CATALYSING NATURAL FOREST RESTORATION ON DEGRADED TROPICAL LANDSCAPES

John A. Parrotta[1]

ABSTRACT

Tropical forest loss and degradation are proceeding at unprecedented rates, eroding biological diversity and prospects for sustainable economic development of agricultural and forest resources. There is increasing evidence that forest plantations can play a key role in harmonising long-term forest ecosystem rehabilitation or restoration goals with near-term socio-economic development objectives. Recent studies have shown that plantations can facilitate or “catalyse,” forest succession and biodiversity enrichment in their understories on sites where persistent ecological barriers to succession would otherwise preclude recolonisation by native forest species. These studies suggest that the catalytic effect of plantations is due to changes in understorey microclimatic conditions, increased vegetation structural complexity, and development of litter and humus layers that occur during the early years of plantation growth. These changes lead to increased seed inputs from neighbouring native forests by seed dispersing wildlife attracted to the plantations, suppression of grasses or other light-demanding species that normally prevent tree seed germination or seedling survival, and improved light, temperature and moisture conditions for seedling growth. Wildlife, particularly birds and bats, are critical "allies" in the restoration process, responsible for seed dispersal for the overwhelming majority of tree, shrub and liana species present in moist tropical forests. Understanding the habitat preferences and behaviour of these restoration facilitators, including their relationship to vegetation structure and composition, can help us to better design restoration treatments (including tree species selection) that will lead to rapid increases in floristic diversity and overall improvements in the value of these forests as wildlife habitat. In this paper, the results of recent studies conducted since 1995 in several countries in Latin America, Africa and the Asia-Pacific region on the phenomenon of plantation-catalysed native forest restoration will be summarised and their potential application in wildlife conservation programmes discussed.

Keywords: Biodiversity, Forest restoration, Plantations, Rehabilitation, Silviculture, Succession

[1] International Institute of Tropical Forestry, USDA Forest Service, PO Box 25000, Río Piedras, PR 0928-5000 USA. Tel: +1-787-766-5335; Fax: +1-787-766-6263;
e-mail: j_parrotta@upr1.upr.clu.edu

INTRODUCTION

Tropical forest loss and degradation, as well as degradation of lands that formerly supported forest, are proceeding at unprecedented rates, eroding biological diversity and prospects for sustainable economic development of agricultural and forest resources. Each year, an estimated 15.4 million ha of tropical forests and woodlands are destroyed or seriously degraded, principally through agricultural expansion, uncontrolled livestock grazing, logging, and fuel-wood collection (WORLD RESOURCES INSTITUTE/IIED, 1988; FAO 1993). Estimated annual losses of forest cover range from 0.6 to 1.1% among tropical forest zones (FAO 1993), with the greatest losses occurring in moist deciduous forests (6.1 m ha y^{-1}) and in tropical rain forests (4.6 m ha y^{-1}). Significant losses are also occurring in upland forest formations (2.5 m ha y^{-1}) as well as in dry and very dry forest zones (2.2 m ha y^{-1}).

Historically the most common response to land degradation has been abandonment, or reliance on natural forest succession to restore lost soil fertility, species richness, and biomass productivity. Periodic land abandonment has been the basis of apparently sustainable traditional shifting cultivation and livestock herding systems. In many tropical regions, however, fallow periods are often shortened or eliminated due to increased population pressures and agricultural intensification. Without adequate inputs (such as plant nutrients), productivity and land utility commonly decline, often precipitously, as in the case of pasture development in the Amazon Basin (UHL *et al.* 1988a, 1988b; NEPSTAD *et al.* 1991). As a result, extensive areas of former forestlands are in varying stages of degradation. Such areas need management to improve their productive capacity, to meet human needs, to improve local and regional watershed management and to contribute to biodiversity conservation, by providing improved habitats for wildlife, both inside and outside protected areas.

Strategies and techniques for rehabilitating degraded areas should be based on the priorities and objectives of stakeholders, as well as the costs and benefits associated with available rehabilitation techniques. A large proportion of marginal lands, currently classified as degraded, can and should be rehabilitated primarily for food production. New cropping practices (such as agro-forestry technologies) and more efficient agricultural resource management systems can assist this process and ensure that agriculture remains sustainable and thereby minimise local pressures on natural forest ecosystems. There remain, however, significant formerly forested areas in many countries that cannot be economically rehabilitated for either agricultural or intensive commercial forestry production in the near term, and degraded lands of high potential value for conservation and watershed protection.

An unknown proportion of these lands would naturally revert fairly quickly to secondary forest, if the pressures on them (i.e., biomass harvesting, grazing, fire) are lifted. This has occurred in parts of Latin America where substantial areas of secondary forest have established following the collapse of cattle raising activities (BROWN & LUGO, 1990; SIPS 1993). In many areas of South and Southeast Asia, Joint Forest Management programmes have resulted in dramatic rates of forest recovery, following implementation of effective community-based forest protection measures (POFFENBERGER & MCGEAN, 1996). Other, more severely degraded, landscapes require some form of human intervention, or management, to facilitate their recovery. On such sites, persistent physical, chemical and biological barriers, or stresses, preclude or severely limit the rate of natural forest succession. These barriers typically include some combination of the following "symptoms": recurrent fires; soil compaction, waterlogging, salinisation or other soil physical and chemical limitations; erosion and soil nutrient limitations; absence of obligate fungal or bacterial root symbionts; seasonal drought; low seed or rootstock availability; lack of suitable microhabitats for seed germination and seedling establishment; seed and seedling predation; and severe competition with grasses or ferns.

At present most tropical reforestation efforts focus on the development of forestry and agro-forestry systems aimed at maximising production of a very limited number of tree species of economic importance. Alternatively, forest restoration projects usually involve planting of a diversity of forest species and aim to recreate the forest ecosystem believed to have formerly occupied the landscape. Intensively managed commercial forestry and agro-forestry systems have limited potential for biodiversity conservation. Although ecosystem restoration can yield extremely good results in terms of biodiversity recovery, their high costs make them economically unattractive for large-scale application in most tropical countries except under very specialised circumstances, such as in the restoration of mine sites (KNOWLES & PARROTTA 1995; PARROTTA & KNOWLES 1999) or degraded habitats in conservation units and on private land (GOOSEM & TUCKER, 1995; TUCKER & MURPHY 1997). What is needed for large-scale application in many regions are forest rehabilitation and management systems that simultaneously accelerate regeneration of species-rich native forest ecosystems and provide economically and socially valued forest products.

PLANTATIONS AS A TOOL FOR CATALYSING NATIVE FOREST SUCCESSION

There is increasing evidence to support the assertion that forest plantations can play a key role in harmonising long-term forest ecosystem rehabilitation or restoration goals with near-term socio-economic development objectives (*cf.* PARHAM *et al.*, 1993; BROWN & LUGO, 1994; LAMB & TOMLINSON 1994, PARROTTA & TURNBULL, 1997; KIKKAWA *et al.*, 1998; LAMB 1998). Several studies conducted between 1985 and 1995 demonstrated that plantations accelerate or catalyse forest succession in their understories (particularly where intensive silvicultural management is neglected) on sites where persistent ecological barriers to succession would otherwise prelude recolonisation by native forest species. See, for example, YU *et al.* (1994) for China; BHASKAR & DASAPPA (1986), KUSHALAPPA (1986), SONI *et al.* (1989), GEORGE *et al.* (1993) and SRIVASTAVA (1994) for India; MITRA & SHELDON (1993) for Malaysia; and KUUSIPALO *et al.* (1995) for Indonesia; KNIGHT *et al.* (1987), LÜBBE & GELDENHUYS (1991), GELDENHUYS (1993, 1996) and VAN WYK *et al.* (1995) for South Africa; FIMBEL & FIMBEL (1996) for Uganda; LUGO (1992), PARROTTA (1992, 1993, 1995), and LUGO *et al.* (1993) for Puerto Rico; GUARIGUATA *et al.* (1995) for Costa Rica; VIEIRA *et al.* (1994) and SILVA JUNIOR *et al.* (1995) for Brazil.

These studies have shown that under certain conditions (particularly where forest remnants and forest seed-dispersing wildlife are present on the landscape), forest plantations significantly accelerate natural succession by overcoming barriers to natural regeneration. This is due to their influence on understorey microclimatic conditions, vegetation structural complexity, and development of litter and humus layers during the early years of plantation growth. These changes lead to increased seed inputs from neighbouring native forests by seed dispersing wildlife attracted to the plantations, suppression of grasses or other light-demanding species that normally prevent tree seed germination or seedling survival, and improved light, temperature and moisture conditions for seedling growth. In the absence of silvicultural management aimed at eliminating woody understorey regeneration, the monospecific plantation system is replaced by a mixed forest comprised of the planted species and an increasing number of early and late successional tree species and other floristic elements drawn from surrounding forest areas. This process can be observed in many tropical countries where plantations established decades ago are no longer being managed for timber production due to changing economic conditions within the forestry sector and, in some cases, environmental legislation banning forestry activities in ecologically sensitive zones such as montane and riparian areas. Eventually, if the planted species are short-lived and light demanding (as are most of the commonly planted commercial species), they may disappear entirely from the system following their harvest of natural mortality, leaving a floristically rich secondary forest.

Plantations as successional catalysts: results of a recent international research programme

Based on these earlier findings, an international collaborative research project on tropical tree plantations and biodiversity rehabilitation was initiated in 1994 by the USDA Forest Service (International Institute of Tropical Forestry) with financial support from the World Bank, the Center for International Forestry Research (CIFOR) and the Overseas Development Authority/UK (ODA). Its purpose was to critically evaluate the effects of forest plantings on native forest succession on severely degraded or deforested tropical landscapes. Specifically the research addressed a series of hypotheses concerning the relative importance of environmental conditions, plantation species selection and other design criteria and silvicultural management practices on the process of native forest regeneration in established plantations. A common set of study protocols was used to quantify floristic composition and other ecological parameters in a variety of plantation systems of different ages and in unplanted "control" areas across a range of site conditions (Table 1). These studies were carried out in 1995-96, and an international symposium/workshop convened in Washington DC in June 1996 to present and discuss the findings of these studies and those of related research by investigators working in a number of other tropical and subtropical locations. The results of this project and associated studies presented at this symposium, were published in a special issue of *Forest Ecology & Management* (PARROTTA & TURNBULL, 1997).

The 1996 symposium/workshop provided an opportunity for participants to evaluate the hypotheses that guided the international research project, to identify areas for further research and to discuss the potential applications of project results under a variety of management conditions. Workshop participants considered the following questions:

- Do plantations accelerate natural forest succession on degraded tropical sites?

- If so, what site conditions, plantation designs (species selection, spacing, etc.), and silvicultural management practices (site preparation, understorey management, thinning regimes) favour the adoption of this technique for native forest rehabilitation/restoration over alternative methods?
- What is the role of wildlife in the process and how can plantations be designed to increase their effectiveness as seed-dispersers?
- To what extent does the regeneration of a diverse understorey flora affect the productivity of the planted crop in plantations established primarily for timber production, and how can the regeneration process be managed to optimise yields of a diverse product mix to meet economic, social and environmental conservation objectives?
- What are the potential uses of the "catalytic effect" of plantations to harmonise forest production goals and forest rehabilitation and/or restoration objectives?

The following conclusions and suggestions for future research emerged from the 1996 workshop:

- Relative to initially similar, unplanted sites, plantations generally have a marked positive effect on native forest redevelopment (succession) on severely degraded sites (such as mined lands and severely eroded areas) and on sites dominated by grasses and ferns which otherwise preclude colonisation by forest species;
- The degree to which plantations accelerate colonisation and establishment by native forest species increases with increased site degradation and from drier to wetter sites, and generally decreases with increasing distance from remnant native forest stands (i.e., seed sources). Further research was recommended to develop techniques for accelerating natural forest succession on drier sites;
- Choice of plantation species can significantly affect the process of understorey regeneration, several studies having shown that plantations of different species of the same or similar age grown on very similar or identical sites showed marked differences in the density and species composition of their woody understorey communities. These differences are due to a combination of factors, including the effect of the overstorey species on understorey light environments and seasonal regimes, soil chemical and biological characteristics, nutrient cycling processes and their relative value to seed-dispersing wildlife;
- Structural complexity of the planted forest is an important determinant of subsequent biodiversity enrichment due to the importance of habitat heterogeneity for attracting seed-dispersing wildlife and microclimatic heterogeneity required for seed germination for a variety of species. This suggests that broadleaf species yield generally better results than conifers, and that mixed-species plantings are preferable to monocultures, due in part to their increased structural complexity. Future studies were suggested to assess the influence of overstorey (planted) species architecture and phenology on understorey microclimate heterogeneity (spatial and temporal patterns), and aspects of forest floor and soil development that influence recruitment of native forest species, under a variety of site and landscape conditions;
- Wildlife, especially bats and birds, are of fundamental importance as seed dispersers

in tropical regions. Their effectiveness in facilitating plantation-catalysed biodiversity development on degraded sites depends on the distances they must travel between seed sources (remnant forests) and plantations, the attractiveness of the plantations to wildlife (ability of plantations to provide habitat and food) and the condition of the forests from which they are transporting seeds (WUNDERLE, 1997). Additional research is needed under a variety of ecological conditions to better understand the dynamics of animal seed dispersal in degraded landscapes, to develop appropriate plantation designs to encourage seed transport from remnant forest stands, and to determine the range of distances between seed sources and rehabilitation sites over which seed dispersal by animals is likely to be effective;

- Larger-seeded forest species are far less likely to colonise degraded sites than smaller-seeded species due to seed dispersal limitations, and therefore require management interventions (e.g., enrichment planting) to facilitate their establishment, particularly where forest restoration is a major objective. Further studies are recommended to develop low-cost techniques for establishing large-seeded species either at the time of plantation establishment, or as enrichment plantings at appropriate stand ages;
- Regarding silvicultural management options, the workshop examined the effects of site preparation alternatives (mechanical, fire, chemical), understorey management practices and plantation thinning regimes on both the planted trees and the species-rich native forest understorey they foster. Due to the complexity of interactions among the many factors involved, however, specific recommendations are dependent on initial site conditions, the goals of plantation management, and the relative importance of the planted trees for timber or biomass, the regenerating understory and other socio-economic and environmental goods and services provided by the rehabilitating forest system. The issue of "trade-offs" between overstorey productivity and understorey development was identified as an important topic for further study, requiring experimental studies to determine the effect of plantation understorey regeneration on overstorey growth and nutrient cycling processes during the course of stand development;
- There was a broad consensus that the “catalytic plantation” approach is a promising tool for degraded land rehabilitation in a variety of contexts. Given the growing recognition in the scientific and development communities, among policy-makers, and in the private sector of the need to incorporate biodiversity rehabilitation and conservation in land-use planning and forest management, this approach is attracting broad interest as a means for integrating social, economic and environmental land management goals. Potential applications of this approach included restoration plantations in riparian areas and on other critical sites (such as steep eroded slopes); plantings designed to foster development of mixed native forests for a variety of locally used and valued species; and alternative management strategies for long-rotation timber plantations, short-rotation fuel-wood or fibre plantations and agro-forestry systems.
- Management issues and potential applications discussed during the workshop clearly indicate the need for additional research in a number of areas related to plantation design and management. Specifically, experimental research is required

to systematically evaluate the effects of site preparation, plantation species selection (both single- and mixed-species alternatives), understorey management practices, and stand manipulation techniques (e.g., pre-commercial thinnings, liberation thinnings, enrichment plantings) on the productivity of both the planted crop and its regenerating understory, the associated economic and social costs and benefits, and the environmental impacts of alternative design and management systems related to biodiversity conservation, soil fertility rehabilitation and carbon sequestration. These questions need to be addressed in the context of local ecological conditions. There must also be recognition of the current and future priorities of local communities, individual landholders and land managers to ensure that forest rehabilitation and management options evaluated are consistent with socio-economic realities, development priorities and conservation goals.

ACKNOWLEDGEMENTS

This work was conducted in cooperation with the University of Puerto Rico and supported in part by a grant from the World Bank to the International Institute of Tropical Forestry, USDA Forest Service (Research Support Budget Grant RPO #680-05: “The catalytic effect of tree plantings on the rehabilitation of native forest biodiversity on degraded tropical lands”).

REFERENCES

BHASKAR, V. and DASAPPA, 1986. Ground flora in Eucalyptus plantations of different ages: in: SHARMA, J. K., C. T. S. NAIR, S. KEDHARMATH and S. KONDAS (Editors), *Eucalypts in India: Past, Present and Future*. Kerala Forest Research Institute, Peechi, Kerala, pp. 213-224.

BONE, R., LAWRENCE and Z. MAGOMBO, 1997. The effect of *Eucalyptus camaldulensis* (Dehn) plantation on native woodland recovery on Ulumba Mountain, southern Malawi. *For. Ecol. Manage*, 99: 83-99.

BROWN, S. and A. E. LUGO, 1990. Tropical secondary forests. *J. Trop. Ecol*., 6: 1-32.

BROWN, S. and A. E. LUGO, 1994. Rehabilitation of tropical lands: a key to sustaining development. *Rest. Ecol.*, 2: 97-111.

FAO, 1993. *Forest resources assessment 1990. Tropical countries*. FAO Forestry Paper 112. United Nations Food and Agriculture Organization, Rome. 61 pp. + appendices and tables.

FIMBEL, R. A. and C. C. FIMBEL, 1996. The role of exotic conifer plantations in rehabilitating degraded tropical forest lands: a case study from the Kibale Forest in Uganda. *For. Ecol. Manage*., 81: 215-226.

GELDENHUYS, C. J., 1993. Management of forestry plantations to become effective stepping stones and corridors for forest migration. In: EVERARD, D. A. (Editor), *The relevance of island biogeography theory in commercial forestry, Environmental Forum Report, FRD, Pretoria*. pp. 102-118.

GELDENHUYS, C. J., 1996. The Blackwood Group System: its relevance for sustainable forest management in the southern Cape. *S. Afr. For. J.*, 177: 1-21.

GELDENHUYS, C. J., 1997. Native forest regeneration in pine and eucalypt plantations in Northern Province, South Africa. *For. Ecol. Manage.*, 99: 101-115.

GEORGE, S. J., B. M. KUMAR, and G. R. RAJIV, 1993. Nature of secondary succession in the abandoned Eucalyptus plantations of Neyyar (Kerala) in peninsular India. *J. Trop. For. Sci.*, 5: 372-386.

GOOSEM, S. and N. I. J. TUCKER, 1995. *Repairing the rainforest: theory and practice of rainforest re-establishment in north Queensland's wet tropics.* Wet Tropics Management Authority, Cairns, Queensland, Australia. 72 p.

GUARIGUATA, M. R., R. RHEINGANS and F. MONTAGNINI, 1995. Early woody invasion under tree plantations in Costa Rica: implications for forest restoration. *Rest. Ecol.*, 3: 252-260.

HAGGAR, J., K. WIGHTMAN and R. FISHER, 1997. The potential of plantations to foster woody regeneration within a deforested landscape in lowland Costa Rica. *For. Ecol. Manage.*, 99: 55-64.

HARRINGTON, R. A. and J. J. EWEL, 1997. Invasibility of tree plantations by native and non-indigenous plant species in Hawaii. *For. Ecol. Manage.*, 99: 153-162.

KEENAN, R., D. LAMB, O. WOLDRING, T. IRVINE and R. JENSEN, 1997. Restoration of plant biodiversity beneath tropical tree plantations in Northern Australia. *For. Ecol. Manage.*, 99: 117-131.

KIKKAWA, J., P. DART, D. DOLEY, K, ISHII, D. LAMB, and K. SUZUKI (Editors),.1998. *Overcoming impediments to reforestation: tropical forest rehabilitation in the Asia-Pacific region.* Proc. 6th Intl. BIO-REFOR Workshop, Brisbane, Australia, 2-5 December 1997. BIO-REFOR, 249 p.

KNIGHT, R. S., C. J. GELDENHUYS, P. H. MASSON, M. L. JARMAN and M. J. CAMERON, (Editors), 1987. The role of aliens in forest edge dynamics: a workshop report. *Occasional Report No. 22, Ecosystems Programmes, FRD, CSIR, Pretoria.* 41 pp.

KNOWLES, O. H., and J. A. PARROTTA, 1995. Amazonian forest restoration: an innovative system for native species selection based on phenological data and performance indices. *Comm. For. Rev.*, 74: 230-243.

KUSHALAPPA, K. A., 1986. Nutrient status in *Eucalyptus* hybrid monoculture. In: SHARMA, J. K., C. T. S. NAIR, S. KEDHARNATH and S. KONDAS (Editors), *Eucalypts in India: Past, Present and Future. Kerala Forest Research Institute, Peechi, Kerala, India.* pp. 213-224.

KUUSIPALO, J., G. ÅDJERS, Y. JAFARSIDIK, O. ANTII, K. TUOMELA, and R. VUOKKO, 1995. Restoration of natural vegetation in degraded *Imperata cylindrica* grassland: understorey development in forest plantations. *J. Veg. Sci.*, 6: 205-210.

LAMB, D. 1998. Large-scale ecological restoration of degraded tropical forestlands: the potential role of timber plantations. *Rest. Ecol.*, 6: 271-279.

LAMB, D. and M. TOMLINSON, 1994. Forest rehabilitation in the Asia-Pacific region: past lessons and present uncertainties. *J. Trop. For. Sci.*, 157-170.

LOUMETO, J. J. and C. HUTTEL, 1997. Understorey vegetation in fast growing tree plantations on savanna soils in Congo. *For. Ecol. Manage.*, 99: 65-81.

LÜBBE, W. A. and C. J. GELDENHUYS, 1991. Regeneration patterns in planted and natural forest stands near Knysa, Southern Cape. *S. Afr. J. For.*, 159: 43-50.

LUGO, A. E., 1992. Tree plantations for rehabilitating damaged lands in the tropics. In: WALI M. K. (Editor), *Environmental Rehabilitation, vol. 2.* SPB Academic Publishing, The Hague. pp. 247-255.

LUGO, A. E., J. A PARROTTA. and S. BROWN, 1993. Loss of species caused by tropical deforestation and their recovery through management. *Ambio*, 22: 106-109.

MBOUKOU-KIMBATSA, I. M. C., F. BERNHARD-REVERSAT and J. J. LOUMETO, 1998. Change in soil magrofauna and vegetation when fast-growing trees are planted on savanna soils. *For. Ecol. Manage.*, 110: 1-12.

MITRA, S. S. and F. H. SHELDON, 1993. Use of exotic tree plantations by Bornean lowland forest birds. *Auk*, 110: 529-540.

NEPSTAD, D., C. UHL and E. A. SERRÃO, 1991. Recuperation of a degraded Amazonian landscape: forest recovery and agricultural restoration. *Ambio*, 20: 248-255.

PARHAM, W. E., P. J. DURANA and A. L. HESS, (Editors). 1993. *Improving degraded lands: promising experiences from South China.* Bishop Museum Bulletin in Botany 3, Bishop Museum Press, Honolulu, Hawaii. 243 p.

PARROTTA, J. A., 1992. The role of plantation forests in rehabilitating degraded ecosystems. *Agric. Ecosys. Environ.*, 41: 115-133.

PARROTTA, J. A., 1993. Secondary forest regeneration on degraded tropical lands: the role of plantations as "foster ecosystems". In: H. LIETH and M. LOHMANN (Editors), *Restoration of Tropical Forest Ecosystems.* Kluwer, Dordrecht, pp. 63-73.

PARROTTA, J. A., 1995. The influence of overstory composition on understorey colonization by native species in plantations on a degraded tropical site. *J. Veg. Sci.*, 6: 627-636.

PARROTTA, J. A. and O. H. KNOWLES, 1999. Restoration of tropical moist forests on bauxite mined lands in the Brazilian Amazon. *Rest. Ecol.*, 7: 103-116.

PARROTTA, J. A., O.H. KNOWLES and J. M. WUNDERLE, 1997. Development of floristic diversity in 10-year-old restoration forests on a bauxite mined site in Amazonia. *For. Ecol. Manage.*, 99: 21-42.

PARROTTA, J. A. and J. W. TURNBULL, (Editors) 1997. Catalyzing native forest regeneration on degraded tropical lands. *For. Ecol. Manage.*, 99: 1-290.

POFFENBERGER, M. and B. MCGEAN, (Editors). 1996. *Village voices, village choices: joint forest management in India.* Oxford University Press: New Delhi. 356 pp.

POWERS, J. S., J. P. HAGGAR and R. F. FISHER, 1997. The effect of overstory composition on understorey woody regeneration and species richness in 7-year-old plantations in Costa Rica. *For. Ecol. Manage.*, 99: 43-54.

SILVA JUNIOR, M. C., F. R. SCARANO and F. SOUZA CARDEL, 1995. Regeneration of an Atlantic forest formation in the understorey of a *Eucalyptus grandis* plantation in southeastern Brazil. *J. Trop. Ecol.*, 11: 147-152.

SIPS, P., 1993. *Management of tropical secondary rain forests in Latin America. Today's challenge, tomorrow's accomplished fact?* Working Document IKC-NBLF No. 27. Foundation Bos, Wageningen, The Netherlands. 71 pp.

SONI, P., H. B. VASISTHA and O. KUMAR, 1989. Biological diversity in surface mined areas after reclamation. *Ind. For.*, 115: 475-482.

SRIVASTAVA, R. K., 1994. Re-establishment of sholas in grassland (a reverse process). *Ind. For.*, 120: 868-870.

TUCKER, N. I. J. and T. M. MURPHY, 1997. The effects of ecological rehabilitation on vegetation recruitment: some observations from the wet tropics of North Queensland. *For. Ecol. Manage.*, 99: 133-152.

UHL, C., R. BUSCHBACHER, and E. A. S., SERRÃO, 1988a. Abandoned pastures in eastern Amazonia. I. Patterns of plant succession. *J. Ecol.*, 76: 663-681.

UHL, C., R. BUSCHBACHER, and E. A. S. SERRÃO, 1988b. Abandoned pastures in eastern Amazonia. II. Nutrient stocks in the soil and vegetation. *J. Ecol.*, 76: 682-699.

VAN WYK, G. F., D. A. EVERARD, and C. J. GELDENHUYS, 1995. *Forest ecotone development and succession: experimental results and guidelines for forest rehabilitation and protection*. Report FOR-DEA 867. CSIR, Pretoria. 34 pp.

VIEIRA, I. C. G., C. UHL, and D. NEPSTAD, 1994. The role of the shrub *Cordia multispicata* Cham. as a "succession facilitator" in an abandoned pasture, Paragominas, Amazônia. *Vegetatio*, 115: 91-99.

WORLD RESOURCES INSTITUTE/IIED, 1988. *World Resources 1988-89.* Basic Books, New York. 372 pp.

WUNDERLE, J.M., Jr., 1997. The role of animal seed dispersal in accelerating native forest regeneration on degraded tropical lands. *For. Ecol. Manage.*, 99: 223-235.

YU, Z.Y., Z. H. WANG, and S. Y. HE, 1994. Rehabilitation of eroded tropical coastal lands in Guangdong, China. *J. Trop. For. Sci.*, 7: 28-38.

Page Break

Table 1. Characteristics of study sites included in international research programme on the effects of forest plantations on natural forest regeneration (1995-1996)

Site	Local Vegetation Type	Elevation (m) & Annual Rainfall (mm)	Plantation Species	Plantation Purpose	Plantation Age (years)	References
Upper Waiakea and Ola'a Forest Reserves, Hawaii, USA	Native rainforest, dominated by *Metrosideros polymorpha* and *Acacia koa*	850-950 m; 4800 mm	*Eucalyptus saligna, Flindersia brayleyana, Fraxinus uhdei*	Large-scale experimental plantations	26-32	HARRINGTON & EWEL 1997
Trombetas, Pará State, Brazil	Bauxite-mined lands surrounded by old-growth upland Amazonian forest	180 m; 2200 mm	Mixed-species plantings of 70+ native forest species	Native forest restoration	10	PARROTTA *et al.* 1997; PARROTTA & KNOWLES 1999

La Selva Biological Station, Atlantic Lowlands, Costa Rica	Abandoned pastures	65 m; 3900 mm	Single-species blocks of 7 native and exotic tree species	Experimental; evaluation of tree plantation effects on soils	7	POWERS *et al.* 1997; HAGGAR *et al.* 1997
Sarapiqui, Atlantic Lowlands, Costa Rica	Abandoned pastures	40-100 m; 3900 mm	*Hyeronima alchorneoides*, *Vochysia ferruginea*, *V. guatamalensis* (all native)	Small-scale timber production on private lands	6	HAGGAR *et al.* 1997
Pointe Noire & Loudima, Congo	Grassland and shrub savanna	40-180 m; 1070-1250 mm	*Eucalyptus* hybrid, *Pinus caribaea*, *Acacia auriculiformis*	Industrial wood production (*Eucalyptus*); Experimental (all species)	6-26	LOUMETO & HUTTEL 1997; MBOUKOU-KimbatSa *et al.* 1998

Site	Local Vegetation Type	Elevation (m) & Annual Rainfall (mm)	Plantation Species	Plantation Purpose	Plantation Age (years)	References
Ulumba Mountain, southern Malawi	Degraded miombo woodland	1075 m; 780 mm	*Eucalyptus camaldulensis*	Community woodlot (fuelwood)	1-8	BONE *et al.* 1997
Eastern Escarpment & Soutpansberg mountains, Northern Province, South Africa	Fire-maintained grasslands with patches of mixed evergreen forest in riparian and other protected sites	1200-1760 m; 1200-1900 mm	*Pinus patula*, *P. elliotii*, *P. taeda*, *Eucalyptus saligna*	Commercial plantations	7-90	GELDENHUYS 1997
Atherton Tablelands, north Queensland, Australia	Deforested lands adjacent to intact rainforest	1425-3625 m	*Araucaria cunninghamii*, *Flindersia brayleyana*, *Toona ciliata* (native); *Pinus caribaea*	Commercial timber plantations	5-64	KEENAN *et al.* 1997

			(exotic)			
Eubenangee Swamp N.P., Lake Barrine N.P., Wooroonooran N.P, Malanda township, north Queensland	Degraded riparian mesophyl vine forest and upland rainforest	0-760 m; 1450-3650 mm	Numerous fleshy-fruited native tree species	Native forest restoration	5-7	TUCKER & MURPHY 1997