# Chapter 5

## Tools for restoring tropical forests

With a project plan in place and funding approved, it's time to start work. In this chapter, we discuss how to implement the five main tools for forest restoration: protection, ANR, planting framework tree species, the maximum diversity approach and nurse plantations (or plantations as catalysts). In Chapter 3, we established that these five basic tools are rarely used in isolation. The greater the degree of degradation, the more tools must be combined to achieve a satisfactory result. In Chapters 6 and 7, we go on to provide more details on growing and planting native forest tree species.

"***The successful restoration of a disturbed ecosystem is the acid test of our understanding of that ecosystem***." Bradshaw (1987).

# 5.1 Protection

There is no point in restoring sites that cannot be protected against the damaging activities that destroyed the original forest. Thus, preventing degradation is fundamental to all forest restoration projects, regardless of the degradation stage being tackled. Protection has two basic elements: i) preventing additional encroachment and ii) removing existing barriers to natural forest regeneration. The former involves the prevention of new harmful human activities at the restoration site, whereas the latter engages existing resident communities in fire prevention, stock exclusion and protecting seed-dispersing animals against hunters.

## Prevention of encroachment

Unoccupied forest land has always been a magnet for landless people with low incomes. In the past, forest clearance amounted to a legal claim of land ownership and a way out of poverty. But in modern civil societies, and as populations have grown exponentially, 'ownership by deforestation' is no longer acceptable. The vast majority of tropical forest land is now under state control, and there are laws to prevent its exploitation for personal gain. Unfortunately, law enforcement to exclude forest encroachers often targets rural poor people and is therefore heavily criticised by human rights groups, especially where corporations and wealthy landowners can get away with encroachment unpunished. Ultimately, these problems can only be solved by better forest governance[1], but several practical measures can be taken at the local level to prevent further encroachment.

Impoverished villagers, many of whom are poorly educated, are often unaware of the law. Therefore, simply ensuring that everyone is aware of the law and the penalties imposed for encroachment can sometimes be enough to deter it (Thira & Sopheary, 2004). Clearly defined boundaries, with conspicuous signs along them explaining the protected status of the area, also help to ensure that all are aware of legal restrictions and where they apply.

Encroachment tends to occur along roads, so preventing road construction and/or improvement in protected forest is perhaps the most effective way to prevent it (Cropper *et al*., 2001), especially in remote areas. Check-points where existing roads enter and leave protected sites can also deter encroachment.

A human presence, such as random patrols, is perhaps the ultimate deterrent to forest encroachment. Maintaining a patrol system is expensive, but forest guardians can have multiple tasks. While on patrol, they may also collect seeds from fruiting trees to supply a tree nursery, or record observations of wildlife, including seed dispersers and pollinators. GPS technology can be used to record the position of seed trees and wildlife, as well as the patrol coverage and signs of encroachment. When integrated into geographic information systems (GIS), the data can be shared and used to predict which areas are most threatened by encroachment. This is the 'smart patrol' concept advocated by the Wildlife Conservation Society (Stokes, 2010).

Preventing further encroachment by communities that are already established within a forest landscape depends on building a strong 'sense of community stewardship'

[1] www.iucn.org/about/work/programmes/forest/fp_our_work/fp_our work_thematic/fp_our_work_flg

for both remaining and restored forest. Local villagers will work together to exclude outside encroachers if they feel that encroachment threatens their community's interests. Community forestry, whereby a village committee (rather than a state agency) becomes responsible for managing a restored forest, provides a strong shared 'sense of stewardship', because the village committee deals with anyone damaging the community's forest resources using self-imposed rules and regulations. Peer pressure replaces the need to involve state law-enforcement agencies. Community forestry is of course impossible where there is no forest. So the prospect of community control over forest resources (once forest has been re-established) provides a powerful motivation for local villagers to contribute to forest restoration projects.

Communities near restoration sites can also benefit from direct employment by restoration projects. Livelihood development schemes can also be provided. These capitalise on the benefits of forest restoration (e.g. the development of ecotourism), reduce the need to clear forest (e.g. by intensifying agriculture) or reduce the exploitation of forest resources (e.g. introducing biogas as a substitute for firewood). If such rewards are offered only to communities in protected areas, however, their effect might be to actually attract outside encroachers who seek to access to the benefits of such development programs.

When protected areas systems were first introduced, the general view was that human settlers should be removed in order to maintain 'pristine' nature. This view disregarded the fact that most areas had in fact been occupied by humans, to a greater or lesser extent, long before they were declared protected. The forced relocation of settlers from protected areas has a sorry history. In most cases, inadequate compensation was paid (if any), the relocation sites were of poor quality and the support promised for agriculture, education and health care at the relocation sites often failed to materialise (Danaiya Usher, 2009). Furthermore, the vacuum left behind when people are moved out of protected areas is often quickly invaded by new encroachers.

Local people who have a long history of living in forest landscapes are a great asset to forest restoration programs. They are a valuable source of local knowledge, especially in regard to the selection of tree species and seed collection. They can provide most of the labour needed for restoration tasks, both in the nursery and in the field, and they can also implement protective measures, such as patrolling and manning road check points, as a civic duty.

## Prevention of fire damage

Protecting forest restoration sites from fire is essential for success. In the seasonally dry tropics, fire prevention is an annual activity, and even in the wet tropics, it is necessary during times of drought. Most fires are started by humans, so the best way to prevent them is to make sure that everyone in the vicinity supports the restoration program and understands the need not to start fires. But no matter how much effort is put into raising awareness of fire prevention amongst local communities, fire remains a common cause of failure for forest restoration projects. Most local forest authorities have fire-suppression units, but they cannot be everywhere, so local, community-based fire prevention initiatives are often the most effective way to tackle the problem. Preventative measures include cutting fire breaks and organising fire patrols to detect and extinguish approaching fires before they can spread to restoration sites.

**Box 5.1. Extractive reserves.**

Extractive reserves provide local communities with a direct interest in protecting tropical forests by allowing them to exploit non-timber forest products (NTFPs) in a sustainable way. It links villagers' incomes to the maintenance of intact forest ecosystems. The survival of the forest and the livelihoods of the villagers become interdependent.

The concept was pioneered in Brazil in the mid 1980s, when rubber-tappers and local rural workers' unions asked for the designation of areas in the Amazon where they could tap forest rubber trees to support the sustainable development of local communities. Extractive reserves were proposed as conservation areas in which local communities could harvest NTFPs such as nuts and latex. Essentially, the designation of such areas aimed to reconcile issues that policy makers traditionally thought of as incompatible, i.e. protecting forests as conservation areas and allowing local people to exploit them sustainably.

In 1989, the Brazilian Government formally included extractive reserves in its national policy. The land was to be taken into Government ownership for the dual purposes of safeguarding the rights of local people and conserving biodiversity. It was decided that extractive reserves would only be established if requested by local people and where a long tradition of forest use was evident. This has now become a major federal strategy for forest conservation and economic development amongst local peoples. In the case of the rubber tapper unions, under the leadership of Chico Mendes, it was envisaged that the forest would remain standing for use by both rubber-tappers and local people who wished to harvest NTFPs.


Map of Acre showing the location of the Chico Mendes Extractive Reserve (© IUCN).

**Box 5.1. continued.**

Chico Mendes demonstrating the process of tapping a rubber tree to produce latex in 1988. (Photo: M. Smith, Miranda Productions Inc.)

The best-known extractive reserve in South America is the 980,000 ha Chico Mendes Reserve in the state of Acre in western Amazonia. Chico Mendes himself was assassinated in 1988, but his legacy lives on in over 20 extractive reserves covering approximately 32,000 $km^2$. In the Chico Medes Reserve, the rights of local people, who are dependent on the forest, are protected. But in this and other extractive reserves, the IUCN recognises that the use of "economically, environmentally and socially viable forest production as a driver for local development" remains a challenge.

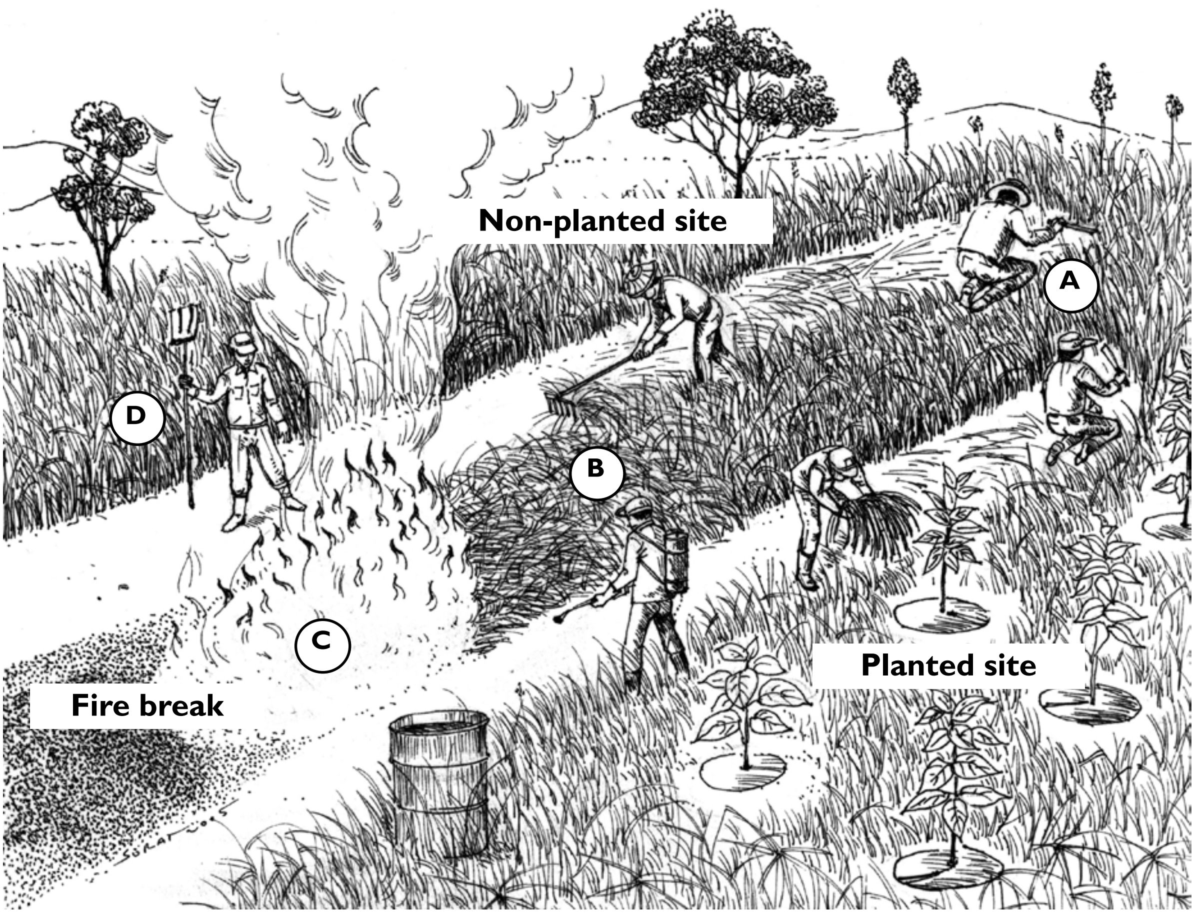
Despite these efforts to protect the Amazon forests, the rate of deforestation in the Amazon increased dramatically in 2010 and 2011, and the Brazilian Parliament had to decide whether to relax environmental laws that protect the forest in favour of farmers seeking more space to raise cattle. It was proposed, for example, that farmers should be allowed to clear 50% of the forest on their land, whereas the existing law allowed them to clear only 20%.

Edinaldo Flor da Silva and his family are benefiting from new rubber production units, which mean they can earn more from their sustainable product. (Photo: © Sarah Hutchison/WWF/Sky Rainforest Rescue)

### *Fire breaks*

Fire breaks are strips of land that are cleared of combustible vegetation to prevent the spread of fire. They are effective at blocking moderate, ground-cover burns. More intense fires throw up burning debris, which can be blown across fire breaks to start new fires far away from where the original fire ignited.

Cut firebreaks at least 8 m wide around restoration sites just before the onset of a dry season. The quickest method is to slash all grasses, herbs and shrubs (trees need not be cut) along the two edges of the firebreak. Pile the cut vegetation at the centre of the firebreak, leave it for a few days to dry out and then burn it. Obviously, using fire to prevent fire can be risky. Make sure plenty of people are available with beaters and water sprayers to prevent accidental escape of the fire into surrounding areas. The risk of fire escaping is considerably reduced by burning fire breaks just before the beginning of a hot, dry season when the surrounding vegetation is too moist to burn easily. Roads and streams act as natural fire breaks. There is usually no need to make fire breaks along streams, but they should be made alongside roads, as fires are often started by drivers throwing cigarettes out of vehicles.




Using fire to fight fire. (A) Slash two strips of vegetation at least 8 m apart. (B) Drag the cut vegetation into the centre. (C) Allow a few days for the cut material to dry out, and then (D) burn it, taking extreme care not to allow the fire to spread outside the firebreak.

### *Suppressing fires*

Organise teams of fire watchers to alert local people when fires are spotted. Try to involve the whole community in the fire prevention programme, so that each household contributes one family member every few weeks to fire prevention duties. Fire watchers must remain alert night and day throughout the dry season.

Place fire-fighting tools and oil drums full of water at strategic places around the planted site. Fire-fighting tools include back-pack water tanks with sprayers, beaters to smother the fire, rakes to remove combustible vegetation from the fire front and a first aid kit. Green tree branches can be used as fire beaters. If a permanent stream runs nearby, above the restoration site, consider laying pipes into the restoration sites. This can greatly increase the efficiency of fire-fighting activities but is very expensive.


Small fires can be controlled with (A) back-pack sprayers, the use of (B) simple tools such as rakes to remove fuel in the fires path, and (C) beaters to extinguish small fires. Oil drums full of water can be placed strategically across the site in advance as refill points for the back-pack sprayers.

Only low-intensity, slow-moving, ground fires can be controlled with hand tools. More serious fires, especially those that move up into tree crowns, must be controlled by professional fire fighters with aerial support. Be ready to contact local fire-fighting authorities if the fire gets out of control, and take extra care, as serious fires move very quickly and can easily cost lives. The forest fire control units of local forest authorities often provide training in fire prevention and fire-fighting techniques to local people. They may be able to supply fire-fighting equipment to community-based fire prevention initiatives, so contact your local forest fire control unit for assistance.

### *What can be done if restoration sites do burn?*

All is not lost. Some tree species can re-sprout (or coppice) from rootstock after having been burnt (see **Section 2.2**). Burnt, dead branches allow the entry of pests and pathogens, so cutting them off can speed recovery after burning. Prune dead branches right back, leaving a stump no longer than 5 mm. After fire, the blackened soil surface absorbs more heat, causing more rapid evaporation of soil moisture. This can subsequently kill young trees that have survived the initial fire. Therefore, laying a mulch of cut vegetation or corrugated cardboard around young, burnt trees can increase their chances of survival and re-growth.

## Livestock management

Cattle, goats, sheep and other livestock can completely prevent forest regeneration by browsing on young trees. Ultimately, the decision to reduce the number of livestock or to remove them altogether depends on careful consideration of their economic value to the community and their potential to play a useful role in forest restoration, balanced against any damaging effects they have on young trees. The severity of the damage obviously increases with stocking density.

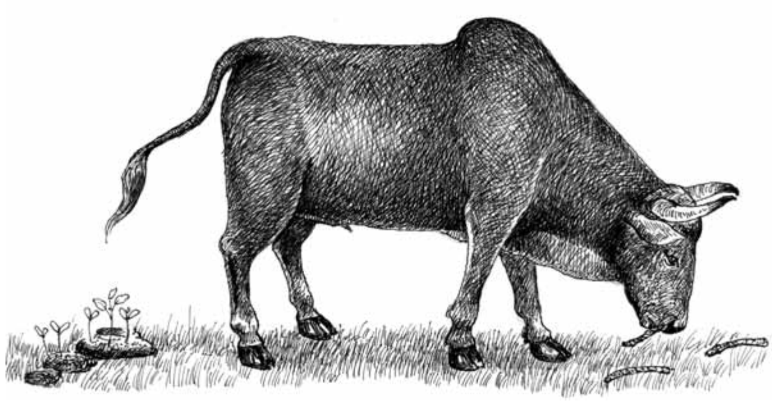
In Area de Conservacion Guanacaste (ACG), Costa Rica, cattle played a positive role in the early stages of a forest restoration project by grazing on an exotic grass species that fuelled wildfires, but as the developing tree crowns began to shade out the grass, the cattle were gradually removed (see **Case Study 3**, p. 149). Similarly in the montane pastures of Columbia, where grasses are a major barrier to forest regeneration, livestock grazing encouraged shrub establishment, which created a micro-climate that was more suitable for the establishment of tropical montane forest tree species (Posada *et al*., 2000).

Livestock can also facilitate natural forest regeneration by dispersing tree seeds, especially in forests where wild ungulate species have become extirpated (Janzen, 1981). Free-ranging cattle often consume tree fruits in forests and deposit them in open areas when grazing. Cattle-dispersed tree species mostly grow in dry tropical forests and commonly have dry, indehiscent, brown-black fruits with hard seeds, averaging 7.0 mm in diameter. The family Leguminosae contains many tree species with seeds that are dispersed by cattle; other families with fewer potentially cattle-dispersed tree species include the Caprifoliaceae, Moraceae, Myrtaceae, Rosaceae, Sapotaceae and Malvaceae. Ranchers in the Central Valleys of Chiapas, Mexico purposefully use cattle to plant tree seeds (Ferguson, 2007).

Careful livestock management can, therefore, have beneficial effects for forest restoration if the stocking density is low and the foliage of the desired tree species is unpalatable. But even in such circumstances, livestock can reduce the richness of tree species in restored forest sites by selective browsing.

The impact of livestock can be managed by tethering animals in the field to restrict their movements or by removing them altogether. Stock fences can be erected to exclude livestock during the early stages of forest restoration, but such fences must be maintained until the trees crowns have grown beyond the reach of livestock.

In Nepal, villagers often do not allow their cows to roam freely in their community forests. To promote rapid forest regeneration, villagers keep their cows outside the forest. They cut grass and fodder from the forests and carry it to their cows. This feeds the cows without damaging the young, regenerating trees and also encourages the effective weeding of forest plots (Ghimire, 2005).



Cattle can act as 'living grass mowers' and can disperse seeds, but dense populations suppress forest regeneration.

## Protecting seed dispersers

For forest restoration to be successful, with acceptable biodiversity recovery, the protection of trees must be complemented with the protection of seed-dispersing animals. Seed dispersal from intact forest into restoration sites is essential for the return of climax forest tree species. The hunting of seed-dispersing animals can therefore substantially reduce tree species recruitment. There is no point in restoring forest habitat to attract seed dispersers if there are no seed dispersers left to attract.

Simple education campaigns can be effective in turning hunters into conservationists. At Ban Mae Sa Mai in northern Thailand, hill tribe children were the main hunters, capturing birds in traps and killing them with catapults, sometimes to eat but mostly for fun. They particularly targeted bulbuls, the main seed-dispersers from forest into open areas. An effective education campaign (sponsored by the Eden Project, UK) introduced the children to the hobby of bird watching, with the potential for further training some of them to become guides for ecotourists. The project provided binoculars and bird identification books and ran regular bird watching trips. The children established their own small bird reserve and the 'bird police', using peer pressure to dissuade their classmates from hunting. They also took the conservation message home to their parents. Both bird traps and catapults are now a rare sight around the village.

S.O.S. 'Save Our Seed-dispersers': simple education campaigns can turn bird hunters into bird guides. (Photos: T. Toktang).

# 5.2 'Assisted' or 'accelerated' natural regeneration (ANR)

## What is ANR?

ANR is any set of activities, short of tree planting, that enhance the natural processes of forest regeneration. It includes the protective measures that remove barriers to natural forest regeneration (e.g. fire and livestock) already described in **Section 5.1**, along with additional actions to i) 'assist' or 'accelerate' the growth of natural regenerants that are already established in the restoration site (i.e. seedlings, saplings and live stumps of indigenous forest tree species) and ii) encourage seed dispersal into the restoration site.

The UN Food and Agriculture Organisation (FAO), in partnership with the Philippines' government and community-based NGOs, supported much of the research that helped to transform ANR from a concept into an effective and practicable technique (see **Box 5.2**, p. 119). The FAO now promotes ANR as a method for enhancing the establishment of secondary forests by protecting and nurturing seed trees and wildlings already present in the area. With ANR, secondary and degraded forests grow faster than they would naturally. Because this method merely enhances already existing natural

**Box 5.2. Origins of ANR.**

Although humans have long manipulated natural forest regeneration, the concept of actively promoting it to restore forest ecosystems is relatively recent. The formal concept of ANR — 'accelerated' or 'assisted' natural regeneration — first emerged in the Philippines in the 1980s (Dalmacio, 1989). A long-standing partnership between the UN Food and Agriculture Organisation (FAO)'s Regional Office for Asia and the Pacific and the Bagong Pagasa (New Hope) Foundation (BPF), a small NGO in the Philippines, has since played a crucial role in propelling this simple concept from obscurity to the fore-front of tropical forest restoration technology.

Sponsored by the Japan Overseas Forestry Consultants Association (JOFCA), BPF established an early ANR project at Kandis village, Puerto Princesa, on Palawan Island, Philippines, with the aim of restoring 250 ha of degraded water catchment that was dominated by grasses. ANR was tested both as a restoration technique and as a development tool for improving the livelihoods of 51 families. The project combined ANR to restore forest with the establishment of fruit orchards. Treatments included fire prevention, ring weeding of tree saplings and grass pressing. The pioneer trees, which grew up rapidly after the weeding treatments, fostered the regeneration of 89 forest tree species (representing 37 tree families), including many climax forest species. The forest trees were inter-planted with coffee and domestic fruit trees to provide the villagers with income. After three years, a self-sustained forest ecosystem began to develop. Systematic monitoring revealed significant biodiversity recovery and soil improvement (Dugan, 2000).

Although there are now many successful ANR projects in the Philippines, very little information was initially published to enable others to learn from the experiences of organisations such as Bagong Pagasa. Therefore, the FAO has funded several projects to promote ANR for forest restoration in several countries. Launched in 2006, the project "Advancing the application of assisted natural regeneration for effective low-cost forest restoration"[2] created demonstration sites on three geographically different Philippines islands. The project focused on restoring forest to degraded *Imperata cylindrica* grasslands, using weed pressing to liberate shaded tree seedlings. More than 200 foresters, NGO members and community representatives have been trained in ANR methods at these demonstration sites. The project concluded that the costs of ANR are approximately half those of conventional tree planting. As a result, the Philippines Department of Environment and Natural Resources (DENR) allocated US$32 million to support the implementation of ANR practices on approximately 9,000 hectares. The project has generated interest and funding from the mining industry and local municipalities seeking to offset their carbon footprints. The FAO, in collaboration with BPF, is now funding similar ANR trials in Thailand, Indonesia, Lao PDR and Cambodia.

Patrick Dugan, founding chairman of Bagong Pagasa. By building partnerships with the Philippines Government (Department of Environment and Natural Resources) and the FAO, the foundation has promoted the concept of ANR well beyond its origins in the Philippines.

[2] www.fao.org/forestry/anr/59224/en/

processes, it requires less labour than tree planting and there are no tree nursery costs. It can, therefore, be a low-cost way to restore forest ecosystems. Shono *et al*. (2007) provide a comprehensive review of ANR techniques.

ANR and tree planting should not be regarded as mutually exclusive alternatives to forest restoration. More often than not, forest restoration combines protection and ANR together with some tree planting. The site survey technique, detailed in **Sections 3.2** and **3.3**, can be used to determine whether protection + ANR are sufficient to achieve restoration goals, whether they should be complemented with tree planting and, if so, how many trees should be planted.

## Where is ANR appropriate?

Protection + ANR may be sufficient to bring about rapid and substantial forest restoration and biodiversity recovery where the forest degradation is at stage-2. At this degradation stage, the density of natural regenerants exceeds 3,100 per hectare, and more than 30 common tree species typical of the target climax forest (or roughly 10% of the estimated number of tree species in the target forest, if known) are present. Where the density of natural regenerants is lower or fewer tree species are represented, ANR should be used in combination with tree planting (see **Section 3.3**). Furthermore, intact forest should remain within a few kilometres of the proposed restoration site, providing a seed source for the re-establishment of climax forest tree species, and seed-dispersing animals should remain fairly common (see **Section 3.1**).

Some advocates of ANR propose its use on highly degraded grasslands, where the density of regenerants (>15 cm tall) is only 200–800 per hectare (i.e. degradation stage 3 or higher, see **Section 3.1**) (Shono *et al*., 2007). The application of ANR alone under such circumstances usually results in forest of low productive and ecological value because of the dominance of a few ubiquitous pioneer tree species. But even a species-poor secondary forest is a considerable improvement, in terms of biodiversity recovery, on the degraded grasslands that it replaces; and further forest recovery is possible as long as seed trees and seed-dispersers remain in the landscape.



(A) About a year before this photograph was taken (photo May 2007), encroachers illegally cleared lowland, evergreen forest from this Reserved Forest site in southern Thailand to establish a rubber tree plantation. Plenty of sources of natural regeneration remained, including both pioneer and climax tree species, making the site ideal for restoration by ANR. Cardboard mulch mats were placed around remaining tree saplings and seedlings, weeds were cleared and fertiliser was applied three times during the rainy season. (B) Just 6 months later, canopy closure had been achieved (photo November 2007). Most of the canopy tree species were pioneers, and so the understory was enriched by planting nursery-raised saplings of climax forest tree species.

## ANR techniques

### *Reducing competition from weeds*

Weeding reduces competition between trees and herbaceous vegetation, increases tree survival and accelerates growth. Before weeding, clearly mark the tree seedlings or saplings with brightly coloured poles to make them more visible. This prevents their being accidentally trampled or cut during weeding.

First, mark sources of natural forest regeneration.

*Ring weeding*

Remove all weeds, including their roots, using hand tools within a circle of 50 cm radius around the base of all natural seedlings and saplings. Hand-pull weeds (wear gloves) close to small seedlings and saplings, as digging out weed roots with hand tools can damage their root system. Then, lay a thick mulch of the cut weeds around each seedling and sapling, leaving a gap of at least 3 cm between the mulch and the stem to help prevent fungal infection. Where the cut weeds do not yield a sufficient volume of mulching material, use corrugated cardboard as mulch.

*Weed pressing or lodging*

Remove shade by flattening all remaining herbaceous vegetation between the exposed natural regenerants using a wooden board (130 × 15 cm). Attach a sturdy rope to both ends of the plank, making a loop long enough to pass over your shoulders (attach shoulder pads for comfort). Lift the plank onto the weed canopy and step on it with full body weight to fold over the stems of grasses and herbs near the base. Repeat this action, moving forward in short steps[3]. The weight of the plants should keep them bent down. This is particularly effective where the vegetation is dominated by soft grasses such as *Imperata*. Old, robust or cane-stemmed grasses (e.g. *Phragmites*, *Saccharum*, *Thysanolaena* spp.) should not be pressed, because they can readily re-sprout from nodes along their stems. Pressing weeds is much easier than slashing them; one experienced person can press about 1,000 m$^2$ per day.

Grass pressing with a wooden board is particularly suitable for suppressing the growth of *Imperata* grass and releasing natural regenerants from competition.

Pressing is best carried out when the weeds are about 1 m tall or taller: shorter plants tend to spring back up shortly after pressing. The best time to press grass is usually about two months after the rains start when grass stems easily crimp (fold). Before pressing on a large scale, conduct a simple test on a small area. Press the grass and wait overnight. If the grass is starts to spring back up by the morning, then wait a few more weeks before trying again. Always press the weeds in the same direction. On slopes, press grasses downhill. If plants are pressed when they are wet, water on the leaves helps them to stick together, so that they are less likely to spring back up.

Pressing effectively uses the weeds' own biomass to shade and kill them. Plants in the lower layers of the pressed mass of vegetation die because of lack of light. Some plants may

[3] www.fs.fed.us/psw/publications/documents/others/5.pdf and www.fao.org/forestry/anr/59221/en/

survive and grow back, but they do so much more slowly than if they had been slashed. Therefore, pressing does not have to be repeated as often as slashing. The pressed vegetation suppresses the germination of weed seeds by blocking light. It also protects the soil surface from erosion and adds nutrients to the soil as the lower layers begin to decompose. Weed pressing opens up the restoration site, making it easier to move around and work with the young trees. It also helps to reduce the severity of fires. Pressed plants are a lot less flammable than erect ones because of the lack of air circulation within the pressed mass of vegetation. They do burn, but the flame height is lower and so tree crowns are less likely to be scorched.

Where the density of natural regenerants is high, the use of herbicides to clear weeds is not recommended because it is very difficult to prevent the spray drifting onto the foliage of the natural regenerants.

### *Use of fertilisers*

Most tree seedlings and saplings of up to about 1.5 m tall will respond well to fertiliser applications, regardless of the soil fertility. Fertiliser application both increases survival and accelerates growth and crown development. This brings about canopy closure and shading out of weeds sooner than if no fertiliser were applied, and thus reduces labour costs for ring weeding and weed pressing. So although chemical fertilisers can be expensive, the costs are partly offset in the long term by the savings in weeding costs. Organic fertilisers, such as manure, can be used as a cheaper alternative to chemical fertilisers. It is probably a waste of effort and expense to apply fertiliser to older saplings and tree stumps, which have already developed deep root systems.

### *Encouraging tree stumps to sprout*

The importance of coppicing tree stumps in accelerating canopy closure and contributing to the richness of tree species in restoration sites was discussed in **Section 2.2**. But besides the general recommendation that tree stumps should be protected from further chopping, burning or browsing, almost no treatments to enhance their potential role in ANR have been tested. Experiments on 'tree stump cultivation' could test the effectiveness of i) applying chemicals to prevent fungal decay or attack by termites, ii) applying plant hormones to stimulate bud growth and coppicing, and iii) pruning back weak coppicing shoots to free up more of the plant's resources for the remaining ones.

### *Thinning out naturally regenerating trees*

Where dense stands of a single species dominate, self-thinning will occur naturally as the taller trees shade out the shorter ones. This process can be accelerated by selectively cutting some of the smaller trees (instead of waiting for them to die back naturally). This provides light gaps in which other, less common, tree species can establish and should increase the overall tree species richness.

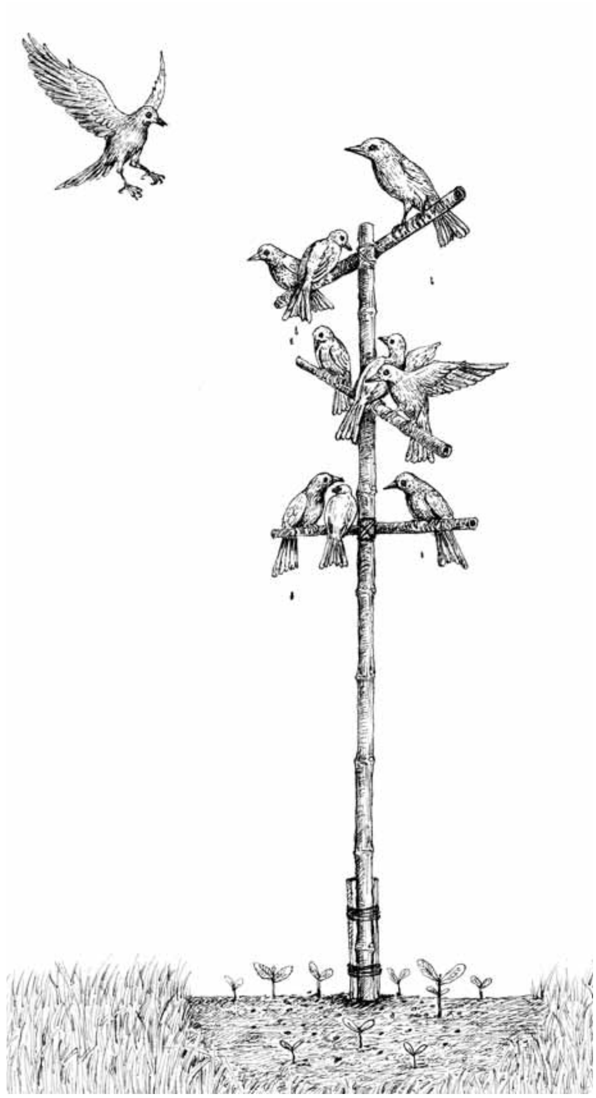
### *Assisting the seed rain*

The importance of seed dispersal as a vital and free ecological service that ensures the re-colonisation of restoration sites by climax forest tree species has been emphasised throughout this book (see **Sections 2.2, 3.1** and **5.1**). So how can it be enhanced?

Artificial bird perches are, in theory, a rapid and cheap way of attracting birds and increasing the seed rain in restoration sites. Perches are usually 2–3 m posts that have cross-bars pointing in different directions. Although the seed rain is increased beneath perches (Scott *et al*., 2000; Holl *et al*., 2000; Vicente *et al*., 2010), seedling establishment increases only if the conditions for germination and seedling growth are favourable beneath the perches. Seeds can be predated or young seedlings can be out-competed by herbaceous weeds (Holl 1998; Shiels & Walker 2003). So weeding beneath perches is necessary if they are not on sites with low weed density.

Although artificial perches attract birds, they do so less effectively than actual trees and shrubs, which provide the added benefit of shading out weeds and thus improve conditions for seedling establishment. Establishing structurally diverse vegetation, including fruiting shrubs or remnant trees, is the best way to attract seed-dispersing birds and animals, but it takes time. In the meantime, artificial bird perches can provide a stop-gap measure.

In disturbed areas, the natural seed rain is dominated by secondary forest tree species, often from trees fruiting within the degraded site itself (Scott *et al*., 2000). Therefore, perches can increase the density of regenerants without increasing species richness. Under such circumstances, the seed rain brought in by birds should be complemented with direct seeding of less common and climax forest trees.



Artificial bird perches can be used to increase the dispersal of tree seeds from intact forest to restoration sites.

## Limitations of ANR

ANR acts solely on natural regenerants that are already present in deforested sites. It can achieve canopy cover rapidly, but only where regenerants are present at sufficiently high densities. Most of the trees that colonise degraded areas are of relatively few, common, light-demanding, pioneer species (see **Section 2.2**), which produce seeds that are dispersed by the wind or small birds. They represent only a small fraction of the tree species that grow in the target forest. Where wildlife remains common, the 'assisted' trees will attract seed-dispersing animals, resulting in tree species recruitment. But where large seed-dispersing animal species have become extirpated, planting large-seeded climax forest tree species can be the only way to transform the secondary forest, created by ANR, into climax forest.

## 5.3 The framework species method

Tree planting should be used to complement protection and ANR wherever fewer than 3,100 natural regenerants can be found per hectare and/or fewer than 30 tree species (or roughly 10% of the estimated number of tree species in the target forest, if known) are represented. The framework species method is the least intensive of the tree planting options: it exploits natural (and cost-free) seed dispersal mechanisms to bring about the recovery of biodiversity. This method involves planting the smallest number of trees necessary to shade out weeds (i.e. to provide site 'recapture') and attract seed-dispersing animals.

For the method to work, remnants of the target forest type that can act as a seed source must survive within a few kilometres of the restoration site. Animals (mostly birds and bats) that are capable of dispersing seeds from remnant forest patches or isolated trees to the restoration site must also remain fairly common (see **Section 3.1**). The framework species method enhances the capacity of natural seed-dispersal to achieve rapid tree species recruitment in restoration plots. Consequently, biodiversity levels recover towards those typical of climax forest ecosystems without the need to plant all of the tree species that comprise the target forest ecosystem. In addition, the planted trees rapidly re-establish forest structure and functioning, and create conditions on the forest floor that are conducive to the germination of tree seeds and seedling establishment. The method was first conceived in Australia, where it was initially used to restore degraded sites within Queensland's Wet Tropics World Heritage Area (see **Box 3.1**, p. 80). It has since been adapted for use in several Southeast Asian countries.

### What are framework tree species?

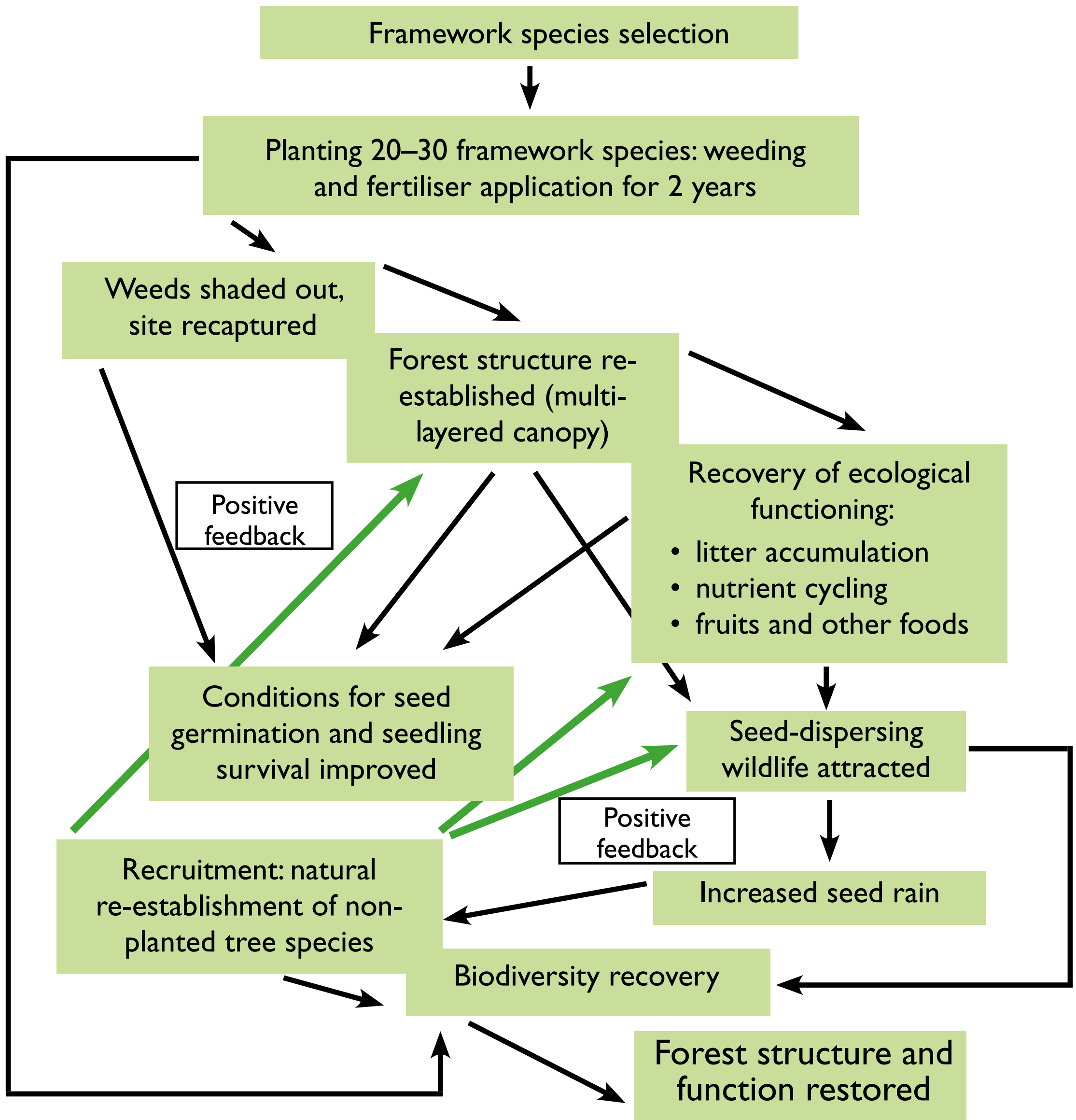
The framework species method involves planting mixtures of 20–30 (or roughly 10% of the estimated number of tree species in the target forest, if known) indigenous forest tree species that are typical of the target forest ecosystem and share the following ecological characteristics:

- high survival rates when planted out in deforested sites;
- rapid growth;
- dense, spreading crowns that shade out herbaceous weeds;
- the provision, at a young age, of flowers, fruits or other resources that attract seed-dispersing wildlife.

In the seasonally dry tropics, where wild fires in the dry season are an annual hazard, an additional desired characteristic of framework species is resilience to burning. When fire prevention measures fail, the success of forest restoration plantings can depend on the ability of the planted trees to re-sprout from their rootstock after fire has burnt their above-ground parts (i.e. coppicing, see **Section 2.2**).

A practical consideration is that framework species should be easy to propagate and, ideally, their seeds should germinate rapidly and synchronously, with subsequent growth of vigorous saplings to a plantable size (30–50 cm tall) in less than 1 year. Furthermore, where forest restoration must yield benefits to local communities, economic criteria such as the productivity and value of the products and ecological services provided by each species can be taken into account.

## How the framework species method works




## Are framework trees pioneer or climax species?

The mixtures of framework tree species chosen for planting should include both pioneer and climax species (or species that represent all the successional 'guilds' explained in **Section 2.2**, if known). Forest succession can be 'short-circuited' by planting both pioneer and climax trees in a single step. But in order to achieve rapid canopy closure, Goosem and Tucker (1995) recommend that at least 30% of the planted trees should be pioneers.

Many climax forest tree species perform well in the open, sunny conditions of deforested areas but they fail to colonise such areas naturally because of a lack of seed dispersal. Climax tree species often have large, animal-dispersed seeds and the decline of large mammals over wide areas prevents the dispersal these trees into deforested sites. By including some of them amongst the trees that are planted, it is possible to overcome this limitation and to accelerate the recovery of climax forest.

The planted pioneer trees make the greatest contribution to early canopy closure and shading out of herbaceous weeds. The point at which the tree crowns dominate over the herbaceous sward is called 'site recapture'. Pioneer tree species mature early and some can begin to flower and fruit just 2–3 years after planting. Nectar from flowers, fleshy fruits, and the perching, nesting and roosting sites created within the tree crowns all attract wildlife from nearby forest. Animal diversity increases dramatically as the new trees become established and, most importantly, many of the animals that visit the restoration sites carry with them tree seeds from climax forest. Furthermore, the cool, shady, moist, humus-rich and weed-free forest floor created beneath the canopy of planted trees provides ideal conditions for seed germination.

Pioneer species begin to die back after 15–20 years, creating light gaps. These allow the saplings of in-coming tree species to grow up and replace the planted pioneers in the forest canopy. If just short-lived, pioneer tree species were planted, they might die back before sufficient numbers of incoming tree species had established, leading to the possibility of re-invasion of the site by herbaceous weeds (Lamb, 2011). Planted climax tree species form an understorey that prevents this. They also add diversity and some of the structural features and niches of climax forest right from the start of the restoration project.

## Rare or endangered tree species

Rare or endangered tree species are unlikely to be recruited into restoration sites on their own because their seed source is probably limited and they may have lost their primary seed dispersal mechanisms. Including such species in forest restoration plantings can help prevent their extinction, even if they lack some framework characteristics. Information on the world's endangered tree species is collated by the World Conservation Monitoring Centre of the United Nations Environment Program[4].

## Selection of framework tree species

There are two stages to the selection of framework species: i) preliminary screening, based on current knowledge, to identify 'candidate' framework species for testing; and ii) nursery and field experiments to confirm framework traits. At the beginning of a project, detailed information about each species is likely to be sparse. Preliminary screening must be based on existing information sources and the target forest survey. As the results of nursery experiments and field trials gradually accumulate, the list of acceptable framework tree species can be gradually refined (see **Section 8.5**). The choice of framework species gradually improves at each planting as poor-performing species are dropped and new species are tried.

Sources of information for preliminary screenings include: i) floras, ii) the results of the target forest survey (see **Section 3.2**), iii) indigenous local knowledge and iv) scientific papers and/or project reports describing any previous work in the area (**Table 5.1**).

[4] www.earthsendangered.com/plant_list.asp

In the framework species method, both pioneer tree species (coloured in blue) and climax species (red) are planted 1.8 m apart in a single step, thereby 'short circuiting' succession while also preserving any naturally occurring trees and saplings (green).

The planted pioneer trees grow rapidly and dominate the upper canopy. They begin to flower and fruit a few years after planting. This attracts seed-dispersing animals. The planted climax tree species form an understorey, while seedlings of 'recruited' (i.e. non-planted) species (brought in by the attracted wildlife) grow on the forest floor.

Within 10–20 years, some of the planted pioneer trees begin to die back, providing light gaps in which recruited species can flourish. Climax tree species rise to dominate the forest canopy and forest structure, ecological functioning and biodiversity levels move towards those of climax forest.

**Table 5.1. The preliminary screening and final selection of framework tree species draws on a diverse range of different information sources*.**

| | Preliminary screening | | | | Final selection | |
|---|---|---|---|---|---|---|
| **Framework characteristic** | **Floras** | **Target forest survey** | **Indigenous knowledge** | **Papers and previous project reports** | **Nursery research (see Section 6.6)** | **Field trials (see Sections 7.5 and 7.6)** |
| Indigenous, non-domesticated, suited to habitat or elevation | Often indicated in plant descriptions in botanical literature | List of tree species from target forest survey | Unreliable: villagers often fail to distinguish between native and exotic species | EIAs and previous surveys for conservation management plans often list local tree species | – | – |
| High survival and growth | – | – | Ask local people which tree species survive well and grow rapidly in fallow fields | Unlikely except for economic species in previous forestry projects | Assess survival and growth of seedlings growing in nurseries | Monitor a sample of planted trees of each species for survival and growth (**Section 7.5**) |
| Dense broad crown shades out weeds | Few texts cover tree crown structure | Observe crown structure of trees in the target forest | – | – | Leaf size and crown architecture can be indicated by saplings in the nursery | Monitor a sample of planted trees of each species for crown breadth and reduced weed cover beneath |
| Attractive to wildlife | Fleshy fruits or nectar-rich flowers indicated in taxonomic descriptions | Observe fruit type and animals eating fruits or flowers in target forest | Villagers often know which tree species attract birds | – | – | Phenology studies of trees after planting |
| Resilient to fire | – | Survey trees in recently burnt areas | Villagers often know which tree species recover after burning in fallow fields | – | – | Where fire-prevention measures fail, survey trees in burnt plots immediately after a fire and 1 year later |
| Easy to propagate | – | – | – | Unlikely except for economic species in forestry projects | Germination experiments and seedling monitoring | – |
| Climax or large-seeded species | Often indicated in plant descriptions in botanical literature | Observe fruits and seeds of trees in target forest | – | – | – | – |

*The organisation and integration of this information is discussed in **Section 8.5**.

Floras can provide basic taxonomic data on species under consideration as well as their suitability to site-specific requirements such as the target forest type being restored or the elevation range. They also indicate if a species produces fleshy fruits or nectar-rich flowers that are likely to attract wildlife.

The target forest survey (see **Section 3.2**) provides a great deal of original information that is useful for the selection of candidate framework tree species, including a list of indigenous tree species, and lists of species that have nectar-rich flowers, fleshy fruits or dense spreading crowns that are capable of shading out weeds. Phenology studies yield information on which trees will attract seed-dispersing wildlife. Studies of the botanical knowledge of local people (ethnobotany) can also provide an insight into the potential of trees to act as framework species. When carrying out such studies, it is important to work with communities that have a long history of living close to the forest, especially those that practice swidden (slash and burn) agriculture. Farmers from such communities usually know which tree species readily colonise fallow fields and grow rapidly and which tree species attract wildlife. The results of such studies must, however, be critically scrutinised. Local people sometimes provide information that they think will please the researcher rather than that based on actual experience. Superstition and traditional beliefs can also distort the objective assessment of a tree species' capabilities. Consequently, ethnobotanical information is reliable only if it is provided independently by members of several different communities with different cultural backgrounds. To design effective ethnobotany surveys, please refer to Martin (1995).

Local people also know if other researchers have been active in the area and which organisations or institutions they come from. Forestry departments and protected areas authorities often carry out biodiversity surveys, although the results might be in unpublished reports. Contact such organisations and ask for access to such reports. The local or national herbarium might also have tree specimens from your project site. Browsing through herbarium labels can reveal a lot of useful information. If any development projects have been carried out near your project site, it is likely that an environmental impact assessment (EIA), including a vegetation survey, was carried out. So it is worth contacting the agency that carried out the EIA. If research students have been active in the area, then universities can also be a source of more detailed information. Finally, there is always the internet. Simply typing the name of your project site into a search engine might reveal major additional sources of information.

Lists of tested framework tree species currently exist only for Australia (Goosem & Tucker, 1995) and Thailand (FORRU, 2006). But trees species in the same genera as those listed for Australia and Thailand might also perform well in other countries, so including some of them in initial framework species trials is well worth a try. Two pan-tropical tree taxa deserve special mention, namely fig trees (*Ficus* spp.) and legumes (Leguminosae). Indigenous species within these two taxa nearly always perform well as framework species. Fig trees have dense and robust root systems, which enable them to survive even the harshest of site conditions. The figs they produce are an irresistible food source for a wide range of seed-dispersing animal species. Leguminous trees often grow rapidly and have the capacity to fix atmospheric nitrogen in root nodules containing symbiotic bacteria, resulting in rapid improvement of soil conditions.

## Site management

First, implement the usual protective measures described in **Section 5.1**, particularly measures to prevent both fire and the hunting of seed-dispersing animals. Second, protect and nurture any existing natural regenerants using the ANR techniques described in **Section 5.2**. Third, plant enough framework tree species to bring the total species on-site (including natural regenerants) up to around 30 (or roughly 10% of the estimated number of tree species in the target forest, if known), spaced about 1.8 m apart or the same distance from natural regenerants: this will bring the total density of trees on site up to around 3,100/ha.

Frequent weeding and application of fertiliser to both planted trees and naturally regenerating saplings is recommended during the first two rainy seasons. Weeding prevents herbs and grasses, particularly vines, from smothering the planted trees, enabling the tree crowns to grow above the weed canopy. Fertiliser application accelerates tree growth, resulting in rapid canopy closure. Finally, monitor the survival and growth of the planted trees and biodiversity recovery in restoration sites, so that the choice of framework tree species for future plantings can be continuously improved.

For further information on planting, and the post-planting management and monitoring of framework trees, see **Chapter 7**.

## Direct seeding as an alternative to tree planting

Some framework tree species can be established in the field directly from seed. Direct seeding involves:

- collecting seeds from native trees in the target forest ecosystem and if necessary storing them until sowing;
- sowing them in the restoration site at the optimal time of year for seed germination;
- manipulating field conditions to maximise germination.

Direct seeding is relatively inexpensive because there are no nursery and planting costs (Doust *et al*., 2006; Engel & Parrotta, 2001). Transporting seeds to the restoration site is obviously easier and cheaper than trucking in seedlings, so this method is particularly suitable for less accessible sites. Trees that are established by direct seeding usually have better root development and grow faster than nursery-raised saplings (Tunjai, 2011) because their roots are not constrained within a container. Direct seeding can be implemented in combination with ANR methods and conventional tree planting to increase both the density and species richness of regenerants. In addition to establishing framework tree species, direct seeding can be used with the maximum diversity method or to establish 'nurse tree' plantations, but it does not work with all tree species. Experiments are needed to determine which species can be established by direct seeding and which cannot.

### *Potential obstacles to direct seeding*

In nature, a very low percentage of dispersed tree seeds germinate and even fewer seedlings survive to become mature trees. The same is true of direct seed sowing (Bonilla-Moheno & Holl, 2010; Cole *et al*., 2011). The biggest threats to sown seeds and seedlings are: i) desiccation, ii) seed predation, particularly by ants and rodents (Hau,

1997) and iii) competition from herbaceous weeds (see **Section 2.2**). By counteracting these factors, it is possible to improve the rates of germination and seedling survival above those for naturally dispersed seeds.

The problem of desiccation can be overcome by selecting tree species whose seeds are tolerant of or resistant to desiccation (i.e. those with thick seed coats) and by burying the seeds or laying mulch over the seeding points (Woods & Elliott, 2004).

Burying can also reduce seed predation by making the seeds more difficult to find. Pre-sowing seed treatments that accelerate germination can reduce the time available for seed predators to find the seeds. Once germination commences, the nutritional value of seeds and their attractiveness to predators decline rapidly. But treatments that break the seed coat and expose the cotyledons sometimes increase the risk of desiccation or make seeds more attractive to ants (Woods & Elliott, 2004). It could also be worth exploring the possibility of using chemicals to repel seed predators. Any carnivores that prey on rodents (e.g. raptors or wild cats) should be regarded as valuable assets on ANR sites. Preventing the hunting of such animals can help to control rodent populations and reduce seed predation.

Carnivores, such as this leopard cat (*Felis bengalensis*), can help to control populations of seed-predating rodents, so capturing or killing them at restoration sites should be strongly discouraged.

Seedlings that germinate from seeds are tiny compared with planted, nursery-raised saplings, so weeding around the seedlings is especially important and it must be carried out with extra care. Such meticulous weeding can greatly increase the cost of direct seeding (Tunjai, 2011).

### *Species suitable for direct seeding*

Species that tend to be successfully established by direct seeding are generally those that have large (>0.1 g dry mass), spherical seeds with medium moisture content (36–70%) (Tunjai, 2012). Large seeds have large food reserves, so they can survive longer than smaller seeds and produce more robust seedlings. Seed predators find it difficult to handle large, round or spherical seeds, especially if such seeds also have a tough and smooth seed coat.

Tree species in the family Leguminosae are most commonly reported as being suitable for direct seeding. Legume seeds typically have tough, smooth seed coats, making them resistant to desiccation and predation. The nitrogen-fixing capability of many legume species can give them a competitive advantage over weeds. Tree species in many other families have also shown promise and are listed in **Table 5.2** (Tunjai, 2011).

Published accounts of direct seeding have tended to concentrate on pioneer tree species (Engel & Parrotta, 2001) because their seedlings grow rapidly, but climax forest tree species can also be successfully established by direct seeding. In fact, because they generally have large seeds and energy reserves, the seeds of climax forest trees may be particularly suited to seeding (Hardwick, 1999; Cole *et al*., 2011; Sansevero *et al*., 2011). With the disappearance of large, vertebrate seed-dispersers over much of their former ranges, direct seeding might be the only way that the large seeds of some climax tree species can reach restoration sites (effectively substituting human labour for the roles formerly played by such animals).

**Table 5.2. Reports of species and techniques for successful direct seeding from around the tropics. (Prepared by Panitnard Tunjai.)**

| Location | Optimal sowing time | Forest type | Elevation (m) | Successful species | Recommended methods | Reference |
|---|---|---|---|---|---|---|
| S. Thailand | Early rainy season | Lowland evergreen | <100 | *Artocarpus dadah* (Moraceae), *Callerya atropurpurea* (Leguminosae), *Vitex pinnata* (Lamiaceae), *Palaquium obovatum* (Sapotaceae) and *Diospyros oblonga* (Ebenaceae) | Tube to prevent seed movement, no mulching and fertiliser in first two years | Tunjai, 2012 |
| N. Thailand | Early rainy season | Dry dipterocarp | 300–400 | *Afzelia xylocarpa* (Leguminosae) and *Schleichera oleosa* (Sapindaceae) | No weeding after sowing in the first year; scarification to accelerate or maximise germination for both species with hard seed coat | Tunjai, 2012 |
| | | Hill evergreen | 1,200–1,300 | *Balakata baccata* (Euphorbiaceae), *Syzygium fruticosum* (Myrtaceae), *Aquilaria crassna* (Thymelaeaceae), *Sarcosperma arboreum* (Sapotaceae) and *Choerospondias axillaris* (Anacardiaceae) | No weeding after sowing in the first year | |
| N. Thailand | Early rainy season | Hill evergreen | 1,200–1,300 | *Choerospondias axillaris* (Anacardiaceae), *Sapindus rarak* (Sapindaceae) and *Lithocarpus elegans* (Fagaceae) | Burying; pre-sowing seed treatments to accelerate or maximise germination | Woods & Elliott, 2004 |
| Cambodia | Wet season | Deciduous | 85 | *Afzelia xylocarpa* (Leguminosae), *Albizia lebbeck* (Leguminosae) and *Leucaena leucocephala* (Leguminosae) | Soil ploughing by tractor and applying cow manure before sowing | Cambodia Tree Seed Project, 2004 |
| Hong Kong | Early rainy season | Tropical semi-evergreen | 200–550 | *Triadica cochinchinensis* (Euphorbiaceae), *Microcos paniculata* (Malvaceae) and *Choerospondias axillaris* (Anacardiaceae) | Burying seeds at 1–2 cm below the soil surface | Hau, 1999 |
| Australia | Rainy season | Complex mesophyll and notophyll vines | 121–1,027 | *Acacia celsa* (Leguminosae), *Acacia aulacocarpa* (Leguminosae), *Alphitonia petriei* (Rhamnaceae), *Aleurites rockinghamensis* (Euphorbiaceae), *Cryptocarya oblata* (Lauraceae) and *Homalanthus novoguineensis* (Euphorbiaceae) | Burying seeds; mechanical and chemical weeding prior to sowing and two subsequent applications of herbicide (glyphosate) 1 month apart; more consistent establishment when using species with large seeds | Doust *et al.*, 2006 |

**Table 5.2. continued.**

| Location | Optimal sowing time | Forest type | Elevation (m) | Successful species | Recommended methods | Reference |
|---|---|---|---|---|---|---|
| Brazil | Early rainy season | Seasonal semi-deciduous | 464–775 | *Enterolobium contorstisiliquum* (Leguminosae) and *Schizolobium parahyba* (Leguminosae) | Herbicide (glyphosate) prior to sowing; additional spot application and manual weeding around seedlings | Engel & Parrotta, 2001 |
| Brazil | Late rainy season | Seasonal semi-deciduous | 574 | *Enterolobium contortisiliquum* (Leguminosae) and *Schizolobium parahyba* (Leguminosae) | Soil ripper to prepare sowing lines at 40 cm depth | Siddique *et al.*, 2008 |
| Brazil | Late rainy season | Terra firme | N/A | *Caryocar villosum* (Caryocaraceae) and *Parkia multijuga* (Leguminosae) | Sowing large-seeded non-pioneer species | Camargo *et al.*, 2002 |
| Brazil | Early rainy season | Evergreen equatorial moist | – | *Spondias mombin* (Anacardiaceae), *Parkia gigantacarpa* (Leguminosae), *Caryocar glabrum* (Caryocaraceae), *Caryocar villosum* (Caryocaraceae), *Couepia* sp. (Chrysobalanaceae), *Bertholletia excelsa* (Lecythidaceae), *Carapa guianensis* (Meliaceae) and 27 other species | On opencast mine: deep ripped to 90 cm, 15 cm top soil added; sow seeds along alternate rip lines, 2 × 2 m. | Knowles & Parrotta, 1995 |
| Costa Rica | Early rainy season | Montane | 1,110–1,290 | *Garcinia intermedia* (Clusiaceae) | Sowing late-successional seeds after establishment of fast-growing and nitrogen-fixing trees | Cole *et al.*, 2011 |
| Mexico | – | Semi-evergreen, seasonal | – | *Brosimum alicastrum* (Moraceae), *Enterolobium cyclocarpum* (Leguminosae) and *Manilkara zapota* (Sapotaceae) | Sowing seeds in young successional forest (8–15 years) or reference forest (>50 years) | Bonilla-Moheno & Holl, 2010 |
| Mexico | Early rainy season | Seasonal tropical | – | *Swietenia macrophylla* (Meliaceae) | Burying seeds 0.5 cm below soil surface; slash and burn to clear sites | Negreros & Hall, 1996 |
| Jamaica | Early rainy season | Dry | 140 | *Eugenia* sp. (Myrtaceae) and *Calyptranthes pallens* (Myrtaceae) | Sowing seeds under shade with moisture supplementation | McLaren & McDonald, 2003 |
| Uganda | Early rainy season | Moist evergeen semi-deciduous | 1,250–1,827 | *Strombosia scheffleri* (Olacaceae), *Craterispermum laurinum* (Rubiaceae), *Musanga leo-errerae* (Urticaceae) and *Funtumia africana* (Apocynaceae) | Loosening soil before sowing | Muhanguzi *et al.*, 2005 |

## Aerial seeding

Aerial seeding is a logical extension of direct seeding. It can be useful where direct seeding must be applied to very large areas, for restoring steep inaccessible sites, or where labour is in short supply. Many of the species choices and pre-sowing seed treatments developed for direct seeding can be applied equally well to aerial seeding.

China leads the way with this technology, having carried out dozens of research programs on aerial seeding since the 1980s and having applied the method to millions of hectares to establish plantations of mostly conifers and to reverse desertification. Burying seeds to prevent seed predation is not an option with aerial seeding, and so the Forestry Research Institute of Guangdong Province developed 'R8', a chemical repellent that deters seed predators. Similarly, the Forestry Research Institute of Beipiao, Liaoning Province developed a 'multi-purpose agent' that repels seed predators, prevents seed desiccation, improves rooting, and increases the resistance of seedlings to disease (Nuyun & Jingchun, 1995).

Previous aerial seeding for forestry in America and Australia (usually to establish monocultures of pines or eucalypts) involved dropping seeds, either unprotected or embedded in clay pellets, from planes or helicopters (Hodgson & McGhee, 1992). A more effective delivery system for mixed native tree species might consist of placing seeds in a biodegradable projectile that is capable of penetrating the weed cover and lodging the seeds in the soil surface. In addition to the seed itself, such projectiles could contain polymer gel (to prevent seed desiccation), slow-release fertiliser pellets, predator-repellent chemicals and microbial inoculae (Nair & Babu, 1994), which together would maximise the potential for seed germination, seedling survival and seedling growth. An aerial drone that is capable of accurately delivering up to 4 kg of seeds per flight using GPS technology is currently being investigated (Hobson, pers. comm.). A drone offers low-cost aerial delivery, provides the option of monitoring on a more frequent basis, and makes it possible to monitor hard-to-reach areas.

One of the major obstacles to the success of aerial seeding of large, inaccessible sites is the inability to carry out effective weeding and the consequent failure to protect the germinating seedlings from competition with herbs and grasses. Spraying herbicides from the air is routine in agriculture and could be used to clear restoration sites of weeds initially, provided there are few natural regenerants worth saving. After the tree seeds germinate, however, aerial herbicide sprays would kill the tree seedlings along with the weeds. Specific herbicides are needed that can kill weeds without killing either natural regenerants or seedlings germinating from aerially-delivered seeds.

## Limitations of the framework species method

For recovery of tree species richness, the framework species method depends on nearby, remnant forest to provide i) a diverse seed source and ii) habitat for seed-dispersing animals. But how close does the nearest remnant forest need to be? In fragmented evergreen forest sites in northern Thailand, medium-sized mammals such as civets can disperse the seeds of some forest tree species up to 10 km. So the technique can potentially work within a few kilometres of forest remnants, but obviously, the closer the restoration site is to remnant climax forest, the faster biodiversity will recover. If seed sources or seed dispersers are absent from the landscape, recovery of tree species richness will not occur unless nearly all of the tree species from the original forest are replanted, either as seeds or as saplings raised in nurseries. This is the 'maximum diversity' approach to forest restoration.

## Box 5.3. Rainforestation.

'Rainforestation' shares many similarities with the framework species method of forest restoration, particularly its emphasis on planting indigenous tree species at high densities to shade out herbaceous weeds and to restore ecological services, forest structure and wildlife habitat. But the Rainforestation method has been adapted to the particular ecological and socio-economic situation of the Philippines. With the most rapidly increasing and densest human population of any country in Southeast Asia (excluding Singapore), growing from 27 million in 1960 to 92 million (or 313 per km$^2$) today, an annual growth rate of 2.1%[5], deforestation has left less than 7% of the country covered in old-growth forest. With so many of the Philippine's species endemic and in imminent danger of extinction because of dwindling primary forest cover, forest restoration clearly has a major role to play in conserving biodiversity. On the other hand, with such intense human pressure, the need is for restoration methods that also generate cash income.

"*Introducing the idea of 'let's plant for our forests', the farmers always said we have to think of improving their farming also, so why not include a livelihood component? Rainforestation is a strategy for restoring the forest but at the same time, it can be a way to improve the income of farmers, so you have to enhance it by including crops … so it becomes a farming system.*" Paciencia Milan (interview 2011)

Pioneer trees are usually planted in the first year, followed by shade-tolerant, climax tree species (often Dipterocarps) that are under-planted in the second year. Planting densities vary according to project objectives: for example, for timber production, 400 trees/ha (25% pioneers to 75% climax timber trees); for agro-forestry, 600–1000 trees/ha (depending on the canopy of the fruit trees being incorporated); and for wildlife conservation, 2,500 trees/ha. Because wind-dispersed, dipterocarp tree species dominate the Philippines' forests and the remaining primary forest is often reduced to remote fragments, seed dispersal from forest to restoration sites by animals is less evident in Rainforestation than it is with the framework species method.

The concept of Rainforestation was jointly developed by Prof. Paciencia Milan of Visaya State University (VSU, formerly Visayas State College of Agriculture) and Dr Josef Margraf of GTZ (Deutsche Gesellschaft für Internationale Zusammenarbeit) under the ViSCA-GTZ Applied Tropical Ecology Program. The first trial plots were established in 1992 on 2.4 ha of *Imperata* grassland within VSU campus that had patches of coffee, cocoa and banana and portions of pasture.

A 19-year-old original Rainforestation demonstration plot, planted in 1992 in VSU's 625-ha forest reserve on the lower slopes of Mt Pangasugan (50 m elevation). Originally *Imperata* grassland, the site now supports forest that has a complex structure and highly diverse flora and fauna, including the endangered Philippines Tarsier.

[5] 2010 figures at www.prb.org/Publications/Datasheets/2010/2010wpds.aspx

**Box 5.3. continued.**

Rainforestation quickly evolved from the original concept of an ecological approach to rain forest restoration into 'Rainforestation Farming' or 'closed-canopy and high-diversity forest farming', designed to meet the economic needs of local people by including the cultivation of fruit trees and other crops alongside forest trees. The basic premise is that "the closer the structure of a tropical farming system is to a natural rain forest; the more sustainable it is". The aim of Rainforestation Farming is to sustain food production from tropical forests, while maintaining the forest's biodiversity and ecological functioning. The idea is to replace the more destructive forms of slash-and-burn agriculture with more ecologically sustainable and profitable agricultural systems.

From 1992 to 2005, VSU established 25 Rainforestation demonstration farms on various soil types on Leyte Island, and monitored them in collaboration with local villagers. Rainforestation not only provided farmers with income, it also re-established forest ecosystems with high biodiversity and improved the soil quality. The technique has now diversified into three major types (with 10 sub-types) for different purposes: i) biodiversity conservation and environmental protection (e.g. the introduction of buffer zones and wildlife corridors into protected areas, landslide prevention or riverbank stabilisation); ii) timber production and agro-ecosystems; and iii) projects in urban areas (e.g. road beautification or the introduction of parks). Different tree species and management techniques are recommended to optimise the conservation and/or economic outputs of each project sub-type, but the use of native forest tree species remains central to the Rainforestation concept.

"*Rainforestation need not be just for forest restoration. It can be used for other reasons, provided native trees are planted*." Paciencia Milan (interview 2011)

A 15-year-old, registered, community-based Rainforestation Farm, established in an over-mature coconut plantation in 1996 by planting 2,123 trees/ha, including 8 species of Dipterocarpaceae and an understorey of shade-tolerant fruit trees (e.g. mangosteen or durian). Benefits are shared amongst community members proportional to their voluntary labour inputs.

**Box 5.3. continued.**

Rainforestation has been accepted as a national strategy for forest restoration by the Philippine Department of Environment and Natural Resources (Memorandum Circular 2004-06). Native species nurseries and Rainforestation demonstration plots are now being established to further develop the technique at more than 20 state universities and colleges throughout the Philippines, supported by the Philippine Tropical Forest Conservation Foundation and the Philippine Forestry Education Network. The Environmental Leadership & Training Initiative, together with the Rain Forest Restoration Initiative and FORRU-CMU, are working with these institutions to promote the adoption of standardised research and monitoring protocols to facilitate the creation of a national database of native tree species, and the adaptation of Rainforestation to the myriad of social and environmental settings in the Philippines.

Sources: Milan *et al*. (undated and interview 2001); Schulte (2002).
For latest information please log on to the Rainforestation Information Portal at
www.rainforestation.ph/

## 5.4 Maximum diversity methods

The term 'maximum diversity method' was first coined by Goosem and Tucker (1995), who defined the approach as "attempts to recreate as much as possible of the original (pre-clearance) diversity". The method effectively attempts to recreate the tree species composition of climax forest by intensive site preparation and a single planting event, simultaneously counteracting both habitat and dispersal constraints. For sites in the wet tropics of Queensland, Australia, Goosem and Tucker (1995) recommended intensive site preparation, including deep ripping, mulching and irrigation, as required, followed by the planting of 50–60 cm saplings of up to 60, mostly climax, tree species, spaced 1.5 m apart.

> "*The method is well-suited to smaller plantings, where intensive management is possible and for areas isolated from any native vegetation, which could provide seeds*." Goosem & Tucker (1995)

The maximum diversity approach becomes applicable wherever natural seed dispersal has declined to such an extent that it is no longer capable of recovering tree species richness in restoration sites at an acceptable rate. This may be because too few individuals or species of seed trees remain within seed-dispersal distances of the restoration sites or because seed-dispersing animals have become rare or extirpated. The absence of this 'free' seed dispersal service must therefore be compensated for by planting most, if not all, of the tree species that comprise the target climax forest, ensuring high tree species richness and the representation of dispersal-limited tree species right from the start of the restoration process.

"*People planting trees, replace birds dispersing seeds.*"

Consequently, maximum diversity methods of forest restoration are much more intensive and costly than framework species techniques. The difference in costs between the two methods can be viewed as the monetary value of the lost seed dispersal mechanisms.

Expenditure is high at all stages of the process. First, a great deal of research is needed to achieve an effective plantation design, and research is not cheap. Seed collection and propagation of the full range of tree species that comprise the target climax forest ecosystem are both technically difficult and expensive.

Forest patches that are restored by this method tend to be isolated from natural forest, so unfortunately, they are affected by all the problems of fragmentation described in **Section 4.3**. Management efforts may be necessary to i) reduce edge effects (e.g. by densely planting buffer zones with shrubs and small trees as wind breaks, see **Section 4.4**) and ii) retain the small plant and animal populations that might eventually colonise such forest patches.

Planted climax forest trees grow slowly, so trees have to be planted close together to compensate for the delay in canopy closure and shading out of herbaceous weeds (see **Box 5.4**, p. 140). When compared with ANR and the framework species method, the delay in canopy closure means that weed control must continue for longer. Furthermore, climax trees take many years to mature and produce seeds from which an understorey of climax tree saplings can develop. In the meantime, restoration plots can become invaded by undesirable woody weed species (Goosem & Tucker, 1995), which eventually compete with the seedling progeny of the planted climax trees. Eradicating such undesirable undergrowth also adds to costs.

Because of the high costs, the maximum diversity approach has only been implemented by organisations with the financial resources and/or the legal obligation to do so, particularly mining companies, other large corporations and urban authorities.

Mining companies were among the first to experiment with the maximum diversity approach, mainly because of legal requirements to restore opencast mines in tropical forest areas to their original condition. Working at an opencast bauxite mine in Central Amazonia, Knowles and Parrotta (1995) recognised the need to screen the widest possible range of native tree species for possible inclusion in reforestation programs "where natural succession is retarded by physical, chemical and/or biological barriers", in order to "replicate, in an accelerated fashion, natural forest successional processes that lead to complex, self-sustaining forest ecosystems".

> "*By including a broad range of tree species in the screening program ... irrespective of their commercial value ... it is far more probable that diversified forests can be re-established that resemble and function as natural forests*."
> Knowles & Parrotta (1995)

Even though primary forest grew close to the mine, seed dispersers rarely visited the restoration sites because on-going mining operations created barriers such as desolate open areas and roads with heavy traffic. So the framework species method, which depends on natural seed-dispersal for its success, would not have facilitated tree species recruitment.

Consequently, Knowles and Parrotta systematically screened 160 tree species (around 76%) of the evergreen equatorial moist forest near the mine, to develop a system for selecting species that were suitable for multi-species plantations on an operational scale. They developed a species ranking system (a similar approach is described in **Section 8.5**) that was based on seed germinability, planting stock type and early growth rates. Tree taxa that were recommended for initial plantings were classed as 'highly suitable sun-tolerant' and 'suitable, though prefer shaded conditions initially' (59 taxa (37% of those tested) and 30 taxa (19%), respectively). The remaining 71 shade-demanding taxa represented nearly half of the tree taxa of the target forest ecosystem, and hence Knowles and Parrotta recommended that these taxa should be planted about 5 years later, once the initially planted trees had created the shade and soil conditions conducive to their establishment. Thus, Knowles and Parrotta essentially advocated a two-stage maximum diversity approach, using mostly sun-tolerant pioneers to create the conditions needed for the subsequent addition of all of the other tree species that were representative of the target forest ecosystem.

Restoration sites were levelled and covered with 15 cm of top soil within a year of forest clearance and bauxite extraction. They were deep ripped to 90 cm depth (1 m between rip lines) and tree propagules (direct seeding (**Table 5.2**), wildlings or nursery-raised seedlings) were planted along alternate rip lines at 2 × 2 m spacing (2,500 plants/ha). At least 70 species were planted in a pattern that ensured that trees of the same species were not planted adjacently.

The maximum diversity approach is also particularly suited to urban forestry, adding biodiversity to cityscapes and providing city-dwellings with a rare opportunity to connect with nature. Urban authorities have the responsibility to take care of parks, gardens and roadsides and have budgets that are large enough to pay for intensive landscaping operations. On urban sites, the high costs of maximum diversity techniques are justified by the heavy use and appreciation of urban forests by dense populations and by the high value of the land. When planting trees on urban land, it is important to ensure that they do not disrupt electricity cables or water pipes. Aesthetic considerations, such as the attractiveness of the planted tree species, must also be considered (Goosem & Tucker, 1995).

In summary, the maximum diversity approach can be implemented by single plantings of mostly climax forest tree species or by two-stage plantings, beginning with mostly pioneer trees and following-up, after the pioneers close canopy, by under-planting with shade-dependent climax tree species. The aim is to plant most of the tree species that comprise the target climax forest. However, the difficulties of seed collection and limited nursery capacity have to date limited maximum diversity trials to 60–90 tree species. Most species should be represented by at least 20–30 trees/ha. Greater prominence can be given to i) large-seeded species, ii) 'keystone' species (e.g. *Ficus* spp.) and iii) endangered, vulnerable or rare species to increase the biodiversity conservation value of the operation. Usually, the planting and maintenance methods that are used for the framework species approach (i.e. weeding, mulching and fertiliser application see **Section 7.3**) can also be used for the maximum diversity approach (Lamb, 2011, pp. 342–3), although more intensive site preparation, such as deep ripping, may be necessary at severely degraded sites (Goosem & Tucker, 1995; Knowles & Parrotta, 1995).

## 5.5 Site amelioration and nurse plantations

At sites with stage-5 degradation, where soil and microclimatic conditions have deteriorated beyond the point at which they can support tree seedling establishment, site amelioration becomes a necessary precursor to forest restoration procedures. Soil compaction and erosion are usually the main problems, but exposure to hot, dry, sunny and windy conditions can also prevent tree establishment, even where soil conditions are not so severely degraded. Site amelioration can involve soil cultivation procedures that are more usually associated with agriculture and commercial forestry (such as those used in the Miyawaki method, see **Box 5.4**, p. 140), and/or establishing plantations of

**Box 5.4. The Miyawaki method.**

One of the earliest, and perhaps most famous, forms of the maximum diversity approach is the Miyawaki method, invented by Dr Akira Miyawaki, Professor Emeritus of Yokohama National University, Japan and director of the IGES-Japanese Centre for International Studies in Ecology (JISE). Developed in the 1970s, the method is based on 40 years of studies of both natural and disturbed vegetation, all around the world. It was first employed to restore forests at hundreds of sites in Japan, and was subsequently modified successfully for application to tropical forests in Brazil[6], Malaysia[7] and Kenya[8].

The Miyawaki method, or 'Native Forest by Native Trees', is based on the concept of 'potential natural vegetation' (PNV) (synonymous with 'target forest type'): the idea that the climax vegetation of any disturbed site can be predicted from current site conditions, such as existing vegetation, soil, topography and climate. Therefore, restoration begins with detailed soil surveys and vegetation mapping (using phytosociological methods), which are combined to produce a map of PNV units across the restoration site. The PNV map is then used to select tree species for planting and to prepare the project plan (Miyawaki, 1993).

The next stage is to collect seeds, locally, of the trees species representative of the PNV(s). Seedlings of all of the dominant tree species within the PNV(s), and as many associated species (particularly mid- to late-successional species) as possible are grown to 30–50 cm tall in containers in nurseries ready for planting out. Site preparation can involve using earth-moving machines to level or terrace the site and developing a 20–30-cm layer of good top soil, by mixing straw, manure or other kinds of organic compost in with the upper soil layers. On eroded sites, top soil is imported from urban construction sites. The soil is then mounded to increase aeration. Up to 90 tree species are planted, randomly, at very high densities, 2–4 trees/m$^2$. After planting, the site is weeded (and the pulled weeds applied as mulch) for up to three years, by which time canopy closure is achieved and maintenance ceases.

"*After three years, no management is the best management*" (Miyawaki, 1993)

Prof. Akira Miyawaki (in the green hat) poses with children planting trees in Kenya as part of a project using his now famous technique. (Photo: Prof. K. Fujiwara.)

[6] www.mitsubishicorp.com/jp/en/csr/contribution/earth/activities03/activities03-04.html

[7] Currently through a collaborative project involving UPM, Universiti Malaysia Sarawak and JISE, which is sponsored by the Mitsubishi Corporation.

[8] www.mitsubishicorp.com/jp/en/pr/archive/2006/files/0000002237_file1.pdf

**Box 5.4. continued.**

The first tropical trials using the Miyawaki method started in 1991 on the Bintulu (Sarawak) Campus of Universiti Pertanian Malaysia (currently known as Universiti Putra Malaysia (UPM))[8]. Eighteen years later, plots restored by the Miyawaki method showed better forest structure and the planted trees were taller, and had wider diameter at breast height (dbh) and greater basal area compared with those of adjacent naturally regenerating secondary forest (Heng *et al*., 2011). Recovery of the soil fauna is particularly rapid (Miyawaki, 1993). Experiments in northern Brazil, however, were less successful: fast-growing economic pioneers were used in the species mix and these both rapidly over-topped and slowed the growth of the late-successional native species and were more susceptible to wind-throw (Miyawaki & Abe, 2004). Although the high planting density rapidly results in a closed canopy, it can sometimes have undesirable effects. Competition among the closely planted trees can result in high initial mortality and low dbh (more than 70% of trees had a dbh of less than 10 cm when measured 18 years after planting (Heng *et al*., 2011)).

Sixteen-yr-old plots restored by the Miyawaki method at the Bintulu Campus of Universiti Pertanian Malaysia (UPM). The closely spaced planted trees grew well, creating a multilayered main canopy (left) and completely eliminating weeds (right). (Photos: Mohd Zaki Hamzah.)

The intensive nature of the Miyawaki method (particularly the need for expert-driven site surveys, mechanical site preparation and very high planting densities) means that it is among the most expensive of all forest restoration techniques. As such, it is heavily dependent on the sponsorship of wealthy corporations (e.g. Mitsubishi[9], Yokohama[10], Toyota[11]) and its use is largely confined to 're-greening' small, high-value, industrial or urban sites for recreational and climate amelioration purposes. Benefits to the corporate sponsors include improved public relations, particularly the promotion of a 'green image'. In Japan, the potential of the method for disaster mitigation in urban areas is also being advocated.

[9] www.mitsubishicorp.com/jp/en/csr/contribution/earth/activities03/
[10] yrc-pressroom.jp/english/html/20089I612mg00I.html
[11] www.toyota.co.th/sustainable_plant_end/ecoforest.html

highly resilient tree species to improve the soil and modify the micro-climate — the so-called 'nurse' plantation approach (also known as "plantations as catalysts" (Parrotta *et al*., 1997a) or "foster ecosystems" (Parrotta, 1993).

Opencast mine sites provide probably the most extreme examples of site degradation. The replacement of top soil and the deep ripping of mine sites have already been mentioned in **Section 5.4** in connection with the maximum diversity method. Deep ripping, sometimes known as sub-soiling, involves slicing thin furrows (up to 90 cm deep, about 1 m apart) through the soil with strong, narrow tines, without inverting the soil. Deep ripping merely opens up soils that have become compacted (e.g. due to machinery or livestock trampling) allowing water and oxygen to penetrate into the subsoil, where the roots of planted trees will subsequently grow. It is carried out by heavy machinery, and so is possible only on relatively flat and accessible sites, and it is very expensive[12]. Mounding is another physical treatment that can improve soil conditions by aerating the soil and reducing the risk of water-logging.

The addition of organic materials such as straw and other organic waste materials (even orange peel from a juice factory was trialled during the ACG project (see **Box 5.2**, p. 119) (Janzen, 2000)) improves soil structure, drainage, aeration and nutrient status and promotes the rapid recovery of soil fauna.

Green mulching (or 'green manure') is a biological approach to soil improvement. It involves sowing the seeds of herbaceous legumes across the restoration site, harvesting their seeds and then mowing the plants. The dead plants are left to decompose on the soil surface or are worked into the upper soil layers with hoes or ploughs. Seeds of commercial legume species can be purchased at agricultural supply stores, but a cheaper and more ecological approach (although more time-consuming) is to select a mix of herbaceous legume species that grow naturally in the area and harvest their seeds for sowing on the restoration site. If seeds are then collected from the plants before mowing them, the seed stock gradually accumulates with each green-mulching cycle, and eventually seeds can be used for other sites. It may be necessary to repeat the procedure for several years before the soil is ready to support tree seedlings. Green mulching can suppress weed growth without the use of herbicide, protect the soil surface from erosion, improve soil structure, drainage, aeration and nutrient status, and facilitate recovery of the soil macro- and micro-fauna.

The application of chemical fertilisers also improves soil nutrient status, but does not provide the benefits to soil structure and fauna offered by organic materials. Several techniques can be employed to determine which soil nutrients are in short supply, including observation of visual symptoms of nutrient deficiency, chemical analyses of soil and/or leaves, and nutrient-omission pot trials (Lamb, 2011, pp. 214–9). However, most of these techniques are expensive and require specialised expertise. If they are considered to be impractical or too expensive, the application of a general-purpose fertiliser (NPK 15:15:15 at 50–100 g per tree) should solve most nutrient-deficiency problems.

Additional opportunities to apply soil treatments arise when holes are dug for tree planting. It is common practice on highly degraded sites to add compost into holes before planting trees (about 50:50 mixed with the backfill from the planting hole). Water-absorbing polymer gels can also be added to planting holes: either 5 g of the dried pellets mixed with the backfill or, in dry soils, two tea-cupfuls of a hydrated gel.

[12] www.nynrm.sa.gov.au/Portals/7/pdf/LandAndSoil/10.pdf

Various types of gel are available and the terminology for naming them is confusing and often inconsistent, so discuss options with your agricultural supplier and read the instructions on the product packaging. Laying mulch around the planted trees also helps to preserve soil moisture, adds nutrients and creates conditions that favour soil fauna.

Severely degraded soils probably lack many of the strains of micro-organisms that are required for high performance all of the tree species being planted (particularly the nitrogen-fixing *Rhizobium* or *Frankia* bacteria that form symbiotic relationships with legumes, and the mycorrhizal fungi that improve nutrient absorption for most tropical tree species). Mixing a handful of soil from the target forest ecosystem with compost added to the planting holes is probably the simplest and cheapest way to initiate the recovery of the soil micro-flora.

Another possibility is to inoculate trees in nurseries. Simply including forest soil in the potting medium usually ensures that the trees become infected with beneficial micro-organisms. Research suggests, however, that applying inoculae obtained by culturing micro-organisms collected from adult trees has additional potential to accelerate tree growth. For example, Maia and Scotti (2010) showed that inoculating the leguminous tree *Inga vera*, which is widely used for riparian forest restoration in Brazil, with *Rhizobia* reduced the fertiliser requirement by up to 80% and improved growth. *Rhizobia* inoculae are commercially produced for agricultural legume crops, but they cannot necessarily be used for forest trees because different legume species require different strains of *Rhizobium* for optimum nitrogen fixation (Pagano, 2008). It is unlikely that the specific strains of *Rhizobium* required for the tree species being planted will be commercially available. Making the inoculum entails collecting bacteria from the same tree species and culturing them in a laboratory. The same is true for mycorrhizal fungi. The application of a commercially produced mix of 'ubiquitous' mycorrhizal fungi species to forest tree seedlings grown in a nursery in northern Thailand failed to produce any benefits (Philachanh, 2003).

The planting of 'nurse trees' (Lamb, 2011, pp. 340–1) can improve site conditions, paving the way for subsequent restoration practices to recover biodiversity. By rapidly re-establishing a closed canopy and litter fall, plantations can create cooler, shadier and more humid conditions both above and below the soil surface. This should lead to the accumulation of humus and soil nutrients and, ultimately, to much better conditions for the subsequent seed germination and seedling establishment of less tolerant tree species (Parrotta *et al*., 1997a)[13]. Such plantations are also capable of producing wood and other forest products at an early stage in the restoration process.

Nurse tree plantations are generally composed of a single (or just a few) fast-growing, pioneer species that is tolerant of the harsh soil and micro-climatic conditions prevalent on sites with stage-5 degradation, but that is also capable of improving the soil. Native tree species are preferred because of their ability to promote biodiversity recovery more rapidly than exotics (Parrotta *et al*., 1997a). A study of the local tree flora will usually reveal indigenous pioneer tree species that grow just as well as any imported exotics.

[13] A special issue of *Forest Ecology and Management* (Vol. 99, Nos. 1–2) published in 1997 was devoted to the potential of tree plantations to 'catalyse' tropical forest restoration. Using 'tree plantations' in its broadest sense (from monocultures to maximum diversity), the 22 papers therein have become essential reading for those involved in tropical forest restoration.

Nevertheless, exotics may be used as nurse trees provided they meet the following conditions:

1) they are incapable of producing viable seedlings and thus becoming woody weeds and ...
2) either, they are short-lived, sun-loving pioneer species that will be shaded out by subsequently introduced climax forest trees or ...
3) they are purposefully killed (e.g. harvested or ring barked and left in place to rot) after they have brought about site improvement and the saplings of replacement trees are well established.

For example, the use of the exotic *Gmelina arborea* in the ACG project (see **Case Study 3**, p. 149) was justified because its sun-loving seedlings could not establish beneath its own canopy and its large, animal-dispersed seeds were not spread outside the plantation. By contrast, the use of the exotic plantation tree *Acacia mangium* in Indonesia is becoming a major problem for future forest restoration because its seedlings rapidly dominate areas around plantations. Their removal from future forest restoration sites will be very expensive. The same is true of *Leucaena leucocephala* in South America and tropical northern Australia. Seedlings of exotic species might be easier to obtain from commercial tree nurseries, but if you are unsure whether the species being considered meets the criteria listed above, it is better to search through the local tree flora for an indigenous alternative.

Plantation species should be light-demanding pioneers (as are many commercial timber trees), extremely hardy and short-lived. In general, better results have been achieved with broadleaved species than with conifers. Planting stock should be of the highest quality (Parrotta *et al*., 1997a).

Legumes (i.e. members of the Family Leguminosae) and indigenous fig tree species (*Ficus* spp.) nearly always make good nurse plantation species as well as useful framework tree species (see **Section 5.3**). The roots of fig trees are capable of invading and breaking apart compacted soils and even rocks on the most degraded of sites, whereas the nitrogen-fixing capability of many leguminous tree species can rapidly improve soil nutrient status. Planting mixtures of figs and legumes as nurse plantations could, therefore, improve both the physical structure and the fertility of soils, without the need for the intensive and expensive physical soil treatments described above or the application of nitrogen fertiliser.

When establishing a conventional tree plantation, it is tempting to follow conventional forestry production practices. But the design and management of nurse plantations for forest restoration requires a more considered approach. Canopy closure is the first objective of the plantation, and so the trees should be planted closer than is usual for commercial forestry (Parrotta *et al*., 1997a). If possible, find trees of the same species planted nearby, and try to determine roughly how broad their crowns are after 2–3 years of growth. This will provide the planting distance necessary to close the canopy in 2–3 years. Lamb (2011) recommends a planting density of 1,100 trees per hectare. The canopy should be dense enough to shade out weeds but not so dense as to inhibit the growth of subsequently planted trees or to prevent colonisation of the site by naturally dispersed, incoming tree species.

Conventional forestry demands intensive weeding or 'cleaning up' of plantations. Provided herbaceous weeds do not threaten the early survival of the planted nurse tree saplings (on stage-5 sites, degradation usually limits even weed growth), then weeding is not necessary. Even where it is required, weeding should cease as soon as the crowns

If fig trees can germinate in and subsequently tear apart the building blocks of Angkor Wat, Cambodia, they will have no difficulty in penetrating even the most severely degraded soils.

of planted saplings have grown above the weed canopy. On sites where incoming seed dispersal could still be possible, over-vigorous weeding will knock back any tree seedlings that do manage to become established.

As site conditions improve, the nurse trees can be thinned out and replaced by planting a wider range of native forest tree species. This should be done gradually to prevent invasion of the now-fertile soil by light-loving herbaceous weeds. If the nurse trees are of a commercial species, the felled trees can provide income to project participants over several years. When carrying out thinning, precautions must be taken so as not to disturb the understory and thus damage the accumulated biodiversity. Hauling logs out from a plantation without damaging the undergrowth is not easy to say the least, but various 'minimum impact' or 'reduced-impact' logging (RIL) techniques (e.g. using animals instead of machinery) are now being promoted (Putz *et al*., 2008).

Where seed-dispersal into a restoration site might still be possible, framework tree species should be planted as the nurse trees are gradually cleared: pioneer framework species to replace the nurse trees and climax framework species to build up the understory. But in most restoration sites with stage-5 degradation, seed sources and/or seed-dispersing animals will have been eliminated from the surrounding area, so biodiversity recovery requires the maximum diversity approach.

The use of nurse plantations is not necessarily restricted to stage-5 degradation with limiting soil conditions. They have often been used on less severely degraded sites, where natural seed dispersal still operates, as a simpler and cheaper alternative to the framework species method. The use of plantations of exotic tree species, such as *Gmelina arborea*, adjacent to surviving forest in Costa Rica is described in **Case study 3**. A native species, *Homalanthus novoguineensis*, was used with similar success in Australia to attract seed-dispersing birds from nearby forest into restoration sites (Tucker, pers. comm.). Plantations of the exotic *Eucalyptus camaldulensis* did not, however, facilitate regeneration of native Miombo woodlands in the Ulumba Mountains of Malawi (Bone *et al.*, 1997).


In Costa Rica, a nurse crop of the exotic *Gmelina arborea* stimulated native tree establishment and generated income from felling after 8 years

## 5.6 Costs and benefits

Practitioners of forest restoration are often asked: "Why don't you just plant economic species?" The answer to this question is: "There is no such thing as a *non*-economic tree species". All trees sequester carbon and produce oxygen, all contribute to watershed stability and all are made of a highly combustible fuel. The question is not whether forest restoration is economic, but whether economic benefits can be converted into cash flows.

### How much does it cost?

Very few accounts of the costs of forest restoration have been published (**Table 5.3**). This reflects both the difficulty of carrying out meaningful cost comparisons and perhaps also poor record-keeping among forest restoration practitioners and/or their unwillingness to disclose financial information. Comparing costs among methods and locations is confounded by fluctuations in exchange rates, inflation and huge variations in the costs of labour and materials. Costs are highly location- and time-specific. But precise cost calculations are not needed to show the obvious: the costs of restoration increase from stage-1 degradation to stage-5 degradation as the intensity of the methods required increases.

**Table 5.3. Examples of published costs for various forest restoration methods.**

| Degradation stage | Method | Country | Published cost (US$/ha) | Date | Reference | Present-day costs US$/ha*[14] |
|---|---|---|---|---|---|---|
| Stage 1 | Protection | Thailand | – | – | Estimated | 300–350 |
| Stage 2 | ANR (**Box 5.2**) | Philippines | 579 | 2006–09 | Bagong Pagasa Foundation, 2009 | 638–739 |
| | ANR (Castillo, 1986) | Philippines | 500–1,000 | 1983–85 | Castillo, 1986 | 1,777–3,920 |
| Stage 3 | Framework species method (**Section 5.3**) | Thailand | 1,623 | 2006 | FORRU, 2006 | 2,071 |
| Stage 4 | Maximum diversity with mine site amelioration (**Section 5.4**) | Brazil | 2,500 | 1985 | Parrotta *et al.*, 1997b | 8,890 |
| | Miyawaki method (**Box 5.4**) | Thailand | 9,000 | 2009 | Toyota, pers. comm. | 9,922 |
| Stage 5 | Site amelioration and nurse plantation | – | – | – | None found | ? |

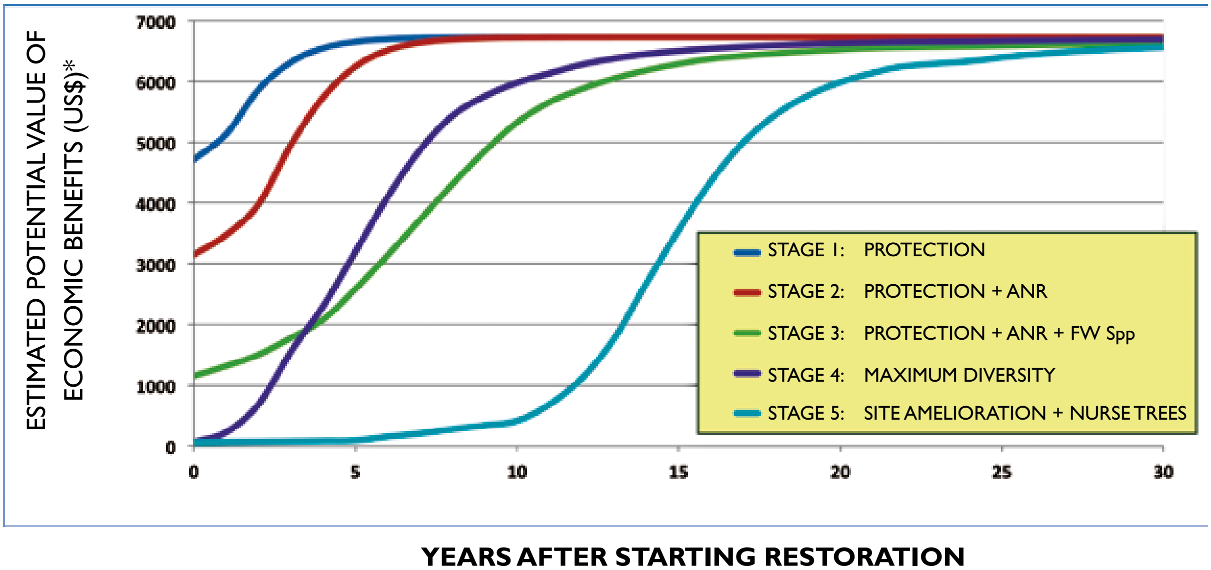
*total costs for whole period needed to achieve a self-sustaining system

## Potential value of the benefits

The potential economic value of the benefits of achieving a climax forest ecosystem, in terms of ecological services and diversity of forest products, is the same, regardless of the starting point. The Economics of Ecosystems and Biodiversity study (TEEB, 2009)[15] put the average annual value of fully restored tropical forests at US$6,120/ha/yr in 2009 (**Table 1.2**), equivalent to US$6,747 today, allowing for inflation. Even the most expensive forest restoration methods do not cost more than US$10,000/ha in total, so the value of potential benefits from a restored forest far outweighs the costs of establishment within very few years after the climax forest condition is achieved.

The speed of delivery of those benefits depends, however, on the initial degradation stage and on the restoration methods used. As the degradation stage increases, the time required to realise the full range of potential benefits increases from a few years to several decades. Therefore, the return on investment is delayed. The full potential benefits of forest restoration, in cash terms, can only be realised if they are marketed and people are prepared to pay for them. Schemes to market forest products and ecotourism or to sell carbon credits and 'payments for environmental services' (PES) all require a great deal of development and upfront investment before the full cash potential of restored forests can be realised (see **Chapter 1**).

[14] estimated by applying a constant 5% annual inflation rate.
[15] www.teebweb.org/




Hypothetical curves representing the increase in potential economic benefits over time of the five major approaches to forest restoration. The restoration of stage-1 degradation yields considerable benefits from the start, whereas projects to restores sites with degradation at stages 4 and 5 start off by yielding zero benefits. At such sites, the initial increase in potential economic benefits is slow, until canopy closure promotes an influx of recruited species, which increase the rate of accumulation of benefits (e.g. more biodiversity leads to more forest products, or leaf litter improves soil water-holding capacity). As the accumulation of benefits nears the maximum, the rate of increase slows because the final few benefits take a long time to achieve (due to their dependence on slow environmental processes or the return of rare species). Note that the maximum diversity method achieves more rapid economic benefits because more tree species are planted at the start. With stage-5 degradation, site amelioration and the cultivation of nurse trees yield low economic benefits until a more diverse tree community is established.

| Degradation | Restoration Costs | Incremental increase in benefits | Delivery of full benefits |
|---|---|---|---|
| Stage 1 | LOW | SMALL | RAPID |
| Stage 2 | ↓ | ↓ | ↓ |
| Stage 3 | | | |
| Stage 4 | | | |
| Stage 5 | HIGH | LARGE | DELAYED |

Summary of the economic costs and benefits of restoring the different stages of forest degradation.

# CASE STUDY 3 Area de Conservacion Guanacaste (ACG)

**Country**: Costa Rica

**Forest type**: A mosaic of dry tropical forest, rain forest and cloud forest fragments surrounded by pasture.

**Ownership**: The Guanacaste Dry Forest Conservation Fund (GDFCF) has funded the purchase of 13,500 hectares of forest from private owners.

**Management and community use:** Cattle grazing and potential to harvest the 'nurse plantation' of *Gmelina arborea*.

**Level of degradation**: Cleared of all but fragments of forest for livestock and crop agriculture.

One of the first large, scientifically based, forest restoration projects in Central America is continuing in the Area de Conservacion Guanacaste (ACG) in north-western Costa Rica (www.gdfcf.org/). Largely the brain-child of American biologist Daniel Janzen and his wife Winnie Hallwachs, the project has become a classic example of how landscape-level forest restoration can be achieved, mostly through the protective measures described in **Section 5.1** and then by letting nature take its course.

The project site, Hacienda Santa Rosa (the second Spanish ranch founded in Costa Rica) was cleared of all but fragments of its dry tropical forest, beginning in the late 1500s, and was used mainly for mule and cattle ranching, wild meat, water for irrigation, and croplands. The Inter-American Highway was carved through its centre in the 1940s and jaragua pasture grass (*Hyparrhenia rufa*) was introduced from East Africa. This grass provided much of the fuel for human-caused, annual dry-season fires, which effectively blocked forest succession, because the ranchers wanted 'clean' pasture. The result was a mosaic of dry forest, rain forest and cloud forest fragments surrounded by pasture.

In 1971, the 10,000 ha Santa Rosa National Park was designated. In the 1990s, the 165,000-ha ACG expansion became part of the new Sistema National de Areas de Conservacion (SINAC), one of 11 conservation units that cover about 25% of Costa Rica. Cattle and horses were removed, but this allowed the jaragua grass to grow up to 2 m tall, fuelling ravenous fires that annually consumed trees and forest remnants. If the fires could not be stopped, there would soon be no forest remnants left to supply the tree seeds needed for restoration.

In September 1985, Janzen and Hallwachs wrote an unsolicited plan for the long-term survival of Santa Rosa's dry forest, which became the Projecto Parque Nacional Guanacaste (PPNG). The project's mission included: i) allowing seeds from forest remnants to restore 700 $km^2$ of the original dry forest to "maintain in perpetuity all animal and plant species and their habitats originally known to occupy the site"; ii) "offering a menu of material goods" to society; and iii) providing a study site for ecological research and a "re-awakening to the intellectual and cultural offerings of the natural world".

"The technological recipe for the restoration of this large dry forest ecosystem was obvious: purchase large tracts of marginal ranch and farmland, adjacent to Santa Rosa, and connect it with the wetter forests to the east, stop the fires, farming, and the occasional hunting and logging, and let nature take back its original terrain" (Janzen, 2002).

Guanacaste Province residents were hired to prevent fires, but with the grass growing so high, the fires were difficult to control with hand tools. A major part of the solution was to bring back the cattle. During the first five years of the project, ACG's to-be-restored-to-forest pastures were rented out as grazing land for up to 7,000 head of cattle at any one time. The cattle acted as 'biotic mowing machines', keeping fuel loads so low that the fire-control program could manage the less-severe fires. As naturally established trees grew up and began to shade out the grass, the cattle were removed.

Tree planting was also tried in a few select sites for a couple of years, but this was abandoned because natural forest regeneration from seeds, which were dispersed by the wind and vertebrates into the restoration sites from the interspersed patches of secondary forest, far outweighed the effort and expense of planting trees.

In the rain forested part of ACG, however, the natural regeneration of abandoned pastures was much slower. Compared with dry forest, fewer plant species were wind-dispersed, fewer animal seed-dispersers ventured out from the forest into rain forest pastures, and the survival of tree seedlings was hindered by the hot, dry and sunny conditions of the pastures. In such areas, a 'nurse plantation' (see **Section 5.5**) approach was employed, using abandoned plantations of the exotic timber tree species, *Gmelina arborea*. The dense canopies of *G. arborea* plantations shaded out grasses in 3–5 years and the understorey filled with a diverse community of rain forest trees, shrubs and vines, which were brought in as seeds by small vertebrates from neighbouring rain forest. After one rotation of 8–12 years, the *G. arborea* logs could have been harvested and the stumps killed with herbicide, generating income to support the project, but owing to a lack of purchasers, ACG elected to let the trees die of old age at 15–20 years. Such trials demonstrated that, provided forest seed sources and seed-dispersing animals remain nearby, rain forest pastures could easily be transformed into young rain forest by planting them with *G. arborea* and then abandoning the forest (rather than pruning and cleaning as is normal with a plantation).

In the 1980s, when Janzen and Hallwachs initiated the project, forest restoration was a new idea, a departure from the classical notion that national parks were created only to protect existing forest. The project was disapproved of by several conservation NGOs, which were surviving largely on the fund-raising slogan of "once tropical forest is cut, it is gone forever." Today, attitudes have changed. ACG and Janzen's publications are regarded as milestones of tropical forest restoration science. Having firmly established many of the practices needed to restore tropical forest in Costa Rica, the need now is to determine how to bring about and maintain the stable political and sociological conditions that will enable such techniques to be implemented elsewhere on a sustainable and long-term basis, and how to maintain the normal annual funding to support the staff and operations needed by any large conserved wildland:

"The key management practice was to stop the assault — fire, hunting, logging, farming — and let the biota re-invade the ACG. The key sociological practice was to gain social acceptability for the project locally, nationally and internationally … The question is not whether a tropical forest can be restored, but rather whether society will allow it to occur" (Janzen, 2002)

Abridged from Janzen (2000, 2002) www.gdfcf.org/articles/Janzen_2000_longmarchforACG.pdf

(A) Jaragua–forest boundaries were characteristic of tens of thousands of hectares of the ACG at the beginning of the restoration process (photo December 1980). At least 200 years old, the pasture was formerly occupied by native grasses and had been burned every 1–3 years. The old secondary oak forest retained more than 100 tree species. (B) The same view (photo November 2000) after 17 years of fire prevention. The oak forest canopy is still visible and Winnie Hallwach's hand is 2 m above the ground. The regeneration is dominated by *Rehdera trinervis* (Verbenaceae), a medium-sized wind-dispersed tree, intermixed with 70 other woody species. Such invasion of pastures by forest as a result of fire prevention is now characteristic of tens of thousands of hectares of the ACG. (Photos: Daniel Janzen.)