Population Dynamics of Some Tropical Trees That Yield Non-Timber Forest Products
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POPULATION DYNAMICS OF SOME TROPICAL TREES THAT YIELD NON-TIMBER FOREST PRODUCTS[1]

JAMES V. LAFRANKIE

LaFrankie, James V. *(Center for Tropical Forest Science, Nanyang Technological University-NIE, 469 Bukit Timah Road, Singapore 1025).* POPULATION DYNAMICS OF SOME TROPICAL TREES THAT YIELD NON-TIMBER FOREST PRODUCTS. *Economic Botany 48(3):301–309. 1994. The population biology of* Aquilaria malaccensis, *one source of gharu, and* Cinnamomum mollissimum, *one source of wild cinnamon, was studied in a 50 ha permanent plot of primary rain forest in Malaysia. Median diameter growth rates of 0.22 cm yr^{-1} and 0.1 cm yr^{-1} should not be prohibitive of economic exploitation, and suggest that the trees could be grown commercially. However, the natural densities were between 2 and 3 trees over 1 cm d.b.h. per ha, which is roughly the median for all trees in the plot, would preclude economic exploitation of these natural populations. The economics of harvesting natural populations is considered in a preliminary fashion by allowing favorable assumptions of quantity and quality of production. The price likely to be fetched from either a first time extraction (on the order of US$10.00 per ha) or from sustained production (on the order of US$0.10 per ha per yr), are too small to be of interest as single-product schemes, and are negligible compared to the extraction of multi-species crops of timber. However, it is possible that by combining multiple products under a "High Diversity Forestry" scheme, one could increase the density of harvestable products, reduce the unit cost of labor and improve the economic portrait.*

La poblacion dinamica de algunos arboles tropicales. *La población biológica de* Aquilaria malaccensis, *un original de gharu, y* Cinnamomum mollissimum, *un original del cinnamon salvage, ha sido estudiado en 50 ha en un terreno primario permanente de lluvia tropical en. Con un índice de crecimiento de medio dimetro 0.22 cm yr^{-1} y 0.1 cm yr^{-1} no deberia prohibirse la explotación económica, y se segiuere que los árboles pueden ser cultivados comercialmente. De cualquier manera, la densidad natural siendo aproximadamente entre 2 y 3 árboles per encima de 1 cm dbh per ha, lo cúal es un promedio de todos los árboles en el terreno, esto representa un impedimento a la explotacion económica de la población natural. La economía de la población natural de recolección de la cosecha está considerada como una moad preliminar por permitirse favorablemente la supuesta cantidad y calidad de producción. Los precios problemente alcanzen, bien sea, la primera vex de su extracción sobre el pedido de US$10.00 per ha o desde una continua producción ininterrumpida, (sobre un pedido US$0.10 per ha per yr), siendo demassiado pequeño para ser de interés tal proyecto comoproducto-unico, y son insignificantes comparados con la extracción de multiples especies de semillas de madera. De caulquier manera es posible que se pueda combinar los multiple productos en el proyecto de "Alta Diversidad Forestal," uno puede la un puede incrementar la densidad de la producción de la cosecha, reduciendo el costo de mano de obra por unidad y mejorando la imagen económica.*

Key Words: forestry; Malaysia; non-timber products; *Aquilaria*; *Cinnamomum*.

Can non-timber forest products offer an economically viable alternative to timber extraction in tropical forests? As the conversion of forested lands continues, policy-makers and conservation agencies would like to think that the answer is yes. The economics of non-timber products appear to be attractive in some cases (De Beer and McDermott 1989; Peters, Gentry, and Mendelsohn 1989) and alternatives to timber may help to bolster forestry's contribution to national economic growth as timber volumes diminish (Ashton and Panayotou 1992). For example, some

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state foresters in Peninsular Malaysia, faced with a collapsing logging industry and a threat of privatization of the forest department, began a regional search for new products that included rattan, bamboos, and both native and exotic sources for wood and fiber (Anonymous 1992a; Samsuddin pers. comm.). From a different perspective, some development agencies, and some conservationists, view non-timber forest products as a means of empowering rural communities in land-use policy, allowing communities to develop sustainable local industries and avoid the social and economic problems usually associated with forest alienation (e.g., Anonymous 1991; Poffenberger 1991).

Whether they are seen as a potential industry or as a tool for social engineering, many non-timber products share with timber the problem of finding extraction rates that are both biologically sustainable and profitable. Are natural populations of these species adequate to provide a regular harvest? Do the biological properties of their populations facilitate or hinder their development as an alternative forest product?

In this paper, I examine the natural population structure and dynamics of two species of trees from Malaysia that provide valued products: *Aquilaria malaccensis* (Thymelaeaceae) and *Cinnamomum mollissimum* (Lauraceae). *Aquilaria malaccensis* is one source of gharu (or gaharu), a black resinous reaction wood found as fine striations or as spatulate or pencil-shaped deposits in the branches, trunk and roots of the mature tree. According to traditional practice in Malaya, the extraction of gharu was a matter of ritual and ceremony, but today it is commonly extracted by cutting the tree apart with chain saws, the wood is pared away, and the gharu collected for sale as a base for the manufacture of incense or medicine (Burkill 1935; Gianno 1986a,b, 1990; Gianno and Kochummen 1981; Jalaluddin 1976). *Cinnamomum mollissimum* is a small tree, with a powerful fragrant oil found in all its parts. The bark is stripped and sold as a spice. The stripping almost always involves a complete harvesting of the tree.

Gharu and cinnamon, and related species, remain highly prized throughout Southeast Asia. The description of the natural demography of these rare species is of some interest in its own right, but my main purpose here is to examine the capacity of natural populations to provide a regular harvest, thereby evaluating, in a preliminary fashion, the economic sensibility of these alternative products.

Study Site and Methods

The study was made at Pasoh Forest Reserve, Malaysia, which is located at 2° 59′ N latitude and 102° 18′ W longitude, or about 140 km southeast of Kuala Lumpur, in the interior portion of Negeri Sembilan amidst a broad expanse of flat lands and gently rolling ridges that abut the westward side of the Main Range. Prior to 1900, this South-Central portion of the Malay Peninsula comprised nearly 100,000 ha of relatively unbroken forest. The plot is situated in the last remnant of that forest (Fig. 1).

Collection of gharu and cinnamon from Pasoh has been illegal without a permit since the Forest Reserve was gazetted in 1917. There is no direct evidence that organized collecting has ever taken place. However, considering the fact that people have lived in the vicinity for many thousands of years, and carried out a trade in gharu and cinnamon for as long (Dunn 1975), we might assume that some trees have been extracted at some time in the past. The same can be said, of course, for all lowlands in the Malay Peninsula, and for the objectives of this study, which is to consider the population structure and dynamics of these species as they occur today, the site at Pasoh is completely representative of the Malayan situation. The ecology of Pasoh has been studied as a part of the International Biological Program; the forest flora and stand structure are described in detail in Kochummen, LaFrankie, and Manokaran (1991) and in Manokaran and LaFrankie (1991).

The present work was conducted as a part of a continuing study of forest dynamics that began with development of a large-scale permanent plot in which all free-standing woody plants 1 cm d.b.h. or greater were tagged, mapped and measured. The permanent plot is a 50-ha rectangle 1 km long and 500 m wide, and lies in a mostly level plain of relatively uniform terrain between two meandering streams.

The methods by which the plot was surveyed, the trees measured and species identified are recounted in Manokaran et al. (1990). The first census of trees was made between 1986 and 1988. In small trees (≤5 cm d.b.h.) the bole was measured to an interval of 0.5 cm, rounding downward to the lower interval limit. In larger trees (≥5.0 cm d.b.h.) the bole was measured to in-

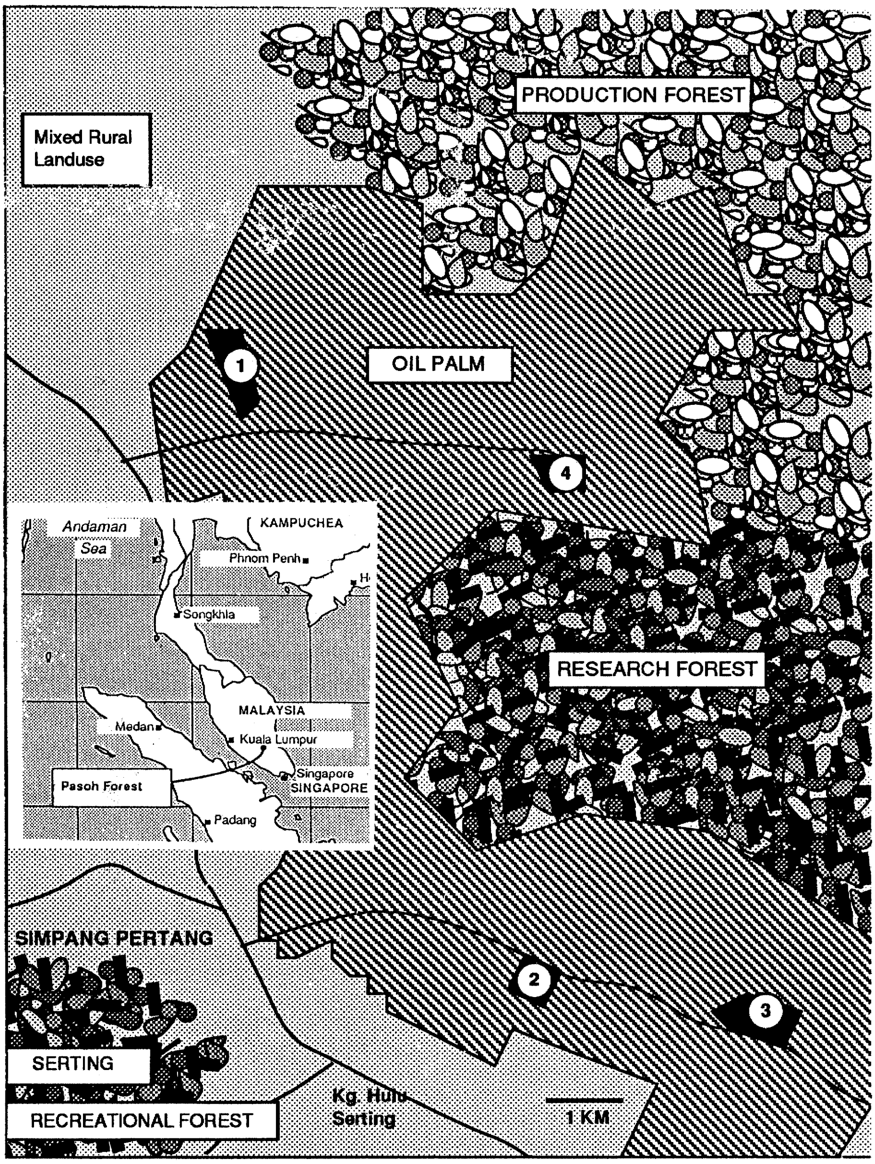

Fig. 1. Map showing the location of Pasoh Forest in Malaysia, and the surrounding land-use patterns at Pasoh. The permanent plot was located in the center of the research forest.

tervals of 0.1 cm d.b.h., again rounding down to the lower interval limit. Measuring methods were highly reliable with repeatability of over 99%. The time between measurements is not the same for all trees, ranging from 2.5–4.0 years, because the first census took nearly two and a half years to complete, while the second took only ten months. Consequently, growth is calculated on an annualized basis by dividing the difference in diameter between successive measurements by the number of elapsed days (expressed as a fraction of the year). Mortality for the species is calculated as the number of trees that died divided by the median time interval between observations. Recruitment rates are calculated similarly. Voucher specimens for the species are: *Aquilaria malaccensis*: Gentry 66956, *Cinnamomum mollissimum*: PFR 4134 (KEP).

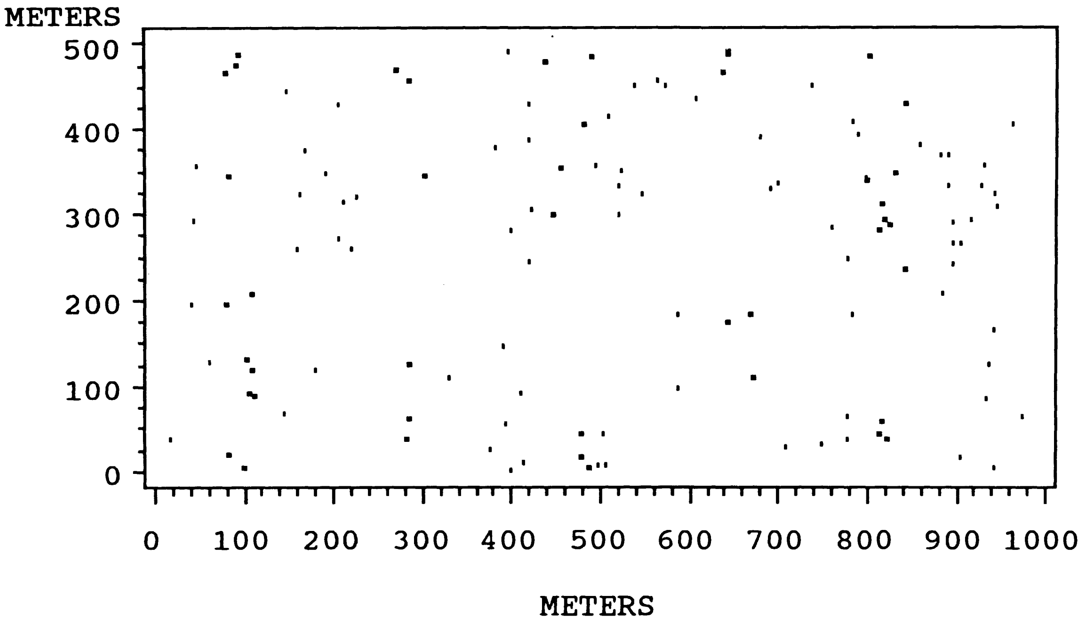

Fig. 2. A map of the distribution of a natural population of *Aquilaria malaccensis* in the 50-ha plot at Pasoh. Small dots equal trees 1–20 cm d.b.h., large dots equal trees over 20 cm d.b.h. Note that the distance of the lowest axis is 1000 m.

Results

Aquilaria malaccensis

The population of *Aquilaria malaccensis* within the large-scale plot consisted of 125 trees ≥1 cm d.b.h., or 2.5 trees per ha, distributed evenly over the plot (Fig. 2). Trees were found in wet ground, hill slopes, on sand and on clay. There is no indication of the strong spatial patterning sometimes found in other forest species (illustrated in Manokaran et al. 1993). The density of 2.5 trees per ha is a typical figure for trees and shrubs in the lowland forests of Malaysia, and is close to the median value for all 820 species of trees and shrubs at Pasoh (Kochummen, LaFrankie, and Manokaran 1991). It is also similar to the natural density reported for *A. agallocha* in India (Beniwal 1989).

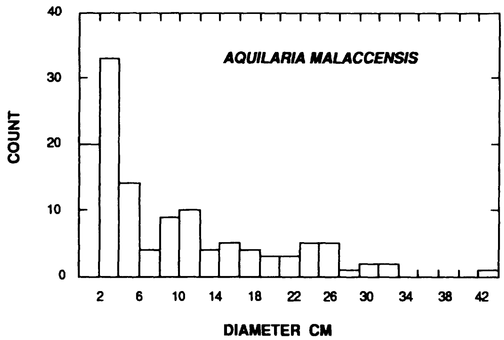

Fig. 3. Frequency distribution among diameter size classes for *Aquilaria malaccensis* at Pasoh Forest Reserve, Malaysia.

The largest tree was 41.3 cm d.b.h., and the density of trees over 10 cm d.b.h. was slightly less than one tree per ha. Assuming a reproductive size of roughly 10 cm d.b.h., the juvenile to adult ratio is only 1.5, much lower than for many trees of a similar maximum diameter (Fig. 3). Canopy trees in the Dipterocarpaceae typically have juvenile/adult ratios of 10–100 (for comparison with other trees at Pasoh see Manokaran et al. 1993). Recruitment may be hampered by low density, but it is not prohibited (one tree was found in fruit during the census); four 1 cm d.b.h. trees were recruited during the census interval. Based on a median inter-census time of 2.81 years, the recruitment rate was 1.42 trees per year for the entire fifty-ha, or 1.13 percent annually. Five trees (4.0% of the initial population) died during the interval, or 1.78 trees per year for the 50 ha, reflecting an annualized mortality rate of about 1.42 percent. Three trees broke during the intercensus interval but coppiced, each tree sending up one new shoot from near the base.

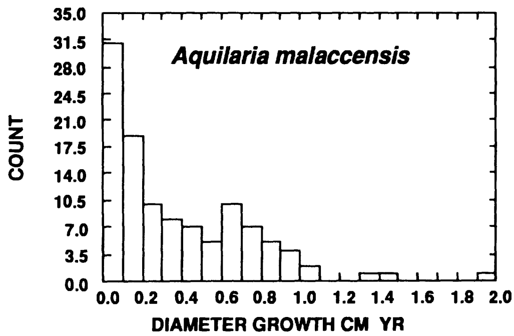

Fig. 4. Frequency distribution among growth rate classes for a natural population of *Aquilaria malaccensis* at Pasoh Forest Reserve, Malaysia.

Growth rates ranged from 0 to 1.95 cm·yr^{-1}. The distribution of growth rates was strongly skewed with a mean value of 0.33 cm·yr^{-1} and a median value of 0.22 cm·yr^{-1} (Fig. 4). The growth rates achieved by the twelve fastest growing trees (the 90% percentile) exceeded 0.80 cm·yr^{-1} and four trees grew faster than 1 cm·yr^{-1}. These rates are relatively high for forest grown trees. Diameter growth rates were uncorrelated with initial diameter (Spearman rank correlation of 0.49).

CINNAMOMUM MOLLISSIMUM

The population of *Cinnamomum mollissimum* consisted of 112 individual trees larger than 1 cm d.b.h., or 2.24 trees per ha, widely distributed throughout the plot (Fig. 5). The largest tree had a diameter of 10.3 cm. Assuming a reproductive adult as 5 cm d.b.h., the juvenile adult ratio is only 3.0, higher than *Aquilaria* but still relatively low (Fig. 6). As with *Aquilaria,* reproduction may be hampered by low density, but it is not prohibited; three new trees were recruited during the census interval. Some trees set fruit at least once in the interval.

Three 1 cm d.b.h. trees were recruited during the census interval. The median inter-census time was 2.68 years, and the recruitment rate was 1.12 trees per year for the 50-ha, or 1.00 percent annually. Five trees, 4.5% of the initial population, died during the interval, or 1.86 trees per year for the 50-ha, reflecting an annualized mortality rate of about 1.66 percent.

Growth rates were relatively small, the median was 0.13 cm·yr^{-1}, and the maximum was only 0.47 cm·yr^{-1} (Fig. 7). Growth and initial diameter were not correlated (Spearman rank correlation 0.29). In three trees the main trunk died but coppiced from the base.

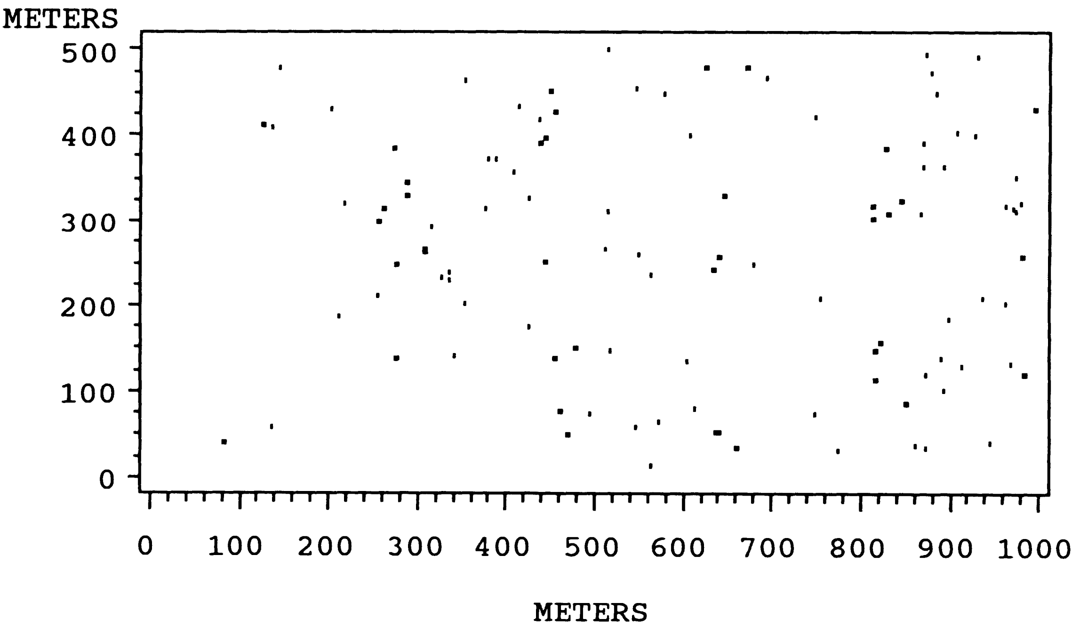

Fig. 5. A map of the distribution of a natural population of *Cinnamomum mollissimum* in the 50-ha plot at Pasoh. Small dots equal trees 1–5 cm d.b.h., large dots equal trees over 5 cm d.b.h. Note that the horizontal distance is 1000 m.

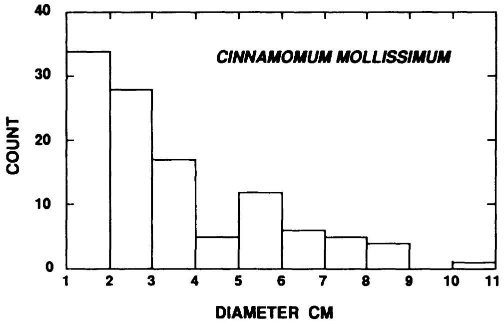

Fig. 6. Frequency distribution among diameter size classes for *Cinnamomum mollissimum* at Pasoh Forest Reserve, Malaysia.

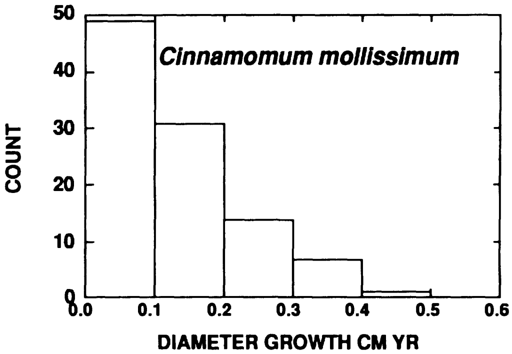

Fig. 7. Frequency distribution among growth rate classes for a natural population of *Cinnamomum mollissimum* at Pasoh Forest Reserve, Malaysia.

DISCUSSION

Ecology shares with economics a special interest in limits. Demographic features of tropical trees limit the potential rate of extraction, and thus, profitability (e.g., Peters 1991; Pinard 1993). When an ecologist describes the abundance and distribution of useful plants, the results will also inform the calculations of the resource economist. In the current example of *Aquilaria* and *Cinnamomum,* the growth, coppicing capacity, mortality and recruitment represent roughly median conditions for tropical trees in Asia, and do not in themselves constrain potential profitable exploitation. However, the naturally low abundance and the widely dispersed spatial patterns, which are likewise typical of lowland tree species, are a great prohibition that will frustrate the commercial harvest of these trees and all similar species.

The growth rates of *Aquilaria* and *Cinnamomum* do not present a problem for its economic exploitation. For *Aquilaria,* the median and maximum growth rates are comparable to growth rates for many timber trees in natural forests (Appanah and Weinland 1993). Also, these rates suggest that *Aquilaria* could be economically grown in plantations or small gardens. The highest rates for *Cinnamomum* were 0.5 $cm \cdot yr^{-1}$, which might be improved upon in plantations, and in any event are adequate to reach a commercial size of 5 cm d.b.h. in 10 years. In addition to adequate growth rates, both species show a capacity for coppicing, suggesting that these species could be rapidly cloned and brought into cultivation. In the light of their growth rates and coppicing capacity, these two species can be recommended for further study as potential crops for the home garden or small plantations.

In a similar way, the short-term data on survivorship and recruitment appears to be favorable. However, both features are known to vary greatly from year to year, and can change dramatically after severe drought and major wind throws: short-term equilibrium often gives way to long-term shifts in abundance (Hubbell and Foster 1990). This cannot be too greatly stressed when extrapolating from short-term data to an equilibrium model (e.g., Peters 1991). Long-term predictions are especially difficult when, as in the present study, we have no estimates of fecundity, or fecundity-size relationships.

By far, the most constraining features of the natural populations of *Aquilaria* and *Cinnamomum* are their low density and wide spatial distribution. This distribution must greatly hinder any effort to collect their bark and resin. In practice, one is very unlikely to ever come across any gharu or cinnamon trees except by making an exhaustive inventory. The situation is even more daunting than indicated by the maps (Fig. 2, 5): finding a single tree within a hectare is all the more difficult when that same hectare is also occupied by 7000 other trees representing 500 or more species. Furthermore, these densities are not unusual or surprising for tropical trees. In fact, they are very nearly the median population size for species at Pasoh (data in Manokaran et al. 1993). Thus, schemes focusing on other forest species will likely face similar problems. As an example we can cite trees bearing edible fruit, for which the median adult population at Pasoh was only 0.2 trees per hectare, and only seven species had more than 3.2 adults per hectare (Saw et al. 1991).

Economists quantitatively compare the alternative ways to use a forest by means of the concept of a net present value calculated per unit area (Norton 1984; Peterson and Fisher 1977). Net present value is the discounted value of future income from a particular investment less the discounted value of expected costs. Costs and benefits of natural resources are notoriously difficult to describe in an accurate and repeatable fashion, and estimates of net present values attached to tropical forest products vary widely (Godoy and Lubowski 1992; Godoy, Lubowski, and Markandaya 1993). In the case of *Aquilaria,* the economic benefits would depend upon: (1) the number of harvestable trees; (2) the quantity of gharu per tree; (3) the quality of gharu per tree. These three factors are sufficiently uncertain so as to preclude the formal calculation of a meaningful net present value. Nonetheless, the process of analysis, while more than a little speculative, is a useful means to examine the range of possible outcomes relative to other land-use alternatives.

The quantity and quality of gharu per tree is unpredictable. Gianno (1986b) suggests only one in ten mature trees (>20 cm d.b.h.) may contain any gharu at all; the lowest price would be roughly comparable to the standard price of MR 2.50 per 100 gm (US\$10.00 kg^{-1}) found in Indian spice shops throughout Malaysia for the lowest grade of *A. agallocha.* Gianno (1986b) reported claims for top prices as high as MR 1500 kg^{-1} (US\$550 kg^{-1}), but her actual observations were for MR 625 kg^{-1} (US\$250 kg^{-1}). It should be emphasized that most trees will have no gharu at all. The lower estimate, and most likely outcome, would be near zero. For an upper estimate we assume, perhaps generously, that one tree in ten produces gharu at the rate of 1 kg for a 20 cm d.b.h. tree, fetching a sale price of US\$200, then the initial crop from Pasoh forest can be estimated as having a potential sale price of US\$7.60 per ha. Assuming a growth rate equal to the observed median of 0.22 cm yr^{-1}, and an annual mortality rate of 1.6%, the crop after 90 years (the time it takes a 1 cm tree to reach 20 cm) would have a sale price (non-discounted) of \$10.00 per ha, or an annualized sale of only about 11 cents per ha per year.

Cinnamon bark is more or less consistently marketable at rates of about US\$0.20 per gm. The present crop of cinnamon can be estimated as 28 trees over 5 cm d.b.h. each providing 100 gms of bark, yielding about US\$11.20 per ha. To estimate a future crop, we assume an annual mortality of 1.8% and a growth rate equal to the observed median of 0.1 cm yr^{-1}, after 40 years there will be 40 trees greater than 5 cm d.b.h. in the 50 hectares, representing a potential (non-discounted) sale of US\$16.00 per ha, or an annualized sale of less than US\$0.30 per ha per year.

Costs associated with the harvest and marketing will be dominated by the labor of searching. The prevailing minimum wage in Malaysia is now about 20 MR per day (US\$8.50). How much labor is required to find trees that are scattered at densities of one adult in every two hectares? Obviously, this is where the low natural densities of these species becomes an overwhelming problem, and, as a single-product scheme, the extraction of either gharu or cinnamon will not likely appeal to self-employed labor. Simply to earn a minimum wage would require the good fortune to find trees that fortuitously bear a good crop of quality product, and as a practical matter, few people bother to search for them. It is highly unrealistic to predicate a rural development program on single-product schemes such as gharu or cinnamon.

In the introduction I asked if the extraction of either of these products, practiced on an industrial scale, might bolster the value of forests that are currently viewed only as sources of timber. In contrast to single-product schemes, timber extraction has the advantage of relying on a mix of potentially commercial species. Consequently, even though individual timber species may have densities no greater than that of *Aquilaria,* first-time exploitation of lowland forests for timber can yield 30–80 m^3 ha^{-1}, or something on the order of US\$3000–5000 ha^{-1}. In 1988, the State of Sarawak had total timber sales (logs, sawntimber and products) of just under one billion US dollars (Anonymous 1992b). In comparison to figures like these, the supplemental contribution from the first harvest of either gharu or cinnamon, amounting to little more than US\$10.00 ha^{-1}, would be negligible. Sustainable rates of timber production in mixed natural forests are controversial: optimists hope for about 3 m^3 ha^{-1} yr^{-1}, or an annualized sale of a few hundred dollars depending on species and grade. Here again, the annualized sale of gharu or cinnamon would be a negligible supplement.

The results of the present study suggest that the main problem with single-product schemes in Asia is the low natural density of the relevant populations, which has the immediate consequence of maintaining low economic benefits per hectare, and high costs of searching per tree. One means of promoting an economic harvest when species naturally occur at low densities is to combine a great many species under the commercial scheme. This would boost the overall population of useful trees and increase the productivity of searching. For example, by combining the two products of this study, *Aquilaria* and *Cinnamomum,* and assuming no ecological or economic interaction between the species, the cost of labor decreases as searching time is combined. If thirty or more alternative forest products could be managed for more or less simultaneous extraction from a forest compartment, then the economic portrait might greatly improve. Tropical forests are famous for their wealth of known and hidden commercial goods. These riches naturally lead to the idea that tropical forests might be managed like a supermarket, where rattan, fruits, nuts, latexes, resins, specialty timbers and myriad other products could be harvested on an ad hoc basis. One could at least imagine that the sum net present value would exceed current net present value for other land uses.

This scheme might be referred to as "High Diversity Forestry" and is a tempting proposition in that its main economic goal of maintaining high diversity would coincide with an important international conservation goal. The feasibility of such a scheme will require a greatly enhanced management capability, extensive work on market development, and a far more complete portrait of individual products than what is available today.

ACKNOWLEDGMENTS

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Book Review

Volatile Oil Crops: Their Biology, Biochemistry and Production. Robert K. M. Hay and Peter G. Waterman (eds.). 1993. John Wiley and Sons Inc., 605 Third Ave, New York, NY 10158. 185 pp. (hardcover). $115.00. ISBN 0-470-22087-2.

Volatile (essential) oil crops yield a wide range of products, like fresh and dried herbs, volatile oils and oil isolates, and various oleoresins. These products find diverse applications in the food, beverage, perfumery and pharmaceutical industries. Increased concern for the environment, and for the safety of food, has led even more towards the use of volatile oil crop products. Many of the more recent fast foods are flavored with these products. In addition, volatile oils have antioxidant and preservative properties, and prevent food spoilage. Thus, the demand for these products has encouraged a number of countries to evaluate a range of volatile oil yielding species as alternative crops. This change has led to the rapid development of scientific and technical literature on the field of essential oils.

Volatile Oil Crops is presented in eight chapters: introduction, botany, physiology, chemistry of volatile oils, genetics, biological activity of volatile oils, biotechnology of aromatic and medicinal products, and commercial aspects. The botany part discusses the taxonomic distribution and geographic origins of plant species exploited for volatile oils. This chapter concentrates on the culinary herbs, mainly members of the Labiatae (Lamiaceae), Umbelliferae (Apiaceae) and Compositae (Asteraceae). The chapter on the physiology of volatile oil crops discusses the influence of the environment and management on growth development and yield. The chemistry part briefly outlines the chemical composition of volatile oils, indicating the range of compound types that are involved, their biosynthesis and quality analysis. The chapter on biological activity of volatile oils addresses issues such as why plants produce volatile oils and their significance to mankind. The part on biotechnology of aromatic and medicinal plants reviews the advances in tissue culture of plants for the production of secondary metabolites, including volatile oils. The last chapter, commercial aspects, presents an analysis of the world trade in the products of volatile oil crops. Each chapter has an extensive and up-to-date reference list. The book then ends with chemical and botanical indices.

We would like to point out one or two minor errors, so they could be corrected in future editions. In page 52, fig. 4.7b, DMAPP, a 5-carbon structure is presented as having 6-carbons, and on page 54, fig. 4.8, the structure for myrcene is incorrect. Otherwise, this highly informative book is a valuable contribution to the advancement in the field of volatile oils. We would like to recommend the volume to all those involved in this area.

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