed natural forest showed that trees in the thinned forest grew more rapidly (24).

Some important economic considerations that require scrutiny are the potential utility of mixed species in local markets; the feasibility of harvest from numerous small, scattered, and increasingly fragmented properties; and the capability of Puerto Rico's road system to handle the heavy traffic associated with logging. Other pertinent issues relate to the uniqueness of Puerto Rico in tropical America. The island is densely populated, has an increasingly affluent 'citizenry, and contains a limited number of natural areas in the mountainous interior for passive recreational use (15). Moreover, it has a growing need for additional water supplies for domestic and commercial use. The economic tradeoffs between a growing demand for wood products (22) and these competing uses remain to be evaluated.

GLOSSARY

Definitions of the important terms used in the text are included in this glossary.

- **Coffee shade:** A multi-story, multi-crop system used principally for the production of coffee and characterized by an upper story of shade trees. Active and abandoned categories refer to current use of the terrain.

- **Cull increment:** The net volume in trees that change from growing stock to rough or rotten, or vice-versa (i.e., because of increment on non-defective logs), during the period between inventories.

- **Disturbance** class: Undisturbed forests not cut between inventories; disturbed — those with evidence of cutting or removal of stems.

- Growing **stock trees:** All live trees (sawtimber, poletimber, saplings, and seedlings), except rough and rotten trees.

- **Growing stock volume:** Volume of all sound wood (excluding sound cull) in the bole of growing stock trees ⩾ 12.5 cm in dbh, from stump to a minimum 10 cm diameter outside bark, or to the point where the central stem breaks into limbs.

- **Ingrowth**: Number or sound volume of trees that reach the minimum diameter class of 12.5 cm in dbh during the period of measurement and that are recorded for the first time.

- **Mortality**: Number or sound volume of live trees dying from natural causes during the period between inventories.

- **Ongrowth**: Number or sound volume of trees > 12.5 cm in dbh that qualified for the new prism sample, but not the original sample, because of diameter increment. Trees that grew from < 12.5 to ⩾ 12.5 cm in dbh were classified as ingrowth.

- Rough or rotten trees: Live trees that are unmerchantable for sawlogs now, or prospectively, because of defect or rot.

- Secondary forest: Forests resulting from the abandonment of cropland or pasture, and forests resulting from the regeneration of previously cutover or disturbed forest land. Young secondary forest ranged in age from 0 to 20 years. and advanced secondary forest was > 20 years old, as determined in 1980. Coffee shade forest is not included in this category.

- Timberland: Forest land that is producing or is capable of producing timber crops and not withdrawn from timber utilization. Forest lands with higher priority uses, yet not specifically withdrawn from timber utilization, are excluded from this class of forest land. Coffee shade and secondary forests are included in this category.

- Timber removals: Net volume of growing stock trees removed from the inventory by harvesting or in cultural operations such as timber stand improvement, land clearing, or change in land use.

- Timber volume: Volume of all sound wood (including sound cull) in the bole and branches of growing stock and rough, rotten, and salvable dead trees ⩾ 12.5 cm in dbh, from stump to a minimum 10 cm diameter outside bark. The minimum length of any section is one meter.

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