Fast-Growth Tree Plantations for Wood Production – Environmental Threat or a Means of "Saving" Natural Forests?

Dr. Jim Bowyer

Dr. Jeff Howe
Phil Guillery
Kathryn Fernholz

October 24, 2005

Dovetail Partners, Inc.

Fast-Growth Tree Plantations for Wood Production – Environmental Threat or a Means of "Saving" Natural Forests?[1]

Introduction

With increasing interest worldwide in forest plantations as a source of wood and industrial fiber, concerns about the potential environmental impacts of establishing forest plantations on a large scale are increasing as well. Specific concerns focus on potential loss of soil fertility and productivity under short harvest rotations, increasing risks of catastrophic disease and insect infestations through cultivation of monocultures, implications of replacing natural forests and associated flora and fauna with less biologically diverse plantations, and risks of introducing exotics.

Among the advantages of plantations is that establishment of highly productive forest plantations can provide large quantities of wood and fiber from relatively small land areas, providing a continuous, renewable stream of industrial raw materials that results in less overall environmental impact than other types of raw materials while also reducing pressures for harvesting in natural forests. Thus, although many of the issues raised about forest plantations are non-trivial, there are several significant environmental advantages of plantation establishment that appear to outweigh concerns, *if* plantation management practices – such as careful matching of species to site, and use of genetically diverse planting stock – can be developed to address concerns regarding sustainability.

500,000 ha. of tree plantations needed

By MELODY M. AGUIBA

The Philippines needs to develop at least 500,000 hectares of forest tree plantations in the next 15 years so as to be self-sufficient in plantation wood for veneer and plywood for the furniture sector for which the country was once Asean's top exporter in the 1970s.

"We have a strategic plan to accelerate the technology for raw material production for this industry. It will involve training, dissemination of technology, and improvement of current policies," said Dr. Filiberto A. Pollisco Jr., forestry and environment program chief of the Philippine Council for Agriculture Forestry Natural Resources Research and Development (PCAFNRD).

The strategic plan which is being coordinated with other government agencies such as the Department of Environment and Natural Resources will tap sub-marginal lands which total to 475,000 hectares and brushlands, 2.2 million hectares.

"This is attainable as the average annual plantation rate in the country was around 50,000 hectares for the last 20 years," the 2005-2020 strategic plan reported.

Plantation species to be propagated are the fastgrowing and long rotation hardwoods like white lauan, palosapis, mahogany, and apitong.

http://www.mb.com.ph/BSNS200509274533 6.html

[1] Based in part on the publication: Bowyer, J. 2001. Environmental implications of wood production in intensively managed plantations. Wood and Fiber Science 33(3): 318-333.

Rising Wood Consumption and Forest Plantations

Population growth is impacting forests in many ways, not the least of which are related to increasing demand for all products and services provided by forests, including wood and wood fiber. Rising demand is accentuated by steadily decreasing forest area per capita. For example, in 1800 the world population was 1 billion and there were approximately 4.5 ha (11.1 acres) of forests for each person in the world. Today the area of forests globally is about two thirds of what it was in 1800; the loss of forestland, coupled with an increase in population to just over 6 billion, has reduced the area of forest land per capita to only about 0.6 ha (1.5 acres). Given a projected population of roughly 11 billion by the end of this century, and assuming zero loss of forests over the next 100 years, the amount of forestland for each person in the world will shrink to about 0.3 ha (0.8 acres) by the year 2100. The net effect of these trends is that it is more and more problematic as to whether it will be physically possible to meet demands placed on the world's natural forests. Plantations are clearly a part of the solution to this growing dilemma.

One of the most compelling reasons for establishment of forest plantations is that consumption of industrial wood and wood for cooking and heating is rising steadily at the same time that efforts to reduce harvesting in natural forests are also increasing. A need for extensive forest plantations was recognized more than a half-century ago. Champion (1949) made a case for establishing forests on millions of hectares, arguing that this would be of great benefit to society. A little over a decade later Marsh (1962) observed that ''natural forests grow too slowly to meet bulk forest products demands.''

In the decade of the '90s, the specter of record population growth led many to take note of rising demand for forest-derived resources. Leslie (1992), for example, had suggested that the forest plantation area would ''have to be increased by 30 percent in the immediate future'' in order to meet needs for fuelwood and industrial wood. These estimates were followed by a stunning conclusion reached by the World Energy Council (WEC) in 1995, which indicated that between 700 million and 1,350 million ha of land would be needed for biomass energy production by 2050. Heering (1997) put the need for plantation establishment at 27 million ha annually; this rate of establishment, if assumed to continue for 50 years, corresponds to the 1,350 million ha estimate of the WEC. These figures imply a need for as much as a seven to thirteen-fold increase in global forest plantation area, *excluding* what might be needed to provide increased volumes of wood for industrial uses. Together, these kinds of estimates have served to greatly intensify interest in forest plantations.

Plantation Trends

In the mid-1990s, forest plantations were estimated to occupy about 124 million hectares (306 million acres) of land worldwide (Table 1), or about 3.5 percent of the forested area globally. Over 100 million hectares (just under 250 million acres) of those plantations were in the industrial plantation category – plantations established for the purpose of producing wood and fiber for industrial uses. A more recent estimate of the extent of

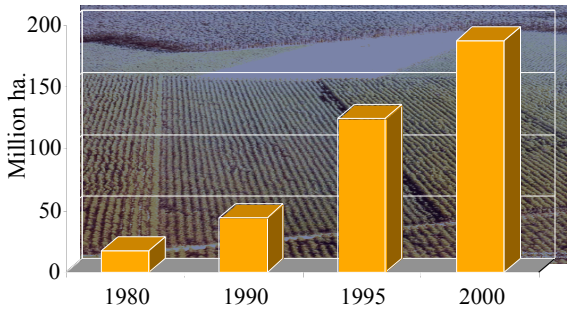
forest plantations (Figure 1) places the area at 187 million hectares (462 million acres). A 1995 estimate of future plantation area (Table 2) suggests ongoing plantation development in the decades ahead. Indeed, significant plantation development is currently underway on six of the seven continents, leading some to question whether markets in some regions will be able to absorb the large volumes of plantation wood that will soon be available.

Table 1
Estimated Plantation Forest Area - 1995

Country or Region	Indust. Plantation Area Area in million ha.	Non-indust. Plantation Area Area in million ha.	Total Plantation Forest Area Area in million ha.
North America	18.4	0	18.4
Cent. & S. Amer.	5.9	3.1	9.0
Asia	41.8	15.1	56.9
Oceania	2.7	0.01	2.7
Africa	3.6	2.2	5.7
Europe	8.7	0	8.7
Former USSR	22.2	0	22.2
Total	103.3	20.4	123.7

Source: Brown and Ball (2000)

Figure 1
Area of Wood Fiber Plantations Globally, 1980 -2000



Source: Brooks, USDA Forest Service (2001)

Table 2
Estimated Plantation Forest Area - 2050

Country or Region	Current Indust. Plantation Area Area in million ha.	Indust. Plant. Area-Scenario 1 Area in million ha.	Indust. Plant. Area-Scenario 2 Area in million ha.
N. & Cent. America	18.9	29.3	43.2
South America	5.4	8.4	13.6
Asia	41.8	64.8	119.5
Oceania	2.7	4.2	5.7
Africa	3.6	5.6	8.9
Europe	8.7	13.5	15.3
Former USSR	22.2	34.4	28.0
Total	103.3	160.2	234.2

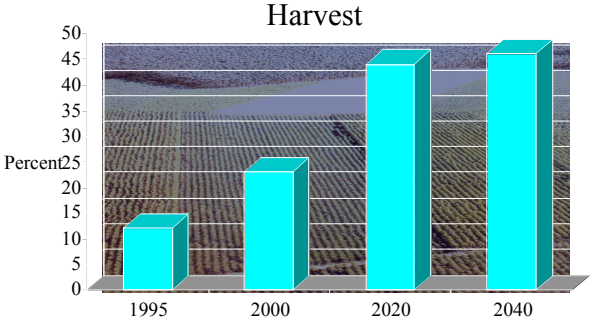
Source: Brown and Ball (2000)

Forest plantations are typically highly productive as compared to natural forests. Plantations often produce 10 m^3 of wood/ha annually, and wood yields of 20–25 m^3/ha/yr are not uncommon. In addition, annual yields as high as 45 to 70 m^3 have been attained with some hardwood species. An illustration of the high productivity of plantations is provided in Figure 2. In contrast to plantations, natural tropical moist forest commonly yields 1 to 2 m^3/ha annually, which can be increased to perhaps 6 m^3/ha with management; similar yields are attainable for natural forests in temperate regions.

The high growth rates attainable in plantations coupled with the fact that plantations are often established on highly productive sites means that a great deal of wood can be produced on a relatively small land area. *In 2000, plantations produced about 27 percent of the industrial wood harvested globally, despite the fact that such plantations occupied less than 3.5 percent of the forested land area worldwide* (Figure 3). Over one-half of industrial wood is expected to originate from plantations within only several decades.

Figure 2
A Three-Year Old Eucalyptus Plantation in Vittoria, Brazil (Aracruz, S.A.) Illustrates the Rapid Growth Potential of Wood Fiber Plantations

Figure 3
Contribution of Plantations to World Timber Harvest



Source: Brooks, USDA Forest Service (2001)

Environmental Issues and Plantations

Despite widely recognized benefits of forest plantations, there are also widely shared concerns about the possibility of development of massive tree plantations in the tropical regions. Concerns include the following:

- Inappropriate practices when planting and harvesting or during the construction of forest roads, resulting in serious erosion problems,
- Disruption of local water cycles as a result of periodic clearcutting, and in some cases, by increased rates of water uptake due to the physiology of the species chosen or the density of planting, and
- Instances of pests, diseases, and large fires associated with large plantations

Ecological problems with plantations have been well publicized, yet most plantation areas have few issues. It has also been pointed out that careful species selection and application of best silvicultural practices can significantly reduce risks of pests and

disease. One team recently studied the large-scale Jari project in Brazil. In their words, ''Jari has been much maligned. In fact, it has brought income to many while safeguarding large areas of native Amazon forest.'' Thus, there is by no means unanimity in the view that plantations, whether large or small, generally lead to environmental problems. Nonetheless, several of the most commonly mentioned problems are briefly examined in this section.

Negative impacts on soil moisture and water yield

Concerns about the impact of plantations on soil moisture and water yield are mostly related to soil moisture depletion and reduced stream flow. Such concerns apply both to situations in which tree plantations are established on pastureland, or on plots adjacent to land used for agriculture, and where tree plantations replace natural forests.

The planting of fast growing trees on grassland has been found to sometimes diminish stream flow after canopy closure, particularly during dry seasons. More specifically, research suggests that the main impact on site hydrology from plantation establishment on grass or agricultural lands is from increased evaporation, which is likely to result in reduced aquifer recharge and reduced runoff. Put differently, the reason for reduced stream flow is not generally a differential rate in transpiration, but instead primarily because of interception and re-evaporation of rainfall at the crown level. Interception has been found to amount to as much as 30 percent of the rainfall, over a fairly wide range of rainfall amounts.

Another plantation related concern is that certain species – mainly eucalypts which account for as much as 25 percent of the plantation area worldwide – may use far more water than species that occur in natural forests, drawing down the water table in some localities. However, available scientific evidence indicates that although interception losses from eucalyptus and other tree species are likely to be greater than from shorter vegetation, such losses are likely to be no more than those of other tree species of similar height and planting density. One caution to these general findings is the observation that in several instances species of eucalyptus that do not naturally regulate the rate of moisture loss from leaf surfaces have been planted in areas where atmospheric demand is high and soil water is freely available; it is noted that under these circumstances eucalyptus may well transpire at very high rates dictated solely by atmospheric demand.

In summary, it does appear that plantation establishment can have a substantial impact on site hydrology, sometimes positive, sometimes negative. Research and field experience suggests that at least some of the negative impacts can be avoided by proper matching of species to site.

Erosion and soil degradation resulting from plantation establishment

The prospect of lowered yields as a result of site deterioration under intensive management of short rotation tree crops has been a concern of foresters for decades. Recent literature suggests that this is still a major concern, with numerous references to adverse effects of plantation establishment, including soil compaction, erosion, and

depletion of soil organic matter, and overall degradation of physical and nutritional properties of soil.

It has been observed, for example, that plantations tend to be kept in an early successional stage, with maximum removal of biomass from the site at harvest. Plantations are also said to be less efficient at trapping released nutrients, due in part to the existence of fewer roots near the surface. The result may be significant nutrient loss from sites where trees are harvested. Researchers have also strongly linked a continued supply of soil nutrients to long-term sustainability of high productivity in tropical plantations, finding that rapid growth of tropical plantations leads to high rates of nutrient accumulation in biomass, and that harvesting at short rotation intervals removes large quantities of nutrients which may, over time, lead to depletion of soil fertility. In addition, plantation species have been found in some cases to reduce the availability of plant nutrients in soil, with such effects varying depending on site conditions. On high quality sites, for instance, there may be little deterioration in soil properties as a result of several rotations of tree crops, whereas on poor sites, common in the tropics, reductions in soil nutrient status and stand productivity are likely to occur. Problems can be particularly serious when leaf litter is deliberately removed from a site. Such problems can be addressed by enrichment of nutrient supplies with fertilizers, or through use of nitrogen-fixing species in mixed-stand environments.

Yet another issue related to soil degradation is soil compaction caused by use of heavy equipment during harvesting. Impacts can range from severe to negligible, depending upon the application or non-application of proper harvesting and management techniques.

These findings notwithstanding, a great number of studies have found that productivity loss over time may not be as serious a problem as may have been feared, and in any case can be effectively addressed by careful management. For instance, a study of widespread decline in second-rotation patula pine plantations that had occurred in the 1960s in southern Australia led to the finding that in subsequent crops the problem was largely overcome by careful treatment of the site at harvesting, increasing the level of silvicultural inputs, and controlling grass competition that had been absent when first rotation crops were planted. An extensive study of the soil degradation question resulted in the observation that in almost every case, tree planting in the tropics represents a more intensive land use than that practiced previously, and that high rates of growth and short rotations suggest the *possibility* that sites will be overstressed, resulting in diminishing fertility and poorer yields. However, it was noted that relatively few studies have been conducted to evaluate the sustainability of intensive plantation practices, and that studies to date (1999) had not indicated significant productivity loss. In fact, there are a number of examples of high productivity over many cutting cycles in the literature. Other studies have shown nutrient decline over time, particularly when cutting cycles are short. In such cases it has generally been demonstrated that nutrient deficiency can be corrected through application of supplemental fertilizer. A common conclusion is that instances of yield decline in the tropics and subtropics often reflect weed mismanagement or mismatching of species to site, rather than inherent shortcomings of plantation forestry practices.

Risks of pests and disease

Exotic species that make up much of the world's plantations have been regarded as both more resistant and more susceptible to pests and diseases. On the one hand, there are many documented instances of insects and disease causing extensive damage in natural forests, as well as an increasing number of examples of plantations that have been grown over many cutting cycles with few problems. The more than 100-year history of exotic rubber plantations in Malaysia is often cited as an example of successful plantation operation over the long term. Indeed, some researchers have noted that exotics face lower risks than native species, since introduction of a species into a region that is outside of its natural range separates that species from its natural pests and can thus improve health and performance, at least in the short term. On the other hand, many researchers have found that plantations, and particularly single species plantations, are at much greater risk to catastrophic insect and disease losses than are natural forests. This is based on the observation that the introduction of exotics tends to alter natural balances that serve to keep pathogenic organisms in check in ecosystems. Several instances have been documented in which introduction of exotic tree species has been accompanied by introduction of pests that have subsequently done serious damage to native species adjoining the new plantation areas. There are also documented instances in South Africa and New Zealand in which introduced pines have, over time, extended their range into surrounding natural forests, suppressing indigenous forest species.

There is increasing evidence in the scientific literature that the genetic base of a forest plantation is more important than the number of species involved. For instance, it is known that establishing a monoculture from rooted cuttings poses a considerable risk over any extended time frame, whereas a plantation composed of genetically diverse planting stock does not present great risk, even if composed of a single species. Risk is also reduced by the reality that relatively short rotations coupled with intensive management allow plantation managers to react quickly to pest and disease problems, something that is often difficult in a natural forest environment. In addition, every crop cycle offers the opportunity for planting superior genetic stock, designed to grow better quality faster.

As with other environmental concerns related to plantations, many view pest and disease problems that have occurred as due to improper planning and management. Four examples are:

1. Inappropriate site choice, leading to stress-induced changes in the trees that increases their vulnerability to pests and diseases,
2. Use of a poorly adapted seed source,
3. Poor silvicultural practices, such as careless pruning and thinning, which can leave scarred live tissue open to infection, and
4. Inadequate attention to nutrient and water requirements.

In summary, while there are pest and disease risks and documented problems associated with plantations, it appears that problems are not necessarily a given, and that proper planning and management can minimize risks.

Impacts on biodiversity

Forest plantations of the southern hemisphere and tropics have been described as "monocultures of introduced species that are of uniform size and spaced geometrically, . . . and that are incapable of supporting biodiversity characteristics of native forests." The typical high stocking density of plantations and lack of structural diversity are often cited as reasons for relatively low species diversity within them, and an impressive array of comparative studies of plant and animal diversity within plantations and natural forests appear to support this contention. One author recently pointed out that not only are forest plantations incapable of supporting a wide array of biodiversity, but management so as to maximize timber yields typically involves systematic reduction of species diversity through elimination of pests, predators, and competitors.

Few researchers dispute that forest plantations support reduced levels of biodiversity than natural forest stands, but an increasing number challenge the contention that plantations necessarily have *vastly* lower biodiversity than surrounding native forests. The oft-expressed contention that exotic forests are "biological deserts" has also been disputed. Indeed, another part of the biodiversity debate involves the positive role that plantations play in restoring biodiversity to an impoverished landscape. There are several examples of this, including:

- planting of caribbean pine on poor savannas in Venezuela has led to a substantial increase in the deer population and the return of the jaguar
- planted cypress forests in Kenya and Tanzania are the home of thriving populations of the Sykes monkey, a species once driven to near extinction,
- the leopard is again found on the Nyika and Vipya plateaus of Malawi as a result of afforestation in these regions.
- in the Canterbury plains area of New Zealand the presence of many plant species that had been mostly absent prior to afforestation has been affirmed.

There is little doubt that plantation forests offer less plant and animal diversity than native forests within the same region. Differences are accentuated when crop rotations are short, and much reduced under management aimed at increasing structural complexity of forest plantations. Thus, it does appear that the way in which plantations are managed has a direct influence on the diversity of plant and animal life found within a plantation.

Will Plantations Take Pressure Off Natural Forests?

Many people have suggested that higher productivity of plantations means that plantation development will take pressure off natural forests by reducing or eliminating the need for harvesting within them. For instance, the Forest Stewardship Council's (FSC's)_Principle 10 regarding plantations states, "Plantations…should complement the management of, reduce pressures on, and promote the restoration and conservation of natural forests." However, there is considerable disagreement within the scientific community on this point. Sargent (1992) was among the first to question this notion, stating that only under very specific circumstances have plantations contributed to the protection of natural forests. She contends, in fact, that because of a higher perceived and realizable value of

plantations as compared to natural forests, plantation growth has actually contributed to the loss of natural forests. Perhaps the most pointed criticism of the natural-forest-saving role of plantations comes from Sargent who notes that production of large volumes of plantation wood will tend to drive down the price of wood in general, thereby stimulating demand for wood from plantations and natural forests alike. Ironically, Sargent's questioning of the environmental role of plantations is given credence by Lovejoy's observation regarding the potential impacts of a boycott of tropical timber (Lovejoy 1990). Lovejoy documented the findings of a workshop that included an assessment of the impact of a loss of timber demand on the value of natural forest. It was concluded that such a development would reduce the value of forests, making more likely a conversion to pasture or cropland. Following the same reasoning, should high wood production in forest plantations, in fact, result in reduced timber value, then the effect on forests could well be similar to that of a boycott.

Figure 4
A Radiata Pine Plantation on North Island, New Zealand

The possibility of adverse impacts arising from timber demand shifts has led some to suggest that regulations and formal agreements may be needed to protect natural forests in conjunction with plantation establishment. Some, in fact, are now calling for the set-aside of vast areas of forestland in natural or non-managed reserves, with wood production shifted entirely to privately owned natural or modified forests or to intensively managed plantations. That is precisely the strategy that was pursued in both New Zealand and Australia as part of efforts to significantly increase the area of forest plantations. This strategy is also promoted in the FSC forest certification standards. Under Principle 10, "A proportion of the overall management area…shall be managed so as to restore…natural forest cover. The ratio of plantations to natural and semi-natural forests…maintains and/or restores the landscape to a condition…similar to a mosaic of natural forests."

FSC Plantations Review

On September 9, 2004 the Forest Stewardship Council International Center (FSC IC) hosted a Plantations Review Meeting in Bonn, Germany to launch its two-year Plantations Review process.

Regarding the possibility of protection of natural forests as part of a plantation strategy, some authors have questioned whether seeking to abandon timber production in natural forests is a wise idea. More than 40 years ago Dawkins (1958), for example, wrote ''Even where plantations are justified, it does not necessarily follow that all remaining naturally regenerated forests are best left unproductive. If they are, they may become vulnerable to destruction . . .'' More recently, Sedjo and Botkin (1997), for example, gained a great deal of attention from the observation that we [society] could produce all the wood we want on very little land. Less noticed was their caution that it is not necessarily a good idea to prevent any harvesting in native forests. Whitmore (1999) echoed this theme, stating that although plantations can diminish pressure on native forests, the native forests should, nonetheless, continue to be managed extensively. The reasoning behind these admonitions is similar to that of Lovejoy: if the value of forests is diminished, the value of the land occupied by forests is diminished as well, making conversion to agriculture or other uses more likely. Thus, the debate about whether forest plantations can take pressure off natural forests appears to have come full circle. An emerging view is that yes or no, it would be a mistake to leave vast areas of natural forests in a non-managed state. The FSC is currently in the middle of a two-review of their standard for plantation management. The goal of the review is to both clarify the implementation of the FSC standard for plantations and also provide a widely accepted standard for responsible plantation management. More information about the review and how to participate is available at the FSC website (www.fsc.org/plantations).

The Bottom Line

Despite environmental concerns and problems associated with the establishment and sustainable management of some forest plantations, the benefits that accrue from plantations of rapidly growing trees are so significant that further development of forest plantations is virtually assured. Benefits include high commodity production on relatively small land areas, vastly reduced overall environmental impact associated with wood production and use in comparison to available alternatives, and potential for concomitant restoration of degraded land areas and associated biodiversity. However, not every aspect of rapidly growing plantations is beneficial. To recognize the tremendous advantages of forest plantations or the inevitability of further development does not mean that environmental concerns linked to plantation development should be dismissed. Rather, it is to the advantage of everyone that forest plantations operate sustainably in every sense of the word, and that they provide the greatest possible array of benefits. In view of the size and growth of the forest plantation enterprise globally, and the nature of problems that have been encountered in conjunction with development and maintenance of some plantations, it is imperative that steps be taken to address known problem areas and concerns. It is worth noting that these are precisely the kinds of issues that certification is intended to address. Attention to management issues, combined with investment in applied research will both be needed going forward.

References

Binkley, D. and C. Giardina. 1997. Nitrogen fixation in tropical forest plantations. Pages 297–337 *in* E. Nambiar, and A. Brown, eds. Management of soil nutrients and water in tropical plantation forests. Australian Centre for International Agricultural Research, ACIAR Monograph Series No. 43.

Boardman, R. 1979. Maintenance of productivity in successive rotations of radiata pine in South Australia. Pages 543–554 *in* E. Ford, D. Malcolm, and J. Atterson, eds. The ecology of even-aged forest plantations. Institute of Terrestrial Ecology, Cambridge, UK.
Brockie, R. 1992. A living New Zealand forest—a community of plants and animals. David Bateman, Ltd., Auckland, NZ.

Brooks, D.A. 2001. Global and Regional Demand for Forest Products, Now and in the Future. In Proceedings: Biotech Branches Out – a Look at the Opportunities and Impacts of Forest Biotechnology. Pew Initiative on Food and Biotechnology, Atlanta, December 4-5. (http://pewagbiotech.org/events/1204/presentations/BrooksEdited.ppt#1)

Brown, C. and J. Ball. 2000. World view of plantation grown wood. In: Proc. XXI IUFRO World Congress. Vol. 1. Sub-Plenary Sessions. B. Krishnapillay et al., eds. Kuala Lumpur, Malaysia. IUFRO, Rome, Italy, pp. 377-389.

Calder, L. 1992. Water use of eucalypts—A review. Pages 167–179 *in* I. Calder, R. Hall, and P. Allard, eds. Growth and water use of forest plantations. John Wiley & Sons, New York, NY.

Calder, L., M. Swaminath, G. Kariyappa, N. Srinivasalu, K. Srinivasa Murthy, and J. Mumtaz. 1992. Measurements of transpiration from eucalyptus plantations, India, using deuterium tracing. Pages 196–215 *in* I. Calder, R. Hall, and P. Allard, eds. Growth and water use of forest plantations. John Wiley & Sons, New York, NY.

Champion, H. 1949. Biology and technique of afforestation. Pages 14–20 *in* Proc. World Forestry Congress, Brazilia, Brazil.

Dawkins, H. 1958. Silvicultural research plan, first revision, period 1959 to 1963 inclusive. Forest Department, Entebbe, Uganda. 24 pp.

Evans, J. 1986. Productivity of second and third rotations of pine in the Usutu forest, Swaziland. Commonw. For. Rev. 65(3):205–214.

Evans. 1988. The Usutu forest: Twenty years later. Unasylva 40(159):19–29.

Evans. 1992. Plantation forestry in the tropics: Tree planting for industrial, social, environmental, and agroforestry purposes. Oxford University Press. 403 pp. New York: NY.

Evans. 1999. Planted forests of the wet and dry tropics: their variety, nature, and significance. New Forests 17: 25–36.

Fahey, B. 1994. The effect of plantation forestry on water yield in New Zealand. New Zealand Forestry 39(3):18–23.

Fahey, and L. Rowe. 1992. Land-use impacts. Pages 265–284 *in* M. Mosley, ed. Waters of New Zealand. New Zealand Hydrological Society.

Hakkila, P. 1994. Pine plantations of the southern hemisphere and tropics as a source of timber. Finnish Forest Research Institute, Research Paper 532. 63 pp.

Heering, M. 1997. Quo vadimus? Pages 21–32 *in* O. Bouman and D. Brand, eds. Sustainable forests: Global challenges and local solutions. Haworth Press, New York, NY.

Leslie, A. 1992. How much wood do we need? Pages 76–91 *in* C. Sargent and S. Bass, eds. Plantation politics—Forest plantations in development. Earthscan Publications, Ltd., London: UK.

Lai, R. 1997. Soils of the tropics and their management for plantation forestry. Pages 97–123 *in* E. Nambiar and A. Brown, eds. 1997. Management of soil nutrients and water in tropical plantation forests. Australian Centre for International Agricultural Research, ACIAR Monograph Series No. 43.

Lovejoy, T. 1990. Consensus statement on commercial forestry sustained yield management and tropical forests. Smithsonian Institution (January). 10 pp.

Lundstrom, A., P. Nilsson, and G. Stahl. 1997. The consequences of certification on possible supply of industrial wood and fuelwood. A Pilot Study. Working Paper No. 23. Department of Forest Resource Management and Geomatics, Swedish University of Agricultural Studies, Umea, Sweden. (Swedish).

Maclaren, J. 1996. Environmental effects of planted forests in New Zealand: The implications of continued afforestation of pasture. New Zealand Forest Research Institute, Bulletin No. 198. 180 pp.

Marsh, E. 1962. The introduction of fast growing exotic tree species for meeting the timber requirements of developing
countries. *In* Papers, UNSAT Conference: E/CONF.39/C/13. Geneva, Switzerland.

Michon, G., F. Mary, and J. Bompard. 1986. Multistoried agroforestry garden system in Sumatra, Indonesia. Agroforestry Systems 4:315–338.

Norton, D. 1989. Indigenous plants in the exotic plantation forests of the Canterbury Plains. J. Canterbury Bot. Soc. 23:21–27.

Sawyer. 1992. Natural forest or plantation? Pages 16–40 *in* C. Sargent and S. Bass, eds. Plantation politics: Forest plantations in development. Earthscan Publishers, London, UK.

Sawyer, J. 1993. Plantations in the tropics: environmental concerns. IUCN/UNEP/WWF, Cambridge, UK.

Sedjo, R. 1999. The potential of high-yield plantation forestry for meeting timber needs. New Forests 17:339–359.

Sedjo, R. and D. Botkin. 1997. Using forest plantations to spare national forests. Environment 39(10):14–20, 30.

Swedish Agency for Research Cooperation with Developing Countries. 1992. Mixed and pure forest plantations in the tropics. A paper based on the work of T.J. Wormald. FAO, Rome: Forestry Paper 103.

Tiarks, A., E. Nambiar, and D. Cossalter. 1998. Site management and productivity in tropical forest plantations. CIFOR Occasional Paper No. 16.

Wadsworth, F. 1997. Forest production for tropical America. USDA, Forest Service, Agricultural Handbook 710. 563 pp.

Whitmore, J. 1999. The social and environmental importance of forest plantations with emphasis on Latin America. J. Tropical Forest Sci. 11(1):255–269.

Will, G. 1984. Monocultures and site productivity. *In*Proc. Productivity of Fast Growing Plantations, IUFRO, Pretoria and Pietermaritzburg, South Africa.

World Energy Council (WEC)/IIASA. 1995. Global energy perspectives to 2050 and beyond. World Energy Council, London, UK.

Zobel, B., G. Vanloyk, and P. Stajl. 1987. Growing exotic forests. John Wiley & Sons, Somerset, NY. 500 pp.

This report was prepared by

DOVETAIL PARTNERS, INC.

Dovetail Partners is a 501(c)(3) nonprofit corporation whose core mission is to assist in the development of increased trade in products from responsible sources.

FOR MORE INFORMATION OR TO REQUEST ADDITIONAL COPIES OF THIS REPORT, CONTACT US AT:

INFO@DOVETAILINC.ORG

WWW.DOVETAILINC.ORG

651-762-4007

This Dovetail Report is made possible through the generous support of the Rockefeller Brothers Fund, Surdna Foundation, and the McKnight Foundation.

DOVETAIL PARTNERS, INC.
4801 N. Highway 61, Suite 108
White Bear Lake, MN 55110
Phone: 651-762-4007
Fax: 651-762-9642
www.dovetailinc.org