Rev. Biol. Trop., 24 (Supl.1): 143-175, 1976

Forests in Central America and Panama: which kind, how large and where?

by

James S. Bethel *

Abstract: Exploitation of natural forests works well as long as they are reasonably accessible, adequate in size and produce materials desired by the society served. However, as natural stands are exploited and lands are diverted to nonforest uses, it is likely that without an input of technical silviculture, the natural development of secondary and residual forests will be inadequate. This is particularly true of the diverse tropical hardwood forests where often relatively few species and even fewer stems per hectare produce desirable material.

A serious technical problem presents itself in trying to match the complex forest production system with the utilization system. In early stages of exploitation of a natural tropical forest this match is likely to be poor as the forest conversion system is often simple with only one or two products and a small spectrum of industry, which usually is highly selective as to species, size and quality. Consequently a very small fraction of the trees and volume in a tropical hardwood stand has marketable utility. As long as there is surplus forest land, this situation can be tolerated. However, this utilization system of low concentration of marketable material per unit of area results in high operating costs in attempting to assemble meaningful quantities of material. This occurs even if the cost of the raw material itself is low. Furthermore, this system can result in depletion of useful material per unit area with time, as the unavoidable high grading that occurs commonly results in the replacement of usable forest stocking by unusable species, qualities, and sizes. As a result the match between the forest production and utilization systems may worsen.

Unfortunately the classical extensive forest inventories often conducted have not always proved a useful tool in assessing the utility of natural tropical forest stands. The usual approach allocates most of the resources to counting and measuring standing trees without regard to utility. In later analysis stages the data may be adjusted to reflect merchantability but merchantability in this sense is often based on arbitrary classifications of trees into use and size categories that often bear little relationship to the conversion system in use. Furthermore, conversion system standards change and the above merchantability impositions in inventories have generally failed to look at merchantable volumes in terms of flexible alternatives. As a result, the data from such inventories can be dangerously misleading in guiding planning discussions,

This paper presents some preliminary results from a study aimed at

* College of Forest Resources, University of Washington, Seattle, Washington 98195, U.S.A.

providing a look at the match between the forest production and conversion systems when different sets of utilization standards are imposed on the forest. The results focus on three Costa Rican forest situations: the mixed natural forest at La Selva, dominated by Gavilán *(Pentaclethra macroloba)*; the mixed natural forest along the Atlantic coast dominated by Cativo *(Prioria copaifera)* and Cedro Macho *(Carapa guianensis)*; and pure even-aged plantations. The mixed forests contain many trees of unusable species or qualities, such that over-all usable productivity is quite poor. This situation may be improved by either simplifying the forest structure by silviculture to favor the more usable species and/or increasing the complexity of the conversion system to enable a greater use efficiency of currently desired species and to include currently unused species.

This paper will address the question of forestry in Central America, primarily in terms of production of wood products. Forests obviously yield other important goods and services that include water, wildlife, recreation, aesthetic values, and forage for livestock. However, the primary driving force for the dedication of large areas of land to the growth of forest trees is the demand for wood which is the subject of this presentation.

Forest utilization has evolved in a standard pattern throughout the world and Central America has not been an exception. Natural forests occupying land not yet required for other uses, such as agriculture or urban development, have typically functioned as a reservoir of wood to serve society's needs. When the demands made on these natural forests for fuel, fiber and shelter have been heavy, those located near the centers of population have been depleted of their usable components and more remote forests have had to be exploited. Sometimes the exploited natural forests have been later converted to nonforest uses. Sometimes they have been allowed to remain as natural forests evolving through secondary stages back to the natural climax form. They may be re-used to supply wood when they have recovered to this natural climax or they may be used again when they are in some secondary stage of recovery. As long as natural forests are adequate in size, reasonably accessible and productive of the wood materials needed by the society they serve, this system works reasonably well. Under these circumstances there is little incentive to engage in the cultural practices required to produce managed forests. Indeed it is axiomatic that silviculture directed primarily toward the systematic production of wood rarely has appeared as a serious technical effort in any region of the world until the original natural timber stands were harvested and their most useful components removed, and until it has become apparent that natural development of secondary forests is inadequate to meet the relevant society's needs for wood.

Natural forests and their secondary offspring vary in their capacity to meet social needs for wood. Some natural forests are comprised largely of trees of species, sizes and qualities that are readily used. These are frequently softwood forests that are simple in their organization and structure. Such forests produce long-fibered woods of relatively uniform quality. The usable component of this kind of forest is often rather large. Natural hardwood stands, on the other hand, tend to be much more diverse in their organization and structure and to yield much smaller fractions of usable products. Even among these hardwood forests the diversity can vary from region to region and the utility varies with the diversity. For example the tropical hardwood forests of much of Southeast Asia are dominated by dipterocarps that are in great demand and the fraction of the natural forest stand that can be used is greater than is the case for many of the much more diverse tropical hardwood forests of Central and South America.

In the early exploitation of a natural forest, the match between the forest production system and the conversion system is likely to be poor. The forest conversion system is commonly simple, involving one or two products and a small spectrum of industries. Such conversion systems may be highly selective with respect to species, size and quality of trees to be used. If the natural forest being exploited is a tropical hardwood forest, it is likely to be very complex, involving a great many species, sizes, and qualities of trees. Under these circumstances only a small number of these trees and a small fraction of their biomass will have any marketable utility. This is illustrated in the profile diagram in Figure 1 which shows only three merchantable trees in the stand and only a portion of these that yield useful products. The utilization efficiency, that is, the ratio of usable biomass to total biomass of such a forest production-conversion system will be very low. This low utilization efficiency can be tolerated as long as there is surplus land that can be left in natural forest and as long as the natural evolution through secondary forests continues to produce a reasonable fraction of usable material.

One difficulty with such a system of product raw material supply is that while its raw material cost is low, its operation costs are high. Low concentrations of usable material per unit of land area increase materials handling costs and the cost of delivery to conversion sites. It is inherent in such a system that relatively little income from the sale of products accrues to the land, most of it being required to meet the great expenses of extraction, transportation, conversion and marketing.

A second difficulty with such a system is that it can result in depletion of usable material per unit of area with the passage of time. A pattern of unregulated use of natural forests which results in the replacement of usable material by unusable material, causes a reduction in the utilization efficiency of the forest production-conversion system. This has occurred, for example, in Northeast Thailand where the natural forests have been high-graded for the dominant dipterocarps for a long time, resulting in a change of species mix. *Lagerstroemia,* a species that is not in great demand, now represents almost 30 percent of the growing stock while it represents only about three percent of the volume of wood being converted. Clearly this mis-match between forest production and forest conversion will result in an even lower future utilization efficiency unless the forests are managed to change the species mix or unless the conversion system is changed to increase the utility of *Lagerstroemia.* The poor match between natural forest production systems and conversion systems in the humid tropics has been recognized by many authorities. Catinot (2) referred to this mis-match in an address to the World Forestry Congress in 1972 when he said with respect to tropical forest ecosystems, "...as knowledge of these ecosystems advances, a certain disappointment is felt, so complicated is their study and so modest their wood production; 400 cubic meters per hectare of biological production and 5 to 50 cubic meters per hectare of economic production". The difference between the 5 to 50 cubic meters per hectare of economic production and the 400 cubic meters per hectare of biological production referred to by Catinot is made up of weeds and non-utilizable residues. Weeds are those species that are occupying forest space but which have no current economic value or whose inventory far exceeds current needs. The non-utilizable residues are comprised of those trees or portions of trees of species of potential economic value which because of quality characteristics have no current economic value.

The classical extensive forest inventory based largely upon temperate zone practice has not always proved to be a useful tool in evaluating the utility of a natural hardwood forest in the humid tropics. This sort of inventory exercise commonly allocates most of its resources to the task of counting and measuring standing trees without regard to their utility. At the analysis stage these data are then frequently adjusted to reflect merchantability. The merchantability adjustments tend to be based upon arbitrary classifications of trees into use categories and size limitations that often bear little relationship to the conversion and marketing systems of the forest. As a result, substantial resources are committed to the counting and measuring of weeds and residues often under an inventory scheme that never really distinguishes between the truly useful portion of the biomass and the weed and residue component. The simple classification of trees into merchantable and non-merchantable components is a case in point. A tree species that has a real but very limited conversion market may represent a very large part of the total tree stem biomass. If there is no adjustment of the inventory to reflect the limited market, the published inventory will be greatly inflated. This is the *Lagerstroemia* syndrome of the inventories of Indo-China. It applies to many species other than *Lagerstroemia* in Indo-China and to a large part of the extensive inventories made of hardwood forests of other tropical regions of the world. It is one of the reasons that expensive large-scale forest inventories made in tropical regions have had such limited utility in forest utilization planning. Too frequently they simply occupy space in filing cabinets of national forestry departments. Even more tragic perhaps are some of the cases where attempts have been made to use these inventories in industrial planning. The bleached bones of unsuccessful forest product conversion enterprises based upon the fictions of such inventories dot the landscapes of many developing tropical countries. This situation is not likely to change until assessments of natural hardwood forests of the humid tropics reflect the utilization efficiency represented by the real match between forest production systems and their counterpart, forest conversion and marketing systems.

In this context it may be useful to examine a Central American natural forest in terms of the conversion system that is available to it. The forest studied was the La Selva experimental forest near Puerto Viejo, at the junction of the Sarapiqui and Puerto Viejo Rivers.

The forest is an all-aged hardwood stand of mixed species that has been essentially undisturbed for a long time in terms of removal of significant volumes of wood. While the forest includes approximately 300 species of tree-sized plants, it is in fact dominated by a single species, Gavilán *(Pentaclethra macroloba)*. It is interesting to note that while a stand table, tabulating trees 10 cm dbh and larger shows Gavilán as representing only 19% of the stems, it is the dominant tree in terms of volume as will be shown later.

The structure of this stand was examined through the use of a series of tree, stand and conversion computerized simulation models that permitted an assessment of potential utilization efficiency under a variety of assumptions. The tree simulation model was based upon an equation of the form;

$$Y = k\sqrt{X^{a}}$$

where Y is the diameter of the tree at point X along the stem and k and a are constants. It may be noted that the equation gives a neiloid section when a = 3, a conical section when a = 2 and a parabaloid section when a = 1. Thus by suitable choice of this coefficient the model will represent an appropriate stem form including the buttressed base typical of many of the hardwood species represented in this tropical forest. In this study a is expressed as a linear function of height with the provision that it pass through point $a = 2$ at the top ot the buttress swell or flare, and point $a = 1$ at the tip of tree. Information required by the model is dbh, total height and height to the top of the butt swell. When used in this fashion the constant k is the estimated diameter of the tree at the ground line. The output of the model is a tabulation of the diameter of the tree at specified stem heights. Figure 2 illustrates an actual stem analysis of a Gavilán stem and the form predicted by the model for this tree. The model has also been validated against stem analyses for other Central American hardwood tree specimens and some specimens from Thailand.

The stand model is based upon the Meyer adaptation of the de Leocourt equation for distribution of diameters in all-aged forest stands:

$$n = c k e^{-aX}$$

where n is the number of trees in the diameter class, c is the class interval, X is the mid-point of the class and k and a are constants appropriate to the stand.

The conversion model is a simulation of the sawmill operation based upon a live sawing assumption.

These models were validated for application to the Costa Rican condition through comparison with data from the La Selva forests and from sawmills in the vicinity.

Applying this tree model to the stand table appropriate to this forest indicates that the total volume of the stems of trees 10 cm dbh and larger was 345 m^3 hectare of which Gavilán comprised 147 m^3 per hectare or 42% (Fig. 3).

If this forest were to be viewed as the resource production component of a combined forest production-conversion system, its utilization efficiency would be a function of the match between this tree stem biomass and the component of it that is acceptable in the conversion market. Accordingly, the conversion market available to the forest was examined. This conversion system consisted essentially of logs saleable to sawmills for conversion into lumber. There was also the potential sale of logs to plywood plants but this was essentially a high grading option in the saw log market, since logs saleable for plywood are also acceptable for manufacture into lumber. A study was made in the summer of 1974 of the logs in sawmill yards, log loading points and log decks along the route to San José between Puerto Viejo and San Miguel. The data collected from this study provided a measure of the conversion potential of the forest at La Selva at that time.

Examination of a tree diameter frequency distribution for the trees of La Selva whose diameter breast high is 10 cm or larger indicates that 19 percent of the stems in this size range are one species; Gavilán *(Pentaclethra macroloba)*. The remaining 81 percent of the stems are distributed among 96 different species. The actual useful component of this stand would have to be determined by comparing it with the conversion and marketing systems related to it.

A study of the mill yards, log dumps and landings provided estimates of utilization standards for the sawmills serving the area of La Selva as of the summer of 1974. Figure 4 indicates the distribution of log sizes for these log supply sources. The simulation models for tree structure, stand structure and product conversion generated a series of projected distributions of log sizes of Gavilán from La Selva, depending upon the assumption of minimum harvesting diameter (Fig. 5). These distributions were based upon a log length of 3.4 m. This standard log length derived from observations that a preponderance of Gavilán logs delivered to utilization points were four *varas* in length with some allowance for trim and in some cases an additional allowance for skidding point (Fig. 4).

These model-generated distributions indicate that a minimum diameter of 45 cm for Gavilán yields a theoretical distribution of log sizes that matches the observed distribution reasonably well. Using this utilization standard, recovery of Gavilán per hectare in logs from the La Selva forest could be expected to be 55 m^3, distributed among 50 logs and yielding a utilization efficiency of 16 percent.

The yield in rough green marketable lumber commodity will vary depending upon log size and the efficiency of the mill that converts the log to lumber. In the case of Gavilán, the average yield observed in mills was 67 percent. Applying this figure to the harvestable stand volume of 55 m^3 per hectare indicates a product volume of 37 m^3 per hectare. This estimated exploitable volume for Gavilán is high, since it makes no allowance for defect due to decay and insect damage or to reduction in merchantable stem length due to branching below the minimum acceptable log diameter–matters which need to be addressed in later studies and that are crucial to a complete utilization efficiency analysis.

There are, of course, other merchantable species of utilizable size in the forest and these would add to the volume that could be harvested. Some of these species yield very valuable woods but this study was examining the La Selva forest as a producer of its most prevalent commercial commodity–Gavilán.

Figure 6 shows the percentage of stems larger than 45 cm diameter by species. Gavilán represents 62 percent of these merchantable size stems. An examination of similar data from an inventory of La Selva made in 1956 by **Petriceks** (8) indicates the distribution illustrated in Figure 7 for the 21 species that he considered merchantable at that time. In each case Gavilán is the species in the first position, having the greatest percentage of occurrence. Clearly this species dominates the stand in terms of numbers of trees of merchantable size. The emphasis on Gavilán production is dictated by the fact that an efficient conversion and marketing system for the products of a tropical hardwood forest is usually dependent upon the development of the utilization potential of its most prevalent product. Gavilán is a species that has a large range in Central America and northern South America that might permit it to be supplied in quantities on the world market, though it is not well known on the export market. It is a species that is readily accepted in the domestic market. Whether it has properties that are sufficiently good to command respect and an adequate price in the world market is something that would have to be tested. The volume per hectare of Gavilán is perhaps not unreasonable for the conduct of an exploitation program based upon natural forests, though it is sufficiently low as to require a considerable land area to supply even a modest conversion facility.

Whether a forestry development based upon Gavilán is viable in the long run is another matter. This depends upon its productivity under various levels of management. Assuming that it requires 80 years for a stand of the general organization and structure of that at La Selva to develop from a clear-cut base, the productivity in terms of currently usable Gavilán product in log form would be 0.69 m^3 per hectare per year. Under the study assumptions, productivity in lumber form would be 0.46 m^3 /ha/yr. The 80 year development assumption may be conservative as **Hartshorn** (4), working with growth data from a limited number of Gavilán trees in the La Selva forest estimated it would take approximately 150 years for an individual to reach 37 cm in diameter, which is smaller than the apparent minimum utilization diameter observed in the log yards. If the period of stand development is longer than 80 years then productivity would be less.

An analysis of the match between the forest system and the conversion system for the associated usable species has not been completed. If these could be added to the forest output, utilization efficiency could be improved somewhat. Examination of the data suggest that improvement in volume would not be great. However, since some of these species command premium prices, the improvement in value might be significant. The marketing problems associated with this more complex species mix would be substantial. This would appear to provide a weak base for substantially improving utilization efficiency. A study of log storage yards of the area confirms that this is a problem. Logs representing species that are present in the forest in small quantities, even when quite valuable, frequently deteriorate in storage to the point where yield and quality of output is very low. This study involves no presumption that a major wood manufacturing development ought to be based upon Gavilán. Such a judgment would have to be based upon more information than was available to us. It is safe to assume, however, that no other species is present in sufficient volume to provide a feasible basis for substantial development of a wood utilization system based upon the natural forest in this area at this time.

Other areas of natural forest in Costa Rica show greater potential for utilization efficiency than the Gavilán forests represented by the La Selva case study. Preliminary examination of data collected in the Cativo forests along the Atlantic Coast and complementary data (3) supplied by the Costa Rican Forestry directorate indicate that these forests are much simpler in structure and dominated by two merchantable species, Cativo and Cedro Macho.

Figure 8 shows the percentage of stems by species in order of decreasing occurrence for a forest at Barra del Pacuare, Limón, Costa Rica. The species in the first and second positions in this distribution are Cativo *(Prioria copaifera)* and Cedro Macho *(Carapa guianensis)* respectively. Such stands provide a much higher utilization efficiency than do the Gavilán forests. This is true even though the conversion system which serves this forest area is limited by a water transportation network which effectively constrains the fraction of the biomass that can be economically delivered to the manufacturing site. Raw material transportation facilities are an important factor in determining the effectiveness of the conversion resources that can be matched with a forest resource.

Productivity in these mixed natural forest stands can be improved if it is feasible to reduce the fraction of weeds and residues in the stand so that more of the space can be occupied by readily marketable trees; such a modification is silviculture and represents a departure from the natural system. This is a level of forest management not now generally practiced in most of Central America and one that would be feasible only if the price of tropical hardwoods continues to rise. In a report recently published by the World Bank it is predicted that just such an increase in price would occur. **Takeuchi** (9) reports:

> There will be a growing shortage of tropical hardwood after 1975, unless new sources of supply–forests in Papua/New Guinea, Latin America and Africa–are tapped extensively. The estimated volume of exports (total sustainable yield minus projected domestic consumption) available from traditional sources will be inadequate to meet demands from importing areas. Since the unit cost of production in new areas is likely to be substantially higher, prices are bound to rise considerably after 1975.

The level of management required to achieve an improvement in stand composition would be justified only if there is a compelling need to increase production of wood to satisfy domestic requirements and/or a desire to share in the opportunities represented by the growing world market for wood. It would be particularly essential if either or both of these objectives were seen to be valid and if at the same time there was a continued erosion of the forest land base. Some clues to this situation with respect to Costa Rica are contained in the May 1973 issue of *World Wood* (7). In the World Wood review, the Director General of Forestry of Costa Rica, Mr. Arnoldo Madriz Vargas, noted that of the 2,206,200 hectares of wooded land in Costa Rica in 1967, 486,400 hectares or approximately 22 percent is thought to be suitable for agricultural use. Protection zones and preserves according to Mr. Madriz are projected to occupy another 687,600 hectares. There is another loss of land to industry set at an annual rate of 32,822 hectares. The area projected to be principally used for timber exploitation is, presumably, on a continuing basis 844,000 hectares. Since these projections were based upon a 1967 study, it may be reasonable to assume that a substantial part of this commercial land base erosion has already taken place. If there is a need to improve per hectare productivity of forest land to increase wood supply and/or accommodate to a smaller forestry land base, then the solution is clear. Either the conversion system must be modified to permit it to utilize a larger fraction of the forest biomass, thus converting weeds and residues to useful products, or the forest system must be simplified to minimize the production of weeds and residues. Some combination of the two alternatives is of course possible.

Modification of the conversion system to increase per tree yield usually involves the introduction of processes that are relatively indiscriminate with respect to species and quality. Normally these are such installations as pulp mills, fiber board plants or particle board plants which are capital intensive installations that are relatively low in labor utilization. Furthermore, for many of these processes, products from long fibered coniferous woods have structural advantages. There are some other options of course. Charcoal, a conversion industry that formerly was important, may be recovering in the climate of the unavailability of fossil fuels and it has the indiscriminate quality required. World markets for chips have been strong until relatively recently and this conversion requires less capital investment than going on to the pulp stage.

These are options to improve the conversion side of the equation. If the forest production side is to be improved, then forest stands need to be modified through manipulation. This latter activity implies a silvicultural operation—the deliberate structuring of stands of timber to more nearly match the conversion system. Since growing wood on a managed basis is a long-term process, it is reasonable to ask what assurance there is that current growing demands for wood world-wide are likely to continue. The signals are positive. Increasing shortages of non-renewable resources are clearly going to create demands for their substitution by renewable resources for industrial materials. All the petrochemicals now used in the world could be replaced by silvi-chemicals in a favorable economic climate.

Substitution of wood for steel in structural use permits a reduction in technical energy input of 87 percent and a comparable substitution of wood for aluminum in structural use permits a technical energy reduction of 97 percent. These are not trivial trade-offs in an energy-short world. While there is a great and growing demand for wood there is an even greater demand for food. Forest products and food supplies are both based upon land. Food has the greater priority and when food and fiber compete for the same land, food usually takes precedence.

It is, however, being increasingly recognized that many hectares of land are much more productive for wood than they are for food and that it may well be an act of economic prudence to grow timber in some food shortage areas and to trade it for food. It is also a fact that the production of food and fiber can sometimes be combined on the same hectares.

The production of forests under intensive management has not been an important activity in Central America. Accordingly, there are relatively few clues to the potential of the land for silviculture. If one looks at the productivity of natural forests as was done in the case of the forest at La Selva, the prospects for high productivity in the absence of silviculture are not too promising. The record of forest production in many areas of the world where there is a history of intensive forest management through the application of silviculture suggests that gradual conversion of natural forests to cultured forests is not as simple as it is often alleged to be.

A second case study was undertaken to look at the potential for production of a species typical of the secondary forest. Professors Holdridge and Tosi have been calling attention to Laurel *(Cordia alliodora)* as a species of great potential in Costa Rica for a long time; as have the professional foresters on the faculty at Turrialba. Tschinkel (10) pointed out in 1966 that, "one of the most striking characteristics of *Cordia alliodora* is its ability to grow as an isolated tree and yet form a straight, self pruned trunk. Costa Rican farmers, among others, have long realized the value of this and leave regeneration of *Cordia alliodora* standing when cleaning their fields and pastures. *Cordia alliodora* is an important, fast growing secondary species throughout a large part of Tropical America". Any careful observer of the rural Costa Rican landscape will also be aware that Laurel is frequently used to provide shade for coffee and cacao.

Laurel occurs as an occasional component of the natural forest at La Selva. It is most prominent in the Puerto Viejo area as a pioneer species in recently disturbed areas, a shade tree for crops such as coffee or cacao or in improved pastures. The logs that were most prevalent in the log yards and landings of the area studied were of the species *Cordia alliodora.* While *Cordia alliodora* is not extensively planted in forest plantations, its behavior in fields and croplands provides some clues to its potential value as a forest species if tree propagation and forest plantation become a reality. For the purpose of this case study *Cordia* growing in the general vicinity of the natural forest at La Selva was examined and an effort was made to compare the production of *Cordia* with that of Gavilán.

Three stands of *Cordia* located on the originally cleared areas of Finca La Selva were included in the study. These represented study plots established by Professor Holdridge when he was the owner of the experiment station. One area was an abandoned field that had grown to a secondary forest with *Cordia* the dominant species. Another was a cacao plantation where *Cordia* was used as a shade species. A third was a small *Cordia* forest plantation. A fourth area studied was a coffee plantation near La Virgen where *Cordia* was planted for shade. With the exception of the small forest plantation, the stand density of the plots was quite low compared to what would be the case if they were established as a silvicultural operation. It should also be noted that all of these plots were on agricultural land on the river terrace and the sites could be expected to be better than would be the sites in many forest areas. The plots in crop areas may also have had the benefit of the manipulation associated with cultivation. Nonetheless they do represent the kinds of areas on which much *Cordia* is currently growing.

As was the case with the natural forest, trees were sampled and the tree model was used to determine the volume, and the utilization model to determine product yield under different assumptions of merchantability. Figure 9 represents a height-diameter relationship for this species based upon data from the plots at La Selva. A study at Turrialba found that the allometric and quadratic functions were equally successful models of the height-diameter relationship in *Cordia* (6). Considering elevational and climatic differences between Turrialba and La Selva, the quadratic height diameter relationships of the two studies are surprisingly similar. Figure 10 illustrates the distribution of logs generated by the utilization model under the log diameter assumptions of 15 cm, 20 cm, 25 cm, and 30 cm. Figure 11 presents the distribution of log diameters for *Cordia* logs found in the mill yards and log landings between Puerto Viejo and San Miguel. The simulated distribution based upon an assumed minimum diameter of 20 cm most nearly approaches the distribution from the conversion sites. It will be noted that the most prevalent length of *Cordia* logs was four varas (3.36 m) as was the case for the Gavilán logs. There was, however, more variation in log length in this species than in any of the species from the natural forest. Figure 12 presents the log volume per hectare for the plot where *Cordia* was used for coffee shade. This value included volumes for a number of trees that had been thinned from the plot earlier in the year. The volumes for these harvested trees were generated using the tree model and information gained from stump measurements, and diameters and heights of the residual stand. Estimates were computed for *total stem volume* and log yield with the minimun log diameter constraints of 15 cm, 20 cm, and 30 cm. Figure 12 also indicates the percent yield or utilization efficiency for this stand under the previously noted constraints. At the 20 cm diameter limit indicated by the log yard data this stand yielded 42 % more log volume than the Gavilán of the natural forest. While the age of this stand was not known, ring counts from stumps suggest that it was 15 years old. **Tschinkel** (10) notes that growth rings in *Cordia* are almost invariably annual. On this basis the mean annual increment of log volume at 15 years was 5.2 m^3/ha/yr or at this age, about 7.5 times the production of usable material of the natural stand rate at La Selva.

In the case of the plots from La Selva, repeated measurements were available, making possible the tracing of productivity over time. The earliest measurements were made by Professor Holdridge while he was the owner of the station and were repeated at intervals by O.T.S. collaborators more recently. Figure 13 illustrates volumes and percent log utilization for the trees in Stand 1 in 1969 and 1972. This stand was established about 1962-63 as a plantation with spacing of approximately 1.5 m x 1.5 m using natural seedlings. The stand represents 251 trees on approximately three quarters of a hectare. Using the closest match between the model predicted and observed log diameter distributions for *Cordia* and Gavilán (20 cm limit for *Cordia* and 45 cm limit for Gavilán), this 10 year old *Cordia* plantation already contains 31% of the volume from the Gavilán forest and is producing a mean annual growth in log volume of 1.7 m^3/ha/yr–2.5 times that of Gavilán on the natural forest at La Selva.

Figure 14 presents the same information for Stand 2 based upon frequent measurements over the course of 14 years. These are 14 large old trees scattered over approximately a hectare with an undetermined time of establishment. Comparison of sizes with the other stands of known ages suggests these trees may have been established some time in the late 1940's. External signs of butt rot were noted on several of these trees during a 1974 re-evaluation. Since *Cordia* is considered to be a rather short-lived species, it is possible that these trees are now slipping into an over mature stage that may produce a reduced volume of logs as loss to defect offsets growth.

Figure 15 shows volume determinations and Figure 16, log utilization efficiencies for Stand 3 at La Selva. This stand was established about 1957 as invading seedlings in Cacao. They were favored by early weeding to become a shade. This *Cordia* shade is composed of 49 trees irregularly scattered over approximately two-thirds of a hectare.

Table 1 presents data for the mean annual growth of these stands at various stages since establishment in terms of total stemwood and product yield.

TABLE 1

Average projected log production from establishment to age indicated m^3 /Ha – Cordia alliodora, *merchantable volume at minimum utilization diameter of logs*

	Stand	15 cm	20 cm	25 cm	30 cm	No. trees/ha	Approx. Age
La Virgen	9.5	6.8	5.2	3.7	2.5	225	15 years
La Selva N. 1	8.6	3.0	.8	--	--	335	7 years
	8.0	3.9	1.7	.5	.1	335	10 years
La Selva N. 2*	1.8	1.6	1.4	1.2	.8	14	15 years
	2.1	2.0	1.9	1.8	1.6	14	27 years
La Selva N. 3	4.0	.5	--	--	--	73	3 years
	4.7	3.2	1.8	.7	.2	73	9 years
	4.0	3.1	2.3	1.4	.5	73	15 years

* Assumed established in 1945

Johnson and **Morales** (5) present a review of *Cordia alliodora* in which they provide a summary of plantation data from Los Diamantes on the Atlantic coastlands and from Turrialba. These authors note that Turrialba lies near what is probably the upper elevational limit of the species in Costa Rica, so growth may be expected to be better at lower elevational sites. Table 2 provides a summary of the results from the present study and from that of Johnson and Morales. The following differences between these studies should be noted:

> The data in the Johnson & Morales tables present merchantable volumes calculated by use of Gerard Form Class 0.75 and assuming merchantable height is 2/3 of total height. The present study uses the stem form equation and calculates merchantable volume to limiting utilization diameters.
> The stands in the Johnson & Morales tables represent plantations with controlled spacing whereas, except for Stand No.1, the stands at La Selva represent more widely spaced and scattered trees originally grown as shade for cacao or coffee.

Although the effect of these differences is difficult to assess, there appears to be reasonable agreement.

TABLE 2

Data for Cordia alliodora *at Los Diamantes, Pococí, and La Virgen and La Selva, Sarapiquí Costa Rica*

Location	Age	No. Surviving Trees	Spacing (m)	Area (ha)	Vol/tree (m^3) [1]
La Selva N. 2	27 (3)	14	(4)	1.00	3.67
Los Diamantes[2]	24	27	3 x 4	.16	1.62
Los Diamantes, East [2]	21	141	3 x 4	.75	.77
Los Diamantes, West [2]	21	116	3 x 4	.50	1.17
Rio Turrialba [2]	21	54	(5)	(5)	.99
La Virgen	15	36	(4)	.16	2.17
La Selva N. 2	15 (3)	14	(4)	1.00	1.53
La Selva N. 3	15	47	(4)	.67	.75
Old Arboretum [2]	13	50	3 x 3	.08	.24
Old Arboretum [2]	13	20	3 x 3	.02	.45
Bajo Chino [2]	12	102	4 x 4	.20	.37
Los Pozos [2]	12	315	4 x 4	1.00	.26
Bajo Chino, Taungya[2]	10	295	4 x 4	1.00	.15
Old Arboretum[2]	10	80	3 x 3	.09	.24
La Isla [2]	10	162	2 x 4	.16	.11
La Selva N. 1	10	251	1.5 x 1.5	.75	.07
La Selva N. 3	9	48	(4)	.67	.35
La Selva N. 1	7	251	1.5 x 1.5	.75	.02
Bajo Reventazon	6	58	2 x 2	.04	.03
La Selva N. 3	3	48	(4)	.67	--
Raigosa–F. Norte [2]	3	130	3.25 x 3.25	.30	.03

1. Merch. Volume: Present study based on 20 cm diameter limit
   : source (5) based on Gerard Form Class .75 and 2/3 total height
2. Source (5)
3. Assumed established about 1945
4. Irregular spacing
5. Single row of trees 3m apart.

These case studies explore in a modest way production capabilities of some tropical forests in Central America. While precise projections cannot be made on the basis of fragmentary data it is quite clear that the hardwood forests can be potentially far more productive than they now are. The question that must be answered is "how important is it to the countries of Central America and Panama to become self sufficient with respect to wood and/or to take advantage of the opportunities presented by the growing world market for wood". If the projections of the Takeuchi report on future growth in world import demand for wood at 6.0 to 6.5 percent per year turn out to be valid, in the long run, the opportunities are there. While the countries of Central America have not experienced the same expansion in wood utilization as have those of Southeast Asia there has nonetheless been dramatic growth in this business sector during the last several years. Unofficial data from FAO (7, 9) on the assumed production of tropical hardwood logs in Costa Rica indicate that for 1967 production was 428,000 m^3, for 1970 it was 718,000 m^3 and for 1973 it was 1,200,000 m^3. A recent study apparently indicated that the forests of Costa Rica yield sawmill output of 980,000 m^3/yr (7). To obtain this volume on a clear-cut basis from forests like the natural forest at La Selva would require the harvesting of almost 20,000 hectares per year, based upon the utilization standards that we assumed. If such a harvest were to be projected on a sustainable harvest basis with an 80 year rotation the forest land requirement would be about 1,745,000 hectares. This is slightly more than twice the 844,000 hectares that Costa Rica anticipates dedicating to forests according to the Director General of Forestry (7). If the average forest supplying the national needs carried a smaller volume than the natural forest at La Selva then the demand on land to maintain the 1973 production would be greater. On the other hand, a doubling of the utilization efficiency of the forest production–conversion system–a modest objective, would cut the land requirements in half. If more intensive culture of selected fast-growing species such as *Cordia* were to be used as a basis for meeting a substantial fraction of the wood requirements, then the land base could be sharply reduced or production could be expanded either for domestic use or for participation in the export market. There are other secondary forest species, such as *Trema micrantha* for example, that could be explored as additional candidates for fast-growing short-rotation plantations.

Modification of forest organization and structure to improve utilization efficiency is a long-term enterprise, but the existence of Central America provides the opportunity to make a transition without an abrupt adjustment in supply. If production is allowed to increase without an appropriate start on the application of silviculture to improve utilization efficiency, then a potentially traumatic adjustment can be projected for the future. Adjustments in the conversion system to achieve a more broadly based product mix offer much greater opportunity to improve utilization efficiency in the short run. Such a development however would require significant capital investments, presumably by the private sector.

In the final analysis, the kind, size and location of commercial forests, regardless of ownership or custody, that will be needed by the several countries of the region will depend upon a number of factors.

One factor is obviously the trade-off between agriculture and forestry with respect to undeveloped lands. Generally speaking, food production will have priority over wood production when lands are useful for both. There is no assurance, however, that simply because undeveloped land is cleared for agriculture it will prove to be good crop or pasture land in the long run. Lands which are shown to be sub-marginal for food production may prove to be excellent candidates for forest plantation culture.

Lacking adequate information on land productivity under a variety of use dedications the region is experiencing a trial and error probing that is not greatly different than that which occurred earlier in the more industrially developed countries. The major forest clearing activities directed to an expansion in pasture area so prevalent throughout Central America is an example of this phenomenon. If past history from other regions is repeated, many of these conversions will prove to be unwise. Hopefully the conversions will be made in such a way as to preserve options for future changes in land use, either to other agricultural crops or to managed forests.

A second factor that is important in determining the extent of commercial forest land ultimately emerging in a country will be related to that nation's objectives with respect to wood self sufficiency and its ambitions to participate in an expanding wood market. Increases in the price of wood, world-wide, improve the economic climate for the intensive forest management required to improve utilization efficiency. A stable and diversified wood conversion industry, also necessary to improve utilization efficiency, will require an assured and stable raw material supply. Since forestry is a long-term activity, stability on the forest production side will require protection to insure that investments in forest establishment and culture are recovered in ultimate harvest. This may involve long-term land use commitments to commercial forestry by the public sector. It may also require a public acceptance of the proposition that land which is growing trees is not unused land.

For too long the efficient utilization of the natural tropical hardwood forests, particularly those of Latin America, has been delayed because of concern for the problems associated with the diversity of those forests. The problems of matching these very diverse and complex forests to a relatively simple conversion system have been so difficult that progress in developing a viable forest has been delayed. If these forests had been less complex in organization and structure, they would have made a greater contribution to the welfare of the people of tropical Latin America.

From an ecological standpoint, these diverse natural forests are exciting, and adequate portions of them ought to be preserved, not only for the purpose of scientific study, but also because in the long run this diversity may become an economic asset of significant dimensions. The gene pools necessary to exploit such opportunities ought to be preserved. Such opportunities are not likely to emerge from the continuing frustration of attempting to match a complex forest with a simple conversion system.

Good progress will come in the forseeable future from determined efforts to understand the relatively small number of species that make up the bulk of the currently useful volume of the natural primary and secondary forests. The most effective use of limited resources available to advance forestry in tropical hardwood areas will come from efforts to increase the volume per hectare in these usable species and to increase the fraction of the trees of these species that end up in useful products.

I have not discussed softwood timber supply from the Central American region since Mr. Flores, who follows me on the program, is much better qualified to do this.

RESUMEN

La utilización de los bosques naturales es factible siempre que éstos estén en lugares accesibles, que su extensión sea adecuada y que sus productos satisfagan las exigencias del consumidor. Sin embargo, a medida que se vaya explotando los rodales naturales y se vaya utilizando las tierras en otras actividades que no sea en bosques sin la aplicación de una silvicultura técnica, es probable que el desarrollo de bosques de segundo crecimiento y residuales no será adecuado. Este concepto abarca especialmente a los bosques tropicales de maderas duras, en donde a menudo hay pocas especies y aun menos tallos por hectárea que produzcan el material deseado.

Al tratar de equiparar el complejo sistema de producción forestal con el de su utilización, se presenta un serio problema técnico. En las fases iniciales de la explotación de un bosque tropical natural casi no hay desequilibrio, ya que el sistema de conversión del bosque es generalmente simple, de solamente uno o dos productos y un ámbito industrial pequeño, generalmente altamente selectivo en cuanto a especies, tamaños y calidades; por lo tanto, únicamente una parte pequeña del volumen de los árboles de un rodal tropical de maderas duras tiene valor comercial. Mientras haya tierras forestales en exceso se puede tolerar esta situación. Sin embargo, este sistema de utilización de baja concentración de material aprovechable por unidad de área significa que los costos de reunir cantidades comerciales significativas son elevados. Esto ocurre aun cuando el costo de la materia prima es bajo. Además, con el tiempo, este sistema puede agotar el material aprovechable por unidad de área, ya que la lógica corta selectiva da como resultado la reposición de especies deseables por aquellas de calidad y tamaño inferiores. Como consecuencia de esto, el equilibrio entre los sistemas de producción forestal y de utilización se perdería.

Desafortunadamente, los clásicos inventarios forestales extensivos no siempre han sido herramientas útiles para evaluar los rodales tropicales naturales. El enfoque general asigna la mayoría de los recursos al conteo y a la medida de los árboles en pie, sin tomar en cuenta su utilización. En las fases posteriores de análisis se pueden ajustar los datos para que reflejen su valor comercial, pero el valor en este sentido se basa a veces en clasificar los árboles en categorías arbitrarias de utilización y de tamaño, que generalmente tienen poca relación con el sistema de conversión en uso. Además, como las normas de los sistemas de conversión cambian constantemente, los requisitos comerciales de los inventarios generalmente no toman en cuenta los volúmenes comerciales en relación con la flexibilidad de las alternativas. Como resultado, los datos de los inventarios pueden ser peligrosamente engañosos como guías de planificación.

Esta exposición presenta algunos resultados preliminares de un estudio orientado hacia la equiparación entre la producción forestal y los sistemas de conversión cuando se le imponen al bosque diferentes alternativas de utilización. Los resultados se basan en tres situaciones forestales en Costa Rica: el bosque mixto natural de La Selva, en donde domina el Gavilán *(Pentaclethra macroloba)*; el bosque mixto natural que bordea la costa atlántica, dominado por Cativo *(Prioria copaifera)* y Cedro Macho *(Carapa guianensis)*; y los rodales coetáneos puros. Los bosques mixtos contienen muchos árboles de especies no aprovechables, por lo que la productividad general es muy baja. Esta situación puede remediarse, ya sea simplificando las estructuras forestales por medio de la silvicultura para favorecer las especies más utilizables y/o incrementar la complejidad del sistema de conversión para permitir un uso más eficiente de las especies deseadas, junto con un aprovechamiento de las especies hasta ahora indeseables.

LITERATURE CITED

1. **Burwell, B.B.**
   1974. *A study of stand structure, spatial wet premontane forest of La Selva, Costa Rica.* University of Washington, College of Forest Resources. Unpublished Report. 50 pp.

2. **Catinot, R.**
   1972. *Biological and economic opportunities and limitations to the manipulation of the tropical forest ecosystem.* VII World Forestry Congress. Buenos Aires, October 4-18, 1972.

3. González, R.
1972. *Inventario forestal, Barra del Pacuare, Limón, Costa Rica.* Ministerio de Agricultura y Ganadería, Dirección General Forestal, San José, Costa Rica. 17 pp. (mimeografiado).

4. Hartshorn, G. S.
1972. *The ecological life history and population dynamics of* Pentaclethra macroloba, *a tropical wet forest dominant and* Stryphnodendron excelsum, *an occasional associate.* Ph.D. Thesis, College of Forest Resources, University of Washington, Seattle. 119 pp.

5. Johnson, P., & R. Morales
1972. A review of *Cordia alliodora* (Ruiz & Pav.) Oken. *Turrialba,* 22: 210-220.

6. Machado, S., & W. Albertin
1973. Algumas relaçôes dasometricas importantes em um bosque secundario tropical. *Turrialba,* 23: 192-199.

7. Madriz Vargas, A.
1973. *In* World Wood Review 1973. *World Wood* 14: 65-67.

8. Petriceks, J.
1956. *Plan de ordenación del bosque de la Finca "La Selva".* M. Agr. Thesis, Instituto Interamericano de Ciencias Agrícolas, Turrialba, Costa Rica. 176 pp.

9. Takeuchi, K.
1974. *Tropical hardwood trade in the Asia-Pacific Region.* World Bank Staff. Occasional Paper No. 17. The John Hopkins Univ. Press. 90 pp.

10. Tschinkel, H. M.
1966. Annual growth rings in *Cordia alliodora. Turriabla,* 16: 73-80.

Fig.1. Profile diagrams of a tropical hardwood forest showing merchantable volume of merchantable species.

a. All trees
b. Non-merchantable volume (unshaded)
c. Merchantable volume of merchantable species.

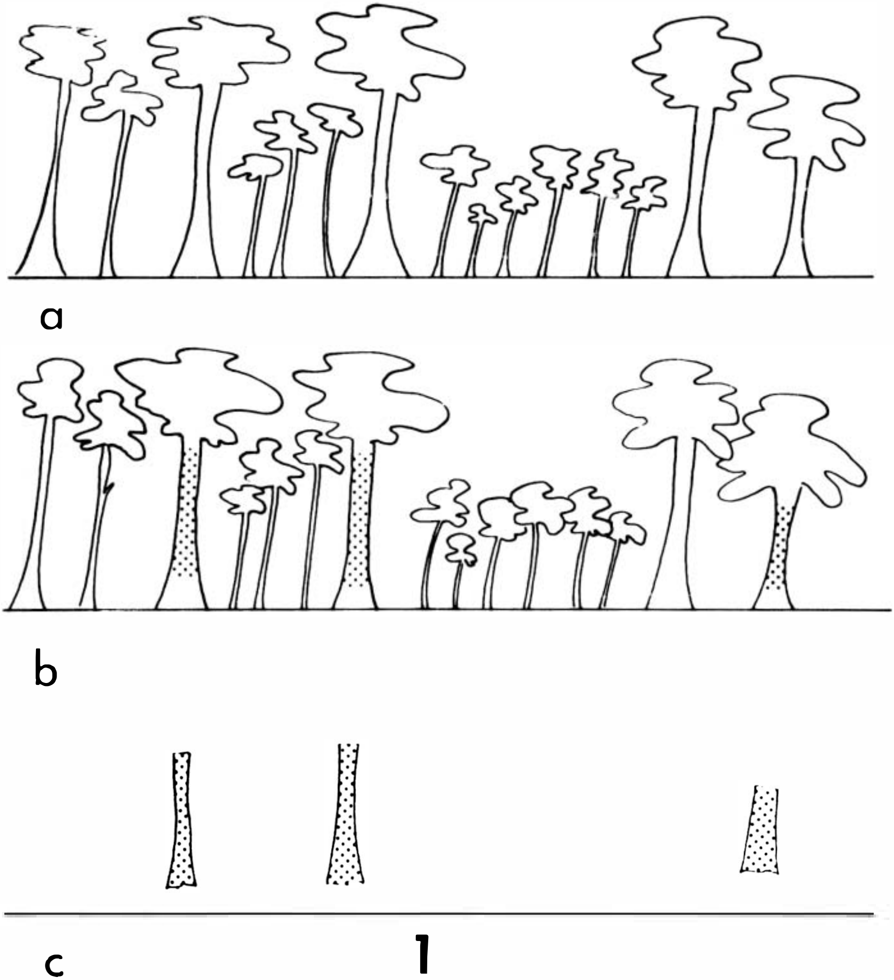
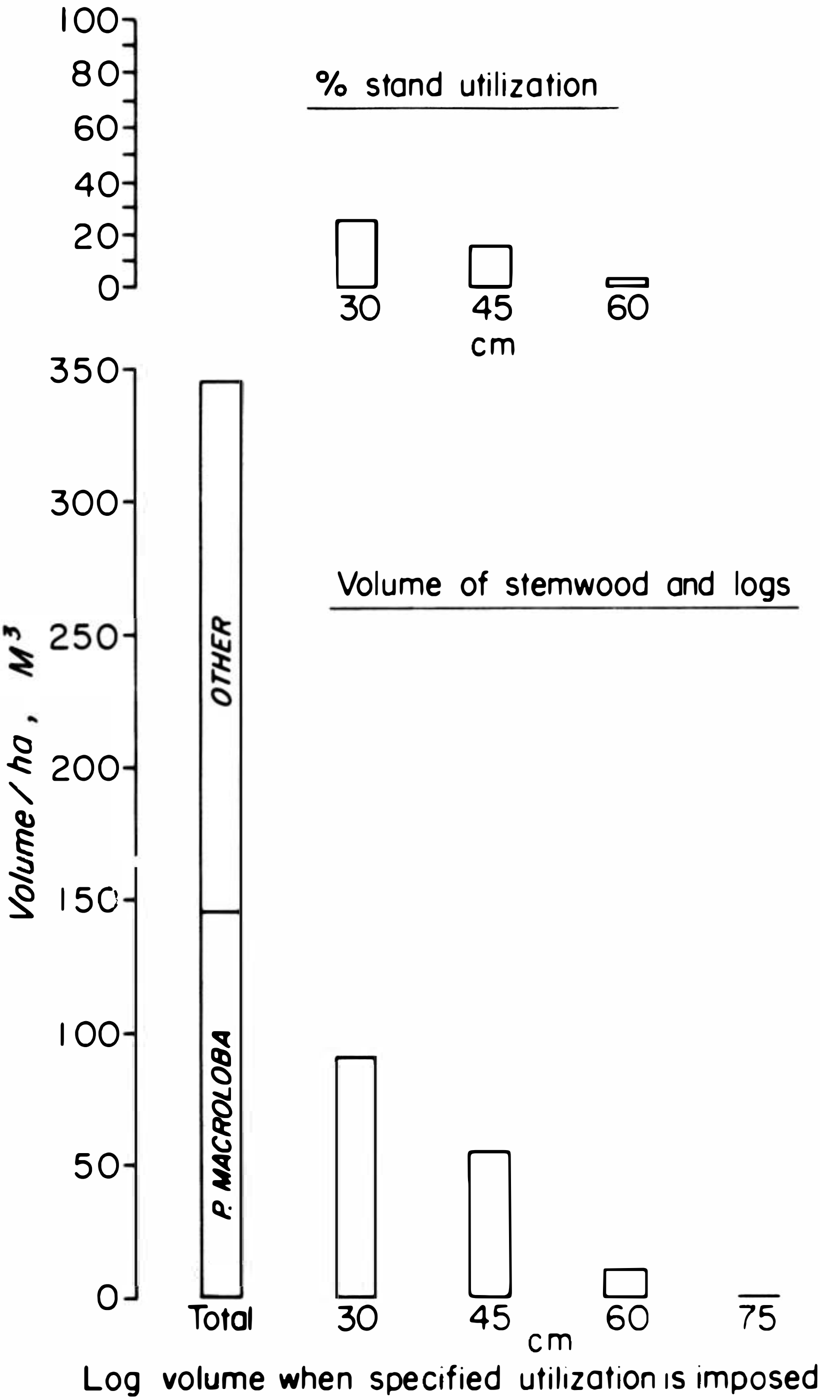

a
b
c
1

Fig.2. Comparison of actual and model predicted stem measurements for a *Pentaclethra macroloba* tree.

2

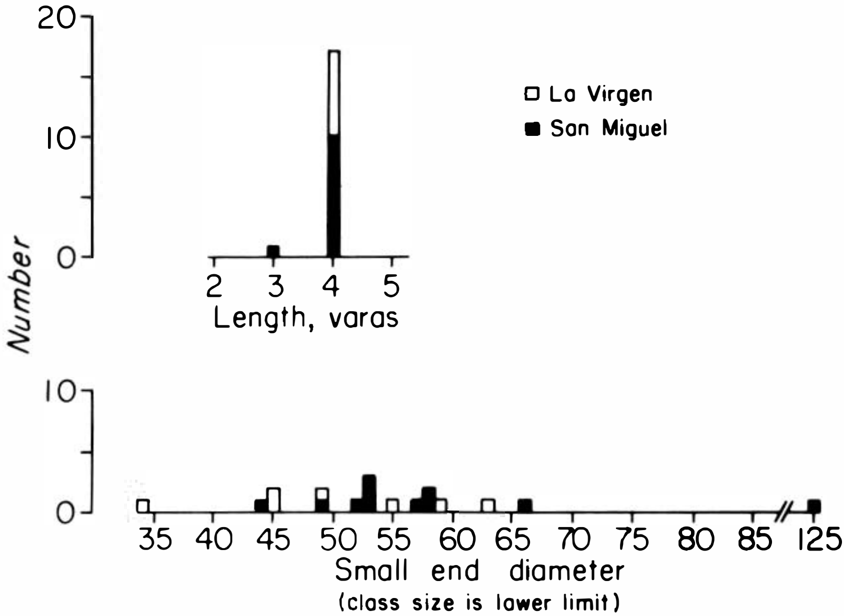
Fig.3. Predicted utilization of mixed forest at La Selva assuming *Pentaclethra macroloba* is the only commercial species.


% stand utilization
100
80
60
40
20
0
30
45
60
cm
Volume of stemwood and logs
Volume / ha , M3
350
300
250
200
150
100
50
0
OTHER
P. MACROLOBA
Total
30
45
60
75
cm
Log volume when specified utilization is imposed

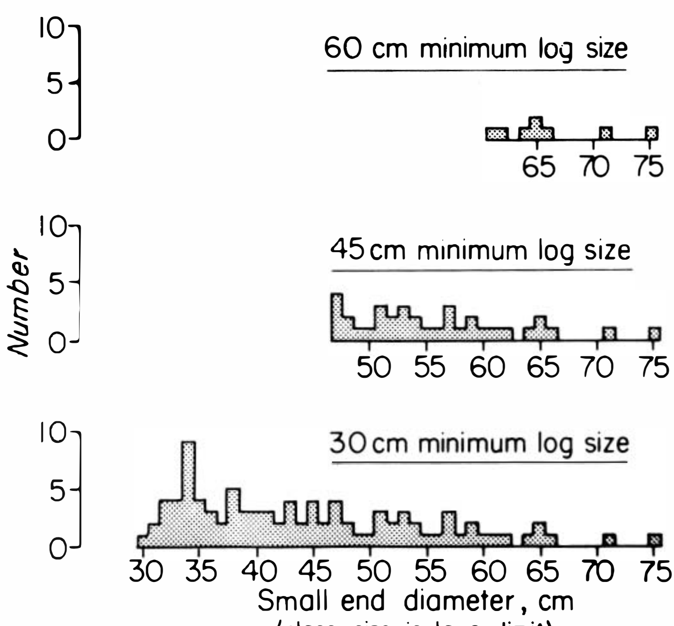
3

Fig.4. Log size frequency of *Pentaclethra macroloba* at La Virgen and San Miguel log yards.

Fig. 5. Model predicted distribution of small log diameters (all logs 3.4 meters length) for *Pentaclethra macroloba* at La Selva.


Number
20
10
0
La Virgen
San Miguel
2 3 4 5
Length, varas
10
0
35 40 45 50 55 60 65 70 75 80 85 125
Small end diameter
(class size is lower limit)

4


Number
60 cm minimum log size
65 70 75
45 cm minimum log size
50 55 60 65 70 75
30 cm minimum log size
30 35 40 45 50 55 60 65 70 75
Small end diameter, cm
(class size is lower limit)

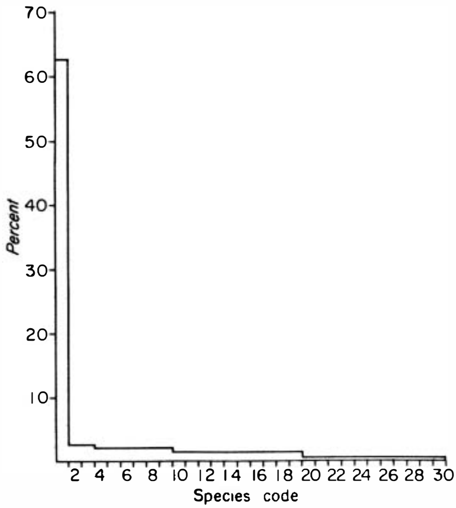
5

Fig. 6. Frequency of stems 45 cm or larger DBH, La Selva intensive study site 1.

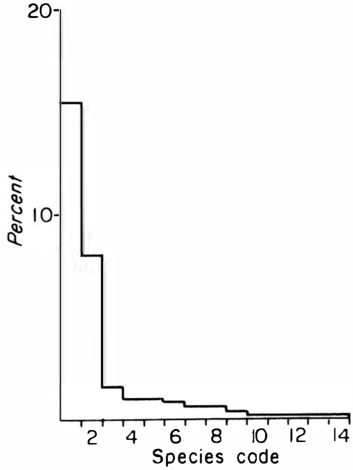
Fig. 7. Frequency of stems 45 cm or larger by species, La Selva, from Petriceks (8).

Fig. 8. Percent frequency of stems by species at Barra del Pacuare, Limón, Costa Rica.

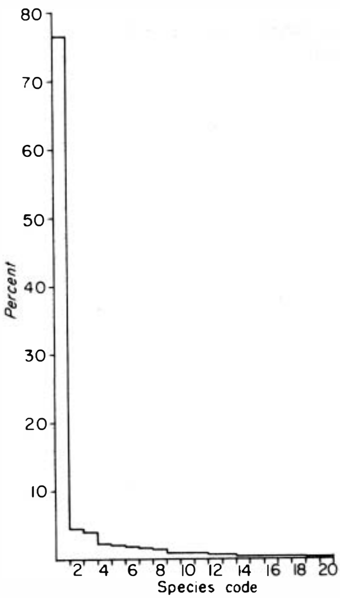
Fig. 9. Relationship between height-diameter for *Cordia alliodora* at La Selva.


70
60
50
40
30
20
10
Percent
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Species code

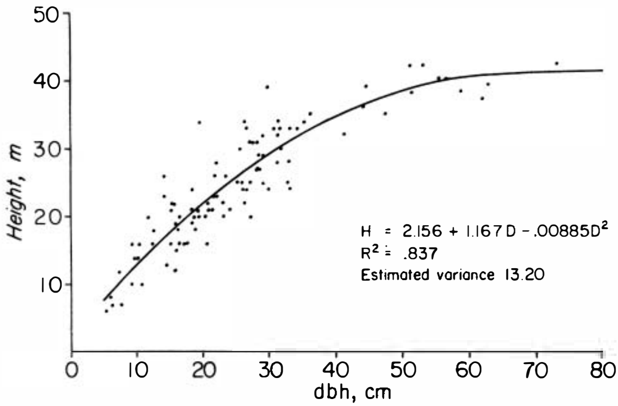
6


20
10
Percent
2 4 6 8 10 12 14
Species code

8

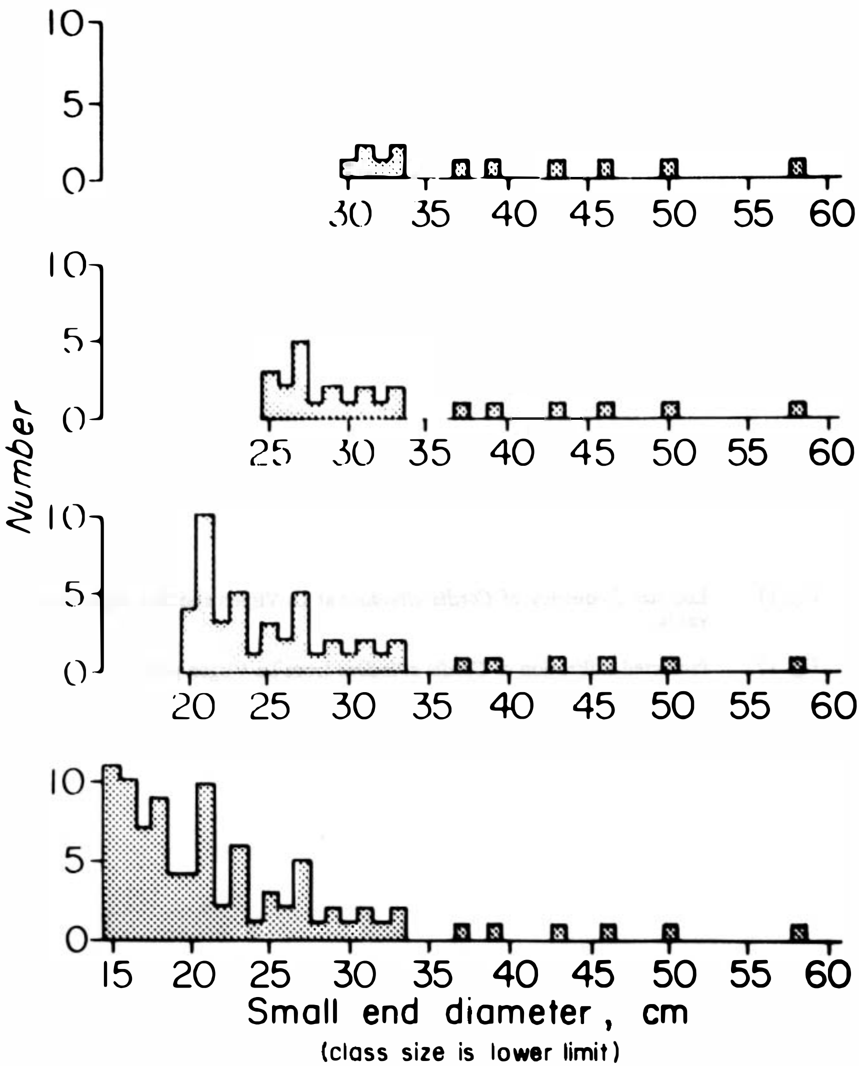

80
70
60
50
40
30
20
10
Percent
2 4 6 8 10 12 14 16 18 20
Species code

7


50
40
30
20
10
Height, m
0 10 20 30 40 50 60 70 80
dbh, cm
H = 2.156 + 1.167D − .00885D²
R² = .837
Estimated variance 13.20

9

Fig. 10. Model predicted distribution of small end log diameters (all logs 3.4 meters length) for *Cordia alliodora* plot at La Virgen.

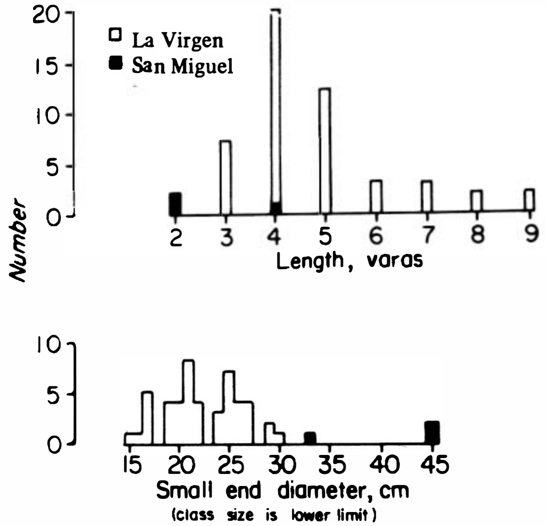


10

Fig. 11. Log size frequency of *Cordia alliodora* at La Virgen and San Miguel log yards.

Fig. 12. Predicted utilization of *Cordia alliodora* from La Virgen plot.

11


La Virgen
San Miguel
Number
20
15
10
5
0
2 3 4 5 6 7 8 9
Length, varas
10
5
0
15 20 25 30 35 40 45
Small end diameter, cm
(class size is lower limit)

12

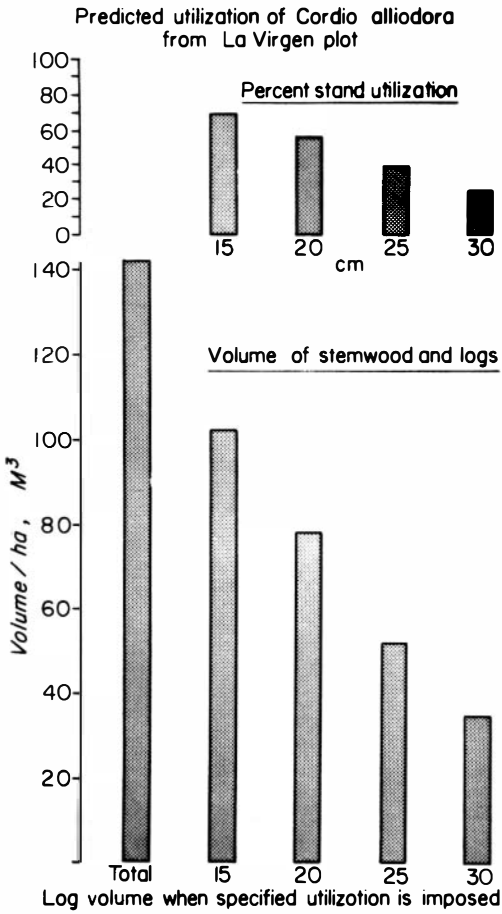
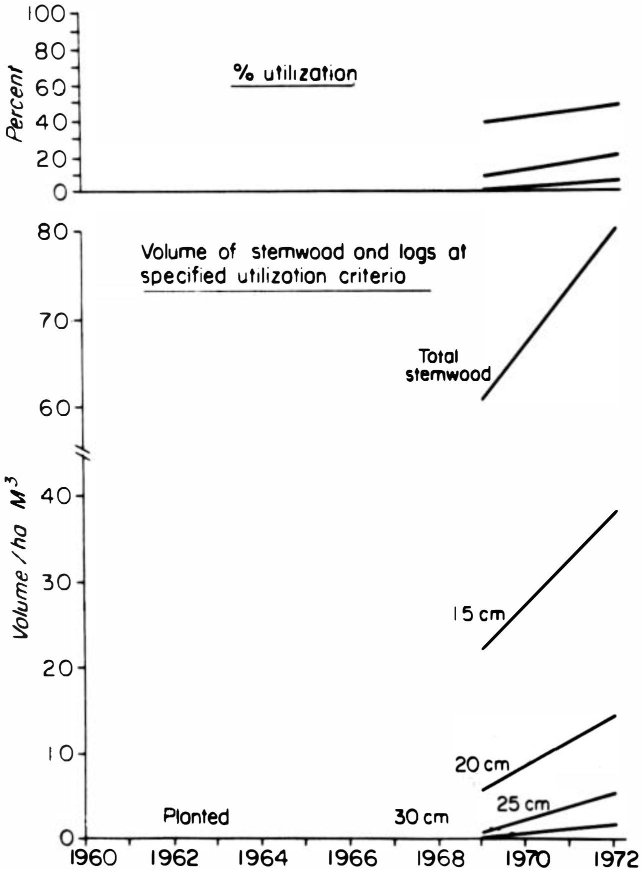
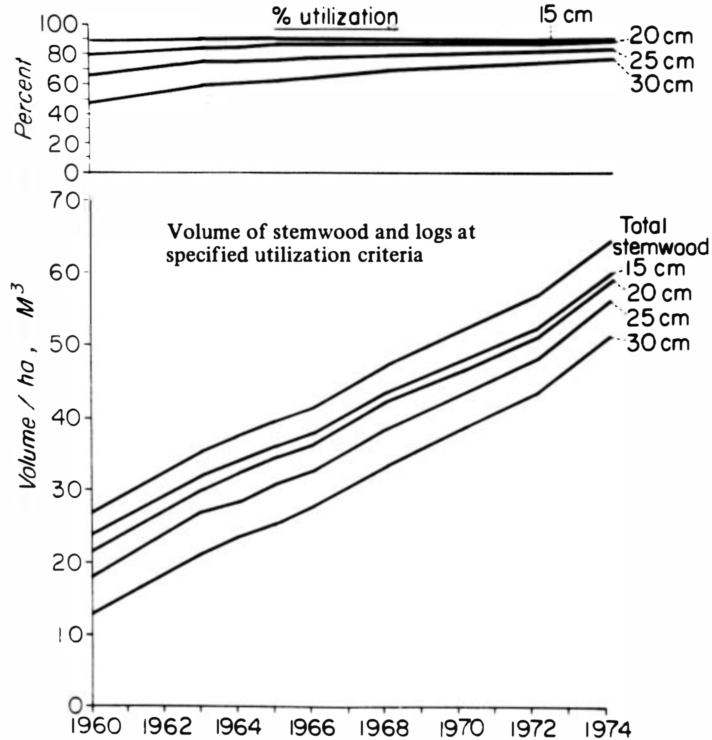

Predicted utilization of Cordio alliodora
from La Virgen plot
Percent stand utilization
100
80
60
40
20
0
15 20 25 30
cm
Volume of stemwood and logs
Volume / ha, M3
140
120
100
80
60
40
20
Total 15 20 25 30
Log volume when specified utilizotion is imposed

Fig. 13. Predicted utilization of *Cordia alliodora*, Stand 1 at La Selva.

Fig. 14. Predicted utilization of *Cordia alliodora*, Stand 2 at La Selva.


% utilization
Percent
100
80
60
40
20
0
Volume of stemwood and logs at specified utilization criteria
Volume / ha M^3
80
70
60
40
30
20
10
0
Total stemwood
15 cm
20 cm
25 cm
30 cm
Planted
1960
1962
1964
1966
1968
1970
1972

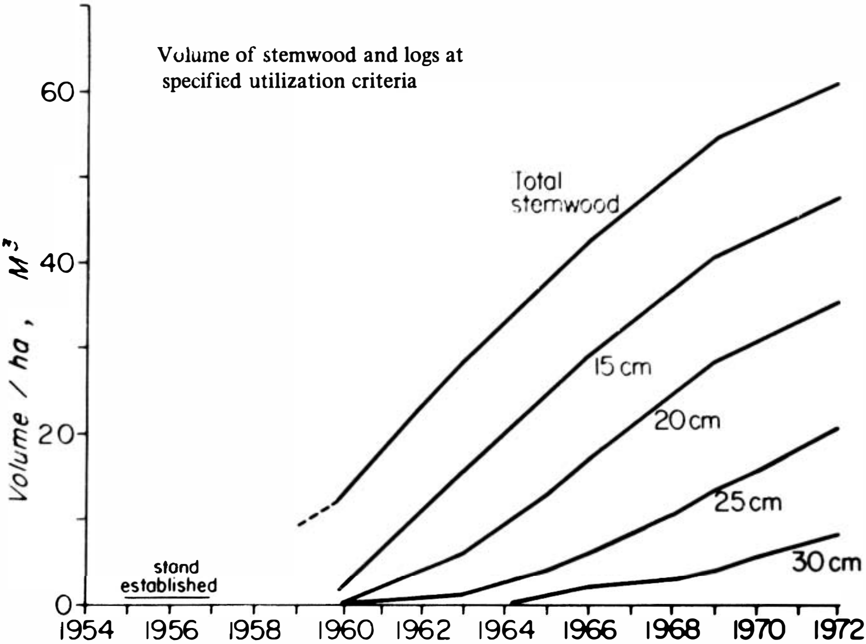
13


% utilization
15 cm
20 cm
25 cm
30 cm
Percent
100
80
60
40
20
0
Volume of stemwood and logs at specified utilization criteria
Volume / ha, M^3
Total stemwood
15 cm
20 cm
25 cm
30 cm
70
60
50
40
30
20
10
0
1960
1962
1964
1966
1968
1970
1972
1974

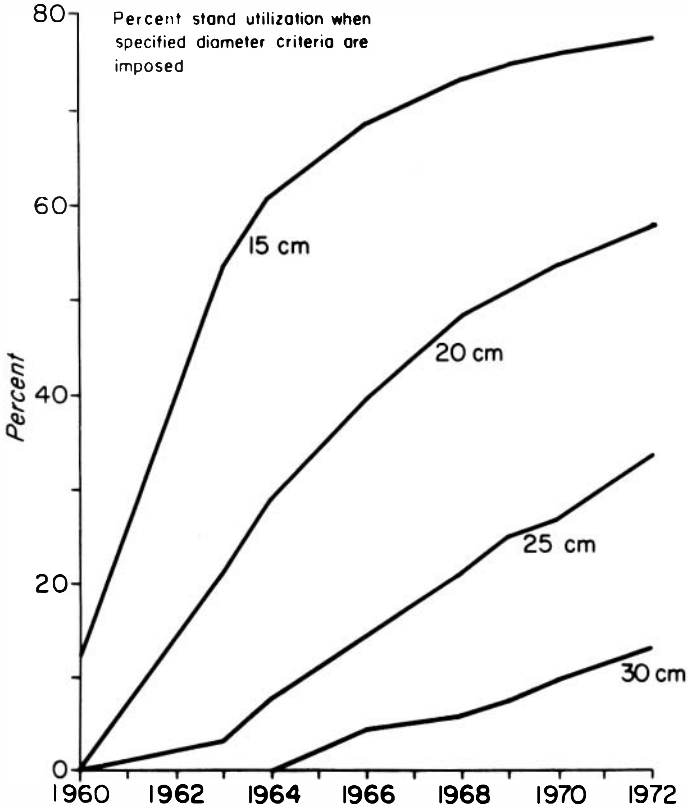
14

Fig. 15. Predicted utilization of *Cordia alliodora*, Stand 3 at La Selva.

Fig. 16. Predicted utilization of *Cordia alliodora*, Stand 3 at La Selva.


Volume of stemwood and logs at specified utilization criteria
Volume / ha , M³
60
40
20
0
Total stemwood
15 cm
20 cm
25 cm
30 cm
stand established
1954
1956
1958
1960
1962
1964
1966
1968
1970
1972

15


Percent stand utilization when specified diameter criteria are imposed
Percent
80
60
40
20
0
15 cm
20 cm
25 cm
30 cm
1960
1962
1964
1966
1968
1970
1972

16