REVIEW

Application of Assisted Natural Regeneration to Restore Degraded Tropical Forestlands

Kenichi Shono,[1,3] Ernesto A. Cadaweng,[2] and Patrick B. Durst[1]

Abstract

Assisted natural regeneration (ANR) is a simple, low-cost forest restoration method that can effectively convert deforested lands of degraded vegetation to more productive forests. The method aims to accelerate, rather than replace, natural successional processes by removing or reducing barriers to natural forest regeneration such as soil degradation, competition with weedy species, and recurring disturbances (e.g., fire, grazing, and wood harvesting). Compared to conventional reforestation methods involving planting of tree seedlings, ANR offers significant cost advantages because it reduces or eliminates the costs associated with propagating, raising, and planting seedlings. It is most effectively utilized at the landscape level in restoring the protective functions of forests such as watershed protection and soil conservation. ANR techniques are flexible and allow for the integration of various values such as timber production, biodiversity recovery, and cultivation of crops, fruit trees, and non-timber forest products in the restored forest. This paper describes the steps of applying ANR and conditions under which it will be most effective. It also discusses ANR's comparative advantages as well as some of its constraints.

Key words: forest restoration, natural regeneration, succession, tropical reforestation.

Introduction

Degraded forestlands and secondary forests cover significant areas throughout the tropics. In most countries, they now exceed areas covered by primary forests (FAO 2005*a*). The cycle of tropical deforestation typically begins with excessive logging that reduces the original forest to a noncommercial resource. Logged-over forests are then converted to agricultural uses, mostly to replace land that has lost productivity due to unsustainable agricultural practices (Harwood et al. 1993). Unproductive farmlands are subsequently abandoned as wastelands that could potentially regenerate to forest, but natural recovery in areas subjected to intensive anthropogenic effects is very slow because of soil degradation, recurring disturbance, and isolation from intact forests. A new equilibrium state is commonly reached when shade-intolerant grasses or ferns invade the deforested areas and become dominant in the altered environment. These weedy species may form a self-perpetuating ecosystem, effectively blocking natural forest regeneration for decades or even centuries. Vast expanses covered by *Imperata* grass in Southeast Asia and open canopy sites on low-fertility soil dominated by *Dicranopteris* ferns throughout wetter parts of the old tropics are such examples (Russell et al. 1998; FAO 2005*b*).

The need to restore these areas to improve their productive capacity, environmental functions, and biodiversity value has been widely recognized (Parrotta 2000). Because of the persistent physical, chemical, and biological barriers to forest regeneration, these severely degraded areas need human intervention to initiate recovery. Various ecological restoration methods involving planting of tree seedlings have been developed to reforest degraded lands (see Lamb et al. 2005). The restoration planting approach covers a range of species and density of planting. Dense planting of a large number of primary forest species (Miyawaki 1999), staggered planting of primary forest species (Knowles & Parrotta 1995), and the framework species method (Goosem & Tucker 1995; FORRU 2005; Shono et al. 2007) have all been implemented with promising results. One constraint of these methods is the high labor and financial inputs required, which limits their application to relatively small-scale projects (Lamb 1998).

Another strategy for overcoming degradation, while ensuring financial returns, is the establishment of commercial tree plantations (Lamb 1998). Numerous studies have demonstrated the catalytic effect of plantations in fostering the regeneration of native forest species in the understory (Parrotta et al. 1997; Carnus et al. 2006). However, the recolonization of the understory by the native flora has limited value if they are cleared in preparation for the next cycle of planting. The need to integrate biodiversity

[1] Food and Agriculture Organization of the United Nations Regional Office for Asia and the Pacific, 39 Phra Atit Road, Bangkok 10200, Thailand
[2] Bagong Pagasa Foundation, Inc., Barangay Kalatagbak, Quezon Municipality, Province of Palawan, Philippines
[3] Address correspondence to K. Shono, email ken.shono@aya.yale.edu

conservation in commercial plantations is becoming increasingly important, and plantation trials involving high-value native trees and species mixtures are underway in many countries (FAO 2001; Lamb et al. 2005). However, monocultures of exotic timber species (e.g., *Acacia*, *Eucalyptus*, *Pinus*, *Paraserianthes falcataria*, and *Gmelina arborea*) continue to be favored in commercial plantations for their well-known silviculture and productivity (FAO 2001).

The approach of assisted natural regeneration (ANR) aims to strike a balance between high-cost restoration planting to restore biodiversity to small areas and the establishment of commercial plantations over large areas to restore productivity (Table 1). ANR is a simple, inexpensive, and effective technique for converting areas of degraded vegetation to more productive forests (Ganz & Durst 2003). ANR accelerates succession by removing or reducing barriers to natural forest regeneration: weed competition is reduced, disturbances are prevented, unsuitable microclimate is ameliorated by the accelerated growth of naturally established pioneers, and seed dispersal into the site by birds and animals is enhanced by the restoration of forest habitat. ANR offers significant cost advantages because the costs associated with propagating, raising, and planting seedlings are eliminated or reduced. Consequently, the need for extensive research on identifying suitable reforestation species and establishing propagation techniques is either forgone or lessened.

The ANR approach has been used to restore forests on *Imperata* grasslands in the Philippines for more than 30 years (Ganz & Durst 2003). Even before its official recognition as a recommended strategy for forest regeneration, indigenous tribes in the Philippines and Thailand have successfully practiced ANR as a method of forest restoration and management (Friday et al. 1999; Butic & Ngidlo 2003; Thongvichit & Sommun 2003). The ANR approach, under different names, has been implemented in combination with other forest restoration methods in China, Nepal, Ethiopia, Nigeria, and Sri Lanka (Bay 2002; Sannai 2003). Liberation of commercial timber species applied in logged-over dipterocarp forests in Malaysia and Indonesia also utilizes the same concept. ANR's applicability covers a broad range of forest types and geographical areas. The techniques can be adapted to meet various objectives such as income generation from non-timber forest products (NTFPs), production of firewood and timber, and biodiversity conservation. Despite its practical benefits, ANR's potential as a low-cost forest restoration method is not well recognized and the method is underutilized. This paper describes the steps of ANR implementation and its rationale and constraints.

Rationale for Using ANR and Required Conditions

ANR is most suitable for restoring areas where some level of natural succession is in progress. As a first condition, sufficient tree regeneration must be present so that their growth can be accelerated. Seedlings of pioneer tree species are often found among and below the weedy vegetation even on a seemingly weed-dominated land. The minimum required number of preexisting seedlings to implement ANR depends on the acceptable length of time for the forest to be restored and site-specific conditions that influence the rate of forest recovery. As a general reference, a density range of 200–800 seedlings (>15 cm in height; counting clumps in 1 m^2 as one seedling) per hectare has been suggested for ANR reforestation, and it has been estimated that at least 700 seedlings/ha are needed during the early treatment period in order to achieve canopy closure within three years (Dalmacio, unpublished data; Jensen & Pfeifer 1989; Sajise, unpublished data). Supplemental planting can be carried out if the density of natural regeneration is not sufficient. To ensure further successional development, remnant forest should be in proximity so that there would be sufficient input of seeds. Most importantly, it must be possible to prevent further disturbances such as fire, grazing, and illegal logging because the success of ANR ultimately depends on the continued protection of the site.

ANR offers distinct advantages over other forest restoration methods but also has some limitations (Table 1). ANR may be less effective than restoration planting approaches in enhancing floristic diversity at the initial stages, but it is much cheaper to implement and can be

Table 1. Various reforestation approaches and their merits.

Reforestation Approach	*Costs (Labor and Capital)*	*Biodiversity*	*Time for Forest Development*	*Research Input Required*
Commercial monoculture plantation	High[a]	Low	Fast	Low
Monoculture of commercial nurse trees	High[b]	Low to medium	Fast[c]	Low
ANR without enrichment planting	Low	Low to medium	Slow to medium	Low
ANR with enrichment planting	Low to medium	Medium	Medium	Low to medium
Framework species method	Medium to high	Medium	Medium	High
High-density planting of forest trees	High	High	Fast	High

[a] The high establishment and operational costs are generally recovered by profits.
[b] Some of the establishment cost may be recovered by harvesting of nurse trees.
[c] Nurse trees grow fast, but understory develops slowly.

applied over larger areas. The forest restored through ANR will have little commercial value in terms of timber, but it will support greater biodiversity and often more effectively provide for subsistence needs of the local people compared to commercial plantations. Some of ANR's disadvantages can be overcome by enrichment planting with desirable species. ANR is best implemented in areas where the main objectives are to enhance the protective roles of the forest and in combination with other restoration methods at the landscape level. The decision on which reforestation approach to use on a particular site depends on the severity of degradation, self-recovery potential of the land, demography of the area, and availability of financial and human resources, among other factors.

Steps of ANR Implementation

Although the ANR method does not require significant research inputs before implementation, it is critical that monitoring and research be a part of the ANR process, so that changes in the vegetation can be evaluated and techniques can be improved as the amount of knowledge increases. The work plan should remain flexible, and the treatments are adjusted according to how the vegetation responds to interventions. A variety of technical methods are used in applying ANR, and the following basic steps can be modified according to site conditions, restoration objectives, and resource availability.

Step 1: Marking of Woody Regeneration. Once the target area is identified and its boundaries are demarcated, the site is surveyed to assess its successional status and to locate any natural woody regeneration growing above and below the weedy vegetation (Fig. 1). The located seedlings should be clearly marked with stakes to facilitate the application of subsequent treatments and to protect them. Decision on the minimum size of seedlings to be protected and released depends on the density and distribution of seedlings in the area, as well as budget and time constraints. However, the seedlings should be large enough to have a reasonable chance of survival. The marked seedlings are tagged, identified, and measured for monitoring of growth and survival rates.

Step 2: Liberation and Tending of Woody Regeneration. The next step is to accelerate the growth of the marked seedlings by reducing competition from the weedy species for water, nutrients, and light. The initial treatment should be implemented at the onset of the rainy season so that the liberated seedlings will have the full growing season of accelerated growth. All competing vegetations such as grasses and vines within at least 0.5 m radius around the stem of the marked seedlings are removed. This can be done by slashing then hand cultivating or by manually digging out the competition. In some cases, clumps of woody seedlings may need to be thinned in order to liberate the largest individuals or the more desirable species (Jensen & Pfeifer 1989). Fertilizers may be applied to the seedlings to further enhance their growth. Soil testing can be conducted to determine the nutrient status of the soil and the need for nutrient inputs. The effect of nutrient addition on seedling growth should be monitored to assess its effectiveness.

Step 3: Suppressing Weedy Vegetation. Once the desired number of wildlings has been marked and ring-weeded, the suppression of other weedy vegetation throughout the site is the next critical step. In addition to reducing weed competition, it reduces fire hazard and makes movement at the site easier. For *Imperata cylindrica* and *Saccharum spontaneum*, pressing or "lodging" has been shown to be an effective suppression method (Jensen & Pfeifer 1989). This is done by stepping with boards of lightweight wood about 15–30 cm wide and 100–120 cm long (Fig. 2). A rope

Figure 1. Uncovering *Shorea* seedlings in *Imperata* grassland.

Figure 2. Pressing grass with the use of wooden board.

is fixed to each end of the board and is looped over the shoulders. The rope handle is used to lift the board, and then it is laid on top of grass and pressed down by stepping. In this process, the grass shoots are pressed down but not broken because the breaking of the stem results in rapid tillering (Sajise 1972). Pressing should be done at the beginning and end of the rainy season when the grass stems are soft. If done properly, the flattening effect of pressing can last up to six months. A steady worker can usually complete 1 ha in five days or 40 working hours, roughly half the time it takes to cut the grass with a bladed tool. For *Dicranopteris* ferns, cutting effectively kills the plant (Cohen et al. 1995; Shono et al. 2006). Herbicides can be used to control weedy growth; however, the cost and risks associated with the use of chemical herbicides should be carefully weighed against the benefits.

Step 4: Protection From Disturbance. Protecting against fire and other forms of disturbance is the most important ANR activity. All work done in the area is wasted if fire destroys the liberated seedlings or if they are damaged by animals or human activities. Establishing firebreaks around blocks of ANR-treated sites is a must, if the area is prone to fire (Fig. 3). The size of each block depends on the terrain and the amount of volatile material. Fires in flatter terrain tend to spread less quickly than on slopes, so blocks can be larger. Logically, where there is more flammable material, blocks should be smaller. A general guideline of four blocks per hectare has been suggested for *Imperata* grassland in the Philippines (Friday et al. 1999). Firebreak width also depends on similar factors, as well as the cost of establishment. Although the wider the better, experience has shown that at least 6 m is needed for firebreaks to be effective (E. A. Cadaweng 2006, Bagong Pagasa Foundation, personal observation). If animal grazing is prevalent in the area, fencing should be established or patrols/guards should be assigned to protect the site from such activity. Long-term community involvement and support is critical in preventing the reoccurrence of disturbance events that will set back succession to the before-treatment state.

Step 5: Maintenance and Enrichment Planting. Sajise (1989) suggested that the maintenance of ring weeding, and liberation of any additional seedlings that establish or that are newly found, should be conducted every 1–1.5 months during the rainy season and every 2–3 months during the dry season. The frequency of maintenance operations can be adjusted according to field observation and monitoring data on the growth of the liberated seedlings and the density of natural woody regeneration. For controlling *Imperata* grass, pressing two to three times a year should be sufficient (Fig. 4). Enrichment planting can also be carried out to accelerate canopy closure, add useful tree species, and increase floristic diversity. Even after the restoration of canopy cover, large-seeded primary forest trees and rare species are unlikely to colonize naturally (Shono et al. 2006). If restoring some of the floristic diversity of the original forest is one of the restoration objectives, species or functional groups of trees lacking in natural regeneration will need to be planted either at the initial treatment stage or after canopy closure depending on the ecological requirements of the species.

Labor Requirements

One person can press an average of 2,000 m^2 of *Imperata* grassland in a day (Cadaweng, personal observation). Initial ring weeding takes twice as long (approximately 1,000 m^2/day), assuming 1,000 stems of marked seedlings per hectare. A team of three persons can therefore initially treat 1 ha of land in five days. Establishment of firebreaks 10 m wide and spaced 40 m apart requires an additional 16 person-days of labor per hectare (Friday et al. 1999). Maintenance operations require about half of the amount of labor needed for the initial establishment. The total labor requirement for implementing ANR would largely depend on the frequency of maintenance operations. As a guideline, Friday et al. (1999) estimated that 49

Figure 3. Initial establishment of firebreak.

Figure 4. Restoration site after grass pressing.

person-days/ha are needed in the first year for the establishment and maintenance of firebreaks, ring weeding around seedlings and three subsequent maintenance weeding, and two applications of grass pressing. In the second and third years, it is estimated that 31 person-days of labor per hectare are required annually for the maintenance of firebreaks twice a year and ring weeding and grass pressing three times annually (Friday et al. 1999). The ANR method is decidedly cheaper to implement than other methods based on planting of trees. However, empirical studies remain to be conducted on the relative costs of ANR vis-à-vis conventional reforestation methods.

Social Foundation Development

This paper focuses on the technology of ANR, but the social aspects are equally important in ensuring the success of any forest restoration project. The local people must understand the benefits of forest restoration and fully participate in the activities. The creation of stable and reliable incentives for the communities is critical. Combining forest restoration with interplanting of agroforestry crops such as coffee, bananas, rambutan (*Nephilium lappaceum*), and durian (*Durio zibethinus*) among the naturally established pioneer trees can diversify income opportunities for local people (Dugan 2000). Cultivation of crops in the firebreaks and planting of marketable NTFPs (e.g., rattan) may further enhance community support and strengthen their sense of ownership of the restored forest and the ANR activities (Fig. 5). Forests provide a safety net for rural populations throughout the world, providing food, medicine, and other plant materials directly needed by them. Forest restoration, through ANR, can be implemented in such a way as to increase the resources and opportunities for local people (Appanah 2003). Awareness raising, capacity building, and promotion of participatory processes in managing the forest resource should be integral components of the ANR approach.

Figure 5. Cultivation of firebreak with taro (*Colocasia esculenta*).

Discussion

Despite its practical advantages, ANR remains underutilized due to lack of awareness and demonstrative results. Its significant potential as well as the need for further research have been noted by tropical restorationists (Elliot 2000). Particularly, research is needed to determine which soil and vegetation variables can best predict the potential of a site to be successfully restored using ANR (Hardwick et al. 2004). Systematic application of ANR and monitoring of forest development are needed to enhance the technique and to validate personal experiences with successful applications of the approach. Although uncertainties exist over the amount of time it takes for closed-canopy forest to establish and the species composition of the restored forest, the implementation of ANR requires relatively small financial inputs and the consequence of unsuccessful application is not nearly as costly as the failure of a conventional reforestation project.

One criticism of ANR is that the restored forest will have little productive and ecological value due to the dominance by a predictable suite of pioneer species and the primary lack of forest components. However, even a species-poor secondary forest is a significant improvement in biodiversity over the deforested land it replaces. It also offers potential in being rehabilitated to a later successional forest, either naturally or by human intervention, where species richness and usefulness to people are greatly enhanced (Brown & Lugo 1990). Moreover, secondary forests are known to provide a wide variety of ecological, environmental, and economical benefits. They protect soils, recycle nutrients, regulate water flow, serve as refuges of biodiversity, reduce fire risk, and help conserve genetic resources (ITTO 2002). Once a secondary forest is established, it can be managed to provide the desired products and services according to specific management objectives and availability of resources.

The process of natural succession is influenced by complex interactions of various factors including edaphic conditions, amount and species composition of seed rain, and levels of seed and seedling predation. At the time of implementing ANR, it would be difficult to estimate the amount of time needed for the forest to be restored. However, experience in the Philippines shows that *Imperata* grassland is regenerated to a secondary forest of pioneer trees and shrubs in about 3 years after the implementation of ANR (Dugan 2000; Cadaweng, personal observation) (Fig. 6). If the treatments are perceived as not affecting the desired changes in the vegetation quickly enough, enrichment planting or a switch to conventional reforestation methods can be considered. This flexibility is one of the strengths of ANR.

Conclusions

There is a growing realization that restoring degraded lands at the landscape level is necessary to guarantee a productive and biologically rich forest estate for the long

Figure 6. Secondary forest developing on *Imperata* grassland after two years of implementing ANR.

run. The ANR approach aims to balance trade-offs at the landscape level, and its novelty lies in the pragmatic rejection of the insistence to return modified landscapes to the original pristine state (FAO 2005*a*). ANR has a definite role to play in the landscape restoration approach.

It can be implemented to regenerate buffer zone forests surrounding a core protected area or to restore biological corridors connecting remnant forest patches. ANR-restored forests can serve as multiuse areas where local communities are given access for sustainable use of the forest resources.

Considerable areas in many tropical countries remain in degraded condition because they cannot be economically rehabilitated for agricultural uses or commercial plantations (Parrotta 2000). Furthermore, the high costs associated with ecological restoration plantings limit their applicability for restoring large areas of forest. ANR presents a potential solution to fill the gap, accelerating native forest regeneration over large areas while simultaneously improving biodiversity and social value of the landscape.

Implications for Practice

- ANR is an effective, low-cost method of forest restoration that can effectively restore forests on degraded lands under certain conditions.
- ANR seeks to remove barriers to natural forest regeneration, thereby accelerating natural forest succession.
- The techniques of ANR are simple and allow for integration of economic and social values in the restored forest.
- ANR offers potential particularly in watershed protection and forest restoration at the landscape level.
- Despite its practical advantages, the technique remains underutilized due to lack of awareness and research results demonstrating its effectiveness.

Acknowledgments

This review was conducted as part of the project on advancing the application of ANR for effective low-cost forest restoration supported by Food and Agriculture Organization of the United Nations. We thank Mr. P. Dugan of Bagong Pagasa Foundation, Inc., for his support to the project and his valuable comments on earlier drafts of this manuscript.

LITERATURE CITED

Appanah, S. 2003. Introduction: restoration of degraded forests as opportunities for development. Pages 7–14 in H. C. Sim, S. Appanah, and P. B. Durst, editors. Proceedings of international conference on bringing back the forests: policies and practices for degraded lands and forests. Food and Agriculture Organization of the United Nations Regional Office for Asia and the Pacific, Bangkok, Thailand.

Bay, D. 2002. Rehabilitation of degraded lands in humid zones of Africa. A report prepared for International Union of Forest Research Organizations, Global Forest Information Service (GFIS) project. Kumasi, Ghana.

Brown, S., and A. E. Lugo. 1990. Tropical secondary forests. Journal of Tropical Ecology **6:**1–23.

Butic, M., and R. Ngidlo. 2003. Muyong forest of Ifugao: assisted natural regeneration in traditional forest management. Pages 23–28 in P. C. Dugan, P. B. Durst, D. J. Ganz, and P. J. McKenzie, editors. Advancing assisted natural regeneration (ANR) in Asia and the Pacific. Food and Agriculture Organization of the United Nations Regional Office for Asia and the Pacific, Bangkok, Thailand.

Carnus, J. M., J. Parrotta., E. G. Brockerhoff, M. Arbez, H. Jactel, A. Kremer, D. Lamb, K. O′Hara, and B. Walters. 2006. Planted forests and biodiversity. Journal of Forestry **104:**65–77.

Cohen, A. L., B. M. P. Singhakumara, and P. M. S. Ashton. 1995. Releasing rain forest succession: a case study in the Dicranopteris linearis fernlands of Sri Lanka. Restoration Ecology **3:**261–270.

Dalmacio, M. V. 1987. Assisted natural regeneration: a strategy for cheap, fast, and effective regeneration of denuded forest lands. Manuscript, Philippines Department of Environment and Natural Resources Regional Office, Tacloban City, Philippines.

Dugan, P. 2000. Assisted natural regeneration: methods, results and issues relevant to sustained participation by communities. Pages 195–200 in S. Elliot, J. Kerby, D. Blakesley, K. Hardwick, K. Woods, and V. Anusarnsunthorn, editors. Forest restoration for wildlife conservation. International Tropical Timber Organization and the Forest Restoration Research Unit, Chiang Mai University, Chiang Mai, Thailand.

Elliot, S. 2000. The Chiang Mai research agenda for the restoration of degraded forest lands for wildlife conservation in Southeast Asia. Pages 383–411 in S. Elliot, J. Kerby, D. Blakesley, K. Hardwick, K. Woods, and V. Anusarnsunthorn, editors. Forest restoration for wildlife conservation. International Tropical Timber Organization and the Forest Restoration Research Unit, Chiang Mai University, Chiang Mai, Thailand.

FAO (Food and Agriculture Organization of the United States). 2001. Global forest resources assessment 2000. FAO Forestry Paper No. 140. FAO, Rome, Italy.

FAO (Food and Agriculture Organization of the United States). 2005*a*. State of the world's forests. FAO, Rome, Italy.

FAO (Food and Agriculture Organization of the United States). 2005*b*. Helping forests take cover: on forest protection, increasing forest cover and future approaches to reforesting degraded tropical landscapes in Asia and the Pacific. RAP Publication No. 2005/13. FAO Regional Office for Asia and the Pacific, Bangkok, Thailand.

FORRU (Forest Restoration Research Unit). 2005. How to plant a forest: the principles and practice of restoring tropical forests. Biology Department, Science Faculty, Chiang Mai University, Chiang Mai, Thailand.

Friday, K., E. Drilling, and D. P. Garrity. 1999. Imperata grassland rehabilitation using agroforestry and assisted natural regeneration. International Center for Research on Agroforestry, Southeast Asia Regional Research Programme, Bogor, Indonesia.

Ganz, D. J., and P. B. Durst. 2003. Assisted natural regeneration: an overview. Pages 1–4 in P. C. Dugan, P. B. Durst, D. J. Ganz and P. J. McKenzie, editors. Advancing assisted natural regeneration (ANR) in Asia and the Pacific. Food and Agriculture Organization of the United Nations Regional Office for Asia and the Pacific, Bangkok, Thailand.

Goosem, S. P., 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, Australia.

Hardwick, K., J. R. Healey, S. Elliot, and D. Blakesley. 2004. Research needs for restoring seasonal tropical forests in Thailand: accelerated natural regeneration. New Forests **27:**285–302.

Harwood, R. R., M. E. Carter, R. Gomaz, S. P. Gliesman, A. Gomez-Pompa, L. S. Hardin, et al. 1993. Sustainable agriculture and the environment in the humid tropics. National Research Council, National Academy Press, Washington, D.C.

ITTO (International Tropical Timber Organization). 2002. ITTO guidelines for the restoration, management and rehabilitation of degraded and secondary tropical forests. ITTO Policy Development Series No. 13. ITTO, Yokohama, Japan.

Jensen, C. L., and S. Pfeifer. 1989. Assisted natural regeneration: a new reforestation approach for DENR? Report to USAID, Manila, and Philippines Department of Environment and Natural Resources, Manila, Philippines.

Knowles, O. H., and J. A. Parrotta. 1995 Amazonian forest restoration: an innovative system for native species selection based on phonological data and field performance indices. Commonwealth Forestry Review **74:**230−243.

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

Lamb, D., P. D. Erskine, and J. A. Parrotta. 2005. Restoration of degraded tropical forest landscapes. Science **310:**1628–1632.

Miyawaki, A. 1999. Creative ecology: restoration of native forests by native trees. Plant Biotechnology **16:**15–25.

Parrotta, J. A. 2000. Catalysing natural forest restoration on degraded tropical landscapes. Pages 45–54 in S. Elliot, J. Kerby, D. Blakesley, K. Hardwick, K. Woods, and V. Anusarnsunthorn, editors. Forest restoration for wildlife conservation. International Tropical Timber Organization and the Forest Restoration Research Unit, Chiang Mai University, Chiang Mai, Thailand.

Parrotta, J. A., J. W. Turnbull, and N. Jones. 1997. Catalyzing native forest regeneration on degraded tropical lands. Forest Ecology and Management **99:**1–7.

Russell, A. E., J. W. Raich, and P. M. Vitousek. 1998. The ecology of the climbing fern *Dicranopteris linearis* on windward Manua Loa, Hawaii. Journal of Ecology **86:**765–779.

Sajise, P. E. 1972. Evaluation of cogon (*Imperata cylindrica* (L.) Beauv.) as a seral stage in Philippine vegetational succession. Ph.D. thesis. Cornell University, Ithaca, New York.

Sajise. P. E. 1989. Assisted natural regeneration (ANR) as an approach to reforestation. Assisted natural regeneration training manual. Department of Environment and Natural Resources, Quezon City, Philippines. Unpublished.

Sannai, J. 2003. Assisted natural regeneration in China. Pages 29–32 in P. C. Dugan, P. B. Durst, D. J. Ganz, and P. J. McKenzie, editors. Advancing assisted natural regeneration (ANR) in Asia and the Pacific. Food and Agriculture Organization of the United Nations Regional Office for Asia and the Pacific, Bangkok, Thailand.

Shono, K., S. J. Davies, and Y. K. Chua. 2006. Regeneration of native plant species in restored forests on degraded lands in Singapore. Forest Ecology and Management **237:**574–582.

Shono, K., S. J. Davies, and Y. K. Chua. 2007. Performance of 45 native tree species on degraded lands in Singapore. Journal of Tropical Forest Science **19:**25–34.

Thongvichit, B., and S. Sommun. 2003. Assisted natural regeneration in Thailand. Pages 37–40 in P. C. Dugan, P. B. Durst, D. J. Ganz, and P. J. McKenzie, editors. Advancing assisted natural regeneration (ANR) in Asia and the Pacific. Food and Agriculture Organization of the United Nations Regional Office for Asia and the Pacific, Bangkok, Thailand.