TREE SUCCESSION AND MANAGEMENT OPPORTUNITIES IN COFFEE SHADE STANDS[1]

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Resumen

Un inventario de los bosques con potencial comercial en Puerto Rico indicó casi 60 000 ha de sombra de café incluyendo rodales activos y abandonados. La densidad de tallos, área basal y volumen de los brinzales y árboles de tamaño de postes eran más altos en los rodales recientemente abandonados. Area basal total y volumen de madera eran más bajos en los rodales de sombra activos y más altos en los rodales abandonados. La proporción de desecho a madera aprovechable, basado en el número de tallos y area basal, era mayor en rodales activos y menor en viejos rodales abandonados, mientras que la proporción de volumen de desecho a madera aprovechable era más alto en los rodales de sombra recientemente abandonados. El número de especies maderables demuestra un aumento gradual, mientras que el número de especies de árboles frutales y de sombra para café disminuye con tiempo. Se encontró un total de 34 especies maderables con potencial comercial en los cafetales.

Las oportunidades para el manejo de la madera aprovechable en los rodales de café abandonado incluyen medidas tales como: el despejar arbolitos en el sotobosque, la entresaca de árboles en el piso dominante, el establecimiento de árboles en línea, o la conversión a plantaciones. Las alternativas agroforestales comprenden el enriquecimiento de rodales de sombra para café con especies maderables; entresacas para favorecer árboles maderables en rodales de café abandonados donde se resumirá la producción de café, o la implementación del sistema de taungya con árboles maderables y cultivos en rodales nuevamente establecidos para la producción de café

Introduction

From the time European explorers found that people in Uganda used coffee beans to sustain their vigor on long journeys (19), the cultivation and use of coffee has spread. First cultivated in southern Arabia, coffee gradually reached throughout the near East and then to Europe in the 16th and 17th centuries. Coffee was introduced into Suriname and Brazil in the early 18th century (19), and by the late 1950's was the most important export crop from the neotropics (28). By 1980-81, total coffee production for the western hemisphere exceeded three billion kg (13); in Mexico alone, coffee stands covered 350 000 ha, and coffee production employed 100 000 planters and 300 000 day workers (15).

In Puerto Rico, coffee shade stands increased from 7 000 ha in 1828 to about 77 000 ha at the turn of the century (30). Later estimates of coffee shade showed a decline to 68 000 ha from 1916 to 1940, and to 57 000 ha in 1948 (27, 21). In the late 1940's, Puerto Rico began to industrialize. Between 1950 and 1970, over 120 000 people migrated out of the principal coffee producing region in the central mountains (6). Many of the traditional coffee farms were no longer tended on a regular basis. By the end of the 1950's, many coffee plantations consisted of old, unselected coffee trees growing under the very dense cover of overgrown coffee shade trees (1).

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Casual observation of numerous abandoned coffee plantations in Puerto Rico showed the presence of valuable timber species. The current lack of wood production on the island, combined with projected needs for the future and the realization that timber production could be a viable enterprise (32), led to an interest in assessing the abundance and condition of timber in the coffee forests.

The purpose of this study was to observe successional trends in coffee shade stands after abandonment. Of particular interest were changes in tree species composition, stem density, tree basal area and volume, and the quality of standing timber. Ultimately, this information may serve as a basis for silvicultural improvement of abandoned coffee shade forests.

Methods

The data analyzed in this study were gathered during a recent inventory of the forest resources of Puerto Rico (4). The island was partitioned geographically to focus the inventory on regions with potential for commercial forest production (Fig. 1). The subtropical moist and subtropical wet life zones defined by Holdridge (20) and mapped by Ewel and Whitmore (11), and four broad soil classifications reflecting geological origin (deep volcanic, shallow volcanic, granitic and limestone soils) were used to stratify the inventory data. The surveyed area included most of the current and abandoned coffee plantations, which are concentrated in the dissected uplands in the western part of the Central Mountains (6). Coffee shade stands, in turn, were stratified by life zone and age class of the forest.

An initial estimate of forest area, including coffee shade, was made from a dot-count on black and white aerial photographs for the whole island as well as the survey region. Some 10 925 photographic classifications of a grid of lines spaced three kilometers apart were selected on U.S. Geological Survey topo-

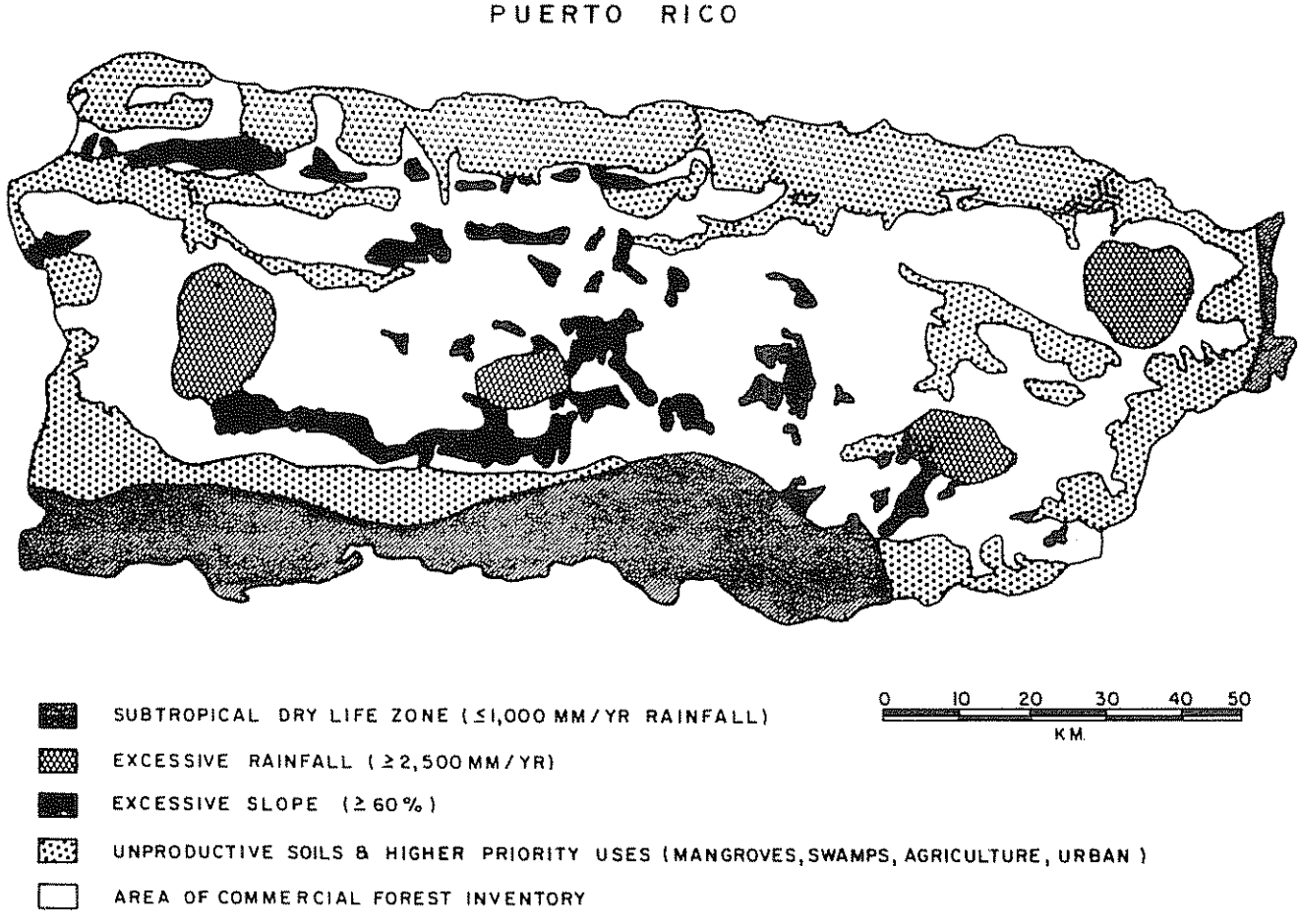

Fig 1 The unshaded area represents the region that has potential for commercial forest production in Puerto Rico. This is the area in which field investigations were conducted

graphic maps and transferred to the photos. The area estimates obtained from the dot-count were adjusted according to a ground check of land use at 437 sample locations.

The data on species composition and timber volume were obtained by establishing permanent sample plots at the 152 sample locations that were forested. A detailed site description was made for each location, and a cluster of three sub-plots was established along a north-south azimuth. Each sub-plot was permanently marked to allow future measurements of growth, mortality, and removals.

At each sub-plot, trees less than 12.5 cm in diameter at breast height were tallied on a 40 m^2 circle. Larger trees were sampled on a variable-radius plot using a prism with a basal area factor of 2.5 m^2/ha (17). All sample trees were measured and assessed to determine wood volume and quality.

Coffee shade stands were classified as active or abandoned. The abandoned coffee shade was divided into two stand age classes: 0 to 30 years and > 30 years, based on field observations and discussion with knowledgable farmers. Throughout the remaining text, recently abandoned coffee shade refers to stands from 0 to 30 years after abandonment, and old abandoned coffee shade to stands abandoned for more than 30 years. All trees found on the plots were identified as to species (23, 24). Fruit trees and other woody species not normally included in timber inventories were tallied as well.

Results and discussion

Of Puerto Rico's 890 000 ha of land area, 31% was considered as forest land, that is, land at least 10% stocked by forest trees of any size or formerly having had such tree cover and not currently developed for nonforest use. Of this forest land, 130 500 ha located within the subtropical moist and subtropical wet forest were classified as timberland with commercial production potential (Table 1). About 46% of this area was in active or abandoned coffee shade stands.

Stem density. There are fewer saplings, poletimber stems, and sawtimber stems in active coffee shade than in either of the two abandoned coffee shade categories (Table 2). This trend reflects the deliberate influence of farmers in maintenance of the stands.

The number of saplings and poletimber stems is greatest in recently abandoned coffee shade, while the number of sawtimber stems increases from active through old abandonded coffee shade. Recently

Table 1. Puerto Rico timberland[1] area classified by life zone and forest class.

Forest class	Life zone		
	Subtropical Moist Forest	Subtropical Wet Forest	Total
	Hectares		
Coffee shade:			
Active	2 400	19 000	21 400
Abandoned 0-30 years	4 600	12 300	16 900
Abandoned 30 + years	6 000	15 300	21 300
	13 000	46 600	59 600
Remaining lands[2]	47 400	23 500	70 900
TOTAL	60 400	70 100	130 500

1 Timberland = forest land that is producing or is capable of producing crops of wood and is not withdrawn from timber utilization. Coffee shade is included, but forest lands with higher priority uses are eliminated.

2 Remaining lands = timberland in secondary forest whose origin was abandoned pasture or previously cultivated lands. Also included are non-stocked areas, that is, land with commercial forest potential that contains less than 10% "normal" stocking with trees. This includes areas covered by brush, vines, and ferns.

Table 2. Number of growing stock[1] and cull[2] stems by tree size class in active and abandoned coffee shade.

Tree size class Quality class	Coffee shade		
	Active	Abandoned 0-30 years	Abandoned > 30 years
	Number of stems/ha		
Saplings			
growing stock	335.8	1 013.3	826.0
cull	879.7	792.8	470.2
Total	1 215.5	1 806.1	1 296.2
Poletimber			
growing stock	87.9	87.9	100.8
cull	71.5	114.7	60.3
Total	159.4	202.6	161.1
Sawtimber			
growing stock	15.2	20.9	30.1
cull	20.6	26.3	24.6
Total	35.8	47.2	54.7
All classes			
growing stock	438.9	1 122.1	956.9
cull	971.8	933.8	555.1
Total	1 410.7	2 055.9	1 512.0

1 Growing stock = trees of good form and vigor which contain, now or prospectively, a merchantable sawlog

2 Cull = all or portions of a tree unusable for industrial wood products because of rot, form, or other defect

abandoned stands that were previously managed for coffee have growing space for additional vegetation. A few years after abandonment, saplings and poletimber increase in numbers. Continued growth of poletimber and existing shade trees accounts for the gradual increase of sawtimber in old abandoned coffee shade.

The percentage of cull based on the number of stems is variable (Table 2). In active coffee shade, over 70% of the saplings are classified as cull or unsuitable for industrial wood products. The percentage of cull saplings progressively declines through recently abandoned coffee shade and reaches a low in the old abandoned shade. The same trend is apparent for sawtimber. The greatest percentage of cull in poletimber is found in recently abandoned coffee shade.

Poorly formed and damaged saplings are most common in active coffee shade because farmers have repeatedly pruned the coffee and shade trees, and cut the remaining arborescent vegetation to ground level. The open nature of active coffee shade stands provides ample light for sprouting and the development of low branches. Sawtimber trees develop poor form by branching low, and developing large crowns in response to little overstory density. Recently abandoned coffee shade includes many poletimber trees with multiple stems and poor form, remnants of when the coffee stand was under management. In contrast, new saplings develop with good form in abandoned coffee shade. Some 30 or more years after abandonment, better poletimber and sawtimber trees begin to appear.

Basal Area. Basal area in saplings and poletimber peak in recently abandoned coffee shade, while basal area in sawtimber is greatest in old abandoned coffee shade (Figure 2). Total basal area for all size classes continues to increase, with the least in active coffee shade stands and the greatest in oldest abandoned stands. Basal area trends in percentages of cull are similar to those for stem density.

Volume. Poletimber volume (all sound wood in the tree bole and branches, from the stump to a minimum top diameter outside bark of 10 cm) is

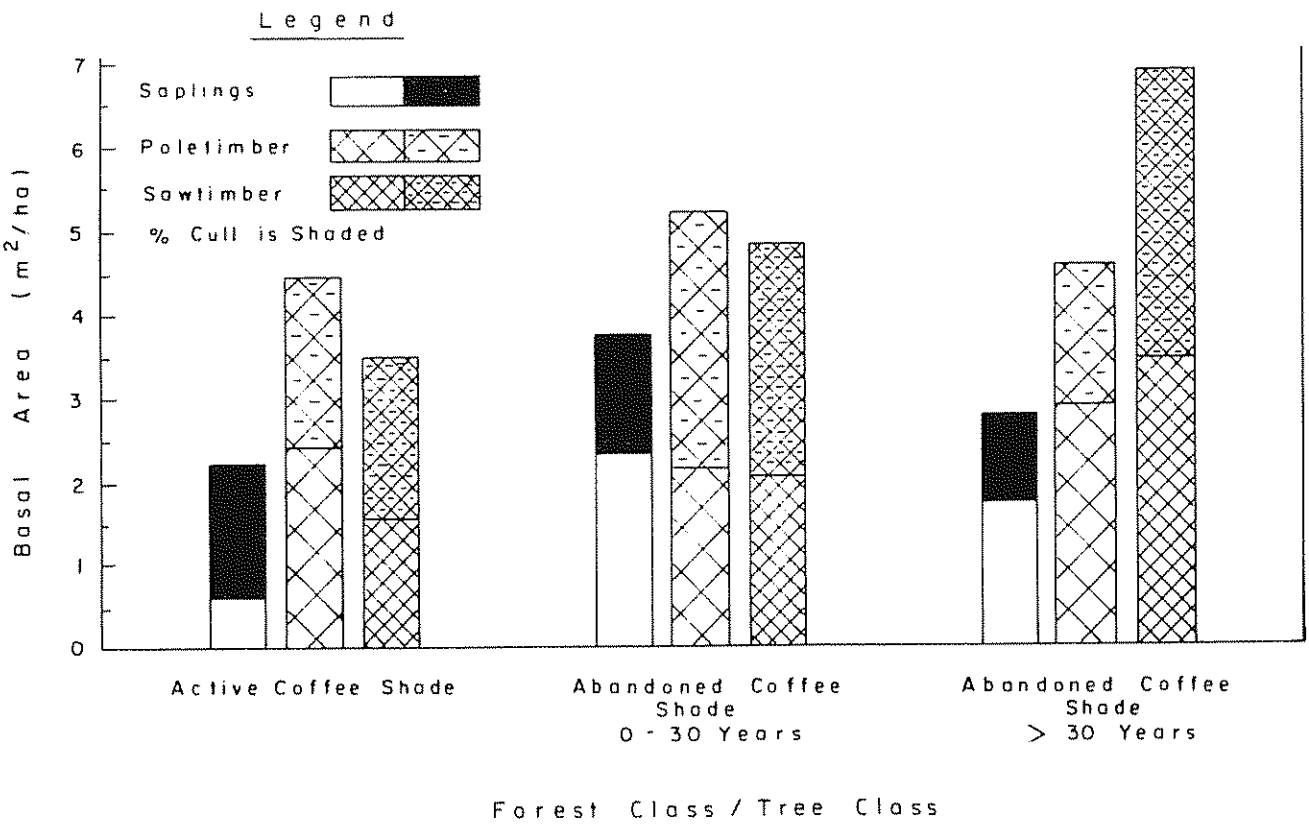

Fig 2. Average basal area by forest and tree class (basal area in cull trees shaded)

greatest in the recently abandoned coffee shade. Volume in sawtimber, for all size classes combined, increases from active coffee shade to the oldest abandoned stands (Figure 3). Percentage of cull volume in both poletimber and sawtimber peak in recently abandoned shade.

Species composition. The five most common tree species in the active coffee shade forests, according to basal area, are *Inga vera*, *I. fagifolia*, *Guarea guidonia*, *Andira inermis*, and *Cecropia peltata* (Figure 4). *C. peltata* and *I. fagifolia* increase in basal area with age, while *I. vera* decreases. The remaining timber tree species and other tree species show a gradual increase in basal area over time, while fruit trees show a slight decline.

A simple count of tree species on the fixed area plots yields 31 in active coffee shade, 47 in recently abandoned coffee shade, and 54 in old abandoned coffee shade (Table 3). Shannon-Wiener diversity indices for the same plots, however, show a slightly greater diversity in recently abandoned coffee shade. This difference is due to a more equitable distribution of species on these plots. If the species tallied on the variable plots are added to those of the fixed plots, the results are 44, 62, and 62 species, respectively, for active, recently abandoned, and old abandoned coffee shade stands.

When species compositions are presented by class of tree species and coffee forests (Table 3), a decline in coffee, shade trees, and fruit trees in observed, while there is an increase in timber species and other tree species. Changes of this nature are expected. Coffee and many of the fruit trees are small in size, and over time they mature and decline in importance within the abandoned stands. In turn, they are replaced by large and faster growing timber species and numerous understory species.

The fact that some 34 timber species are found scattered in coffee forests is impressive (Table 4). Their potential use ranges from posts and poles in poletimber size classes to sawtimber, novelty timbers, and quality furniture woods in larger size classes.

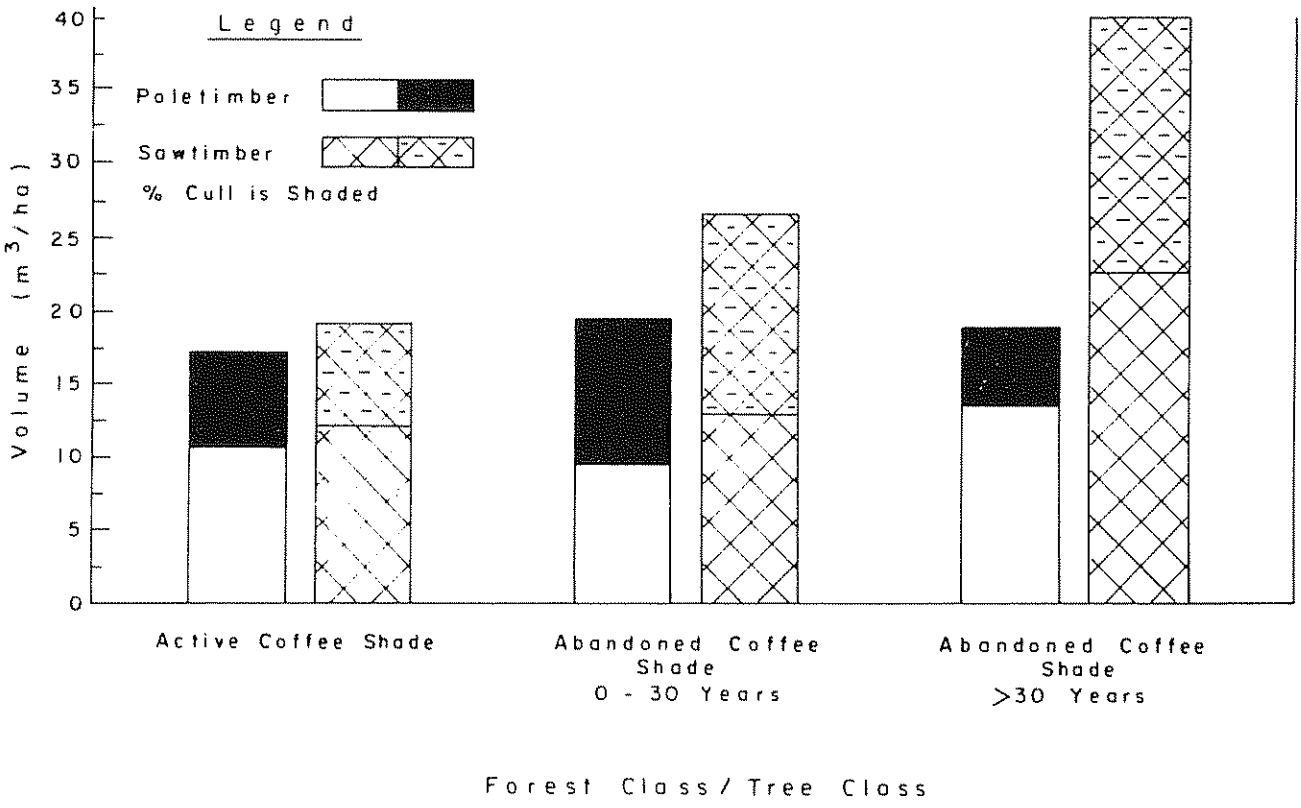

Fig. 3 Average volume by forest and tree class (volume in cull trees shaded)

Table 3. Changes in forest composition over time in three age classes of coffee shade forests.

Class of trees	Age Class		
	Active	Abandoned 0-30 years	Abandoned > 30 years
	Number		
Species: fixed + variable radius plots:			
Coffee and coffee shade species	9	9	7
Fruit tree species[1]	10	9	7
Timber tree species	13 (20)[2]	16 (22)	19 (25)
Other species	12	28	29
Total species	44	62	62
Number of species on fixed radius plots[3]	31	47	54
Shannon-Weiner Index (fixed radius plots only[4]	2.85	4.77	4.68

1 Includes those fruit trees that are also timber trees

2 Number in parentheses includes coffee shade and fruit trees when these are also timber species

3 Areas involved in fixed plots: 2 806 m², 2 440 m², and 2 806 m² respectively

4 Shannon-Wiener Index: $H = \sum_{i=1}^{S} (pi) (\log_2 pi)$

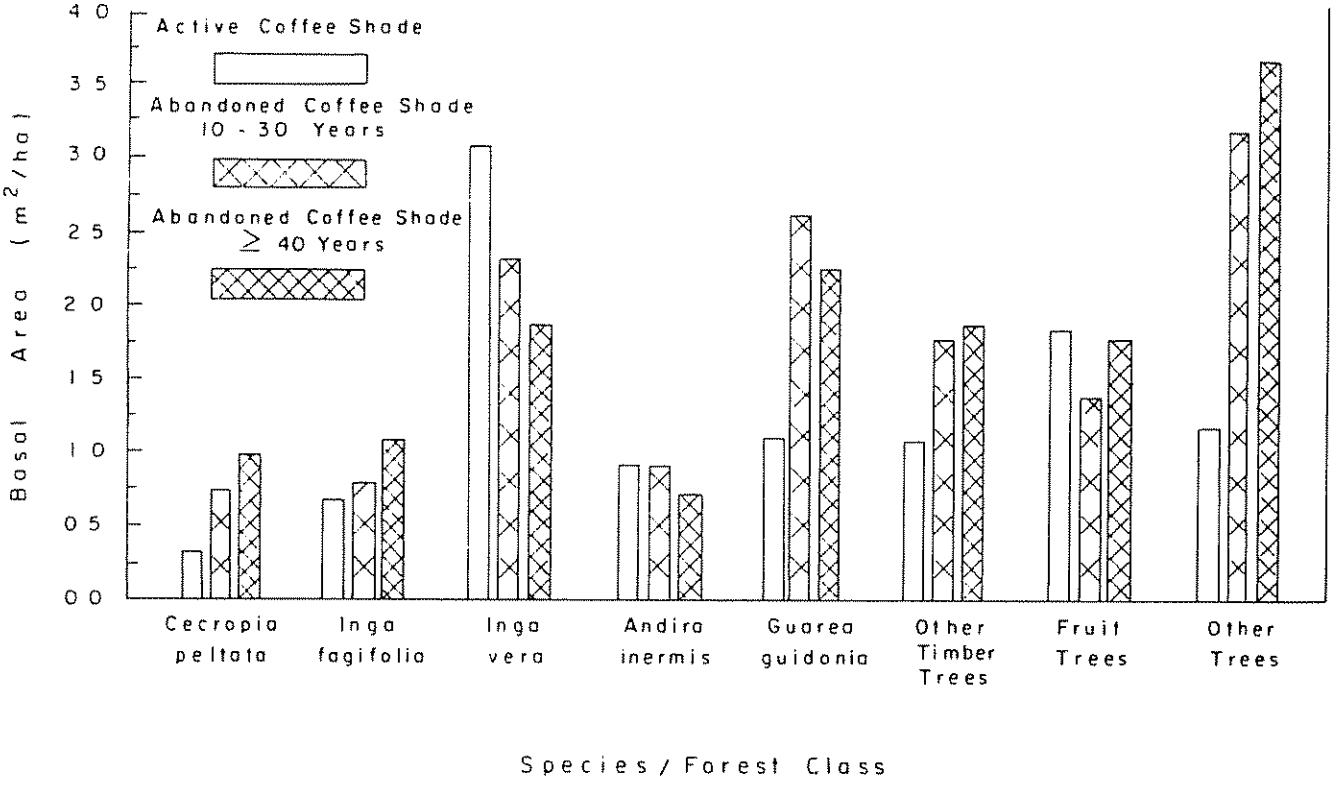

Fig. 4 Average basal area by species and forest class. In cases where trees are both fruit and timber species, they have been classified as fruit trees

Management opportunities in coffee shade

Coffee production on a world-wide basis in the years 1979-80 occupied 95 820 km^2 (13), or an area roughly equivalent to Hungary or the State of Indiana. Sixty-six percent of this area was in the Western Hemisphere, 23 percent in Africa, and 11 percent in Asia and Oceania. Although figures were not available, most of this land is probably cultivated under coffee shade, and in some instances, interspersed with known timber species (16, 8). It may be that the farmers recognize the timber species for their potential and allow them to persist in the coffee stands.

Several opportunities exist for the management of active and abandoned coffee shade forests (Fig. 5). The techniques selected depend upon the existing forests and the objectives, resources, and opportunities available to the landowners. Given current economic conditions in Puerto Rico, it is unlikely that coffee production will ever approach past levels. In other countries within the neotropics, coffee production will probably not be abandoned in the near future. In the following discussion, the alternatives related to timber production are more applicable to Puerto Rico, and those regarding agroforestry apply more to other countries within the region.

Timber management alternatives. In existing coffee shade forest, one alternative is the complete removal of all vegetative cover and the establishment of a timber plantation. Such a conversion might occur when harvestable timber was growing on the site or when the site contained an intermediate basal area, many cull trees, and few trees with commercial potential (4). In Puerto Rico, candidates for plantations would be *Pinus caribaea, P. oocarpa, Eucalyptus deglupta, Swietenia macrophylla* x *mahagoni, Hibiscus elatus, Calophyllum calaba, Tectona grandis,* and possibly *Anthocephalus chinensis*. Pulpwood, sawtimber, and cabinet woods are possible end products.

A more likely alternative would involve modification of abandoned coffee shade forests to enhance species composition and growth of desirable crop trees. The first step would be a stand inventory. If the overstory had acceptable species composition and form, thinning undesirable trees that were competing with potential crop trees would be appropriate. In

Table 4. List of timber species found in three age classes of coffee forest and their potential uses.

Tree Species	Age Class			Timber use		Maximum Dimensions[1]	
		Abandoned		Furniture and saw wood	Novelty	Height (m)	Diameter (cm)
	Active	0-30 yrs	> 30 yrs				
Alchornea latifolia	X	X	X	X		15	46
Andira inermis	X	X	X	X		15	30
Anthocephalus chinensis	X			X		30	76
Buchenavia capitata			X	X		24	122
Byrsonima coriacea	X	X	X		X	18	46
Calophyllum calaba		X	X	X		20	46
Cassia fistula		X	X		X	15	46
Cedrela odorata	X	X	X	X		30	91
Citharexylon fruticosum		X	X		X	12	30
Cordia alliodora	X	X	X		X	20	46
Cordia sulcata	X	X	X		X	20	46
Cupania americana		X	X		X	15	25
Didymopanax morototoni	X	X	X		X	18	46
Ficus laevigata	X	X	X		X	18	76
Guarea guigonia	X	X	X	X		23	91
Hibiscus elatus	X				X	24	38
Inga fagifolia	X	X	X		X	21	46
Inga vera	X	X	X		X	18	46
Magnolia portoricensis		X		X		21	91
Mangifera indica	X	X	X		X	20	91
Meliosma herbertii		X			X	18	61
Micropholis chrysophylloides			X		X	18	61
Montezuma speciosissima		X	X		X	15	46
Nectandra membranaceae	X				X	24	41
Nectandra sintenisii		X	X		X	18	36
Ocotea leucoxylon	X	X	X		X	15	25
Petitia domingensis			X		X	21	30
Phoebe elongata	X	X	X		X	30	41
Pouteria multiflora			X		X	24	46
Spondias mombin	X		X		X	18	91
Tabebuia heterophylla	X		X		X	18	46
Trichilia pallida		X	X		X	9	15
Vitex divaricata	X	X	X	X		20	76
Zanthoxylum martinicense		X	X		X	20	46

1 Source: Little, Woodbury and Wadsworth 1964

cases where the overstory was unacceptable but the understory contained sufficient timber species stocking, silvicultural operations aimed at release of desirable saplings would be followed by thinning at a later date.

If the landowner elects to resume coffee production under shade, the existing overstory could be thinned to accommodate both coffee and shade tolerant foodstuffs. Thinning should favor the better timber trees, based on their compatibility with coffee production as well as stem form, spacing, and amount of cull. If coffee production is abandoned again in the future, desirable timber species would already be established to reseed the area. This strategy simultaneously meets short term demands to feed increasing populations while improving the forest in the long run (29).

In cases where the overstory and understory are inadequate, three alternatives remain (Fig. 5). The first is to wait until the understory attains a satisfactory species composition and density for silvicultural operations such as cleaning or release. Usually the tangle of climbers and other herbaceous growth is overgrown by saplings in about five years (10). The second alternative is complete removal of the vegetation followed by the establishment of

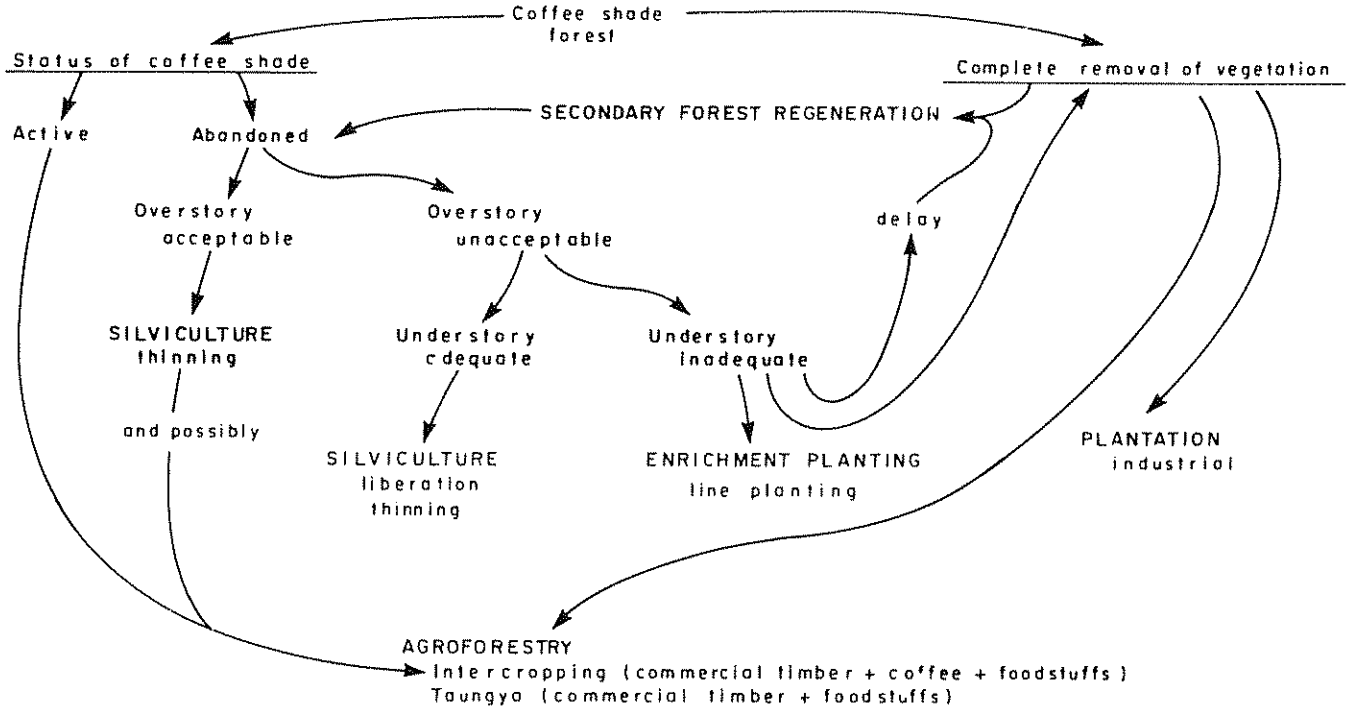

Fig. 5 Flow chart of forest management alternatives for coffee forests and secondary vegetation. Selection of most appropriate alternative is based on local resources and needs (Adapted from Wadsworth, 1966)

plantations. The last alternative is enrichment of the forest through line planting. In Puerto Rico, the most widely used species for line planting is the *Swietenia macrophylla* x *mahagoni* hybrid. Dawkins' five necessary conditions and seven technical guides serve as a basis for the successful establishment and management of line plantings (22).

Agroforestry alternatives. With the exception of Brazil, the traditional system prevails in which coffee is interspersed with several fruit trees, plaintains or bananas, and select species of shade trees. *Inga*, *Gliricidia*, and *Erythrina* are genera used as shade trees in many areas (5, 7, 18, 26). For years the advantages and disadvantages of this practice have been debated (9, 28). An overstory reduces light, leaf temperatures, transpiration rates, and the diurnal range of temperatures in the understory (34). Moreover, the litterfall from deep rooted trees contributes organic matter to the soil, reduces the loss of nitrogen because decomposition of humus is slower, and lessens the amount of soil erosion, especially on steep slopes. In wet areas of Colombia, shaded and unfertilized coffee had more leaves, more total leaf area, more primary branches, greater root weight, and higher total production than comparable open grown stands (28). In contrast, the yields of several coffee varieties in Puerto Rico were greater when grown in full sunlight than in shade (2). These plants, however, were grown in limed, fertilized, and weeded soils that had been sprayed to control leaf miner infestation. A subsequent study showed that although the yields of export grade beans were higher under full sunlight than in shade, the proportion of export grade beans was greater in shaded stands (3).

Shade delays the ripening of coffee berries (8). This delay has been viewed as beneficial by some in that it prolongs the harvest period, allowing the use of domestic labor. The period of income is also prolonged. Others feel that the net effect is to postpone harvest operations.

The subsistence farmer receives many benefits from the use of shade. These may include sustained yields in balance with available nutrients or control over weeds and certain pests (34). Other benefits might include firewood, posts, stakes, charcoal, and possibly forage along with intercropped foodstuffs and fruits. Moreover, experience may have shown the farmer that an integrated system is the best defense against the vagaries of climate or failure of any particular component in the system. As is evident, the effect of shade is complex and dependent

upon climate, cultural practices, and tradition. To evaluate agroforestry techniques properly, a comprehensive index based on all these variables would have to be devised (3).

Three possible starting points for the development of an integrated coffee shade forest are outlined in Figure 5. The first is an enrichment of active coffee forest where it already exists. Often trees with commercial forest potential are allowed to persist in traditional coffee stands (8), and species such as *Cordia lliodora*, *Cedrela odorata*, and *Alnus jorullensis* in Costa Rica have shown favorable growth rates when intercropped with coffee (12, 14). These timber trees may be harvested and sold locally to provide additional income to the farmer. Another way to enrich the coffee forest is through deliberate planting of valuable timber species when old shade trees need replacement.

A second alternative is the modification of abandoned coffee forest with an acceptable overstory. In this case, thinnings could be implemented favoring valuable timber species, and coffee could be interspersed where required. In Puerto Rico, several species with timber potential could be favored, including *Inga fagifolia*, *Guarea guidonia*, *Dendropanax arboreum*, *Cordia alliodora*, *Andira inermis*, *Tabebuia heterophylla*, and species of *Ocotea*, all of which have been employed as coffee shade (26).

The last alternative would the complete removal of vegetation. This could be done to harvest or salvage timber. A taungya system might then be the preferred approach to reestablish coffee shade (Figure 5). Foodstuffs could be intercropped with coffee, bananas or plantains, and selected shade trees. Intercroppings such as these yield net income during the period that preceeds coffee production (25) and have resulted in greater yields of bananas than in unshaded conditions because of reduced leaf spot damage (29).

Conclusions

Forest managers in Puerto Rico have several alternatives they can use to improve the species composition and growth rates of abandoned coffee shade forests. As these stands mature, there is an influx of well-formed young trees of numerous species, many suitable for timber products. In the absence of management, the remnant shade tree overstory persists for many years, suppressing the growth of these vigorous and more desirable trees. Thinning of the overstory, liberation of the understory, or line planting, where appropriate, are the silvicultural techniques that should be employed. Establishment of industrial plantations after timber harvest is also an alternative.

In other countries within the neotropics, where coffee production is likely to persist for many years, opportunities exist for the improvement of agroforestry. Active coffee plantations may be enriched with valuable timber species, abandoned coffee plantations may be modified through silviculture favoring timber species as shade, and taungya may be used to establish new coffee plantations profitably.

Summary

A forest inventory of Puerto Rico's timberland showed nearly 60 000 ha of active and abandoned coffee shade stands. Stem density, basal area and volume of saplings and poletimber were greatest in recently abandoned stands. Total basal area and timber volume were lowest in active stands and greatest in the oldest abandoned stands. The proportion of cull to growing stock based on number of stems and basal area was greatest in active stands and least in old abandoned stands, while the proportion of cull volume peaked in recently abandoned shade. The number of timber species shows a gradual increase while the number of fruit and coffee shade species declines over time. Thirty-four potentially valuable timber species were found in coffee shade stands.

Timber management opportunities in abandoned coffee stands include release of the understory, thinning the overstory, line planting, or conversion to plantations. Agroforestry alternatives include enriching active coffee shade stands with timber species; thinning to favor timber species in abandoned coffee shade where coffee production is to be resumed; or using a taungya system, with foodstuffs and timber species, in newly established coffee forests.

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