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ECOLOGICAL IMPLICATIONS OF TROPICAL PLANTATION FORESTRY

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SUMMARY

Rampant tropical deforestation requires major expansion of tree plantations to meet the projected demands for forest products. Fast-growing trees have the potential to meet these rapidly increasing demands in developing countries. Serious ecological problems of tropical plantation forestry that need to be avoided include inappropriate land use, site degradation, pests and diseases, and the dangers associated with the small set of plantation species being promoted.

Rapid population growth and inequitable distribution of arable land in tropical developing countries are forcing slash and burn agriculturalists into the wet lowlands and higher in the watersheds where the land is unsuitable for repetitive cropping. Inappropriate land use causes site degradation that can often be changed through reforestation. Despite several potential site improvements associated with plantation forestry, some site degradation may also occur. Successive rotations of a single species plantation may differentially deplete certain nutrients, resulting in diminished growth rates. Complete harvesting may impoverish the site through export of nutrients in the harvested wood. Mechanical site preparation or harvesting may greatly increase soil erosion or lead to physical deterioration of the site. Labor intensive methods may be more appropriate in some cases.

The success of exotic species has been in part attributed to escaping from native pests and diseases. Yet there is also danger for exotics in that pests and disease to which they are susceptible and for which they have no developed resistance may be at their new site. Recent evidence suggests the accumulation of pests and diseases is related to area in plantation. The favorable tropical climates tend to lessen economic risks by reducing rotation length, but also increase some biological risks by providing a benign environment for the growth of pests and diseases.

The dependence upon a small number of tree species for tropical plantations may not be adequate for the reforestation needs of the wet tropics. In spite of the considerable research needs on potential species, site indexing, pest and disease susceptibility, genetic selection and improvement, the greatly increasing demands for wood products and site rehabilitation demand an urgent and massive increase in tropical forestry plantations.

The direct conversion of natural forests to plantations is a minuscule percentage of total tropical deforestation. The establishment of tropical forest

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plantations on suitable lands abandoned by the advancing agricultural frontier has lower social and ecological costs than the conversion of indigenous forests to forest plantations. Given the abundance of abandoned and degraded lands in the tropics and the successful establishment of tree plantations on many of these sites, there are no compelling reasons for converting natural forests directly to tree plantations.

INTRODUCTION

Although opinions differ on the rate of tropical deforestation and how many decades of survival remain for tropical forests (Richards 1973, Persson 1974, Sommer 1976, Pringle 1976, Anon. 1978, Lanly and Clement 1979, Spears 1979, Myers 1980, Zerbe et al. 1980), no one denies the ongoing destruction of the world's tropical forests. In view of the extensive deforestation of the tropics and the pessimistic prognosis for the remaining tropical forests, it is clear that plantation forestry (including agroforestry) must play a rapidly expanded role in the production of forest products in most tropical countries. According to John Spears (1978) of the World Bank, by the year 2000 the developing world will need a minimum of 20 to 25 million hectares of new plantations just for fuelwood consumption. Yet, continuation of the current rate of plantation establishment will produce less than one-tenth of the projected requirement. The firewood crisis affecting the drier tropics like sub-Sahara Africa has been well publicized (e.g. Eckholm 1975). Less well known is the rapid deforestation of once richly forested countries such as Thailand, Philippines, Malaysia, Ivory Coast, Ecuador, Panama and Costa Rica. Depletion of the species-rich lowland dipterocarp forests of peninsular Malaysia has been so rapid, government foresters estimate Malaysia will be a net importer of timber by 1990.

Even in countries undergoing moderate or slow loss of tropical forests, plantation forestry and agroforestry can play important roles in reducing pressures on remaining natural forests as well as alleviating local scarcities of wood. Decision-makers are realizing that unless energy and wood needs of local people are met, the efforts to conserve forest will be doomed. Easily accessible (that is, exploitable) forest resources no longer exist in most tropical countries; hence populated areas may experience scarcity of wood even though extensive areas of forest remain in remote regions of a country. For example, the Andean Altiplano and intermountain valleys of Colombia, Ecuador, Peru and Bolivia have been heavily populated and deforested for centuries, contrasting starkly to the vast forests covering their Amazonian slopes and lowlands (e.g. Freeman et al. 1980).

Fast-growing trees have the potential to meet the increasing demands for fuelwood, paper pulp, lumber and site rehabilitation in developing tropical countries. Decision-makers must understand the ecological implications and constraints to tropical plantation forestry if ecological failures are to be avoided and if the potential of tropical trees is to be successfully used. Ecological aspects of appropriate land use, site rehabilitation and degradation, pests and diseases, and plantation species, are here reviewed from a tropical perspective. A commentary on the role of plantations in the issue of tropical deforestation is also offered.

APPROPRIATE LAND USE

Trees grow in a great variety of environmental sites and conditions. Indeed, trees have been and can be successfully introduced into areas historically devoid of trees. Tree introduction (afforestation) and reforestation have some outstanding successes, e.g. *Eucalyptus globulus* in the high tropical Andes, *Tectona grandis* in the tropical Far East, and *Pinus radiata* in Chile and New Zealand. Reforestation and afforestation are certainly not appropriate for all tropical areas. Land capable of sustained production of crops seldom can be justified for use in plantation forestry. At the other extreme, extensive areas of rugged topography with high rainfall require absolute protection of the natural vegetation in order to regulate stream flow from watersheds, thereby lessening stream flow extremes, and to minimize soil erosion and streambed aggradation (Pereira 1973).

Between the extremes of land suitable for permanent agriculture and of watersheds requiring natural forest protection is the great bulk of tropical land suitable for pasture, perennial crops or forestry. The intermediate forest lands in humid, perhumid and superhumid ecological life zones (sensu Holdridge 1967) have been traditionally used by slash and burn agriculturalists, generally through shifting cultivation (c.f. Watters 1971, Braun 1974, Spencer 1977). Under low population densities shifting cultivation is an ecologically sound use of tropical forests in areas of poor soils, steep terrain and high rainfall unsuitable for sustained agriculture. Third World human population explosion and unequal distribution of arable land force increasing numbers of peasants to practice slash and burn agriculture on less suitable land in the wet lowlands or higher in the watersheds. Larger clearings and shortened fallow periods--often practiced by inexperienced colonists from different ecological regions--lead to site degradation.

The quickening advance of the "agricultural frontier" into the wet tropics has caused extensive deterioration of the natural resources, including destruction of timber, lowered soil fertility, increased soil erosion, and loss of native habitat (Smith 1976, Nations and Nigh 1978, Hecht 1980, GSH-15). Heterogeneous tropical forests are the most species-rich ecosystems on earth, with an astonishing array of highly-evolved interactions and interdependence of species. The conversion of forest to non-forest, i.e. loss of habitat, is devastating to most resident species, and may lead to the extinction of native species (Eckholm 1978, Myers 1979). Native species loss is often due to the restricted geographic range of many species inhabiting tropical forests (Prance 1981). Wherever roads are built opening up "new land" for oil exploration or logging, slash and burn agriculturalists soon colonize the road margins--or even precede the road builders. In fact the dominant landscape along most roads in the wet tropics is not productive crops or forest, but scrubby successional vegetation or brushy pasture.

The abandoned agricultural lands and unproductive pastures prevalent in the tropics are generally biologically suitable for plantation forestry. Land-use capability studies indicate large areas in the perhumid tropics where production forestry is the most appropriate and sustainable land use without causing serious, irreversible environmental degradation (Tosi 1976, Hartshorn 1977). Unfortunately, decision-makers in developing countries largely ignore soil capability, preferring instead politically expedient actions such as colonization or agribusiness.

Tree plantations are not suitable for every site or deforested area. Soil capability studies are an essential prerequisite for determining general suitability for plantation forestry. Detailed knowledge of site capability is just as important as information on appropriate plantation species.

SITE REHABILITATION

If trees can be established on a degraded site, they usually contribute to site rehabilitation. Tree plantations generally improve soil structure, increase soil organic matter and fertility, lessen erosion, favorably change microclimate, and improve local habitat. Tree plantations effectively stabilize degraded land that otherwise would continue to deteriorate. Although practically any degraded site can be improved with tree plantations, such ecological successes may be very costly or even uneconomic, particularly if the primary objective is wood or fiber production. Nevertheless, successful afforestation of savanna or grasslands, as in Africa, Brazil, and the Venezuelan llanos, has produced quite acceptable yields of wood.

Establishment of trees may be the most difficult aspect of site reclamation. To establish tree plantations, protection from grazing animals, fire, pests and weedy competition is often necessary. In severely deforested areas such as the African Sahel, the local demand for fuelwood caused premature harvesting of planted trees before substantial growth could occur. The desperate need for fuelwood in many parts of the tropics (Eckholm 1975, NAS 1980) and the lack of an adequate appreciation for trees in the forested tropics clearly indicate the importance of considering the native people's needs and attitudes in assessing the risks and problems associated with tropical plantation forestry. General governmental disinterest or incompetence in the protection of forests and plantations from illegal or undesirable human interventions (e.g. squatters, clandestine tree cutters) further complicates plantation forestry efforts in tropical developing countries.

Rehabilitation of degraded sites is most critical in watersheds where slash and burn agriculture is practiced. A country's important watersheds tend to be in the highest rainfall areas (perhumid or superhumid ecological life zones), hence land use for seasonal or annual crops is particularly inappropriate for areas usually suitable only for protection or production forests.

Tropical countries have until recently ignored protection and management of watersheds above hydroelectric and irrigation reservoirs. The destruction of natural vegetation by slash and burn agriculturalists causes a severalfold increase in erosion, drastically reducing the capacity, and therefore, the life of the reservoir. Project development for major tropical impoundments seems to assign a standard life of fifty years for a reservoir; however, rapid accumulation of sediments often reduces the useful period to less than half the original estimate, as has occurred to reservoirs in El Salvador, Colombia, and the Dominican Republic.

Deforestation and inappropriate land use in the Panama Canal watershed has caused considerable sedimentation in Lake Alajuela and is seriously threatening the dry season water supply for operation of the Panama Canal (Wadsworth 1978). Rehabilitation efforts have begun in this watershed through the Panama Office for Renewable Natural Resources (RENARE) with funding from the U.S. Agency for International Development and the Panamanian government. Reforestation of this watershed seemed to be the obvious solution in this situation, but consideration of the 60,000 people living there points toward a combination of reforestation and incentives to encourage appropriate agricultural practices and natural resource conservation (Bob Otto, AID, pers. comm.).

Plantation forestry can play an important role in helping rehabilitate degraded watersheds. But in areas where harvesting of timber may be too damaging to the watershed, it makes little sense to establish costly plantations. Natural regeneration techniques may be a more appropriate and much cheaper means of obtaining protective tree cover in critical watersheds.

SITE DEGRADATION

Even though most forestry plantations are established on degraded or non-forest lands and generally contribute to site reclamation (see previous section) there is legitimate concern that plantation forestry may cause certain types of ecological deterioration. Specific issues include loss of soil fertility and reduced productivity in successive rotations, detrimental effects of site preparation and tree harvesting on soils, and reduction in water yields in dry areas.

Most inhabitants of developed countries have an image of tropical forests as lush, green, fertile jungle. Indeed, many tropical forests give the appearance of above-ground luxuriance growing on a bounteous and fertile earth. For the majority of tropical forest soils nothing could be further from the truth; many (e.g. Oxisols, Ultisols, Spodosols) have high erodibility and low nutrient fertility; the latter due to low organic matter content, low cation exchange capacity, low base saturation and a predominance of 1:1 type clays (Sanchez 1976). In contrast to 2:1 and 2:2 type clays, 1:1 clays have appreciably less adsorptive capacity, hence colloidal organic matter is the primary source of nutrients. Some of the nutrient-poor Oxisols and Spodosols have a surprisingly thick humus layer on the soil surface (see GSH-9). Fertile agricultural soils are also prevalent, such as those derived from andesitic volcanic ash (Andepts) in Central America, East Africa and Java, as well as the <u>terra roxa</u> soils (Alfisols) of Brazil.

The luxuriance of tropical forests is built upon and maintained by a highly evolved and remarkably efficient nutrient cycling system. Keystone to the system is a symbiotic association of tree roots and mycorrhizal fungi that quickly absorb nutrients, preventing substantive leakage of nutrients from the ecosystem (Went and Stark 1968, Herrera et al. 1978). Recent evidence indicates mycorrhizal fungi are necessary to the survival and growth of most tropical trees (Janos 1975); hence mycorrhizae are a key factor in the establishment of tree plantations on non-forest or degraded lands.

Site degradation through loss of fertility may have varied and complex causes including high nutrient demand by the plantation species, nutrient export in harvested wood, and inappropriate site preparation or harvesting. Evidence of a tropical forest plantation depleting specific nutrients is meager (e.g. Kadeba 1978). However, it is not unreasonable to assume a single-species plantation to differentially extract specific nutrients, similar to many short-term agricultural crops. Successive rotations of the same tree species may imbalance the small nutrient pool in the soil, leading to nutrient-limited growth.

The growing trend towards complete utilization of wood or fiber resources in forests and plantations has prompted questions about the ecological consequences of total harvesting. In addition to removal of forest-like structure and abrupt exposure of the soil, complete harvesting of mixed, indigenous tropical hardwoods by clear-cutting results in a major export of wood-stored nutrients from the site (Ewel and Conde 1978). Similar nutrient depletion may occur when tropical sites planted with pine, eucalypts, or other fast-growing pioneer species are harvested, but data on these species is sparse. Harvesting of all boles and branches may seriously deplete the low nutrient stocks of many tropical soils such that the next harvest is delayed or impossible. Serious site degradation to the point of precluding a subsequent harvest is most probable on nearly sterile white-sand soils (Spodosols). As part of the international MAB project in San Carlos, Venezuela, German scientists planted rubber trees (*Hevea brasiliensis*) after clearing the virgin forest on white-sand soils, but very few rubber trees survived on the extremely poor site (GSH-9).

Burning the organic debris left from clearing or harvesting may increase nutrient mobility, permitting further site degradation through wind-blown ash or leaching below the rooting zone. However, on a relatively fertile tropical soil (Inceptisol) natural successional vegetation of fast-growing trees quickly tie up available nutrients and within a few years restore site nutrient levels (Harcombe 1977). In the JARI plantations of *Gmelina arborea* in Brazil, the very rapid establishment of melina regeneration following clear-cutting appears to minimize soil erosion and loss of fertility (GSH-12).

Sandy tropical soils, especially Ultisols and Spodosols, are highly susceptible to surface erosion. Removal of the vegetative cover, whether natural forest or plantations, exposes the unprotected surface soil to the awesome erosive capability of tropical rains. There is no question that logging increases erosion, but it is very poorly documented (e.g. see Anderson 1972, Pereira 1973, Sanchez 1976).

Mechanical clearing by bulldozers and harvesting with tracked vehicles or skidders generally cause serious damage to the soil. Bulldozing of forest or brush into windrows may remove most of the fertile topsoil from some soils, such as occurred in the initial clearings for melina establishment on sand soils at JARI. Physical compaction by heavy machinery may substantially reduce the infiltration capacity of the soil, leading to greater surface runoff and erosion. Less damaging site preparation and harvesting techniques, e.g. labor intensive methods, may be more appropriate on poor sites.

Afforestation of savanna soils may tend to deplete soil moisture because tree roots can tap a deeper volume of soil than do grass roots. In arid regions greater evapotranspirative use of limited soil moisture by trees may be undesirable. But the potential drying effect of exotic tree afforestation in arid regions is considered insignificant when compared with the numerous ecological benefits of afforestation (Cuzzo 1976).

PESTS AND DISEASES

The risk of pests or diseases decimating a plantation is a prominent concern of the forester, company or government agency considering commercial plantation forestry. This section addresses that concern, with emphasis on the situation for exotic (non-native) tree species, since exotics are often used in tropical forest plantations.

Tropical plantation forestry has not yet had the centuries of botanical exploration, plant introduction and economic successes and failures associated with edible plants. Nevertheless, the mixtures of successes and failures found with food plants are also occurring in tropical plantation forestry, albeit on a smaller economic scale: the ubiquitous pine and eucalypt trees document their successful pantropical dissemination. Only 17 years ago, a listing of forest tree diseases reported no entries for *Pinus caribaea, Eucalyptus deglupta* and *Swietenia* spp. (IUFRO 1964).

Although climate and soil factors affect the success or failure of an exotic species, success is often attributed to having left behind or escaped "from diseases and pests that have evolved along with them" (Baker 1970, p. 109). The failure of Henry Ford's vast rubber plantations at Fordilandia in the Brazilian Amazon due to the fungal leaf blight, *Dothidella ulei*, is often cited as the principal example that extensive monocultures in a species' native region are impossible. The mahogany shoot borer, *Hypsipyla grandella*, has seriously damaged native area plantations of mahogany (*Swietenia macrophylla* and *S. mahogani*, Meliaceae) and Spanish cedar (*Cedrela odorata*, Meliaceae) and has received considerable research effort (Whitmore 1976a, 1976b), yet most Asian and African Meliaceae, especially *Toona*, are resistant to tropical American mahogany shoot borer. Tropical American *Cedrela* is commonly planted in Africa, unmolested by local pests.

While exotic species have left behind "diseases and pests that have evolved along with them", they may also be moving to a new location where indigenous pests and diseases can successfully adapt to the exotics as hosts, and for which the exotics have no evolved resistance. Sri Lanka's preeminence as a tea exporter had its origin in the rapid demise of coffee (an exotic) in the eighteenth century due to a leaf-spot disease caused by the fungus *Hemileia vastatrix* (Baker 1970). In Southeast Asia the native *Hypsipyla robusta* attacks introduced *Swietenia macrophylla* (Chaiglom 1975) and in the U.S. Virgin Islands introduced *Chukrasia* (from Bangladesh) is attacked by native *H. grandella* (J. L. Whitmore, pers. comm.). *Anthocephalus chinensis* (Rubiaceae) from Southeast Asia, a successful plantation tree in the 1960's suffered complete mortality due to fungal attacks on 4-5 year old stands in Turrialba, Costa Rica, and is no longer considered as a candidate species for plantation forestry. Leaf-cutter ants (*Atta*) are a major pest to *Gmelina arborea* (an exotic) in tropical America as well as on many other trees and crops. The heartwood of young *Eucalyptus deglupta* (Myrtaceae) trees are attacked by *Coptotermes crassus* termites in Turrialba, Costa Rica (Ford 1980). In peninsular Malaysia, termites attack live wood of introduced pine trees (Tho Yow Pong, pers. comm.).

There is a considerable literature of pests and diseases switching from native hosts to introduced tree species (e.g. Camacho 1966, Boerboom & Mass 1970, Drooz and Bustillo 1972, Gray 1972, Ivory 1977, Schönherr 1977, Muchovej et al. 1978, Ford 1980). Reasons for insects switching on to exotic hosts are not well understood; however, Gray (1972) concludes that the abundant and extensive resource offered by a monoculture is usually of major importance. Strong (1974) found that the number of insect pests of cacao (*Theobroma cacao*, Sterculiaceae) is best described as a function of the area in cultivation rather than time since introduction. In fact, for similar-sized areas, the number of insect pests did not differ significantly between native and non-native cacao producing areas. Strong's thesis predicts pest and disease problems will increase as the area of plantation increases, regardless of the crop's geographic origin. The outbreak of serious diseases on exotic crops in major exporting areas, such as happened with cacao in Ghana (see Baker 1970) and coffee in Sri Lanka or now with sugarcane in Cuba, conform to Strong's predictions. The clear implications are that native pests and diseases switch to the plantation crop and that as the area planted increases, more diseases and pests will switch to the increasingly abundant resource.

The appropriateness of site may be an underestimated factor in susceptibility or resistance of a species to pests and diseases. A plantation species may have serious pest or disease problems if grown "off-site", i.e. grown under unsuitable soil or site conditions that may put the trees under stress and make them more susceptible to attack. On the other hand, an excellent site may lessen or eliminate pest or disease problems, e.g. on fertile alluvium in Surinam, *Cedrela angustifolia* trees attacked by *Hypsipyla grandella* have better average growth than non-attacked trees in the same plantation (Vega 1976).

Insect outbreaks in exotic tree plantations occasionally occur during droughts (Brown 1965b, cited in Gray 1972). Trees under moisture stress generally have less resistance to insect attack and may also have a decreased ability to recover.

The biological risks of pests and diseases for tropical plantation forestry are probably no greater than they are in extra-tropical regions (Johnson 1976). Tropical plantation forestry depends on appreciable wild populations of tree species with considerable genetic variability, hence tropical foresters and tree geneticists have the opportunity to select for resistant individuals and species. The failure of *Anthocephalus chinensis* in Turrialba is probably related to the use of a geographically restricted seed source. Plantation forestry can fairly easily substitute one species for another, in contrast to many major edible crops that lack substitute species in case of an epidemic outbreak.

Tropical regions also have the advantage of much shorter rotation periods, where fast-growing tropical trees are being harvested for pulp in only six to ten years. The much shorter generation time of tree plantations in the tropics as opposed to the temperate zones lowers the biological risks for tropical plantation forestry. However, the tropical climate also enhances the growth of insects and diseases, and the rate at which they compete for food. Tropical plantation forestry may require much closer attention to potential outbreaks of pests and diseases if the growth potentials of planted trees are to be realized.

PLANTATION SPECIES

If someone asked the national forest service in almost any tropical country what species to plant commercially, it is highly probable that the recommendations would be drawn from a short list of species. If information on the continent, elevation and rainfall were available, most tropical foresters could tell you with some certainty the recommended species. Although local exceptions occur, tropical plantation forestry depends on a rather small set of species. Though perhaps 1,000 species have been tested, the genera *Pinus* and *Eucalyptus* dominate the list of a few dozen species that have high potential for successful tropical forest plantations. Some 700 tree and shrub species made the master list of potential firewood species (NAS 1980).

Recommended forest plantation species are often pioneer species, i.e. fast-growing in clear-cut or deforested areas with poor soils; their wood usually has recognized utility and marketability; and they usually require relatively simple seed collection, storage, and nursery technology. In the future, the potential to be genetically improved will most likely be an increasingly important criterion.

Additional research on potential forest plantation species is needed. If fast-growing tropical trees are to make significant contributions to the urgent needs of developing countries, tropical foresters and forestry agencies must rapidly increase the available knowledge on potential species, matching species to site, pest and disease susceptibility, genetic selection and improvement, as well as general silviculture and autecology.

The most widely preferred species for commercial forestry plantations in the tropics largely come from moist and dry ecological life zones (sensu Holdridge 1967). The advance of the agricultural frontier into the wet lowlands will require different species for reforestation. A concerted effort is needed to find the fast-growing tree species that can be used in plantations to meet the increasing needs for wood products and site reclamation in the wet tropics.

Yet the ecological problems and environmental degradation rampant in the tropics can't await another decade of research. Massive plantation forestry can make a significant impact by supplying tropical and extra-tropical demands for wood products, as well as reducing the ecological deterioration so pervasive in the tropics.

PLANTATION FORESTS AND INDIGENOUS FORESTS IN THE TROPICS

Indigenous forests in many areas of the tropics have been and continue to be destroyed or degraded, causing loss of habitat and concurrent loss of or threats to native plant and animal species, soil erosion, sedimentation, floods and droughts, desertification, and diminished land productivity. Given the dearth of information on species diversity and tropical ecosystems, it is impossible to quantify the future benefits being lost due to deforestation.

Tropical forest conversion to non-forest use is primarily due to expansion of the "agricultural frontier" through slash and burn agriculture. Direct conversion of natural forest to plantations is a minuscule percentage of the amount of tropical deforestation. However, direct conversions do occur, sometimes on a large scale (e.g. JARI, GSH-12).

Since the social and ecological opportunity costs of establishing tropical forest plantations on abandoned or degraded land suitable for plantation forestry would be relatively low when compared with the benefits foregone by the destruction of indigenous tropical forests, logic would dictate that conversion of natural forest directly to plantations should be avoided.

There are many reasons for conserving tropical forest resources, but the pressures for exploiting these resources are immediate and unavoidable. Research and the development of positive alternatives such as forest plantations and agroforestry may take some of the pressure off the remaining indigenous forests.

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