BRINGING BACK THE FORESTS

Policies and Practices for Degraded Lands and Forests

Proceedings of an International Conference
7–10 October 2002, Kuala Lumpur, Malaysia

Food and Agriculture Organization of the United Nations
Regional Office for Asia and the Pacific
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Editors:
H.C. Sim, S. Appanah and P.B. Durst

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FOREWORD

Forests are important natural resources that fuel the continuous economic and social development of many countries. This is especially true for many of the developing countries in the Asia Pacific region. However, the rather rapid economic and social development experienced by many of these countries was partly fuelled through exploiting these natural resources in an unsustainable manner. Additionally, inappropriate logging practices, shifting cultivation, repeated burning and other human disturbances are also rampant in many of these countries. All these unsustainable practices and rapid expansion for agriculture production have resulted in vast tracts of degraded forests and lands. A critical consequence has been the reduction in productive forest area, lowering of genetic diversity, changes in global climate, greater frequency and severity of floods and storms, and increasing poverty.

Concerned with the severity of the problems, a number of countries in the region have initiated national policies and implemented numerous forest rehabilitation projects to *Bring Back the Forests*. While much knowledge and experience have been gained from these initiatives, they have not been widely publicized or adopted. There is an urgent need to bring this understanding to the natural resource managers and policy-makers so that appropriate action is taken and supporting policies are adopted. This International Conference on Bringing Back the Forests: Policies and Practices for Degraded Lands and Forests was therefore designed to bring together all the stakeholders, including the project planners and implementers, as well as beneficiaries, to exchange experiences and knowledge and to promote successful approaches. Besides new technological advances, much care was given to the critical issues of policy and implementation. Furthermore, the Conference also provided opportunities to establish closer collaboration and networking among all the concerned parties for future undertakings.

This volume, the proceedings of the conference, is a collection of some of the most valuable papers that have been recently produced on the subject. Professionals and practitioners in forest rehabilitation should find this volume valuable, and avoid repeating mistakes and errors and wasting already scarce resources in this region.

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and Regional Representative
for Asia and the Pacific
FAO Regional Office
for Asia and the Pacific

Dato' Dr. Abdul Razak Mohd. Ali
Chairperson,
Asia Pacific Association of Forestry Research Institutions
Director-General,
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The International Conference on **"Bringing Back the Forests: Policies and Practices for Degraded Lands and Forests"** was jointly organized by the Asia Pacific Association of Forestry Research Institutions (APAFRI), the Forest Research Institute Malaysia (FRIM), the Food and Agriculture Organization of the United Nations (FAO), the Forestry Research Support Programme for Asia and the Pacific (FORSPA) and the International Union of Forest Research Organizations (IUFRO) from 7 to 10 October 2002, in Kuala Lumpur, Malaysia.

The conference was attended by delegates from Australia, Bangladesh, China, Cambodia, Denmark, Germany, India, Indonesia, Lao PDR, Malaysia, Nepal, Netherlands, Papua New Guinea, Philippines, Sri Lanka, Sweden, Syria, Thailand, United States of America and Viet Nam. FRIM and Cambodia's Department of Forestry and Wildlife greatly facilitated the field trips in Malaysia and Cambodia.

A major portion of the funds for organizing this Conference was provided by FAO-FORSPA. A number of other organizations and private enterprises have also contributed financially and in kind.

We wish to thank the delegates and authors for their contributions to the Conference and the proceedings. Special thanks are due to the sub-committee headed by Dr. Raja Barizan of FRIM for the initial compilation of this publication.

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SESSION V

OPENING

1 Welcoming address on behalf of FAO

Patrick B. Durst*

Honorable Minister of Primary Industries, Datuk Seri Dr. Lim Keng Yaik,
Dato' Dr. M.A.A. Razak, Director-General of FRIM,
Distinguished Guests, Ladies and Gentlemen,

It's a great pleasure for me to be here this morning and to offer a few remarks on behalf of the Food and Agriculture Organizationof the United Nations (FAO). At the outset, allow me to convey the greetings of FAO's Assistant Director-General for Forestry, Dr. Hosny El-Lakany, who asked me to extend his warm regards and best wishes for the success of this conference. And likewise, I'd like to extend the greetings of my colleague, Dr. S. Appanah, Senior Adviser for the FAO-supported Forestry Research Support Programme for Asia and the Pacific (or FORSPA, as many of you know it), as FORSPA is also one of the organizers of this conference.

The origins of the *Bringing Back the Forests* Conference can be traced to a meeting of the Executive Board of the Asia Pacific Association of Forestry Research Institutions (APAFRI), held early last year in Chiang Mai, Thailand. Members of the Executive Board agreed that there was a need for APAFRI to raise its institutional profile by regularly organizing major technical and policy-oriented conferences on key forestry topics, in partnership with other leading organizations in the region. FAO and FORSPA were happy to support this idea and we went on to discuss potential topics.

Collectively, we agreed that an area with enormous potential synergies—and one desperately in need of critical attention in this region—is that of forest rehabilitation. Following the discussions in Chiang Mai, a group of energetic individuals from APAFRI, FORSPA, Forest Research Institute Malaysia, International Union of Forest Research Organizations and FAO have worked tirelessly to bring the vision of this conference to reality.

Many of you are probably aware that the United Nations Forum on Forests (UNFF) has given special attention to forest rehabilitation in its deliberations during the past two years. Coincidentally, and somewhat unfortunately (for those of us who can't be

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in two places at the same time), some of our colleagues are also meeting in Seoul, South Korea, this week, under the umbrella of IUFRO and the Korean Ecological Society, also to discuss forest restoration and rehabilitation. Several other national and international meetings and workshops have been held, or are being planned, to address these topics.

So why forest rehabilitation—and why now?

One important reason is that, until recently, rehabilitation has been one of the more neglected of the major strands of forest management. For decades, there has been intense efforts to conserve the remaining natural forests and protect their associated biodiversity. Enormous attention has also been given to plantation establishment, but primarily for timber production purposes.

In comparison, the focus on rehabilitating degraded forests and degraded lands has been much less intense, especially here in the Asia Pacific region. This is somewhat surprising when we consider that FAO's Global Forest Resource Assessment 2000 estimates that there are more than 140 million hectares of "other wooded land" in Asia. Most of these areas were once forest, but are now largely covered with shrubs or bushes, or too few trees to still be considered "forest."

Of course, there are also many tens of millions of hectares that still meet the formal definition of "forest," but which have been degraded or damaged—sometimes severely—as a result of inappropriate logging techniques, shifting cultivation, fire, insect attacks, and other factors.

Another area of concern and opportunity is the region's vast *Imperata* grasslands—which now extend across more than 50 million hectares in South and Southeast Asia alone. As I'm sure most of you know, *Imperata* is a highly aggressive grass that quickly dominates areas that are subjected to regular burning or grazing. And although perhaps not all of the 50 million hectares were historically forested, evidence suggests that most were indeed covered by trees at some point in the past. FAO has recently increased efforts to promote "assisted natural regeneration"—an approach developed in the Philippines to restore *Imperata* grasslands to more productive forest.

Just from this brief review of the areas involved, we can see that there is enormous scope for rehabilitation activities. There are also many good reasons for doing so. Obviously, when forests are cleared or heavily degraded, their economic, social and ecological contributions are removed or impaired. We may easily see, as a result:

- reduced capacity to supply wood, fiber, energy and biomass;
- increased release of greenhouse gases;
- deterioration of water quality;
- accelerated loss of biodiversity; and
- increased impoverishment of forest-dependent people.

To a large extent, broader recognition of these detrimental impacts—both locally and internationally—is helping to stimulate interest in forest rehabilitation. For starters, recent concerns about climate change, and subsequent interest in carbon offsets and the Clean Development Mechanism have brought renewed focus on improved forest management for enhancing carbon sequestration. Similarly, significant reductions in timber harvesting in many countries of the region highlight the need for new sources of wood. One alternative is to gear up production on degraded sites where current productivity is very low.

There's also growing appreciation of the potential for forest rehabilitation to advance objectives related to biodiversity conservation and protection of water quality.

Finally, the past decade has seen major advances in policies related to rural poverty and social stability. There's increased recognition of the contributions that forests make, both in providing subsistence "safety nets" for the poorest segments of society and in generating broad levels of employment and income. There's also greater understanding of the ramifications of failing to address rural poverty adequately.

Despite the heightened interest in forest rehabilitation, actual progress on the ground remains rather limited. While there are plans for ambitious forest rehabilitation programmes in a few countries, such as Vietnam and China, most initiatives are still small scale in nature. There's a tremendous need to "scale up" successful pilot activities, based on sound research and realistic financial incentives. In this respect, I would like to mention the role that FORSPA has played in supporting five large-scale rehabilitation research and demonstration sites—one each in Cambodia, Laos, Papua New Guinea, Sri Lanka and Vietnam. But, still, these efforts are minimal compared to the scale of the problem and the challenges.

It's important to recognize that the constraints are rarely technical in nature. The main constraints lie in the realm of policy, finance, land-ownership and related problems. Governments are gradually recognizing that their forest departments alone can't rehabilitate all the degraded areas needing attention. And yet, private companies and individual farmers are all too often viewed more as adversaries rather than as partners in rehabilitation efforts. If the laws or regulations of a country prevent a farmer from cutting, or transporting, or selling the teak tree that he's planted in his garden plot (as is the case in several countries), we will continue to find it difficult to bring back the forests. If neither corporations nor individual farmers can be assured of secure tenure over land and resources, how can we expect them to invest in forest restoration? If bribes have to be paid to corrupt officials in order to obtain cutting and transport permits, and at multiple checkpoints along the highway, what motivation exists for planting trees? If taxes on the sale of plantation-grown wood exceed 50 percent of gross revenue, who will be interested in bringing back the forests?

There are many such policy issues constraining forest rehabilitation. You will note, therefore, that we are giving strong emphasis to policy measures and financial instruments at this conference. It's only when these fundamental constraints are removed that we will likely see significant gains in forest rehabilitation.

Ladies and Gentlemen,

FAO is delighted to be a partner in organizing this Conference. I'd like to take this opportunity to thank our partner organizations–APAFRI, FORSPA, FRIM and IUFRO—for the fabulous job they've done in planning and preparing for this Conference, and particularly for ensuring such an impressive programme and comprehensive participation.

Speaking from a personal perspective, I'm very much looking forward to this Conference. Forest rehabilitation and regeneration are virtually etched into the soul of every forester. Probably nothing can be more rewarding for a forester than to return an area of scrub, or wasteland, or degraded pasture, back into thriving forest. And, while we're not going to rehabilitate any forests directly in the next four days, our programme should give us ample opportunity to discuss the key issues and learn about some potential solutions. It's the sincere hope of FAO that this Conference will sow the seeds for expanded forest rehabilitation throughout the region, and indeed throughout the world. I wish all of you a productive, rewarding, and enjoyable conference.

Thank you.

2 Introduction: restoration of degraded forests as opportunities for development

S. Appanah*

ABSTRACT

Despite earnest efforts by the international community, forest and land degradation has advanced to such a degree that many countries in the Asia Pacific region have practically lost a major income-earning sector. Besides, loss and degradation of forests are bringing a backlash of problems, environmental, social, and others which were never unexpected. Under the circumstances, there is now pressure to rehabilitate those degraded forests and lands. In the past, such activities were limited to monoculture plantings. Now, rehabilitation procedures seek to go beyond that of commercial timber production—trials are underway to increase biodiversity and ecological services as additional products. Fortunately, such efforts can also be linked to social development. The vast majority of forest restoration schemes can also provide additional income to rural communities, besides increasing their resources. Attempts are also underway to find more innovative ways to support such developments.

INTRODUCTION

Nature inherently has a duality about it—it can be benevolent or otherwise depending on how you treat it. When Unasylva, FAO's forestry journal was launched in 1947, Sir John Boyd Orr, the first Director-General, was enthusiastic when he wrote in the foreword that "The tie between forests and the good things of the earth runs back through history" (Orr 1947). Just half a century later, following much maltreatment, the forests may perhaps be revealing their other side too.

Not too long back, some states in Malaysia were reverberating from the shock of a viral epidemic. The effect on human life and the economy was devastating. An unknown virus, subsequently named the Nipah virus, spread from swine to humans and

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killed over a hundred of the latter. The epidemic could only be contained after about a million animals were culled. What is the connection between these sudden viral epidemics and forests? If new research is confirmed, there is a very strong link, at least with the Nipah virus (Helpin *et al*. 2000). The story goes that the huge forest fires in Borneo and Sumatra in 1997–1998 led to mass migration of flying foxes to Peninsular Malaysia. Here the bats were feeding on fruits in orchards, and their droppings with the Nipah virus were picked up by pigs that foraged on the floor. The virus was eventually transmitted to humans. This is perhaps a small indication that if we continue with the unabated destruction and degradation of the world's forests, the link between forests and bad things of the earth may become our future inheritance.

FOREST DEGRADATION AND DESTRUCTION—ASIA AND THE PACIFIC

In the same Unasylva issue (ibid.), Aubreville (1947) expresses strong concern about the disappearance of tropical forests (in Africa) and warns of the consequences which ensue such a folly, such as loss of timber wealth, climate change, impoverishment of soil, poverty and so on. Yet he did believe the process can be halted and even reversed. In his view, the salvation will be a gigantic task, and has to be undertaken on an international scale.

Five decades later, despite enormous efforts from national and international agencies, progress remains quite limited, however. A quick glance at the change in the forested land area in the last decade in the Asia Pacific region would convey the view quite trenchantly (Table 1).

Table 1. Change in forested land in the Asia Pacific region (1990–2000) (million ha) (FAO 2001)

Countries	Total land area	Total forest 1990	Total forest 2000	% of land forested in 2000	Change 1990–2000	% change per year
Australia and New Zealand	795.0	164.9	162.5	20.4	–2.4	–0.1
Central Asia	391.6	16.6	19.3	4.9	2.7	1.6
NW Pacific and East Asia	1 147.8	195.2	212.7	18.5	17.4	0.9
South Asia	640.3	86.3	85.3	13.3	–1.0	–0.1
Southeast Asia	434.5	234.7	211.4	48.7	–23.3	–1.0
South Pacific	53.9	36.4	35.1	65.2	–1.2	–0.4
Asia and the Pacific	3 463.2	734.0	726.3	21.0	–7.7	–0.1

The Asia and the Pacific, with more than half the world's population, has only about 20% of the world's forests. The average per capita availability of forest area in the region is only around 0.2 ha, which is very low compared to the world average of 0.65 ha per person (FAO 2001). Within the region, Southeast Asia had the highest deforestation, with a loss of about 2.3 million ha per year. The causes for deforestation and degradation have been well researched: they include population pressure, heavy dependence on fuelwood, timber and other products, along with conversion of forests to agricultural, urban and industrial land. Overgrazing, shifting cultivation and armed conflict have added to the toll. With continued degradation, fires have increasingly become

major agents for forest loss in recent times. The Indonesian fires of 1996–97 are stark reminders of what disasters can be wrought with poor management. These are critical issues, as they accelerate loss of biodiversity, threaten ecosystem stability and the continuous flow of forest products, and the depletion of the natural resources underpinning many national economies (UNESCAP & ADB 2000).

NATIONAL AND INTERNATIONAL RESPONSES TO FOREST LOSS

The loss and degradation of forests is well recognized, and most governments have implemented a variety of instruments and programmes to counter the problems and bring about sustainable management. Some countries like Bhutan have mandated that 60% of the country should remain under forest cover. Others have introduced controls on clearance of land outside the conservation and production areas. Yet others have introduced logging bans—some 10 million ha in the region have been thus protected, albeit with mixed results. In many countries, implementation is still inadequate, while in a few cases like Sri Lanka and New Zealand it has been effective with harvesting shifting to alternative sources. Overall, the bans have also resulted in accelerated cuttings in neighboring countries. Countries like Malaysia and Thailand have adopted zero burning policies. Economic instruments have also been employed to conserve forests—China has introduced afforestation fees and licenses to strengthen cultivation, management and protection of forests. Plantations, although a poor substitute for natural forests in terms of biodiversity maintenance, have been stepped up as an alternative source of wood. Now the region has 60% of the world's plantation forests, although it will take a decade or more before they begin producing wood.

REHABILITATION OF FORESTS

Of all the measures, one that can reverse somewhat the process of deforestation and degradation is attempt to rehabilitate them. Research work on forest rehabilitation can be traced back to the very beginning (see Appanah & Weinland 1993). For example, those familiar with Malayan forestry research still recall the work of J.H.M. Robson in 1899 (in Wyatt-Smith 1963). When concern with over-exploitation of *Palaquium gutta* (gutta percha) grew, planting trials of the plants were conducted in forests depauperate of the species (Hill 1900). The work in Burma and India would date further back. The early work was mainly confined to rehabilitating degraded forests, and afforestation of denuded lands and mined areas. The importance of such work was seen to benefit landless communities, either as cash for labour or opportunities for cropping the land in the earlier planting years, e.g. the taungya system, developed in the 1830s in Burma by Brandis (in Champion & Seth 1968). Rehabilitation as a tool for development began thus. In fact, the bulk of the work FAO and other institutions initiated had social objectives primarily. It created employment, additional resources, use of land that otherwise had no agricultural value, and environmental benefits (FAO 1985).

Briefly, the following rehabilitation methods have been employed:

i. Secondary/degraded forests management

Logging using crawler-tractor systems have without exception caused much damage to the young regeneration and pole growth. The regeneration may be extremely depauperate or patchy. Enrichment planting, usually through line planting (Dawkins 1958) of desired species is the usual method to rehabilitate such areas. The success of these plantings has been rather variable (Adjers *et al*. 1995). The main problem is light—usually the canopies close back rapidly, and the small seedlings may be shaded out rapidly, pioneers may outgrow them, and creepers may entwine them. The problem has clearly been overcome—older seedlings, over 1 m in height have been tested, and plantings done in areas that have much more canopy openings. Height growth of 1 m per year has been achieved in Malaysia and Cambodia (unpublished, pers. obsns.). The advantages of rehabilitating secondary forests are the low costs, ensuring the many ecological services and retaining socially important products.

ii. Monocultures

The vast majority of afforestation and reafforestation work used single species, plantation concepts. This included rehabilitating extremely degraded forest sites, lands occupied by hardy weeds, mined lands, and sites that were prone to heavy erosion such as water catchment areas. Besides bringing about environmental benefits, commercial profits were also a consideration. As a result, many fast-growing exotics were used in such plantings.

iii. Multi-species plantations

Monocultures are not always the best options—they lack biodiversity, and the multiple other non-timber forest products which local communities seek. Planting mixtures of species, either upper-storey timber species or mix of species in various canopy levels, and meeting a variety of products, from timber, food, medicines, spices, etc. have been tried out. They are, however, complicated to establish. But properly constructed mixtures can have significant advantages in certain situations (Keenan *et al*. 1995). Mixtures can be less susceptible to disease, and enhance production arising from light and nutritional resources. A number of rehabilitation approaches are being tested out to achieve a semblance of the natural ecosystem. One is to accelerate restoration without consideration for commercial return. Degraded sites are rehabilitated by planting groups of relatively fast-growing species that are considered as ecosystem building blocks (Goosem & Tucker 1995). It only requires one planting, and thereafter depends on the local gene pool to increase species and structural diversity. This would work provided a neighbouring forest site is near enough to act as a seed source. When such a source is absent, a large number of mature phase canopy species can be planted. This would be more costly, however. Another related method includes establishing high-value mixed-species timber plantations in farmland.

Overall, there are several technical approaches available for rehabilitating tropical landscapes. All the approaches offer additional improvements in the ecological integrity of the new forest cover, while meeting the benefits of the communities that depend on them.

FAO'S RECENT INITIATIVES ON FOREST REHABILITATION

In recent years several international institutions have initiated new programmes on forest and land rehabilitation in the Asia Pacific region. They include ITTO's Criteria and Indicators, CIFOR's research on secondary forest, JIRCAS BIOREFOR initiative, Korea Ecological Society's Reforestation Programme, and FAO/FORSPA's own initiatives. Following is a brief outline of the work of FAO/FORSPA initiated in the region over the last few years:

i. Assisted Natural Regeneration Workshop in collaboration with the Department of Environment and Natural Resources, Philippines (2001)—Improved planting techniques, nursery practices, mixed-species plantings, biodiversity conservation, community participation, and economic issues were discussed.
ii. 100-ha Demonstration Plots—FORSPA developed a network of 100-ha demonstration plots in Vietnam, Cambodia, Laos, Papua New Guinea and Sri Lanka. The objective of the plots is to test out the best rehabilitation practices in a permanent site, and carry out the work long enough to demonstrate the success of the various planting designs, and estimate the costs. Establishment and management protocols have been developed, and preparation and treatment methods refined. The national scientists conduct most of the work, and hence technology transfer and future implementation in the countries are guaranteed.
iii. International Conference "Bringing Back the Forests: Policies and Practices for Degraded Lands and Forests" in collaboration with APAFRI (2002)—This current conference has brought together policy makers, researchers, managers and NGOs to review the status of forest rehabilitation in the region, and explore additional approaches, particularly the economic and policy issues needed to support rehabilitation work.
iv. Asia Pacific Forest Rehabilitation Network (APFReN)—FAO/FORSPA initiated this network, and is now managed by a group of researchers of the Forest Research Institute Malaysia. The purpose of the network is to bring about the critical mass of the researchers, and exchange information, ideas, and promote the development of their scientific work.
v. Documentation of the best practices in "Assisted Natural Regeneration Techniques for Southeast Asian Countries"—A team of experts will soon meet in Kuala Lumpur (2002) to produce a user's guidebook on the best practices in assisted natural regeneration suitable for managing Southeast Asian forests.
vi. Report "Rehabilitation of Degraded Forests and Lands in Southeast Asia: the Way Forward."—This work, to be done in collaboration with University of Queensland, will review the work so far undertaken in the region, the silvicultural knowledge, the linkage to alleviating poverty, economics and the policy settings to bring about development in forest and degraded land rehabilitation.

RESTORATION OF FORESTS AND SOCIAL DEVELOPMENT

Perhaps the most important development in restoration work in recent years is the direct link it has with alleviating poverty. There are many initiatives undergoing trials in various countries in the region. They include the Joint Forest Management in India, Food for Forests in China, and Farm Forestry Programme in Vietnam. With all these initiatives,

the participatory processes are being refined so the most vulnerable people are brought into the centre-stage in deciding the future management of forest resources. The successes are already apparent both in the improvement of livelihoods of people and the increase in forested area. This is bringing back the original role of forests, which provides a safety net for indigent societies throughout the world. The question remains—how to increase the resources and opportunities for the landless communities. Through restoration work, forestry has been able to channel more income and protection to the rural communities. For one, it can provide labour to undertake such restoration work. With careful rehabilitation work, additional resources, mainly food, medicines and other plant materials directly needed by the communities, can be added into the planting schemes. Further development in the restoration work for benefiting the poor would be tapping funds from carbon credits, Clean Development Mechanisms, biodiversity conservation and payments for ecological services. While the potential is there to reverse the trends, and bring more responsible development to the poor through the above arrangements, it may still require considerable work and political pressure to bring such benefits. Finally, ownership of forest lands and the products of restored lands and forests, a real tricky issue must be tackled in an equitable manner if forestry is ever going to bring about real development for the rural poor. Overall, for a start forest restoration work has begun to bring some improvements for the rural communities, and has been able to recapture the ideals which forestry in the first place was meant for—a resource for the benefit of rural populations.

CONCLUDING REMARKS

It is possible to state that there are several reasonably good approaches already available for rehabilitation of degraded lands and forests in the region. There are several species trials and silvicultural methods well developed to undertake large-scale reforestation in the region. Even farm forestry techniques are now available to complement the progress made in natural forests. Considering many plantations have failed for a number of reasons, rehabilitation of degraded forests is a superior alternative. While the focus in the past was on production of timber, more attention is being given to optimizing ecological services such as watershed protection and biodiversity conservation. However, the pace of reforestation has not kept pace with deforestation. With this in view, I express a few thoughts on the future needs:

i. Research—Research is particularly important, but has never been well thought out. Most research explores the causes and problems with deforestation and degradation, but few offer pragmatic solutions. Researchers are often carried away trying to explain tiny nuances between whether the degradation came from anthropogenic origin or fire or other causes. While the causes are important, especially if they recur, no amount of solutions will work. However, at the end of the day, clear, pragmatic solutions have to be offered if one wishes to see actual development. Researchers need to place more emphasis on solutions if they are going to make any impact. Next, there is a lot of re-research going on—some work that has already yielded excellent results are forgotten, and researchers attempt to redo the whole work at great costs, instead of using the past research as a step forward. One good example is the eradication of lalang (*Imperata*) infested sites. For example, Strugnell (1934) developed very practical methods to eradicate lalang by planting hardy early successional species such as *Vitex pubescens*. Yet very recently, a whole volume was devoted to the subject

of rehabilitating *Imperata* grassland with apparently no reference or knowledge of the earlier work (Friday *et al*. 1999). These are indications of problems, and the research community must work to overcome these serious difficulties.

ii. Networking—As indicated earlier, there are many initiatives on forest rehabilitation in the region. But I strongly doubt all the parties meet together, exchange views and ideas, and collaborate on at least a few common issues. This will seriously limit the overall success of each other's programmes, and it is time the various parties find additional mechanisms to work together and build on each others' strengths and successes.

iii. Some future needs—Several authors (this proceedings) have provided their insights into what needs to be immediately done. These can be paraphrased briefly into the following:

- reforestation systems which supply a wider range of goods and services;
- silvicultural systems designed for small-scale farmers (farm forestry);
- means to pay the land-owner for the additional environmental benefits societies receive from forest rehabilitation;
- cheaper finances for rehabilitation by private land-owners
- more robust application of improved enrichment planting techniques to degraded secondary forests;
- better communication of silvicultural knowledge and market information to small growers;
- better policies to facilitate rehabilitation and prevent further deforestation and degradation.

REFERENCES

Adjers, G., Hadengganan, S., Kuusipalo, J., Nuryanto, K. & Vesa, L. 1995. Enrichment planting of dipterocarps in logged-over secondary forests—effect of width, direction and maintenance method of planting line on selected *Shorea* species. *Forest Ecology and Management* 73:259–270.

Appanah, S. & Weinland, G. 1993. *Planting quality timber trees in Peninsular Malaysia—a review*. Malayan Forest Records No. 38, Kuala Lumpur, FRIM, 221 pp.

Aubreville, A.M.A. 1947. The disappearance of the tropical forests of Africa. *Unasylva* 1/1:4–15.

Champion, H.G. & Seth, S.K. 1968. *General silviculture for India*. Government of India.

Dawkins, H.C. 1958. *The management of natural tropical high forest with special reference to Uganda*. Commonwealth Forestry Institute Paper No. 34, Oxford.

FAO. 1985. *Tropical Forestry Action Plan*. Committee on Forest Development in the Tropics. Rome.

FAO. 2001. *Global forest resource assessment 2000*. FAO Forestry Paper 140. Rome.

Friday, K.S., Drilling, M.E. & Garrity, D.P. 1999. *Imperata grassland rehabilitation using agroforestry and assisted natural regeneration*. Bogor, Indonesia. International Centre for Research in Agroforestry, Southeast Asian Regional Research Programme.

Goosem, S. & Tucker, N.I.J. 1995. *Repairing the rainforest: theory and practice of rainforest reestablishment*. Cairns, Queensland, Australia, Wet Tropics Management Authority, 72 pp.

Helpin, K., Young, P.L., Field, H.E. & Mackenzie, J.S. 2000. Isolation of *Hendra* virus from pteropid bats: a natural reservoir of *Hendra* virus. *J. Gen. Virol*. 81(8):1927–1932.

Hill, H.C. 1900. *Report on the present system of forest administration in the Federated Malay States, with suggestions for future management of the forests of those States.* Her Majesty's Indian Forest Service. Selangor, Government Printer.

Keenan, R., Lamb, D. & Sexton, G. 1995. Experience with mixed species rainforest plantings in North Queensland. *Commonwealth Forestry Review* 74:315–321.

Orr, J.B. 1947. One World—one forest. *Unasylva* 1/1:1–3.

Strugnell, E.J. 1934. Lalang and its eradication. *Malayan Forester* 3:186–188.

UNESCAP & ADB 2000. *State of the Environment in Asia and the Pacific 2000*. Economic and Social Commission for Asia and the Pacific, Asian Development Bank, New York, United Nations.

Wyatt-Smith, J. 1963. *Manual of Malayan silviculture for inland forests*. Malayan Forest Records No. 23. Kepong, Forest Research Institute.

SESSION I

3 Is it possible to reforest degraded tropical lands to achieve economic and also biodiversity benefits?

David Lamb*

ABSTRACT

Deforestation has led to a simplification of the world's landscapes. Only some of this deforested land is now being used productively and large areas are available for reforestation. Reforestation can be carried out in a variety of ways. The most common forms of reforestation such as monocultures of fast-growing exotic species often provide only a limited range of benefit but are widely used despite this disadvantage. While such plantations have a role to play they should not be seen as the only option available. Other alternative forms of reforestation involving secondary forests and more complicated plantation designs can potentially provide a wider range of goods, services and functional benefits. The paper briefly reviews some of these alternatives.

INTRODUCTION

The last 100 years have seen a major reduction in global forest cover, especially in the tropics. This has occurred despite efforts to improve the silvicultural and management practices in production forests, to protect forests in national parks and other types of nature reserves and to overcome the rural poverty that is one of the causes of deforestation. These forest losses have helped feed a growing population but they have also led to a simplification of these species-rich and biologically diverse landscapes. These original forests have been replaced by a variety of simple agricultural monocultures such as rice or industrial forest monocultures made up of species such as *Pinus, Eucalyptus, Acacia* or *Tectona.* Large areas of degraded land have also been created. These are unproductive and are biologically impoverished. The changes have led to the loss of a variety of goods and services once provided by the original forests. They have also left many people still in a state of poverty.

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The question is—what should be done about this? The most common response until now has been to try and slow the loss of further forest lands and to use the lands already cleared for agriculture or plantation forestry. In most cases land managers have also sought to maximize the productivity of these by whatever means available. In the case of forest plantations, the most common approach has been to use fast-growing exotic tree species. This approach has achieved some notable successes and some large areas have been reforested to produce industrial timbers. On the other hand, it has done little to overcome the loss of the previously supplied variety of goods and ecological services. Can we do better?

OPTIONS FOR OVERCOMING FOREST DEGRADATION

There are, in fact, several other possible alternatives. One is to try to restore the original forest by re-establishing the previous plant and animal communities once present on these sites. This approach, referred to as *ecological restoration,* results in the return of the original biodiversity and the original productivity of the site. The task is difficult and some have expressed doubt whether true restoration is ever possible. However, promising examples of ecological restoration are now being reported from several tropical areas (Goosem & Tucker 1995, Dobson *et al*. 1997, Parrotta & Knowles 1999, Elliott *et al*. 2000). Another approach is to undertake forest *rehabilitation*. This means seeking to restore the original productivity and some, but not all, of the original biodiversity. In this case a trade-off is made between optimising productivity and optimising biodiversity. Again some interesting examples are being reported (Kelty 1992, Wormald 1992, Montagnini *et al*. 1995, Lamb 1998). The three approaches (i.e. reforestation with exotic monocultures, rehabilitation and ecological restoration) are summarised in Table 1.

Table 1. Definition of terms describing ways of overcoming forest degradation at a site level

Reclamation
To recover productivity (but little of the original biodiversity) at a degraded site. (In time the protective function and many of the original species may be able to recolonize if natural forests are not too distant.) Reclamation is often done with exotic species grown in plantation monocultures but may also involve monocultures of native species. In some highly degraded sites the only way of overcoming degradation may be by using exotic species because natives can no longer tolerate the new site conditions.
Rehabilitation
To re-establish the productivity and some, but not necessarily all, of the plant and animal species thought to be originally present at a site. For ecological or economic reasons the new forest may include species not originally present at the site. In time, the protective function and many of the ecological services of the original forest may be re-established. Rehabilitation can be carried out using mixed species plantations, plantation monocultures with diverse understoreys or by managing secondary or regrowth forests.
Ecological Restoration
To re-establish the presumed structure, productivity and species diversity of the forest originally present at a site. In time, the ecological processes and functions of the restored forest will match those of the original forest. This is most likely to be achieved in most tropical forests using secondary or regrowth forests with or without enrichment.

These three ecological alternatives can be matched with a conceptual model of the trade-offs between the ecosystem integrity of the reforested ecosystem and the human well-being reforestation promotes (Figure 1). *Ecosystem integrity* is an expression including both the degree of ecological authenticity achieved by the reforestation method used and the extent to which this reforestation provides environmental benefits or improves ecological functioning. Ecological restoration would obviously provide a greater degree of ecosystem integrity than would a monoculture of an exotic species. *Human well-being* is a measure of the ecological services or environmental benefits received from reforestation (e.g. watershed protection, the establishment of food or medicinal plants) and the social and economic improvements to rural communities following reforestation.

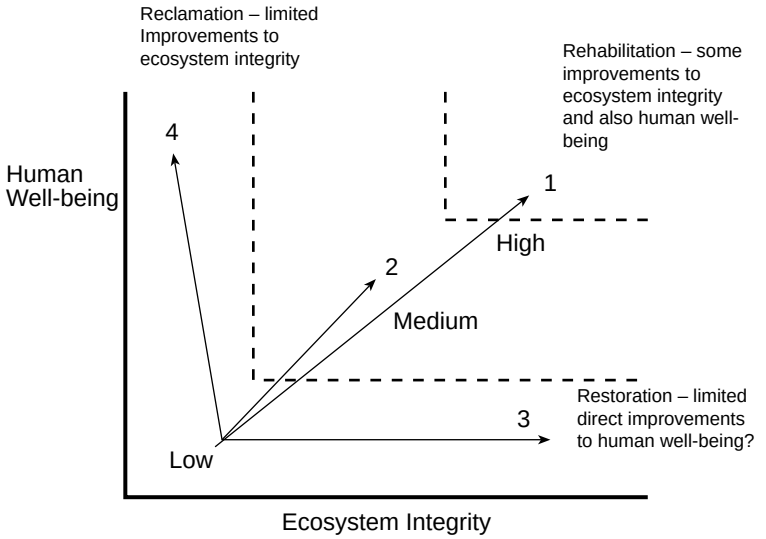

Figure 1. Trade-offs in reforestation

The best form of reforestation, therefore, would be that which improved both ecological integrity of a degraded site and which also increased the human well-being of people living in or around the area. Reforestation in the form of ecological restoration would certainly improve the ecological authenticity of a previously degraded site but may do little to improve human well-being, at least in the short term. This could result in the clearing of such reforestation by people living in the area. Reforestation in the form of industrial monoculture plantations of exotic species might not sufficiently improve the ecological services needed to help local people let alone directly improve their social or economic circumstances (with the benefits going primarily to the companies and their shareholders). Again the outcome would be sub-optimal. These trade-offs are illustrated in Figure 1.

This means we need some new options for dealing with degraded lands beyond simply improving the production of cellulose or timber. These new forms of reforestation need to be commercially attractive, to provide economic and social benefits for rural communities and be able to re-establish the key ecological functions of the original forest such as watershed protection, nutrient cycles, biodiversity protection, etc. Plantations of fast-growing exotic species will still have a place in some circumstances but these should not be seen as the only option available.

REHABILITATION METHODS

There are a variety of ways degraded forests might be rehabilitated to enhance both ecological authenticity and human well-being. Four key approaches are outlined below.

(a) Secondary forests management

Large areas of secondary forests are now common in many tropical countries (Finegan 1992, Chokkalingam *et al*. 2001). These have originated in a variety of ways but most commonly develop after intensive logging has created large canopy gaps or as regrowth following some form of agricultural clearing once these agricultural sites are abandoned. Until comparatively recently most forest management agencies have regarded these as being commercially worthless. By contrast, many rural communities living in or near these forests have recogniZed that many can have considerable value and have harvested a variety of resources from them including foods, medicines and building materials.

There are two options open to managers. One is to simply protect these forests from further significant disturbances (intensive logging, agricultural clearing, fire) and allow natural successional processes to re-establish the former forest structure. This may mean reaching some agreement with local people using the forest for subsistence purposes to constrain the degree to which they disturb this regeneration and succesional development. The other option is to seek to enrich the forest with commercially or socially valuable species. This might be done as line plantings or as clump plantings in areas where sufficient canopy openings are present. Past experiences with enrichment plantings have been varied (Adjers *et al*. 1995, Tuomela *et al*. 1995, Bebber *et al*. 2002). The responses have been promising in situations where care has been taken to use good planting stock and where weeds and overstorey cover have been controlled. In other situations, particularly where canopy cover is too great, many of the planted seedlings stagnate or are overcome by weed competition and the approach has failed (e.g. Ramos & Delamo 1992) . Methodologies need to be developed for the specific conditions present at each site. Enrichment may be especially difficult in old regrowth forests where a canopy of pioneers is well established.

The advantage of using existing secondary forest is that the cost of retaining these and developing ways of managing them is likely to be much lower than clearing and replanting the site. Their retention also ensures many ecological services and socially important products are retained. The primary disadvantage is that the yields of commercially valuable products are often low (though yields of socially useful and domestic products may be high) and that the methods for enhancing the site productivity (e.g. by enrichment planting) can be difficult.

(b) Monocultures

Monocultures are attractive because trees of a commercially valuable species are planted at a high density. Fast-growing species have mostly been favoured in the past because the volume increments of these are greater and, consequently, they have shorter rotations. Besides, any tree cover, including that provided by exotic species, usually provides some ecological benefits (e.g. protecting soil erosion). But the commercial value of many of these fast-growing exotic species is now being questioned and the potential gains from using slower-growing but higher-value native species are looking rather more attractive. These changes are being prompted by the large areas of exotic plantations now established

and because of the reduced areas of natural forest now left for commercial logging. Besides commonly having a higher market value, native species often provide some additional ecological benefits by being better adapted to local conditions and being more attractive to local wildlife. (On the other hand, they are also more prone to damage from their traditional pests and diseases than exotic species that may now have been separated from many of these.)

The ecological benefits of monocultures can be enhanced in two ways. One is to use buffer strips of natural vegetation, regrowth or ecologically restored vegetation along streams and rivers to protect these from any erosion. Similar buffer strips can be also used to separate compartments of the plantation and acts as firebreaks. That is, the extensive monoculture is broken into compartments embedded in a framework of buffers.

The other way ecological benefits might be enhanced is to use a mosaic of monocultures. That is, native species might be planted at particular sites depending on their site preferences. These, too, might be embedded in a matrix of buffer strips. Both approaches can add considerable structural complexity to the landscape and help the retention of many native plants and animals as well as facilitate their movement across the landscape (Lamb 1998).

These approaches might be more useful where large areas of cleared land are present. The advantage of these approaches is that the plantations can provide high timber yield per hectare (cf. the regrowth forests). High-value species can be used and the buffers help with watershed protection and biodiversity conservation. The main disadvantage of using native species is that the silviculture of most of these is comparatively poorly understood. Raising large numbers of most species in nurseries is difficult. Developing ways of establishing these in the field can also be problematic although promising results are now being obtained from quite different regions suggesting many of these difficulties will be overcome in time.

(c) Monocultures with understoreys

The main disadvantage of monocultures is their lack of biological diversity. This may not matter if industrial timber production is the sole objective but it may be a disadvantage if the local communities living in the surrounding areas need or expect to obtain resources such as foods and medicines or other ecological services from these new forests. In fact, many monoculture plantations acquire an understorey of other plant species over time as a result of colonisation by species from nearby intact native forests (Keenan *et al*. 1997). The extent to which this takes place depends very much on the distance to these forests and on the presence of wildlife such as birds and bats able to cross the landscape and disperse seeds. Such understoreys can also be deliberately planted (i.e. using the original plantation as a nurse crop).

The extent and diversity of these new understoreys can be large and many can contain a large variety of plant species. Over time many of these new colonists can grow up and join the forest canopy. One the one hand, this means the silvicultural opportunities increase because of the greater variety of tree species present. On the other hand, the increased tree density means that the growth of individual trees will slow unless some thinning takes place. A variety of options are available depending on the ecological, economic and social circumstances prevailing. These range from removing the new understorey to concentrate solely on the original plantation species, abandoning the plantation as a source of future timber and concentrating management on the fostering of the biodiversity values it now contains or perhaps managing the new, uneven-aged, multi-species forest as a selection forest. Some of these options are reviewed further in Keenan *et al*. (1997).

Fostering and managing understoreys as a means of increasing the value of plantations can improve the social value of plantation monocultures. These understoreys may also enhance the extent of watershed protection provided by the plantations. The primary disadvantage is they may necessitate a revision of the plantation management objectives from being simply to maximise timber production to trying to achieve something else. But this dilemma may be more common than is frquently supposed. Tree plantations are long lived and many social and economic situations can change during the time of a rotation, especially in plantations located near towns or cities. This means the opportunities to change may sometimes be a benefit rather than a problem.

(d) Multi-species plantations

Monoculture plantations offer very little in the way of biological diversity (although this may change over time as discussed above). In some situations there may be advantages in establishing mixtures of species rather than monocultures (Lamb 1998). These mixtures can have significant advantages over monocultures under certain circumstances (Montagnini *et al*. 1995) (Table 2). This may be because of enhanced production arising from improved use of the sites' above- or below-ground resources. Thus the mixture has a higher productivity than monocultures of its constituent species. Alternatively, the mixture may be less susceptible to pests or diseases because of microclimate changes or because the target trees are hidden in space (Keenan *et al*. 1995, Wazihuuah *et al*. 1996). Increased productivity may also arise from improved nutrition resulting from the use of a nitrogen fixing tree (de Bell *et al*. 1989, Binkley 1992). Or, finally, the mixture may be more financially secure because early maturing species can be harvested comparatively quickly and so provide a quicker financial return. The mixture can also act as an insurance policy at a time when it is difficult to estimate the market worth of species some time in the future.

Table 2. Mechanisms by which a plantation mixture might yield a greater benefit than plantation monocultures of the same species

Potential benefit	Mechanism
Reduced between-tree competition leading to increased productivity	From: • phenological separation in time • root separation in space (depth) • foliar separation in space (canopy architectural differences)
Reduced insect and pest damage leading to increased productivity	From: • microenvironment changes resulting from underplanting (e.g. red cedar) • target species being "hidden" in space or too distant for disease transfer
Improved nutrition—especially at degraded sites with infertile soils—leading to increased productivity	From: • inclusion of nitrogen fixing species in mixtures • faster litter decay and improved nutrient turnover
Improved financial returns	Early harvest of fast-growing and easily marketed species leaving slower-growing but more valuable species to develop over time. This harvest also acts as a thinning allowing improved growth of residual trees

The main problem with mixtures is that they are much more complicated to establish and manage. A variety of mixed species designs are available including permanent and temporary mixtures (i.e. temporal changes) as well as line plantings and random assemblages (i.e. spatial changes). But *ad hoc* plantings or assemblages are unlikely to work. Care needs to be taken to identify and match complementary species to ensure the theoretical advantages of mixtures are achieved in practice. This means that foresters have been reluctant to embark on large-scale mixed species plantings in the past because this knowledge is rarely available. However, evidence is beginning to develop from different regions suggesting that properly constructed mixtures can have significant advantages in particular circumstances (Keenan *et al*. 1995, Montagnini *et al*. 1995, Zhou *et al*. 2002).

In summary, there are a variety of approaches that might be used in tropical landscapes to overcome degradation. All require knowledge of the ecology and silviculture of native species, all require knowledge of the site preferences of these species and all require acceptance that native species may be rather slower growing, at least initially, than many well-known exotic species. On the other hand, all these approaches offer improvements in the ecological integrity of the new forest cover and in the benefits to human well-being that this reforest effort will provide.

THE SIGNIFICANCE OF SCALE

The forms of reforestation discussed above are necessarily concerned with changes at a site level. Many functional benefits (e.g. to biodiversity, to watershed protection) are only achieved when larger areas of landscape are reforested. The degree of ecological change can be measured at both scales. Thus diversity at a local scale is referred to as alpha diversity and is usually taken to mean the numbers of species present at a particular site. The gamma diversity, on the other hand, is the collective diversity of all species across a landscape. The beta diversity is the rate of change across the landscape in gamma diversity. Hence,

Gamma diversity = alpha diversity x beta diversity

This means biological diversity might be achieved via complex mixtures across the whole landscape or, alterntively, by a mosaic of different monocultures (i.e. each monoculture has a low alpha diversity but, collectively, they generate a high landscape or gamma diversity).

The interesting question is—which approach yields the optimum functional outcome? Ecologists have not yet explored this question in sufficient detail to answer it with any confidence. Some things are reasonably clear. Most wildlife biodiversity is probably best conserved by reforestation that involves high numbers of plant species (i.e. using secondary forest, using mixed species plantations). These sites then have high levels of alpha diversity. Such sites are also probably better able to protect watersheds, sequester carbon and restore soil fertility lost during the degradation process. On the other hand, landscapes with high levels of gamma diversity may be equally suited for many wildlife species and equally effective at stabilizing hillsides or overcoming salinity problems. And such diversity may be much easier to establish (via mosaics of monocultures) than that involving mixed-species plantations. This topic is clearly one deserving much more attention in future.

CONCLUSION

The scale of the losses in tropical forest cover are now so great that new forms of reforestation must be found to provide more than just timber production. Without these new forms of reforestation the most biological diverse regions of the world will have been converted to impoverished and simplified landscapes unable to supply the diverse range of goods and services once supplied by the original forests. There is increasing evidence that this extensive loss of forest cover is likely to reduce the sustainability of much of the newly created agricultural landscapes (Hobbs & Morton 1999, Lefroy *et al*. 1999). This will leave the many people now living in poverty in even more desperate circumstances. What is needed, therefore, are ways of reforesting degraded lands that provide human benefits as well as biodiversity and functional improvements.

There are, in fact, a number of promising possibilities. No single alternative can be prescribed because each landscape has a different ecological and social situation. This means that the final outcome in any landscape will probably contain a number of alternative approaches to overcoming degradation including monocultures of exotic species as well as various versions of forest rehabilitation using some of the approaches outlined above and, in some particular situations, ecologically restored forests. The task for forest managers will then be to ensure that these options are combined in such a way as to maximize the overall ecosystem integrity across the landscape while also maximizing an improvement in human well-being.

REFERENCES

Adjers, G., Hadengganan, S., Kuusipalo, J., Nuryanto, K. & Vesa, L. 1995. Enrichment planting of dipterocarps in logged-over secondary forests—effect of width, direction and maintenance method of planting line on selected *Shorea* species. *Forest Ecology and Management* 73: 259–270.

Bebber, D., Brown, N., Speight, M., Moura-Costa, P. & Wai, Y.S. 2002. Spatial structure of light and dipterocarp seedling growth in a tropical secondary forest. *Forest Ecology and Management* 157: 65–75.

Binkley, D. 1992. Mixtures of nitrogen fixing and non-nitrogen fixing tree species. *In* M.G.R. Cannell, D.C. Malcolm, & P.A. Robertson, eds. *The ecology of mixed species stands of trees*, pp. 99–123. Blackwell Scientific.

Chokkalingam, U., Bhat, D.M. & von Gemmingen, G. 2001. Secondary forests associated with the rehabilitation of degraded lands in tropical Asia: a synthesis. *Journal of Tropical Forest Science* 13: 816–831.

De Bell, D.S., Whitesell, C.D. & Schubert, T.S. 1989. Using N^2 fixing *Albizia* to increase growth of *Eucalyptus* plantations in Hawaii. *Forest Science* 35: 64–75.

Dobson, A., Bradshaw, A. & Baker, A. 1997. Hopes for the future: restoration ecology and conservation biology. *Science* 277: 515–522.

Elliott, S., Kirby, J., Blakesley, D., Hardwick, K., Woods, K. & Anusarnsunthorn, V. (eds.) 2000. *Forest restoration for wildlife conservation*. Proceedings of a Workshop, January 30–February 4, 2000, Forest Restoration Research Unit, University of Chiang Mai, Thailand.

Finegan, B. 1992. The management potential of neotropical secondary lowland rainforest. *Forest Ecology and Management* 47: 295–321.

Goosem, S. & Tucker, N. 1995. *Repairing the rainforest: theory and practice of rainforest re-establishment in North Queensland's wet tropics*. Cairns, Australia, Wet Tropics Management Authority.

Hobbs, R.J. & Morton, S.R. 1999. Moving from descriptive to predictive ecology. *Agroforestry Systems* 45: 43–55.

Keenan, R., Lamb, D. & Sexton, G. 1995. Experience with mixed species rainforest plantings in North Queensland. *Commonwealth Forestry Review* 74: 315–321.

Keenan, R., Lamb, D., Woldring, O., Irvine, A. & Jensen, R. 1997. Restoration of plant diversity beneath tropical tree plantations in northern Australia. *Forest Ecology and Management* 99: 117–132.

Kelty, M.J. 1992. Comparative productivity of monocultures and mixed species stands. *In* M.J. Kelty, B.C. Larson, & C.D. Oliver, eds. *The ecology and silviculture of mixed species forests*, pp. 125–141. Dordrecht, Kluwer Academic Publishers.

Lamb, D. 1998. Large-scale ecological restoration of degraded tropical forest land: the potential role of timber plantations. *Restoration Ecology* 6: 271–279.

Lefroy, E.C., Hobbs, R., O'Connor, M.H. & Pate, J.S. 1999. What can agriculture learn from natural systems? *Agroforestry Systems* 45: 423–436.

Montagnini, F., Gonzalez, E., Porras, C. & Rheingans, R. 1995. Mixed and pure forest plantations in the humid neotropics: a comparison of early growth, pest damage and establishment costs. *Commonwealth Forestry Review* 74: 306–314.

Parrotta, J. & Knowles, H. 1999. Restoration of tropical moist forests on bauxite mined lands in the Brazillian Amazon. *Restoration Ecology* 7: 103–116.

Ramos, J. & Delamo, S. 1992. Enrichment planting in a tropical secondary forest in Veracruz, Mexico. *Forest Ecology and Management* 54: 289–304.

Tuomela, K., Kuusipalo, J., Vesa, L., Nuryanto, K., Sagala, A. & Adjers, G. 1995. Growth of dipterocarp seedlings in artificial gaps: an experiment in logged-over rainforest in South Kalimantan, Indonesia. *Forest Ecology and Management* 81: 95–100.

Wazihuuah, A.K.M., Islam, S.S., Rahman, F. & Das, S. 1996. Reduced attack of keora (*Sonneratia apetala*) by stem borer in mixed species plantations in Bangladesh. *Journal of Tropical Forest Science* 8: 476–48.

Wormald, T.J. 1992. *Mixed and pure forest plantations in the tropics and sub-tropics*. Rome, FAO.

Zhou, G.Y., Morris, J.D., Yan, J.H., Yu, Z.Y. & Peng, S.L. 2002. Hydrological impacts of reafforestation with eucalypts and indigenous species: a case study in southern China. *Forest Ecology and Management* 167: 209–222.