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VARIABILITY IN FLOWER INITIATION IN FOREST TREES

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I. INTRODUCTION

Most species of forest trees scarcely qualify as 'crop plants' at present. Among the primary reasons for this are the irregularity in their reproductive behaviour, and our general ignorance about its control, which prevent forest trees from being subjected to the regular improvement by selection and breeding that is routine for the majority of herbaceous and plantation crops. The extent to which forest trees lag behind can be appreciated by imagining the response from farmers if they were offered cereal, root crop or grass seed described only by the geographical region from which it originated.

In the tropics, seed supplies are frequently limited because of sparse flowering and/or short periods of seed viability (eg Dipterocarps, Wycherley 1973; Longman 1984a; *Triplochiton scleroxylon*, Leakey *et al.* 1981; *Agathis* spp., Bowen & Whitmore 1980). Seed-set is often poor in *Pinus caribaea* var. *hondurensis*, giving few viable seeds when the species is grown as an exotic at low elevations between 9°N and 9°S (Gallegos 1981). In Britain, home-produced seed is seldom or never available of *Abies grandis*, *Sequoia sempervirens*, *Metasequoia glyptostroboides* and some *Nothofagus* spp., and this is one factor restricting their use in arboriculture and forestry.

Differences in flowering among provenances and individual trees can cause problems, even where seed supplies are plentiful. For instance, provenances of *Pinus contorta* from south and central interior British Columbia, which are of special interest in the UK, produce heavy seed crops in Britain less regularly than some other less desirable provenances. In general, the progenies of individual forest trees with inherently profuse pollen and ovule production will tend to predominate in seed collected from plantations and seed orchards, so that special steps may be needed to avoid an inadvertent tendency to select profusely flowering trees.

Indeed, without reliable flower induction it is quite difficult to start reaping the benefits of genetic selection of forest trees through seed. Identifying desirable parents is relatively inefficient because it is phenotypically based, and the trees are already too large for easy handling. Even when they have been vegetatively propagated as adult clones, and established at a single site, several years may pass before flowering begins. Variability in the occurrence, timing and sex of flowers adds to the problems, and the flowers become progressively more inaccessible. Because of the long juvenile period, a succession of crosses in a planned breeding programme is out of the question. Not surprisingly, therefore, a high priority has been assigned over the last few decades to the solution of problems concerning flowering.

Progress to date has been slow, but two promising developments may be mentioned, both of which allow substantial miniaturization and standardization of research plant material. First, by using standard horticultural techniques for rooting cuttings, clones can easily be produced of many forest tree species, at least from young trees. Attention can then be concentrated on species and selected clones which flower regularly and early in life. Second, in the Cupressaceae, the initiation of large numbers of male and female cones can be reliably stimulated with gibberellic acid (GA_3) in known positions on the shoots. These two approaches enable forest tree research itself to be 'domesticated', such that the physiology of flowering can now be studied experimentally with known genotypes under defined conditions (Longman 1982; Manurung 1982).

The key steps in floral induction are the initial stages during which an apex is transformed from a vegetative to a reproductive state: once initiation can be obtained at will, later development can be studied relatively easily. Ross and Pharis (this volume) have reviewed the factors affecting flower induction in forest trees. In this paper, I shall review the changes in flowering ability that occur with age, variation in the distribution, timing and sex of flowers, variation between species and genotypes; and I shall suggest approaches to solving problems concerning flowering.

II. CHANGES WITH AGE

The great majority of forest trees do not start flowering until they have grown vegetatively for a number of years (Wareing 1959; Doorenbos 1965; Zimmerman 1972, 1976), and frequent reference is made in the literature to the presence of a juvenile period and to studies with *Hedera* (ivy) which changes abruptly from a juvenile to a mature leaf shape. Tables showing the ages when reproduction usually begins have been produced for forest trees in the UK (Matthews 1955) and USA (Schopmeyer 1974), and for some commonly planted tropical forest trees (Longman 1984a). Various modifications in shoot morphology, growth habit and phenology also occur as a tree becomes older, but these are not necessarily coincident with each other or with the onset of reproductive ability. An example is the 'grass' stage of *Pinus palustris* and *Pinus merkusii*, in which the elongation of the stem (but not of the leaves or roots) is inhibited for several years, starting from germination in *P. palustris* (Brown 1964). In this species, the 'grass' stage persists for much longer than the period of months during which young seedlings produce only primary needles, and is shorter than the time to first flowering, which averages at least 20 years (Krugman & Jenkinson 1974).

A broad distinction may be made between changes that occur with age which can be easily reversed, and those which are relatively permanent. For example, vigorous branches on young seedlings tend to show a progressive decline in growth rate, and in the production of lateral buds, as the number of competing apices increases with time. This process of *ageing* (Wareing 1959) can be reversed, for instance by pruning (Moorby & Wareing 1963), or by detaching the shoots and propagating them as rooted cuttings or grafted scionwood. However, other characteristics which trees attain when they grow older are quite firmly retained after vegetative propagation, suggesting that a process of *maturation* or *phase-change* has taken place. Thus rejuvenation (in its strict sense) of adult or mature tissue is rather uncommon (see, however, Paton *et al.* 1981).

Evidence for ageing may be readily observed in conifers from changes in the number, vigour and type of vegetative shoot on successively older branches. For instance, at the tops of mature *Picea sitchensis* grafts, and on first-order shoots on the main branches, most or all of the terminal buds contain preformed shoots and lateral bud primordia in winter. The total number of buds with preformed shoots per branch increases from the one-year-old branches at the top of the trees to the four-year-old branches below, but below this level the number decreases because an increasing proportion of the buds contain only a living apex and bud scales. Failure to form preformed shoots is particularly true of third- and fourth-order shoots, which are mostly weak and fail to produce lateral bud primordia.

Adult grafts or cuttings of forest trees may not flower for several years, possibly because the shoot apices are close to the roots, or because time is needed to produce the type of branches on which reproduction is possible – the term 'secondary juvenility' has been coined to distinguish this phenomenon from the 'primary juvenility' of young seedlings. Shoots arising near the base of older plants, and especially coppice sprouts, are generally held to have retained much or all of the primary juvenility of the seedling plant (Sax 1962; Doorenbos 1965).

These concepts of ageing and maturation emphasize the difference between plants developing 'ripeness-to-flower' (Klebs 1918), and their response to what might be described as the 'opportunity-to-flower'. In practice, however, it is often difficult to know when the juvenile period has ended, particularly in irregularly flowering species. When a dominant tree flowers, and a suppressed tree does not, both might be mature, but the latter could just be inhibited by competition. Moreover, some fundamental contradictions appear if the classical *Hedera* situation is used as a rigid model for forest trees.

One problem is that certain treatments will induce flowering during the first three years of life in supposedly juvenile seedlings and cuttings. For example, three sexual generations have been achieved in eight years with *Triplochiton scleroxylon* grown in glasshouses in Scotland (Leakey *et al.* 1981),

B. Topic organization

Economics is useful in (a) evaluating possible tree crop alternatives, (b) selecting the best of the possible alternatives, (c) tracking performance, and (d) assisting designers to specify criteria for, and to develop, more productive patterns for tree crops. In this discussion, I do not dwell on these classic roles for the forest economist, but focus instead on a broader understanding of why research on trees as crop plants makes economic and social sense, especially in the Third World.

My comments are organized around the following six topics:

1. the concept of a 'production function', and its usefulness in organizing managerial information produced by research;
2. the economics of timber scarcity, and the causes of real increases in the price of standing timber (stumpage prices);
3. the evolution toward design-orientated research to create the forests of the future;
4. the implications of timber economics, regarding the distribution of net benefits between this and future generations, and between rich and poor people today;
5. the synthesis of factors affecting efficiency and the distribution of wealth in the context of timber scarcity; and
6. the criteria suggested by these lines of reasoning that might guide the design of future forests.

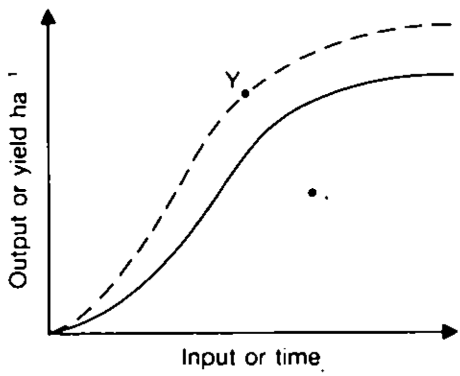

FIGURE 1. The economic 'production function' is the S-shaped biological growth function that defines the technically most efficient input–output relationship. It separates the possible but technically inefficient (point X) from the technically impossible (point Y).

II. TREE AND STAND PRODUCTION PROCESSES

The 19th century agronomic experiments at Rothamsted provided the economist with a conceptual linkage to biophysical reality. This was because the S-shaped curve between plant growth and time, and often between yield and an input, is the form of the 'production function' which is the foundation of production economics, and underlies much of what follows about economic supply and macro-relationships between costs and prices (Fig. 1). While as useful empirically today as it was to the emerging agricultural science of 100 years ago, the 'production function' hides a chain of causal relationships inside a simple predictive model. It implies that changes in input levels 'cause' changes in output levels; explicitly it implies that the output resulting from input manipulation by forest managers can be predicted with known levels of precision and accuracy.

A. Disciplinary concerns

Some of the confusion in communication between economists and biologists results from their approach towards cause and effect.

Economists, as disciplinarians, are concerned with the variety of cause and effect relationships pertinent to why prices for goods and services change, why goods and services are reallocated, why the total sum of goods and services changes, and why societies and the individuals who compose them become richer or poorer as a consequence. Economists often assume that biophysical relationships are stable, or they treat them as if they were exogenous to the causal interactions under consideration. If research and development are key input factors under managerial control, then it is essential to consider the production relationships that are central to the dynamics of prices and quantities of goods and services.

Biologists, as disciplinarians, are searching for more and more fundamental causal relationships, although in applied biology attempts to extend the frontiers of knowledge must be balanced against the practical goal of useful results. Usefulness virtually always is defined in economic terms, although hopefully not as narrowly as is common in financial analysis.

The conjunction between applied biology and applied economics is defined by a central question: how can we improve the design of future forest stands in terms of their economic productivity?

B. Applied research and production functions

Optimization is a mathematical term which means maximization (or minimization) of a function subject to constraints. A 'production function' describes a basic constraint on the maximization of profit or present net worth, and research produces information which relaxes that constraint.

Managerial intensification really begins when it makes sense to control regeneration – that is, to control the species which is grown, the spacing, level of competition, and so forth. The basic relationships between inputs and benefits are understood for simple forest systems. Most applied silvicultural research is, in effect, the calibration or quantification of equations for specific sites and needs, so that basic standards are established about what is possible.

Once this standard is in place, two rather different research tasks are possible. First, we can diagnose why a given stand is below the possible level (point X in Fig. 1). Second, we can design new alternatives that enable us to raise the production function (point Y in Fig. 1).

The objective of design research is to shift the production function or growth and yield relationships upward. Examples include (a) earlier establishment of new growing stock after harvest, (b) spacing operations to increase stemwood quality, (c) fertilization where early root development or mature photosynthetic rates are constraints, and (d) redesign of harvest and processing equipment to favour smaller logs and shorter rotations (Brown *et al.* 1982). There is room for considerable refinement in most situations, especially when tree improvement and genetics are part of the total strategy. Physical gains of 200–300% are possible when solid-wood cubic volumes are the objective.

Measurements of production functions and stand productivities require that we define the product of value. The product may be total biomass (dry t $ha^{-1}yr^{-1}$), above-ground biomass (dry t $ha^{-1}yr^{-1}$), above-ground cubic volume to a large top diameter for solid-wood products (m^3 $ha^{-1}yr^{-1}$), fruit or seeds for food, oil, or regeneration purposes (kg $ha^{-1}yr^{-1}$). These different perceptions of production can be defined in terms of stand age and stems per hectare (spacing) as the inputs that are manipulated (Cannell 1983a,b; Huxley, this volume). Obviously, more and more of the total production is ignored (made invisible) as we refine what we consider to be the valuable part of the plant. Because it is difficult to increase total biomass production per hectare, it is usually easier to increase the production of parts of trees and stands that are biologically scarce (like fruits or extractives) than those that are biologically abundant (like leaves and wood).

III. TIMBER SCARCITY AND PRICE

When we say that something such as trees, fruits or pleasant sylvan environments are scarcer, we mean that it costs more to acquire or rent them than in an earlier time. Scarcity, in other words, is a measure of change, and the index is 'change in real price per unit'. The quality of the index depends upon how well the markets function that determine price, and the time interval involved. Although many markets for fuelwood, timber, various amenities and other forest products are imperfect, over substantial time periods even imperfect price responses give quantitative, if often imprecise, evidence of scarcity.

A. Supply and demand

Price is the result of interactions between supply and demand. As concepts, both supply and demand are schedules, or functions, that relate quantities to prices in a given time period and market area. Supply is the collective term for the quantities sellers would market at various prices, and demand is the quantities buyers would purchase at various prices. Where both are equal, an equilibrium exists and the market clears. Scarcity occurs whenever demand increases, or 'shifts out', supply decreases or 'shifts back', or both (Fig. 2A).

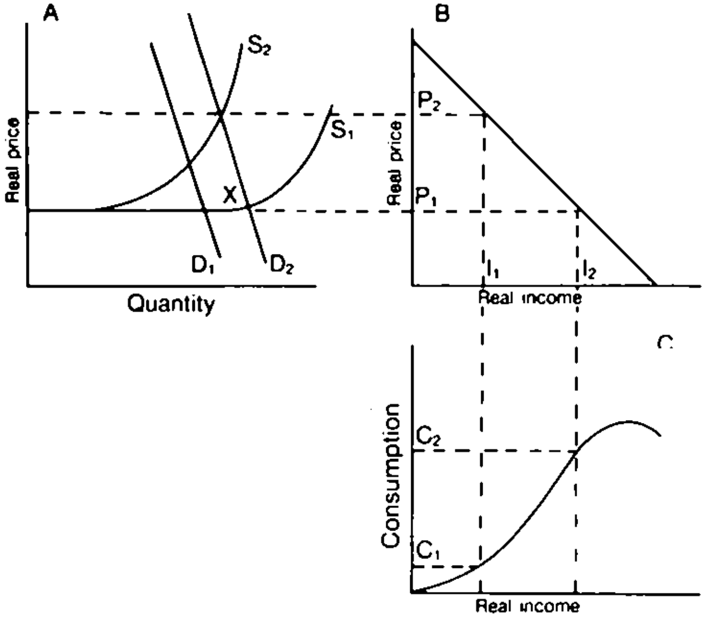

FIGURE 2.

A. The relationship between the price of goods or services and the quantity of those goods or services. A decrease or 'backward shift' in supply from S_1 to S_2, and an increase or 'outward shift' in supply from D_1 to D_2, lead to a price increase from P_1 to P_2. This price increase is a measure of the scarcity of those goods or services. Point X is explained in the text.

B, C. An increase in price from P_1 to P_2 is equivalent to a decrease in income from I_2 to I_1, which leads to reduced consumption from C_2 to C_1. The relationship between income and consumption, for most goods and services, has a phase of increasing rates of consumption per increment of income, followed by decreasing rates, and finally a decline in total consumption.

Demand for timber comes from its various end uses such as fuel, pulp, plywood or lumber. The markets for most of these products have 'demand functions' that are quite inelastic; that is, a major price change does not have much effect on the quantity purchased. This is so either because the product is essential (eg as fuel for cooking) or because it forms a minor part of the total consumer cost (eg lumber in a new house). Shifts in demand occur with changes in population size and composition, discretionary income, availability of mortgage funds, and so forth. With some exceptions, the inelastic demands for timber-based products are translated into even more inelastic demands for standing timber.

The supply of timber, in most cases, can vary over a broad range with little change in price. The price rises as access costs are incurred, which has been an important factor in the supply of timber from mountainous areas of North America. At some point (X in Fig. 2A), the capacity to harvest and supply more timber from a given forest begins to have a negative impact on its future growth. At this point, a balancing act begins between today and tomorrow, based on rational expectations (Berck 1979; Lyon & Sedjo 1983). Expectations about the future, with regard to increased value resulting from biological growth, quality changes and price changes, are balanced against the perfect certainty of today's values (Bentley *et al.* 1985). Individuals, and collectively the market, attempt to earn the real rate of interest, plus an appropriate 'risk premium' (Sharpe 1981). To do so, thay must anticipate shifts in demand, and shifts in supply, especially those resulting from a decrease in the amount of standing timber.

B. Scarcity

Assuming that the market period is one year (over which biological growth and consequent quality changes are not of major importance), the current supply of timber inventory to the market is the reciprocal of current demand for future inventory (Bentley *et al.* 1985). An equilibrium between supply of, and demand for, inventory is achieved when the rate of value increase is equal to the real rate of interest (about 3%) plus the premium for accepting both biological and market risks, which appears to be 2–5% for timber investments in commercial species. The argument is not that such a market works perfectly, especially as judged after the fact, but rather that there is an understandable and predictable process that rations timber inventories into the marketplace.

Worldwide, timber has been getting scarcer. Berck (1979) estimated that *Pseudotsuga menziesii* timber prices were rising at 5% per year; Bentley *et al.* (1985) found that Connecticut *Quercus rubra* prices for standing timber have increased since 1972 at 8·6% per year; and Bentley (1985) estimated that the general timber prices in India have been rising at 5·8% per year for over a decade. Other investigations of natural resource prices have identified timber to be among the few resources where scarcity is an issue (eg Barnett & Morse 1963; Smith 1979; Skog & Risbrandt 1982). Although the phenomenon of timber scarcity has not been fully explained, prices are rising to yield a rate of growth in investment of 5–9% per year in real terms (after subtracting the effects of inflation). There have been occasional short-term rates of increase that are considerably higher as species enter new markets – for example, *Tsuga heterophylla* and *Populus tremuloides* after World War II, *Q. rubra* in Connecticut over the past decade, and many tropical hardwood species today.

Owners of young, rapidly growing timber stands also benefit from biological growth and increases in bole sizes and wood quality with age. Real rates of return of 10%, to occasionally even 20%, are possible for new investors in timber, if they take advantage of current knowledge and the latest methods for plantation management. At the market level, we can envisage a 'net inventory adjustment' between the increment in growth and the amount harvested. Harvest of inventory, with subsequent reinvestment in protection, regeneration and other inputs, eventually leads to a balancing between growth and removal. At this balance point, there are no changes in the amount of standing timber, so that this factor cannot cause the supply of timber in the current market to decrease. In that case, the price can rise only if demand increases. But when the amount of standing timber increases (ie when growth exceeds removals), then prices will fall, unless demand is increasing faster than supply.

IV. EVOLUTION TOWARDS FOREST DESIGN

Several implications can be drawn from our understanding of timber scarcity that are important in the design of future forests. One is a reinterpretation of the history of forest harvesting and reinvestment. To illustrate these points, I shall consider the Indian subcontinent and North America, which have experienced similar histories of forest exploitation in general terms. Originally, what is now India, Pakistan and Bangladesh was 80% or more forested (Warner 1982). The original percentage forest over North America as a whole was much less than 80%, but there were many regions with 75% or more forest cover (Dana & Fairfax 1980). Starting over 3,000 years ago on the Indian subcontinent, and 350 years ago in North America, forests were deliberately cleared to provide land for cultivated food crops. More or less simultaneously, trees were harvested for construction materials, fuelwood and other purposes. No particular plan guided what was cleared or harvested, or for what purpose. Both land and timber were abundant, and the costs of cultivatable land, fuelwood and construction materials were essentially the costs of the labour required to obtain them.

A. Depletion and conservation

Serious overcutting of forests began in both regions about 1860, usually accompanied by fire, grazing and other ecological factors that retard regeneration and reduce total biomass productivity. Such practices are often described as forest exploitation. However, Ciriacy-Wantrup (1952) defined the shift of use-rates toward the present as 'depletion' and the shift of use-rates toward the future as 'conservation'. When accompanied by explicit objectives, and active reinvestment, both conservation and depletion become resource management. A critical question is why do these shifts occur?

Forests are overcut, in the sense that removal rates exceed timber growth, for four reasons (Bentley *et al.* 1985). First, overcutting occurs when capital and raw materials are scarce, and when they can be obtained by cutting timber which is abundant (eg in past times). Second, overcutting occurs when a forest is mature and its growth rate is virtually zero, so that the only way to increase growth is to harvest some of the old trees and to replace them with new ones. Third, overcutting occurs when interest rates, which guide investment and liquidation rates, exceed the rate of increase in value of the forests; as a result, the inventory is decreased by cutting older trees, thereby increasing the value growth rate of the remaining forest. Fourth, overcutting occurs when this can make forest assets more 'efficient', in the sense that a given annual growth can be obtained from less standing timber capital or more annual growth can be obtained from the current forest capital. Points one to four are roughly a historical sequence, with forest design becoming an important activity after improvement in the input-output 'efficiency' of timber assets.

B. Forest management

The first sign of timber scarcity is a concerted effort to protect forests. Clearly, protection makes sense only if what is protected has value, taking into account any expectation of future price increases. About the same time, extensive management begins. This management is most successful if it (a) imitates the natural ecosystem, (b) is a selection, group selection, or 'patch clearcut' system, and (c) requires little initial investment. Hibbs and Bentley (1984), for example, established that spacing is the critical factor to manage with *Quercus rubra*/mixed hardwood stands, established by natural regeneration in southern New England. Extensive management systems, if focused on high-quality logs, can produce competitive real rates of return with virtually no net investment. Unfortunately, many of the early extensive management systems observed were based on faulty ecological and economic premises. The consequences were dramatic shifts in forest composition, often away from the most valuable subclimax species and towards scrubs of one kind or another. This move was especially pronounced in areas where seasonal droughts and grazing combined to make natural regeneration of desired species a slow process, if it occurred at all. Many vivid examples of these shifts following initial harvesting can be observed in the American west and in the semi-arid tropics of India.

The shift towards intensive management is stimulated by scarcity. Intensive management was first practised on a major scale in nations that either had seriously depleted their natural forests (such as Great Britain) or found the native species difficult to utilize (such as Australia and New Zealand). Plantations were established in North America before World War II, but most were the products of public works or soil conservation programmes, not of real concerns about timber scarcity. In the post-War period, demand for house-building and other construction increased the prices of lumber and plywood, and these higher product prices were then translated into higher timber prices. The market has reflected a steady increase in scarcity since the early 1950s.

C. Research and forest design

It is not by chance that the 1950s was the period of rapid transition toward intensive plantation forestry in the American south and Pacific Northwest, with the concurrent development of forestry research groups in several industrial firms. During this period, tropical forest depletion rates increased dramatically (Gillis 1984). European, North American and Japanese firms were looking for new sources of raw material for conversion (to fibre board, etc), to meet product demands, and to bridge age gaps in their local timber resources. And Third World nations had entered into a period where conversion of natural capital into liquid assets made sense in terms of currently conceived development strategies. Gordon and Bentley (1970) described this shift to intensive plantation forestry as similar to the transition from a 'hunt and gather' economy to a rational and scientifically based agriculture. It is at this point that forest design makes sense.

V. DISTRIBUTION OF WEALTH

There are some implications regarding the distribution of wealth that should not be overlooked in our understanding of this transition. Conservation has often been viewed as a public responsibility. In part, this view reflects the traditional ownership of forests, water, wildlife and many other renewable natural resources by the raj, king or modern nation state. It also represents a response to market failures caused by (a) traditions and institutions, such as common property rights, (b) 'spatial externalities', especially of the upstream/-downstream variety, and (c) low to zero prices (lack of scarcity), which inhibit efficient market function. One reason for public intervention to stop tropical forest destruction is that it may be too late if left until scarcity is recognized and acted upon by the market. Another reason, although seldom stated in these terms, is that the rich want to take benefits from the poor of today and tomorrow.

A. Distribution over time

There are many questions about the optimal balance between conservation and depletion that have yet to be resolved, especially where markets do not reflect critical values. The most obvious omission, of course, is that the unborn cannot vote in the current marketplace. Nonetheless, once markets for timber 'futures' (timber to be delivered at future dates) begin to function, there will be a process that allows actual and potential holders of timber assets to anticipate how future markets might vote, and to act accordingly. At best, this process will be imperfect, but it can only be judged in the light of the alternatives. The performance of public agencies in lieu of the market does not provide much basis, in my opinion, for optimism about administrative non-market mechanisms for allocating between rich and poor, or between present and future generations.

B. The poor as consumers

Foresters and tree scientists should become conscious of the issues concerning the distribution of wealth that are inherent in the flow of forest assets and products between rich and poor, because these issues will be relevant for several decades. The consequences of poverty are most obvious in terms of consumption. The relationship between income and consumption, shown in

Figure 2C, looks a bit like the 'production function' mentioned earlier: a phase of increasing rates of consumption per increment of income is followed by decreasing rates, and finally a decline, in consumption.

Fuelwood provides a useful illustration. The extremely poor cannot acquire adequate fuelwood for cooking or heating, either because their incomes are very low, or because it takes too much time and energy to gather wood in wood-scarce areas. Consequently, increases in real income go disproportionately to acquiring more fuelwood. At some point, basic needs are met. Further increases in income may be used to have more hot water or a bit more comfort in cold weather, but these increased comforts take smaller proportions of the increments in income. Above some level of income, families shift towards more convenient fuels, such as bottled gas, charcoal and coal, and total fuelwood consumption drops. This happened long ago in North America, and the recent return to fuelwood is largely an adjustment to the rapid upward shift in the real price of alternative energy sources. The same phenomenon can be observed in India, where virtually all rural people use fuelwood, leaves, crop residues and dung for cooking and heating. Even in this context, rural families aspire to shift towards other fuels, and do so when their incomes rise (Pendse 1984). City dwellers do so at even lower incomes because of access to lower cost, more convenient fuels. In New Delhi, for example, the fuelwood demand has been cut substantially by this shift to bottled gas and other convenient fuels (Bentley 1985). Given the role that fuelwood harvesting for urban areas plays in forest degradation, this income-driven substitution is helpful, because it gives more time to resolve several critical forestry issues.

C. The poor as producers

The poor as consumers represent one aspect of the question concerning the distribution of wealth. Another aspect is the poor as suppliers of labour. A simple, but not false, way of looking at poverty is in terms of labour scarcity, especially when considering the plight of people at or below subsistence levels. Just as there is a modest minimum price for timber over a wide quantity range, so there is a modest minimum price for unskilled labour at more or less subsistence wages. Scarcity of such labour occurs when (a) the general economy has a high demand for both skilled and unskilled labour, (b) people invest in their own 'human capital', upgrading their skills and moving into better paid jobs, and (c) wages are driven up by the interaction between increasing demands for labour and decreasing supplies of labour. If increased demand does not cause scarcity of unskilled labour – a not uncommon problem in western nations – a combination of minimum wage laws and various income transfers can lift the minimum income above subsistence levels, but at the price of higher permanent unemployment. In Third World nations, the gap is simply too large to use such schemes; the only possible strategy is to increase the demand for unskilled labour.

One means of increasing the demand for labour is the so-called 'supply-side' or 'trickle down' approach. Basically, 'aggregate economic growth' in terms of total production of goods and services is expanded more rapidly than the population, thereby creating a labour scarcity. Although population growth rates have fallen drastically in India, and in many other tropical nations, there is an enormous challenge to find enough jobs for the currently unemployed and underemployed, and for those who will join the labour force in the next two decades. Economic expansion alone is unlikely to bridge this gap in most Third World countries until well into the next century (eg Krishna 1980).

One of the appeals of 'community forestry', wasteland rehabilitation and similar schemes is that they have high labour/capital ratios, and potentially they use massive amounts of unskilled labour. In fact, some preliminary analyses in India suggest that labour would be a constraint, if there were nationwide schemes for rehabilitation of commonland forests, pastures and wastes (eg Gupta 1978). The obvious additional advantage of such schemes is that capital assets would be produced in the form of 'tree factories' that could be harvested, thinned and spaced, or just left to grow.

D. Institutional issues

There are several institutional and organizational problems that need to be resolved before all the benefits of 'social forestry' and similar schemes can be realized (Bentley 1985). Most of these centre on tenure rights for land, trees and grass (eg Fortmann 1984), and community-based organization of credit, technical knowledge and the like (eg Chowdhry 1982). In time, applied research can contribute greatly to assisting the rural poor. The first step is simply for applied scientists to recognize the poor as one of their clients (Biggs 1982; Chambers 1983).

VI. SYNTHESIS OF EFFICIENCY AND DISTRIBUTION

'Economic efficiency' issues are concerned with the impact on future timber supplies of units of investment, and 'distribution' issues are concerned with who receives the benefits of those supplies.

A. Price effects

The relationships between quantities of goods, prices and incomes (efficiency and distribution) are shown in Figure 2. A supply-demand shift that leads to a higher price (P_1 to P_2) is the same as reducing a consumer's income (I_2 to I_1), other things remaining the same, because the same nominal income will now buy less. The decrease in income is clearly a welfare loss, and it translates into less consumption of certain goods or services (C_2 to C_1). In other words, timber scarcity leads to poor people being worse off as consumers.

B. Income and employment growth

If timber scarcity leads to a major programme of tree planting, and other silvicultural activities that are targeted to hire poor people, the opposite

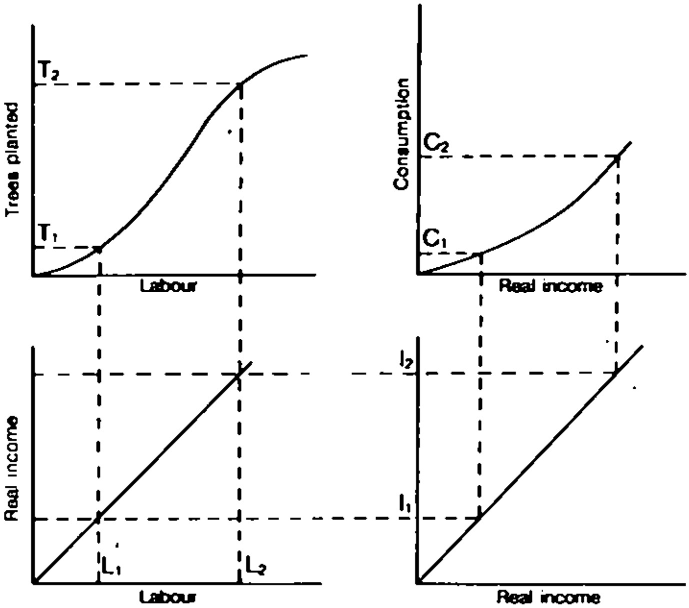

FIGURE 3. Effect of tree planting on incomes and consumption. An increase in tree planting (T_1 to T_2) requires more labour (L_1 to L_2), which translates into higher incomes (I_1 to I_2), and more consumption of essential commodities such as fuelwood (C_1 to C_2).

sequence can take place (Fig. 3): more tree planting (T_1 to T_2) means that more labour is hired (L_1 to L_2), and then real incomes rise (I_1 to I_2), which enables people to buy more fuelwood and other goods or services (C_1 to C_2). The longer term impact is to increase future supplies (shifting the supply function outwards, S_2 to S_1 in Figure 2A), so that future fuelwood prices decline (or at least do not rise as fast), which further adds to the economic well-being of poor people. The rise in wage rates is more substantial if labour scarcity occurs, whether through increases in demand, or decreases in supply because of 'human capital' development. Consequently, responses to timber scarcity can make poor people better off, as both consumers of forest-based products and as suppliers of labour.

C. Household economics and intrafamily distribution

Issues concerning the distribution of wealth also occur within many Third World family or clan units, because the household unit is both producer and consumer (eg Bennett 1983). The most striking issues to the outsider are between women (and often children), who are responsible for non-market activities, and men who are more concerned with cash income. These issues may have implications for forest designs, when a village is at the subsistence level, or in transition to a market economy, especially with regard to energy needs (Vidyarthi 1984). Time or energy savings are equivalent to gains in income and economic welfare, and conversely timber scarcity is the same as an income and welfare loss. The location of tree crops, and the species grown, could be important in determining how the benefits are distributed within families.

D. Asset ownership

Social mechanisms that assist poor people to plant and own trees, especially the allocation of some tenure rights and access to credit or subsidies, may be even more beneficial than hiring the people for public forestry activities. If their preference for consumption, and their aversion to risk, can be dealt with, owning and managing timber investments may provide poor people with higher incomes than the usual minimum wages paid to them for public tree planting. Although the evidence is scanty, there are reasons to believe that the impact on tree planting, and the consequent beneficial changes in incomes and consumption discussed in Section VI B, could be greater if poor people became owners and managers of forest assets (Bentley 1985).

VII. FUTURE FOREST DESIGN

This review of economic efficiency, and the distribution of wealth, suggests the following nine criteria for forest design. The first four concern productivity and efficiency, and are obvious to anyone who has been concerned with applied research on commercial tree crop production; the other five are of more concern if distributional issues are involved, and may conflict to some degree with the first four.

A. Design criteria

1. *Area*

Perhaps the single most important criterion for a design is the area over which it can be applied. It is the criterion that gives tree improvement programmes such high reliable pay-offs.

2. *Time*

The most expensive production expense in forestry is the cost of waiting. A real interest cost of 6% means that costs double every 12 years; current nominal rates of 12% double in 6 years. Planned industrial rotations of *Pseudotsuga menziesii* have declined from over 100 years to 40 or 50 years because of the cost of capital. Intensive systems of growing trees for fuelwood and fibre over rotations of 2 to 6 years are feasible in much of the world with warm, moist growing seasons.

3. *Uniformity*

The most critical characteristics affecting timber values are stem uniformity, roundness, straightness and taper. These characteristics obviously increase timber values for solid-wood products, and they also reduce handling costs for low-value products like fuelwood.

4. *Simplicity*

The common characteristic of large-scale grain farmers, and of large coffee, tea, fruit and timber plantations worldwide, is simplicity. Simplicity enables managers to avoid the constant choices inherent in complexity, and enables them to focus their operational planning and control.

5. *Sustainability*

In its simplest form, a sustainable system never loses productivity. The concept of sustainability is common to many agrarian cultures; forestry's heritage comes from Germany and central Europe (Greeley 1950). The most obvious criteria for sustainable design concern soil stability, water percolation, and nutrient cycling. Simple systems, which often involve single species, may not be sustainable over extended periods in many tropical or near-tropical conditions. Designs that are based on natural balances to control insects and pathogens biologically are likely to be sustainable, but they also are complex.

6. *Flexibility/adaptability*

Markets are sure to change, which has been the undoing of many classical sustained-yield designs. Also, the rate at which new biological knowledge is being applied is remarkable. Usually there are trade-offs between the high efficiency and high-risk option of producing a well-defined tree-based product, and the less efficient, lower-risk option of producing multiple products: risk rises as designs become more rigid. 'Flexibility' anticipates that changes will occur, whereas 'adaptability' reflects a positive response after change has occurred.

7. *Subsistence needs*

Poor families, especially the women and children, have food and energy needs that are often not recognized by professional foresters and agriculturalists. Fuelwood, leaves, fodder and similar goods do not pass through formal markets in isolated villages. Traditionally, these goods have been free, except for the energy women and children have expended on gathering them. During the transition from subsistence to market economic conditions, desirable design criteria may include (a) those that favour a reduction in the effort needed to gather forest-based non-market goods, and (b) those that favour some effort in growing species that aid subsistence, like *Prosopis* spp., rather than those that yield products with a cash value, such as *Eucalyptus* spp.

8. *Initial investment*

For obvious reasons, the poor cannot afford to make high 'front end' investments in agroforestry or forestry. While subsidies, or better access to rural credit, would encourage poor families to use land for social or community forestry, poor people generally prefer to trade their labour (including the farmer as a manager) for capital. By contrast, most corporations favour trading capital for labour, at least up to the point where expected wages equal the expected 'marginal value product' of the labour. One probable reason why poor and corporate forest farmers see this choice differently is that poor farm and family enterprises pay their household members lower wages than corporations pay their employees (eg Galbraith 1979). Consequently, poor families benefit from working for corporations, and corporations benefit from hiring labour from poor farming families.

9. *Risk*

Another substantial difference between poor marginal farmers and corporations (and probably large public forestry agencies) is the nature of the risks that they attempt to minimize. The modern technically based corporation wants predictable cash flows and profits, which it attempts to achieve by substituting capital for labour, and by planning and quality control. By contrast, subsistence farmers have, naturally, an aversion to risks that could bring their food supplies below survival levels.

B. Social science research

Most of this meeting on 'Trees as crop plants' is concerned with improved applied biological research, but I would like to make a plea for concomitant applied work in the social sciences. My illustrations reflect mainly my own interests in economic issues, but many of the problems discussed cannot be resolved without considerable information on applied anthropology, social psychology and other behavioural sciences. Equity and social justice are values to which many of us subscribe, but the actual needs and responses of the poor are factual matters that should be studied with the same objectivity that we apply to the more affluent consumers and producers in the western economies. This requires more applied social science.

IX. CONCLUSIONS

The effective design of future forests requires that biological and social sciences be integrated and focused on the needs of particular 'client groups'. This integration serves two purposes; it shifts our attention to new opportunities where research is not in progress, and it helps us to avoid efforts in areas where results are not possible. 'Client groups' are defined as people and organizations that have similar problems. The client focus is a device to assist us in allocating resources to applied research. Applied research, like virtually all other rational activities, is more effective if focused on a few, rather than many, goals, and progress toward those goals is measured over time by results.

In the Third World, we need to consider the distribution of wealth when defining the 'client groups', for both operational and ethical reasons. Many of the current development activities by national and donor organizations recognize that the poorer half of rural societies will not share in economic progress unless programmes are targeted on them. This is the basis for many of the social or community forestry programmes, and some of the applied forestry research programmes in tropical nations, especially those concerned with agroforestry. The underlying issues are ones of equity and social justice. The poor as consumers are more adversely affected by scarcity than are the rich, but they can benefit from activities to alleviate forest resource scarcity as both consumers and as producers of forest-based income and wealth.

The design criteria that emerge from this discussion are orientated towards productivity and efficiency, in the general sense of attempting to maximize the impact on future timber supplies per cost-unit invested. However, some criteria have implications regarding the distribution of wealth. These involve explicit recognition of the distribution of resources between today's and tomorrow's generations (ie sustainability), between the poor and rich of today (eg fuelwood and fodder vs timber), and between the risks that concern the poor (especially food security) and those that concern the rich (stability and predictability of cash flows).

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