Cutover tropical forest productivity potential merits assessment, Puerto Rico

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Logged moist forest in Puerto Rico, showing the mixed nature of the residual forest.
Photography F. H. Wadsworth.

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RÉSUMÉ

LA PRODUCTIVITÉ POTENTIELLE DES FORÊTS TROPICALES SUREXPLOITÉES MÉRITE UNE ÉVALUATION, PUERTO RICO

L'exploitation de bois d'œuvre continue à augmenter l'étendue des forêts tropicales surexploitées. Elles ne sont pas économiquement attractives du fait de la perte d'espèces commercialisables et du long délai à prévoir pour leur reconstitution. En dépit de ceci, le bois au sein des forêts intensément parcourues par l'exploitation est à même d'offrir des perspectives de commercialisation, compte tenu de la demande et de l'accès de plus en plus difficile aux zones de forêts intouchées. Dans une forêt jadis surexploitée de Puerto Rico, ont été identifiés des arbres de valeur bien conformés n'ayant pas atteint l'âge de maturité. Ils s'avèrent ubiquistes et se trouvent tout au long des contreforts d'une montagne, indifféremment sur des surfaces concaves ou convexes avec des pentes abruptes ou faibles et protégées ou non des vents dominants. En général, la forte productivité des arbres est la conséquence d'une situation favorable vis-à-vis des arbres concurrents, de l'exposition ou de la taille du houppier. Un quart de ces arbres, en principe en suffisance pour un second prélèvement, sont à l'origine d'une production qui s'avère être le double de celle du reste du peuplement, atteignant ainsi la taille d'exploitabilité en deux fois moins de temps. La valorisation de ce potentiel serait à même d'éviter la conversion inconsidérée des forêts, ainsi parcourues par l'exploitation, à d'autres utilisations des terres.

Mots-clés : productivité des arbres, arbre concurrent, forêt tropicale, forêt surexploitée, station forestière, Puerto Rico.

ABSTRACT

CUTOVER TROPICAL FOREST PRODUCTIVITY POTENTIAL MERITS ASSESSMENT, PUERTO RICO

Timber extraction continues to add to vast cutover tropical forests. They are unattractive economically because of the loss of merchantable timber and the long delay foreseen for recovery. Despite this, wood in cutover tropical forests is in line to become more marketable as demand continues and old-growth forests become less accessible. In a cutover forest in Puerto Rico a well formed immature trees of timber species was found. They were ubiquitous, growing throughout the foothills of a mountain on both convex and concave land surfaces, on steep as well as low slopes, and exposed to prevailing winds as well as protected. Higher tree productivity generally accompanied freedom from competitors, crown exposure, or crown size. One quarter of these trees, apparently enough for a second crop, had been producing at more than double the rate of the rest, approaching maturity in half the time. Appreciation of this potential might prevent wanton conversion of cutover forests to other land uses.

Keywords: tree productivity, tree competition, tropical forest, cutover forest, forest site, Puerto Rico.

RESUMEN

LA PRODUCTIVIDAD POTENCIAL DE LAS ÁREAS BAJO EXPLOTACIÓN EXCESIVA DE BOSQUES TROPICALES MERECE UNA ESTIMACIÓN, PUERTO RICO

La explotación maderera amplía cada vez más la extensión de las áreas de corta abusiva de bosques tropicales. Estas zonas son de escaso interés económico debido a la desaparición de la madera comercializable y al largo plazo requerido para su regeneración. A pesar de ello, la madera de dichas áreas intensamente explotadas está a punto de ofrecer oportunidades de comercialización, teniendo en cuenta la demanda existente y el acceso más dificultoso a zonas de bosque intacto. En un bosque de Puerto Rico anteriormente sometido a intensa tala, se localizaron árboles jóvenes y con buena forma de especies maderables. Estos árboles, que resultan ser ubicuos, se extienden a lo largo de las estribaciones de una montaña, tanto en áreas convexas como cóncavas, en pendientes moderadas o fuertes, y protegidos o no de los vientos dominantes. La alta productividad de los árboles, resulta de una situación idónea en cuanto a los árboles competidores, la exposición o la dimensión de la copa. La cuarta parte de estos árboles, a priori bastando para justificar una segunda corta, presentan una tasa de productividad dos veces superior a la de los demás, llegando así a madurez en la mitad de tiempo. Valorar este potencial debe permitir que se evite desrazonablemente convertir, áreas previamente así explotadas, en otros usos del suelo.

Palabras clave: productividad de los árboles, competencia entre árboles, bosque tropical, bosques bajo explotación excesiva, sitios forestales, Puerto Rico.

Introduction

Wood extraction from tropical forests rose by 80 million cubic meters per year between 2001 and 2005 (Fao, 2005). Millions of hectares of cutover forests are seen not only ecologically degraded but economically worthless, because of perceived slow natural recovery (Liebach *et al.*, 2008). With reduced-impact logging leaving cutover forests more intact, interest in the remaining forest is appearing (Peña-Carlos *et al.*, 2008). For timber, with two potentials: well-formed trees of potentially useful species sufficient to justify their future extraction and conditions favorable for their growth, cutover forests could be an attractive start on a second crop toward an unquestionable market. This study set out to find empirical evidence of the two potentials in a cutover forest.

The trees were on foothills between 200 to 600 meters (m) above sea level in the El Yunque National Forest (Luquillo Experimental Forest) (figure 1). The Latitude is 18° North and the Life Zone is Subtropical Wet (Ewel, Whitmore, 1973), meaning rainfall of 200 to 400 centimeters per year. The forest is on acid clay soil (Usda Soil Conservation Service, 1977). About twenty years prior to the study, logging with oxen removed about half of the trees of ≥ 60 cm dbh (trunk diameter 1.4 m above ground level on the high side) of tabonuco, *Dacryodes excelsa* Vahl; ausubo, *Manilkara bidentata* (A. DC.) Chev.; and nuez moscada, *Ocotea moschata* (Meisn.) Mez., possibly 15 trees per hectare.

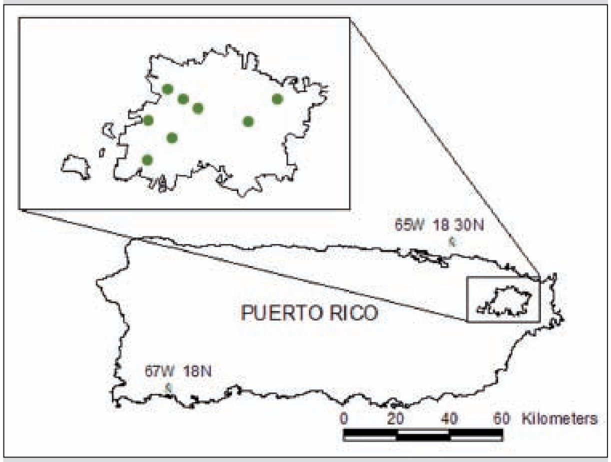

Figure 1.
The location in Puerto Rico of the forest studied and the plots from which the selected trees were taken.

Methods

Trees were selected in 206 widely dispersed plots (figure 1) of from 0.08 to 0.4 hectare (ha), mostly circular with boundaries dictated by tree size and distance, and aggregating not less than 25 ha. Tree growth during the longest measured period with no serious hurricanes, 1958 to 1982, was selected as the dependent variable. Measured were 1,425 trees of timber species between 10 and 60 cm dbh at the beginning of the period (figure 2) with erect trunks of ≥ 4 m, and apparently in good health, termed hereinafter "crop trees". Included were 12 species with at least 40 crop trees each (table I).

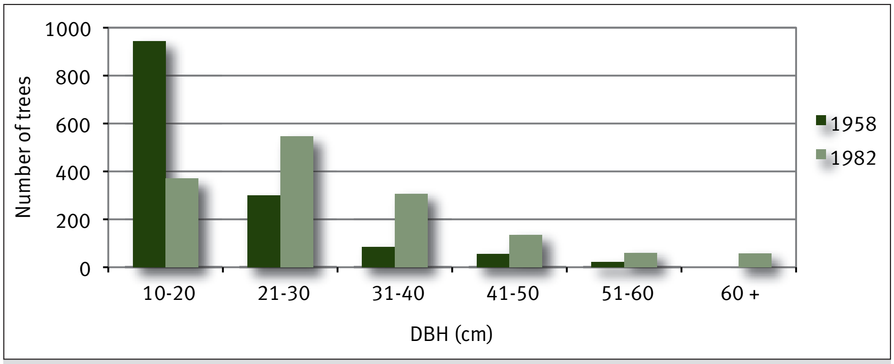

Figure 2.
Distribution of trees by dbh in 1958 and 1982, beginning and end of the study period.

In 1982, in addition to dbh, were recorded for each crop tree surrounding forest basal area, crown position in the canopy, and crown area. Surrounding forest basal area was approximated by 3-diopter prism and converted to m²/ha (Usda, 1933). Crown position in the canopy distinguished crop trees free of canopy interference as dominants; those about half free, as codominants; those with direct sunlight only from above, as intermediates; and those with less direct illumination than the area of their crowns, as suppressed (Daniel *et al.*, 1979). The crown areas of crop trees were measured in square meters (m²), computed from radii out to beneath the edge of the crowns. Also recorded were crop tree buttresses: none, slight (only at ground level) and pronounced (ascending the trunk).

With tree growth rates in this forest historically unpredictable (Wadsworth, 1953) was recorded additionally tree occupancy on three sites of topographic significance as possible contributing factors. For each site were paired options, convex versus concave land surface; slopes of ≤ 20° versus ≥ 40°; and on slopes of ≥ 20° aspects windward (NE-SE) versus leeward (NW-SW). To accentuate contrast between occupancy of the two options of each pair was divided the sum of the basal areas of the trees in one by that in the other.

Increment was related to tree access to the resources of the forest, illumination, nutrients, and moisture, a function of tree size. To get the "productivity", 24-year basal area increment of each crop tree were divided by the 24-year mean basal area of its trunk at breast height, converted to annual percent. The magnitude of productivity was shown more meaningfully by the number of years required by each crop tree to grow from 20 to 50 cm in dbh, determined by compounding its production percent into the (individual) basal area increase from 1 to 6.25.

Another scene of cutover moist tropical forest in Puerto Rico where surplus straight trees remain.
Photography F. H. Wadsworth.

A cutover moist tropical forest in Puerto Rico 20 years after silvicultural treatment when the crop trees were marked and liberated.
Photography F. H. Wadsworth.

Results

The 12 crop tree species included proved to be diverse, each in a different botanical family (table I). They or other species of their genera are widely distributed elsewhere in tropical America (Liogier, 1985-1995). One species, *Dacryodes excelsa*, made up about 40 percent of the initial basal area of the crop trees selected. The mean crop tree dbh was initially 20 cm, those of individual species ranging from 15 to 29 cm, and tree dbh extremes to 60 cm (figure 2). The woods of the crop trees ranged in specific gravity from 0.32 to 0.98, seven rated as suitable for furniture and cabinet work and the others for different products (Longwood, 1961).

Trends of dbh growth and basal area increment relative to tree dbh proved impressive (figures 3a and 3b), showing a need for a comparable measure of productivity of trees of different sizes free of this bias. Relative uniformity of productivity with tree size resulting from this elimination is evident in table II. Despite the selected quality of the crop trees, at the rate of their past productivity the average tree requires 57 years to grow from 20 to 50 cm dbh (table III). Remaining wide variation in productivity per tree led us to isolate the data for the 25 percent of the trees of highest productivity. This subsample, of 356 trees, included all 12 species and averaged about 14 trees per hectare, a number similar to that logged. These 25 percent trees outgrew the rest of the crop trees by 2.5 times in dbh (0.69 versus 0.28 cm/yr), by 2.3 times in productivity (5.0 versus 2.3 percent/year), and could reduce the average wait for growth from 20 to 50 cm dbh by 49 percent (70 versus 32 years) (table III).

Forty-nine percent of the crop trees were on convex surfaces (sloping downward from tree bases) and only 10 percent on concave bottoms (figure 3c). Of the basal area about 7/8 was on convex surfaces (table IV). Those species with the highest ratios of basal area on convex surfaces included

Table I.
The crop trees studied; botanical identity, number, percentage of 1958 basal area, mean dbh and uses.

Species[1]	Family	Trees	Basal area (%)	DBH (cm)	Uses[2]
Buchenavia tetraphylla (Aub,) How.	Combretaceae	49	7.3	28.9	67 FC
Cecropia schreberiana Miq.	Moraceae	61	4.0	20.3	32 O
Chionanthes domingensis Lam.	Oleaceae	41	1.6	15.6	90 O
Dacryodes excelsa Vahl	Burseraceae	354	39.4	25.7	59 FC
Homalium racemosum Jacq.	Flacourtaceae	41	3.3	17.9	90 FC
Inga laurina (Sw.) Willd. Ex. L.	Mimosaceae	62	3.6	18.1	70 FC
Manilkara bidentata (A.DC.) A. Chev.	Sapotaceae	120	7.5	18.0	98 CO
Matayba domingensis (DC.) Radlk	Sapindaceae	141	6.6	17.3	84 C
Ormosia krugii Urban	Fabaceae	108	7.4	20.9	56 FC
Schefflera morototoni (Aub.) M.S.F.	Araliaceae	121	5.5	17.7	41 O
Sloanea berteriana Choisy	Eliocarpaceae	43	2.7	20.2	95
Tabebuia heterophylla (DC.) Britton	Bignoniaceae	284	11.1	15.9	64 FC
Totals and weighted average		1 425	100.0	20.1	

[1] Nomenclature follows Liogier (1985-1995).
[2] Specific gravities (oven-dry weight/oven-dry volume) in hundredths and uses mostly from Longwood (1961).
Uses of the timber are keyed as follows:
F = furniture, cabinet-making, milling; C = carpentry and construction; O = turnery, ornaments, toys.

Buchenavia (30/1), *Dacryodes* (11/1), and *Chionanthes* (7/1). Only *Sloanea*, occupied more concave surfaces (10/9). Productivity for all crop trees averaged higher on the concave surfaces (3.2 versus 2.9 percent) but the difference was less than statistically significant. The ratio of basal area of 1.7 for all crop trees on slopes (table IV) showed predominance on ≤ 20°. The species with the highest proportion of basal area on slopes of ≤ 20 ° were *Manilkara* (5/1), *Matayba* (3.3/1), and *Buchenavia* (2.5/1). In contrast, *Chionanthes*, *Cecropia*, *Dacryodes*, and *Schefflera* were better represented on slopes of ≥ 40° (ratios 10/3 to 10/6). Productivity was significantly higher on slopes of ≤ 20° (3.2 versus 2.6 percent) (figure 3d). On windward slopes of ≥ 20° were found *Manilkara* (2.5/1), *Tabebuia*(2.2/1), *Chionanthes*(2.2/1), *Buchenavia* (1.9/1), and *Sloanea* (1.6/1). Chiefly on leeward slopes were *Inga* (10/1) and *Cecropia* (5/1). Productivity averaged 2.9 percent on windward slopes and 3.0 percent on those leeward, the difference less than statistically significant. Pronounced buttresses were found on all of the 12 species and on 32 percent of the basal area. Twenty percent of the basal area was without buttresses. Species extremes with percent with pronounced buttresses included *Schefflera* (1%), *Dacryodes* (5%) and *Sloanea* (99%). The mean productivity of the crop trees with pronounced buttresses was 3.2 versus 2.6 percent without buttresses, a difference statistically significant.

The average forest basal area around all crop trees was 18.6 m²/ha and around the 25 percent of high productivity was 23.4 m²/ha, corroborating a lack of competition from these levels. But beyond 25 m²/ha productivity of both the mean and the top 25 % producers declined significantly (figure 3e). In crown positions intermediate crop trees unexpectedly were producing about as much as the dominants (2.8 versus 2.9 percent) (figure 3F). But the 47 percent of crop trees suppressed produced only 2.3 percent. Thirty-five percent of the crop trees with crowns of less than 20 m² produced only 2.7 percent (figure 3g).

Table II.
Tree productivity relative to dbh, indicating greater freedom from trends as dbh increases (figure 3a), and basal area increment (figure 3b).

	Crop tree 1982 dbh, cm 10-20	21-30	31-40	41-50	›51
Number of crop trees	358	536	303	128	55
Mean productivity, %/yr	2.3	3.5	3.5	2.7	2.2
Top 25%	3.9	5.3	5.7	5.0	4.2
Maximum	5.1	6.6	7.1	7.2	5.7

Table III.
Mean and top 25 % growth and productivity of the crop trees by species.
Years required based on productive percentages from 20 to 50 cm dbh.

Species (genus)	DBH growth (cm/y)r		Productivity (%/yr)		Years required (20-50 cm dbh)	
	Mean	25%	Mean	25%	Mean	25%
Buchenavia	0.52	0.86	3.0	4.9	57	34
Cecropia	0.43	0.81	3.2	5.3	53	32
Chionanthes	0.32	0.56	3.2	5.0	53	33
Dacryodes	0.38	0.70	2.6	5.0	64	35
Homalium	0.43	0.74	3.4	5.4	49	32
Inga	0.44	0.80	3.4	5.5	49	31
Manilkara	0.47	0.83	3.6	5.3	48	32
Matayba	0.37	0.59	3.2	5.0	53	33
Ormosia	0.45	0.73	3.3	5.0	52	33
Schefflera	0.34	0.69	2.7	5.0	63	33
Sloanea	0.30	0.67	2.3	4.4	73	37
Tabebuia	0.31	0.58	2.9	4.8	53	36
Weighted averages	0.38	0.69	2.97	5.01	57.0	32.1

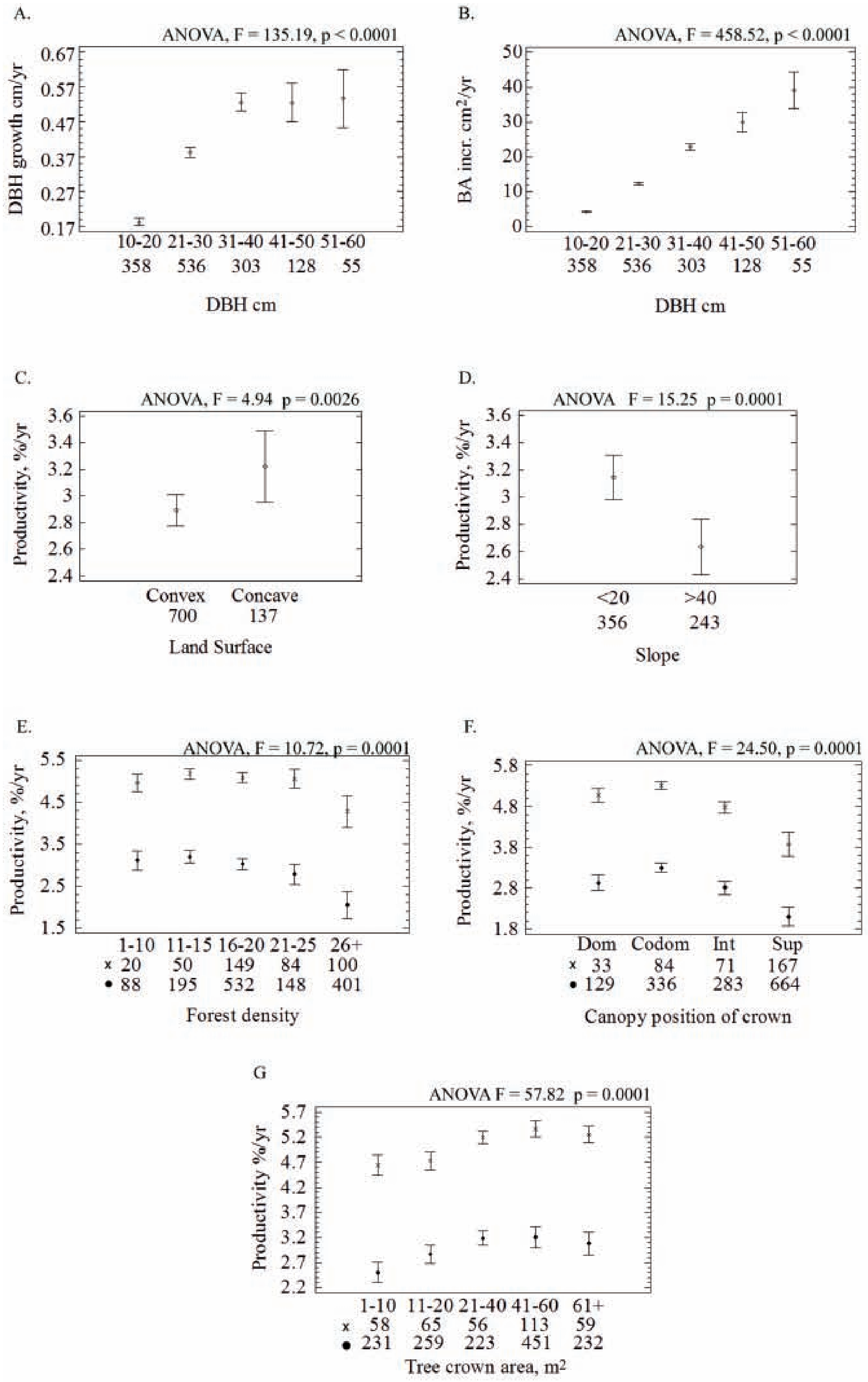

Figure 3.
Relationships between trees and tree environments for all crop trees and the 25 percent with highest productivity. Tree productivity in percentage per year is indicated by the vertical scales. Tree numbers are given below each chart. Averages and 95.0 Percent Confidence Intervals.
● = Productivity of all crop trees, x = 25% most productive trees.

Table IV.
Crop tree species occupancy in the forest sites indicated by relative basal areas.

Species (genus)	Crop tree basal area ratios Convex ÷ Concave	 ≤ 20° ÷ ≥ 40°	 Wind ÷ Lee
Buchenavia	30.5	2.5	1.9
Cecropia	1.7	0.3	0.2
Chionanthes	6.9	0.0	2.2
Dacryodes	11.4	0.3	1.0
Homalium	2.6	1.4	0.9
Inga	3.4	1.7	0.1
Manilkara	3.7	5.0	2.5
Matayba	5.9	3.3	0.6
Ormosia	5.1	0.6	0.7
Schefflera	2.8	0.3	0.6
Sloanea	0.9	0.6	1.6
Tabebuia	3.9	1.4	2.2
Weighted means	7.5	1.7	1.2

A convex ÷ concave figure higher than 1 indicates higher frequency on convex ground. A figure higher than 1 for ≤ 20° ÷ ≥ 40° shows higher frequency on slopes of ≤ 20°. Less than 1 shows that ≥ 40° slopes are more favourable to the crop tree. A figure higher than 1 for windward ÷ leeward basal areas shows that a windward exposure is more favourable. Less than 1 shows that a leeward exposure is more favourable for the tree.

Overall view of cutover rain forest in Panama.
Photography F. H. Wadsworth.

Discussion

The mean productivity of the crop trees supports perceptions of cutover tropical forests without promise. Partial causes could be the 47 % of the crop trees with crowns suppressed, the 35 % with crowns of less than 20 m^2, and the 26 % surrounded by a forest basal area denser than 25 m^2/ha. Only the most productive trees in such forests could attract timber management.

Crude differences found in crop tree occupancy of sites, as shown in table IV, may in part reflect merely inequalities in their respective total numbers. Nevertheless, occupancy of options of the same site by some species differs so much as to suggest significance to tree health or productivity. Whatever this significance, some of the trees in the 25 percent of highest productivity were found on both land surfaces, on both slopes, or on both aspects. The good news is that as few as 12 species are highly productive everywhere on the entire mountainside.

The basal area of the top 25 percent of producers on convex surfaces divided by that on concaves averaged 5.3, compared to 7.5 for all crop trees (table III), meaning that the high producers, although mostly also on convex surfaces, had a higher percent on the concave surfaces than the crop trees as a whole. On steepness of slope, the mean basal area ratio for the 25 % of high producers was 1.5, compared to 1.7 for all the crop trees, indicating similarly that, whereas mostly also on slopes of ≤ 20° where the mean productivity averaged significantly higher, a larger percent of these had been highly productive on slopes of ≥ 40°. Pronounced buttresses may not be the full cause for the higher productivity found associated because their prevalence is known to be confounded with site.

Crop tree crown positions in the canopy, crown sizes, and surrounding forest basal areas drift over time and yet were assessed only at the end of the growth period, not for the entire 24 years. Drift during this period may not have been great. About one third of the trees changed crown position during the 24 years (figure 2), but for most trees it is evident in figure 3f that this must have had little effect on productivity before and after.

Surrounding forest basal area in excess of 25 m^2/ha apparently so affected even high producing trees (figure 3e), that it may prove a silvicultural bench mark applicable in other tropical moist forests. Cutover forests with more basal area than this may be common and responsible for slow growth, particularly

Profile of cutover moist forest
in the lower Amazon Valley, Brazil.
Photography F. H. Wadsworth.

Cutover dry forest in Mexico's Yucatan Peninsula,
showing the variety of trees remaining.
Photography F. H. Wadsworth.

Cutover rain forest showing density in Dominica, West Indies.
Photography F. H. Wadsworth.

after reduced impact logging. Cutover forest basal area increases continuously with no attention. Of the crop trees, almost 30 % were surrounded by more than 25 m^2/ha basal area. The higher forest basal area found around the top productive crop trees, 23 m^2/ha versus the 19 m^2/ha of the mean for all crop trees may reflect a larger number of trees on more productive sites. One cutover forest in Puerto Rico reached 49 m^2/ha, with productivity of the main timber trees reduced by two-thirds (Usda Forest Service, 1939). Competition within dense forests is confirmed by response of crop trees to liberation, increasing growth significantly in Costa Rica (Hutchinson, Wadsworth, 2004) and in Brazil (Wadsworth, Zweede, 2006).

However attractive highly productive crop trees might make cutover tropical forests, their presence was not apparent during the field measurements of the study. Moreover, few forests have growth records to identify trees of high productivity. Those we found were trees 10 to 60 cm dbh, with ≥ 4 m straight trunks not limited by forest site, or native timber tree species. But their crown positions in the canopy were at least intermediate, they were surrounded by forest basal area of less than 25 m^2/ha, and they had crowns of more than 20 m^2. With timber becoming increasingly competitive as a sustainable, versatile, solid material, the productivity of trees so selected could start the preservation and management of cutover tropical forests.

Conclusions

The development of the term "productivity" for the increase of tree basal area in percent per year, reflecting crown illumination and root system spread divided by tree basal area, eliminated the bias in comparing trees of different sizes. Ranging up to 7 percent per year, it provided a direct measure of proximity of trees in years to maturity.

The 25 percent of the trees with the highest productivity in a 20-year-old cutover forest were producing at a rate double that of the rest of the trees. These included a dozen species with a wide array of useful woods distributed at the generic level widely in tropical America, many of them suitable for cabinet work and furniture. Among these species are some most commonly found on convex land surfaces and others on concave. Some are on lower slopes and others on steep slopes. Some are on windward aspects and others on leeward aspects. There are some species among the high producers for all conditions, indicating the compatibility of timber production with a degree of biodiversity. The natural differences in abundance by species suggest what on a mountain may be site preferences to be recognized in the selection of crop trees for high productivity.

Despite the visible favorable species and good form of more than 1,000 trees selected as crop trees only about one quarter were also of rapid growth and therefore of high productivity. Whereas it is true that 25 percent of them were of high productivity, 75 percent of them were not. The difference of double productivity makes recognition an important need. By species it remains to be seen if high productivity is most likely on the topographic sites where the majority of trees was found. In addition to this, more detail as to the appearance of high producers is needed.

Cutover mixed moist forest along Rio Curuá
in the Amazon Basin.
Photography F. H. Wadsworth.

One characteristic relative to productivity that was exposed was the proximity of competing trees, expressed as the forest basal area within the distance dictated by a wedge prism. Below surrounding forest densities of 25 m^2/ha there is no perceptible effect on productivity, possibly explaining why basal area may not appear of significance under many conditions. At surrounding forest densities above 25 m^2/ha productivity of all of the crop trees falls off, including even those with high productivity at lower densities. This trend appears so general as to indicate improbable significant variation by tree species. Proximity can be determined in the forest by summing the dbh's of each crop tree and each adjacent tree (as tall or taller) as an indicator of necessary separation, tabulated in the study.

A finding significant to silvicultural releasing of suppressed crop trees is that the mean productivity of those in intermediate crown position, with side shade and illumination mostly from directly above, was not significantly inferior to that of the dominants. This permits the retention of a semi-dense canopy with high productivity if the surrounding basal area is kept below 25 m^2/ha.

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