Chapter 3

Recognising the problem

Forest degradation reverses and impedes natural forest succession, whereas forest restoration releases succession and accelerates it towards achieving the climax forest condition. The overall management approach that is required to restore a climax forest ecosystem depends on how far back in the successional sequence the vegetation has been “pushed” by degradation and the factors that are limiting succession. The complexity, intensity and cost of restoration all increase as the level of degradation increases.

The diagrams and notes in this chapter will help you to recognise the general level of degradation in your restoration area and to decide which broad restoration strategy to adopt (i.e. protection, accelerated natural regeneration, framework forestry, maximum diversity techniques, foster ecosystems etc.). Once you have chosen a restoration strategy, the next step is to carry out a site assessment that will allow you to determine the detailed management operations necessary to implement that strategy (see Section 3.2). You will then be ready to plan your restoration project (see Chapter 4). The implementation of each restoration strategy is then explained in detail in Chapter 5, whereas the growing and planting of trees (which may be necessary for the restoration of sites where the degradation has reached stages 3–5) are described in Chapters 6 and 7.

3.1 Recognising levels of degradation

There are five broad levels of degradation, each of which requires a different restoration strategy. They can be distinguished by recognising six critical "thresholds" of degradation; three pertain to the site being restored and three to the surrounding landscape.

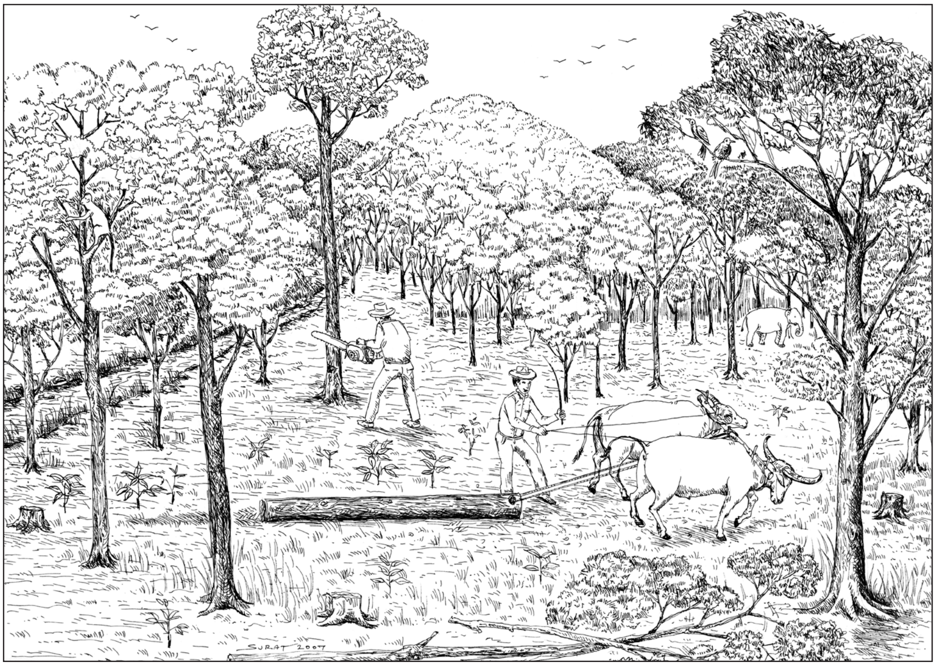
Site-critical thresholds:

1) The density of trees is reduced such that herbaceous weeds dominate the site and suppress tree seedling establishment (see **Section 2.2**).
2) On-site sources of forest regeneration (i.e. the seed or seedling bank, live stumps, seed trees etc.) decline below the levels needed to maintain viable populations of climax forest tree species (see **Section 2.2**).
3) Soil degradation has proceeded to such an extent that poor soil conditions limit the establishment of tree seedlings.

Landscape-critical thresholds:

4) There are only small and sparse remnants of climax forest in the landscape, such that the diversity of tree species within dispersal distance of the forest restoration site is not sufficient to represent the climax forest.
5) Populations of seed-dispersing animals are reduced to the point that seeds are no longer transported to the forest restoration site in sufficiently high densities to re-establish all of the required tree species (see **Section 2.2**).
6) Fire risk is increased such that naturally established trees are unlikely to survive because of the increased cover of combustible herbaceous weeds in the landscape immediately surrounding the restoration site.

Dominance of a site by herbaceous weeds marks a critical point, at which protection alone ceases to be sufficient to restore forest. Tree seedlings beneath the weed canopy must be "assisted" by weeding or supplemented by planting framework tree species.



Stage-1 degradation

SITE-CRITICAL THRESHOLDS		LANDSCAPE-CRITICAL THRESHOLDS	
Vegetation	Trees dominate over herbaceous weeds	**Forest**	Large remnants remain as seed sources
Sources of Regeneration	Plentiful: soil seed bank viable; dense seedling bank; dense seed rain; live tree stumps	**Seed Dispersers**	Common; both large and small species
Soil	Little localised disturbance; remains mostly fertile	**Fire Risk**	Low to medium

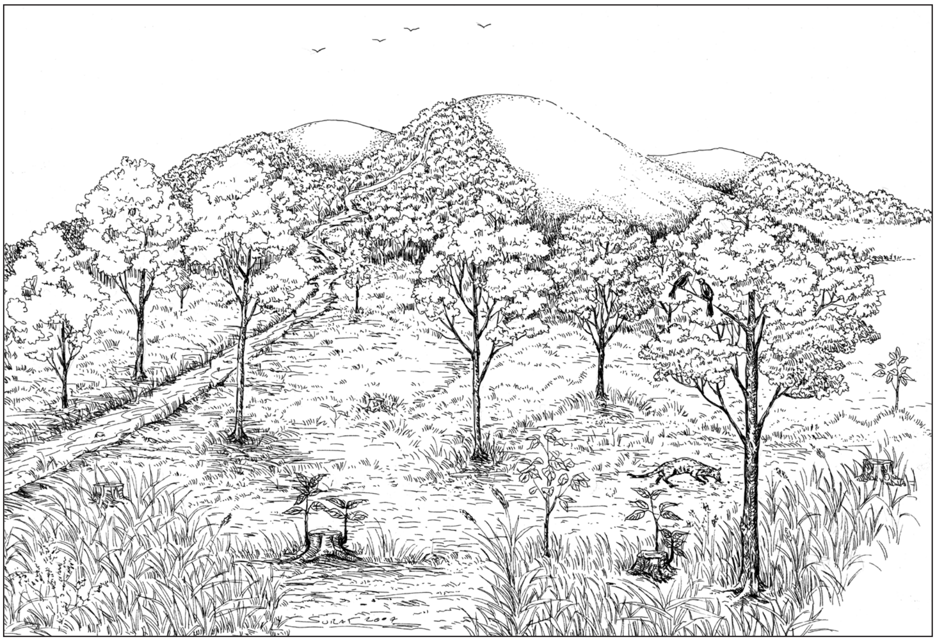
RECOMMENDED RESTORATION STRATEGY:

- Protection from encroachment, cattle, fire and any other further disturbances and prevention of the hunting of seed-dispersing animals
- Re-introduction of locally extirpated species

OPTIONS TO INCREASE ECONOMIC BENEFITS:

- Extractive reserves for sustainable use of forest products
- Ecotourism

Stage-2 degradation



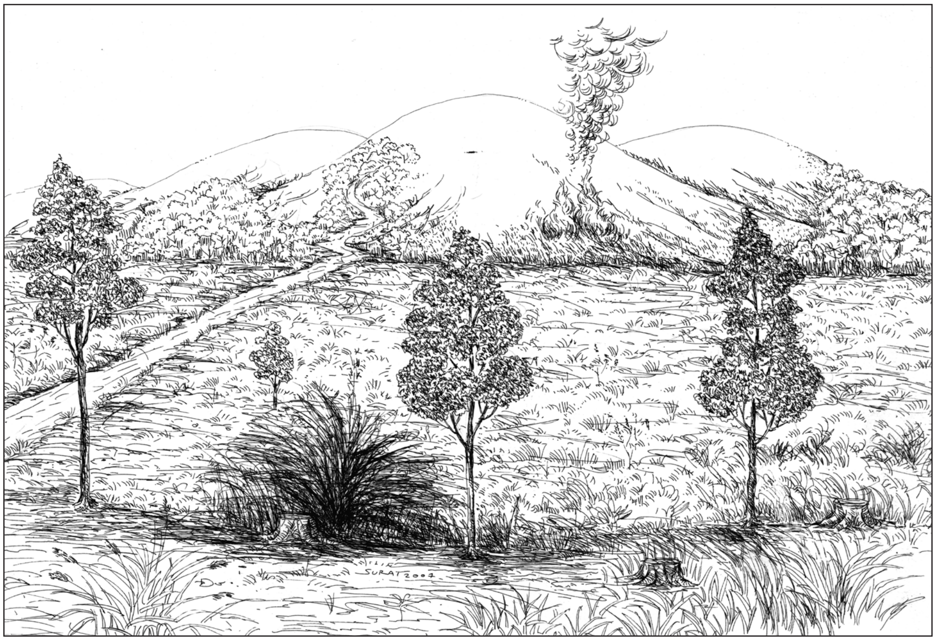
SITE-CRITICAL THRESHOLDS		LANDSCAPE-CRITICAL THRESHOLDS	
Vegetation	Mixed trees and herbaceous weeds	**Forest**	Remnants remain as seed sources
Sources of Regeneration	Seeds and seedling banks depleted live tree stumps common	**Seed Dispersers**	Large species becoming rare, but small species still common
Soil	Remains mostly fertile: erosion low	**Fire Risk**	Medium to high

RECOMMENDED RESTORATION STRATEGY:

- Protection + ANR
- Re-introduction of locally extirpated species

OPTIONS TO INCREASE ECONOMIC BENEFITS:

- Enrichment planting with economic species that have been lost through unsustainable use
- Establishment of extractive reserves to ensure the sustainable use of forest products
- Ecotourism



Stage-3 degradation

SITE-CRITICAL THRESHOLDS		LANDSCAPE-CRITICAL THRESHOLDS	
Vegetation	Herbaceous weeds dominate	**Forest**	Remnants remain as seed sources
Sources of Regeneration	Mostly from incoming seed rain; a few saplings and live tree stumps might remain	**Seed Dispersers**	Mostly small species dispersing small seeds
Soil	Remains mostly fertile; erosion low	**Fire Risk**	High

RECOMMENDED RESTORATION STRATEGY:

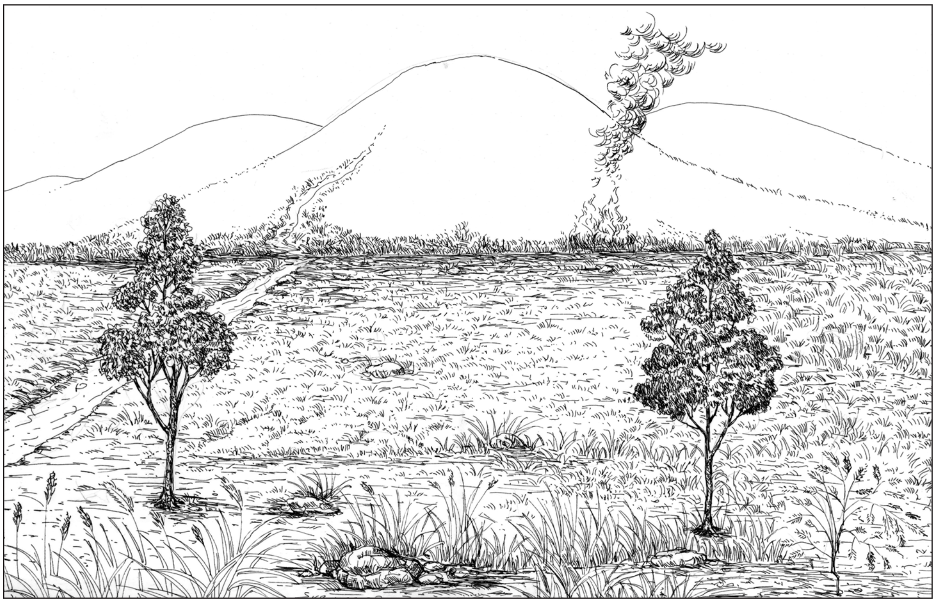
- Site protection + ANR + planting framework species

OPTIONS TO INCREASE ECONOMIC BENEFITS:

- Planting framework species that have economic benefits
- Ensuring local people benefit from funding of tree planting and site maintenance
- Analogue Forestry[1] or "Rainforestation" farming[2]

[1] en.wikipedia.org/wiki/Analog_forestry
[2] www.rainforestation.ph/index.html

Stage-4 degradation



SITE-CRITICAL THRESHOLDS		LANDSCAPE-CRITICAL THRESHOLDS	
Vegetation	Herbaceous weeds dominate	**Forest**	Remnants too few or too distant to disperse tree seeds to site
Sources of Regeneration	Low	**Seed Dispersers**	Mostly gone
Soil	Erosion risk increasing	**Fire Risk**	High

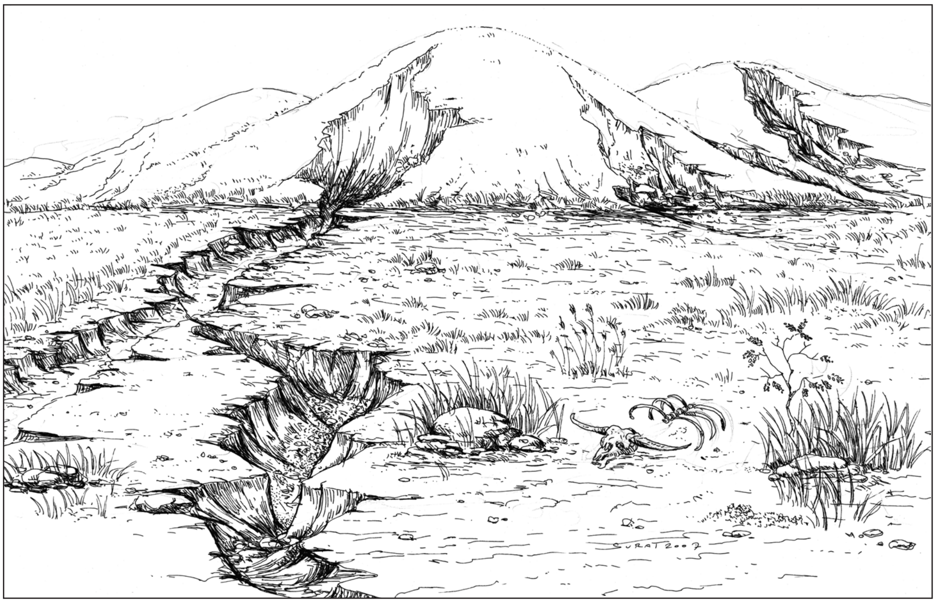
RECOMMENDED RESTORATION STRATEGY:

- Site protection + ANR + planting framework species + enrichment planting with climax species
- Maximum diversity methods (Goosem & Tucker, 1995) such as the Miyawaki method[3]

OPTIONS TO INCREASE ECONOMIC BENEFITS:

- Enrichment planting with economic species + sustainable harvesting of non-timber forest products
- Employment of local people in the restoration program
- Analogue forestry or "Rainforestation" farming[4]

[3] www.rainforestation.ph/news/pdfs/Fujiwara.pdf
[4] www.rainforestation.ph/index.html



Stage-5 degradation

SITE-CRITICAL THRESHOLDS		LANDSCAPE-CRITICAL THRESHOLDS	
Vegetation	No tree cover. Poor soil might limit growth of herbaceous weeds	**Forest**	Usually absent within seed dispersal distances of the site
Sources of Regeneration	Very few or none	**Seed Dispersers**	Mostly gone
Soil	Poor soil conditions limit tree establishment	**Fire Risk**	Initially low (soil conditions limit plant growth); higher as the vegetation recovers

RECOMMENDED RESTORATION STRATEGY:

- Soil improvement by planting green mulches and the addition of compost, fertilisers or soil micro-organisms.
- ... followed by planting "nurse trees" – i.e. hardy nitrogen-fixing trees that will further improve the soil (also known as the "plantations as catalysts" method (Parrotta, 2000))
- ... and then thinning of nurse trees and their gradual replacement by planting a wide range of native forest tree species

OPTIONS TO INCREASE ECONOMIC BENEFITS:

- There will be few economic benefits until the soil ecosystem has recovered
- Plantations of commercial tree species can be used as nurse trees to generate revenue from thinning
- Mechanisms to ensure that local people benefit from the harvesting of commercial tree species
- Once the nurse-tree crop is ready for thinning and modification, the option for achieving economic benefits are the same as those for stage-4 degradation

3.2 Rapid site assessment

Recognising which of the five stages of degradation has been reached at a site will determine which broad restoration strategy will be most suitable (**Table 3.1**). A more detailed site assessment is then needed to determine the existing potential for natural forest regeneration and to identify factors that could be limiting it. These factors will determine which activities should be implemented and the intensity of the work required for each site (and hence the labour requirements and costs). The project plan can then begin to take shape.

To carry out a simple site assessment, you will need the following equipment: a compass, a topographic map, a global positioning system (GPS), a camera, plastic bags, a 2m bamboo cane or similar, a piece of string with a mark exactly 5 m from the end and datasheets (see opposite and **Appendix A1.1**) on a clip board with a pencil.

Invite all stakeholders (particularly local people) to participate in the site survey and begin by marking the boundaries of the site on a map and recording the GPS co-ordinates. Next, survey natural regeneration along a transect across the site at its widest point. Select the starting point and decide on a compass bearing to follow for the line.

At the starting point, position the bamboo pole and use the string attached to it to mark out a circular sample plot of radius 5 m. If there are any signs that livestock have been present in the sample plot (e.g. dung, hoof prints, bite marks on vegetation etc.) place a tick in the 'livestock' column on the datasheet; likewise for signs of fire (ash, or black marks at the base of woody vegetation). Record any information provided by local participants when asked about the land-use history of the site. Estimate the extent of exposed soil in the circle (as a percentage of the area), ask local participants to rank the soil condition (good, medium, poor etc.) and make note of any signs of soil erosion. Estimate the percentage cover and average height of grasses and herbaceous weeds across the plot and note whether tree seedlings are strongly represented in the ground flora.

Record the number of a) trees larger than 30 cm girth at breast height (gbh) (i.e. 1.3 m from the ground), b) saplings taller than 50 cm (but smaller than 30 cm gbh) and c) live tree stumps (with green shoots) within the circle. The number of 'regenerants' per circle is the total number of trees in all three of these categories. Place leaf samples from each of the tree species you find into plastic bags. Finally take photos facing due north, south, east and west from the centre pole.

Pace out the required distance along the pre-determined compass bearing to the next sample point. Collect data at a minimum of 10 sample points across the site, at least 20 paces apart. If the site is large, position the sample points further apart and use more points (at least 5 per hectare). If the site is small and the required number of points cannot be fitted into a single transect, then use two or more parallel lines placed at representative locations across the site. Once you have decided on a compass bearing for the transect heading and a distance between sample points for each line, stick strictly to these parameters during the survey.

At the end of the survey, find a clear space and sort through the leaf samples. Group leaves of the same species together and count the number of common tree species on the site (i.e. those represented in more than 20% of the circles). Ask local people to

Example of rapid site assessment

Circle	Livestock signs	Fire signs	Soil – % exposed/ condition/ erosion	Weeds — % cover/mean height/± tree seedlings	No. trees >50 cm tall (<30 cm gbh)	No. live tree stumps	No. trees >30 cm gbh	Total no. regenerants
1	✓	✓	5%/poor/no	95%/1.0 m/none	6	14	0	20
2	✓	✕	15%/poor/no	85%/0.5 m/few	9	15	0	24
3	✓	✕	5%/poor/no	95%/1.5 m/none	12	12	1	25
4	✓	✓	30%/poor/no	70%/0.3 m/none	4	3	0	7
5	✓	✓	5%/poor/no	95%/1.5 m/many	14	15	2	31
6	✕	✓	0%/poor/no	100%/1.5 m/few	7	13	1	21
7	✓	✓	5%/poor/no	95%/0.8 m/many	10	15	1	26
8	✓	✓	10%/poor/no	90%/1.2 m/many	9	12	2	23
9	✓	✓	20%/poor/yes	80%/0.5 cm/none	9	5	1	15
10	✕	✓	20%/poor/no	80%/1.2 m/none	6	10	0	16

Location, GPS	Siem Reap, Cambodia, 13°34'3.24"N, 104° 2'59.80"E	Total	208
Recorder	Kim Sobon	(= total/10) Mean	20.8
Date	1st June 2010	(= mean x 10,000/78) Average/ha	2,667
Total no. of regenerant species 18	Pioneers 16; Climax 2	(= 3,100 – Average/ha) No. of trees to plant per ha	433

Other Comments: *Villagers said that large mammal seed dispersers are absent, but fruit-eating birds and small mammals are commonly seen. Hunting is common in the area. Villagers want to use the forest to make charcoal.*

Rapid site surveys to record existing natural forest regeneration and the most prominent factors preventing it are carried out using circular sample area of 5 m radius.

Rapid site surveys to record existing natural forest regeneration and the most prominent factors preventing it are carried out using circular sample plots of 5 m radius.

provide local names for the species and try to determine if they are pioneer or climax species. If possible, make dried specimens, including flowers and fruits, and ask a botanist to provide scientific names. Then calculate the average number of regenerants per circle and per hectare.

At the end of the survey, hold a short discussion session with the participants to identify any other factors that could impede forest regeneration that have not already been recorded on the data sheets, especially the activities of local people such as the collection of fuel-wood. The abundance of seed-dispersing animals in the area cannot be assessed in the rapid site survey, but local people will probably know which seed dispersers remain common in the area. Try to determine if the seed dispersers are threatened by hunting.

3.3 Interpreting data from a rapid site assessment

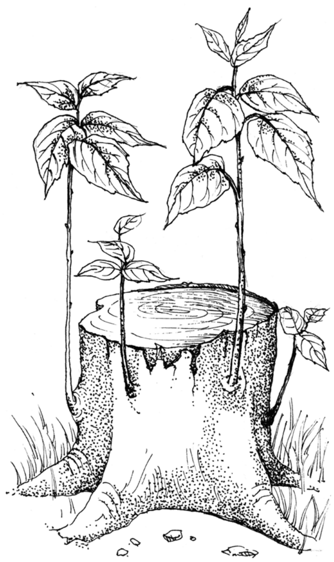
Initial restoration activities should aim to:

i) counteract the factors that impede forest regeneration (e.g. fire, cattle, hunting of seed dispersers etc.);
ii) maintain or increase the number of regenerants to 3,100/ha;
iii) maintain the density of common tree species (if already high) or increase tree-species richness until at least 10% of the tree species characteristic of the target climax forest are represented.

Table 3.1. Simplified guide to choosing a restoration strategy

LANDSCAPE-CRITICAL THRESHOLDS			SUGGESTED RESTORATION STRATEGY	SITE-CRITICAL THRESHOLDS		
Forest in landscape	**Seed-dispersal mechanisms**	**Fire risk**		**Vegetation cover**	**Natural regenerants**	**Soil**
Remnant forest remains within a few km of the restoration site	Mostly intact, limiting the recovery of tree species richness	Low to medium	**PROTECTION**	Tree canopy cover exceeds herbaceous weed cover	Natural regenerants exceeds 3,100/ ha with more than 30[1] common tree species represented	Soil does not limit tree seedling establishment
		Medium to high	**PROTECTION + ANR +**	Tree crown cover insufficient to shade out herbaceous weeds		
		High	**PROTECTION + ANR + PLANTING FRAMEWORK TREE SPECIES**	Herbaceous weed cover greatly exceeds tree crown cover	Natural regenerants sparser than 3,100/ ha with fewer than 30[1] common tree species represented	
Remnant forest patches very sparse or absent from the surrounding landscape	Seed-dispersing animals rare or absent such that the recruitment of tree species to the restoration site will be limited		**PROTECTION + ANR + MAXIMUM DIVERSITY TREE PLANTING**			Soil degradation limits tree seedling establishment
		Initially low (soil conditions limit plant growth); higher as the vegetation recovers	**SOIL AMELIORATION + NURSE TREE PLANTATION, FOLLOWED BY THINNING AND GRADUAL REPLACEMENT OF MAXIMUM DIVERSITY TREE PLANTING**	Herbaceous weed cover limited by poor soil conditions		

[1]Or roughly 10% of the estimated number of tree species in the target forest, if known.



Coppicing tree stumps must be counted in the site survey along with saplings and larger trees.

The site survey will determine which factors are preventing natural forest regeneration. Achieving a density of 3,100 regenerants per hectare results in an average spacing of 1.8 m between them. For most tropical forest ecosystems, this is close enough to ensure that weeds are shaded out and canopy closure is achieved within 2–3 years after the restoration work commences. The guideline of "approximately 10% of the species richness of the target forest ecosystem" is adjustable, depending on the diversity of the target ecosystem. If you do not know the species richness of the target ecosystem, aim to re-establish roughly 30 tree species (by planting and/or encouraging natural regeneration). This is usually sufficient to "kick start" biodiversity recovery in most tropical forest ecosystems, and 30 tree species is about the maximum that can be produced in a small-scale tree nursery. The overall rate of biodiversity recovery will increase with the number of tree species that can be re-instated at the start of restoration, but some low-diversity tropical forest ecosystems (e.g. high-altitude montane forests and mangrove forests) can be restored by initially establishing fewer than 30 tree species.

Compare the site assessment results with the guidelines below to confirm the degradation level of your restoration site. Select the broad restoration strategy to match the recorded conditions and start to plan management tasks, including protective measures (e.g. livestock exclusion and/or fire prevention), the balance between tree planting and nurturing natural regeneration, the types of tree species to plant, the need for soil improvement and so on.

Stage-1 degradation

Survey results: The total number of regenerants averages more than 25 per circle, with more than 30 tree species (or roughly 10% of the estimated number of tree species in the target forest, if known) commonly represented across 10 circles, including several climax species. Saplings taller than 50 cm are common in all circles, with larger trees found in most. Small tree seedlings are common amongst the ground flora. Herbs and grasses cover less than 50% of circles and their average height is usually lower than that of the regenerants.

Strategy: Neither tree planting nor ANR are needed. Protection, i.e. preventing encroachment and any further disturbance to the site, should be sufficient to restore climax forest conditions fairly rapidly. The site survey and discussion with local people will determine if fire prevention, removal of livestock, and/or measures to prevent the hunting of seed-dispersing animals are necessary. If crucial seed-dispersing animals have been extirpated from the area, consider re-introducing them.

Stage-2 degradation

Survey results: The average number of regenerants remains higher than 25 per circle, with more than 30 tree species (or roughly 10% of the estimated number of tree species in the target forest, if known) represented across 10 circles, but pioneer tree species are more common than climax species. Saplings taller than 50 cm remain common in all circles, but larger trees are rare and the crown cover is insufficient to shade out weeds. Herbs and grasses therefore dominate, covering more than 50% of the circle areas on average, although small tree seedlings might still be represented amongst the ground flora. Herbs and grasses overtop the tree seedlings and often also the saplings and sprouts from tree stumps.

Strategy: Under these conditions, the protective measures described for stage-1 degradation must be complemented with additional measures to "assist" natural regeneration in order to accelerate canopy closure. ANR is necessary to break the feedback loop whereby the high light levels, created by the open canopy, promote the growth of grasses and herbs, which discourages tree seed dispersers and makes the site vulnerable to burning. This in turn inhibits further tree establishment. ANR measures can include weeding, fertiliser application and/or mulching around natural regenerants. If several climax forest species do not naturally colonise the site after canopy closure has been achieved (because the nearest intact forest remnants are too far away, and/or seed dispersers have been extirpated), then enrichment planting may be necessary.

Stage-3 degradation

Survey results: The total number of regenerants falls below 25 per circle, with fewer than 30 tree species represented across 10 circles (or roughly 10% of the estimated number of trees in the target forest, if known). Climax tree species are absent or very rare. Tree seedlings are rarely found amongst the ground flora. Herbs and grasses dominate, covering more than 70% of the circle areas on average, and they usually grow taller than the few natural regenerants that may survive. Remnants of intact climax forest remain in the landscape within a few kilometres of the site and viable populations of seed-dispersing animals remain.

Strategy: Under these conditions, protection and ANR must be complemented with the planting of framework tree species. Prevention of encroachment and the exclusion of livestock (if present) remain necessary and fire prevention is important because of the abundance of highly flammable grasses. The ANR methods needed to repair stage-2 degradation must be applied to the few natural regenerants that remain, but in addition, the density of regenerants must be increased by planting framework tree species to shade out weeds and attract seed-dispersing animals.

The number of trees planted should be 3,100 per hectare minus the estimated number of natural regenerants per hectare (not counting small seedlings in the ground flora). The number of species planted across the whole site should be 30 (or roughly 10% of the estimated number of tree species in the target forest, if known), minus the total number of species recorded during the site assessment. For example, the site assessment data presented on p. 73 suggest that 433 trees per hectare of 12 species should be planted at this site. These trees should mostly be of climax species because the assessment shows that 18 pioneer species are already represented by surviving regenerants.

Framework tree species should be selected for planting using the criteria defined in **Section 5.3**. They might include both pioneer and climax species, but should be different species to those recorded during the site assessment. The planting of framework species re-captures the site from invasive grasses and herbs and re-establishes seed-dispersal mechanisms, thereby enhancing the re-colonisation of the restoration site by most of the other trees species that comprise the target climax forest ecosystem. If any important tree species fail to re-colonise the site, they can be re-introduced in subsequent enrichment plantings.

Stage-4 degradation

Survey results: The conditions recorded during the site assessment are similar to those of stage-3 degradation, but at the landscape level, intact forest no longer remains within 10 km of the site and/or seed-dispersing animals have become so rare that they are no longer able to bring the seeds of climax tree species into the site in sufficient quantities. Re-colonisation of the site by the vast majority of tree species is therefore impossible by natural means.

Strategy: Protective measures, ANR actions and the planting of framework tree species should all be carried out as for stage-3 degradation. These measures should be sufficient to re-establish basic forest structure and functioning, but with insufficient seed sources and seed dispersers in the landscape, the tree species composition can fully recover only when all of the absent tree species that characterise the target climax forest are manually established, either by planting and/or by direct seeding. This 'maximum diversity approach' (Goosem & Tucker, 1995; Lamb, 2011) is technically challenging and costly.

Stage-5 degradation

Survey results: The total number of regenerants falls below 2 per circle (average spacing between regenerants >6–7 m), with fewer than 3 tree species (or roughly 1% of the estimated number of tree species in the target forest, if known) represented across 10 circles. Climax tree species are absent. Bare earth is exposed over more than 30% of the circle areas on average and the soil is often compacted. Local people regard the soil conditions as exceedingly poor, and signs of erosion are recorded during the site assessment. Erosion gullies can be present, along with siltation of watercourses. The ground flora is limited by the poor soil conditions to less than 70% cover on average and is devoid of tree seedlings.

Strategy: Under such conditions, soil improvement is usually necessary before tree planting can commence. Soil conditions may be improved by ploughing, adding fertiliser and/or by green mulching (e.g. establishing a crop of leguminous herbs to add organic matter and nutrients to the soil). Additional soil improvement techniques can be applied during tree planting, such as the addition of compost, water absorbent polymers and/or mycorrhizal inocula to planting holes and mulching around planted trees (see **Section 5.5**).

Further improvements to site conditions might be achieved by first planting "nurse" trees (Lamb, 2011): tree species that are tolerant of the harsh soil conditions, but which are also capable of improving the soil. These should gradually be thinned out as the site conditions improve; a wider range of native forest tree species should be planted in their place. To achieve full biodiversity recovery, the maximum diversity approach must be used in most cases, but where forest and seed dispersers remain in the landscape, planting a smaller range of framework tree species might suffice. This is known as the "plantations as catalysts" or "foster ecosystem" approach (Parrotta, 2000).

Nurse trees can be specialist framework species that are capable of growing in very poor site conditions, particularly nitrogen-fixing trees of the family Leguminosae. Plantations of commercial tree species have sometimes been used as nurse crops because their thinning generates early revenue that can help to pay for this expensive process. Protective measures, such as fire and encroachment prevention and the exclusion of cattle, all remain essential throughout the lengthy process to protect the substantial investment required to repair stage-5 degradation.

Due to the very high costs involved, forest restoration is rarely carried out on sites with stage-5 degradation. An exception is where wealthy companies are legally required to rehabilitate open caste mines.

Rehabilitation of an open-cast lignite mine in northern Thailand. Usually, only wealthy companies can afford the high costs of forest restoration on stage-5 sites.

Box 3.1. Origins of the frameworks-species method.

The framework species method of forest restoration originated in the Wet Tropics of Queensland, in Australia's tropical zone. Nearly 1 million hectares of tropical forest remain (some in fragments) in this region and the restoration of rain forest ecosystems to degraded areas began in the early 1980s, shortly before the region was collectively declared a UNESCO World Heritage Area in 1988. The challenging task of restoration was the responsibility of the Queensland Parks and Wildlife Service (QPWS) and much of the work was delegated to QPWS officer Nigel Tucker and his small team, based at Lake Eacham National Park. There, the team set up a tree nursery to grow many of the area's native rain forest tree species.

Nigel Tucker points to dense undergrowth, 27 years after restoration work at Eubenangee Swamp.

One of the early restoration trials began in 1983 at Eubenangee Swamp National Park on the coastal plain. This swamp forest area had been degraded by logging, clearing and agriculture, which had disrupted the water flow needed to maintain the swamp. The project aimed to restore the riparian vegetation along the stream that feeds into the swamp. A mix of native rain forest tree species was planted, including *Omalanthus novo-guineensis*, *Nauclea orientalis*, *Terminalia sericocarpa* and *Cardwellia sublimis*. The seedlings were planted among grasses and herbaceous weeds (without weeding for site preparation) and fertiliser was applied. After 3 years, the initial results were disappointing. Canopy closure had not been achieved and

Restored forest, fringing Eubenangee Swamp, now blends imperceptibly with natural forest.

Box 3.1. continued.

Omalanthus novo-guineensis, one of the first recognised framework species.

the density of naturally established seedlings was lower than hoped for. However, the experiment resulted in the crucial observation that natural regeneration occurred under certain tree species far more than under others. Species that fostered most natural regeneration were often fast-growing pioneers with fleshy fruits, and top of the list was the bleeding heart tree (*Omalanthus novo-guineensis*).

Forest restoration at Eubenangee Swamp created habitat for thousands of wildlife species, including this 4 o'clock moth caterpillar

From those early observations at Eubenangee Swamp, the idea of selecting tree species to attract seed-dispersing wildlife became established. This, along with recognising the need for more intensive site preparation and weed control, developed into the framework species method of forest restoration. Today, more than 160 of Queensland's rain forest tree species are recognised as framework tree species. The term first appeared in a booklet, '*Repairing the Rainforest*'[5] published by the Wet Tropics Management Authority in 1995, which Nigel Tucker co-authored with QPWS colleague Steve Goosem. The concept recognises that where remnant trees and seed-dispersing wildlife remain (i.e. stages of degradation 1–3), planting relatively few tree species, which are selected to enhance natural seed dispersal mechanisms and re-establish basic forest structure, is enough to 'kick start' forest succession towards the climax forest ecosystem, with a minimum of subsequent management inputs. Now, more than 20 years after its inception, the framework species approach is widely accepted as one of the standard methods of tropical forest restoration. It has has been adapted for restoring other forest types, well beyond the borders of Queensland.

By Sutthathorn Chairuangsri

[5] www.wettropics.gov.au/media/med_landholders.html

CASE STUDY 2 Littoral forest restoration in southern-eastern Madagascar

Country: Madagascar.

Forest type: Humid littoral forest, nutrient-poor sandy soil.

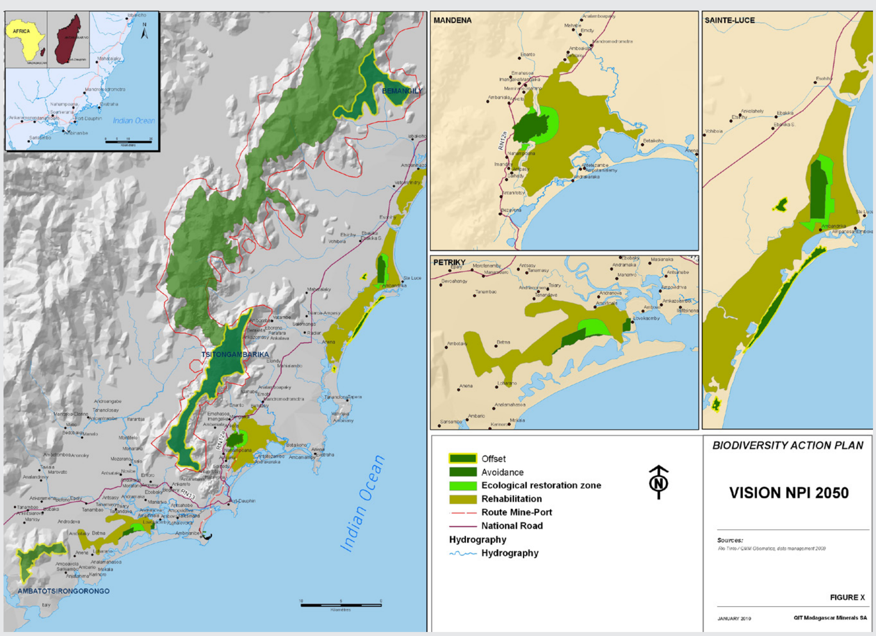
Nature of ownership: State-owned land with a long-term lease for ilmenite mining.

Management and community use: The landscape of open bush land, fragmented degraded forests, wetlands and protected forest was co-managed by the community, the government and QIT Madagascar Minerals (QMM). Years of harvesting and non-sustainable management for construction, firewood, and charcoal have led to the current landscape. Uses are now regulated by a Dina, a credible social contract for natural resources management.

Level of degradation: Open degraded bush land with residual fragments of highly degraded forests.

Background

The study area, close to the Mandena QMM mine site, lies in the south-eastern region of Madagascar near Tolagnaro (Fort Dauphin). QMM is 80% owned by the international mining group Rio Tinto and 20% owned by the Government of Madagascar, and will exploit the mineral sands in the Anosy region over the next 40 years. One of the world's most important biodiversity hotspots, Madagascar continues to experience environmental trauma. The restoration of natural forests has become an important issue in Madagascar's forestry and conservation activities. There are a few initiatives in which native trees have been being planted as buffer zones around natural forests or as corridors to provide continuity of forest habitats. There have also been a few attempts to restore natural forests after exploitation or complete destruction, but the work and knowledge in this field is still very preliminary. One of the commitments within QMM's Environmental Management Plan, which must be carried out under the terms of its



Location of the study area.

Tree species included in the study, according to their assigned category.

	Sun-loving	Pioneer	Intermediate	Climax and shade-loving
Characteristics	• True forest species • Require sunlight	• Full sunlight needed for optimal growth	• Neither sun-loving nor shade-loving • Mediocre germination rate under unshaded tree-nursery conditions	• Shade for optimal growth
Species	*Canarium bullatum* inedit (Burseraceae), *Eugenia cloiselii* (Myrtaceae), and *Rhopalocarpus coriaceus* (Sphaerosepalaceae)	*Vernoniopsis caudata* (Asteraceae), *Campylospermum obtusifolium* (Ochnaceae), *Dodonaea viscosa* (Sapindaceae), *Aphloia theiformis* (Aphloiaceae), *Scutia myrtina* (Rhamnaceae), and *Cerbera manghas* (Apocynaceae)	*Tambourissa castri-delphinii* (Monimiaceae), *Vepris elliottii* (Rutaceae), *Dracaena bakeri* (Convallariaceae), *Psorospermum revolutum* (Clusiaceae), *Eugenia* sp. (Myrtaceae), and *Ophiocolea delphinensis* (Bignoniaceae)	*Dypsis prestoniana* and *D. lutescens* (Arecaceae), *Pandanus dauphinensis* (Pandanaceae), *Podocarpus madagas- cariensis* (Podocarpaceae), *Diospyros gracilipes* (Ebenaceae), *Apodytes bebile* (Icacinaceae), and *Dombeya mandenense* (Malvaceae)

mining permit, is the restoration of natural forests and wetlands after mining. The plan is to double the surface area of the existing conservation zone at Mandena by restoring approximately 200 ha of natural forests and 350 ha of wetlands after mining. Trials have been underway for the past 15 years.

Investigating species selection

This case study summarises 10 years of restoration experiments. During the first round of qualitative data collection, the growth characteristics of the saplings of several species of littoral forest trees growing in a tree nursery were observed and described qualitatively. The objective of the first stage of the plantation program was to install vegetation that could serve as a starting point for a natural or facilitated succession towards restoration of the desired forest components. The tree species were categorised according to their tolerance of sun exposure, high evaporation and poor soil conditions, and their capacity to develop an extensive and dense root system rapidly. Ninety-two species of native trees were examined and assigned as sun-loving, pioneer, intermediate or late-successional (climax or shade-loving) species.

Exploring impact factors for restoration

Trials were conducted to test the effects of various factors on tree growth and survival rates:

1. The effects of the extent of demineralisation on restoration and succession were examined in an experiment in which post-mining soil conditions were simulated. Plants were grown in soils that were demineralised to one of three levels: a) large-scale demineralisation to a depth of 2 m (mimicking the mining process), b) stimulated demineralisation (mimicking the removal of humus after exploitation) or c) no demineralisation.
2. The effects of adding topsoil were tested in an experiment in which saplings were planted in topsoil that had been either a) added to continuously cover the plantation area to a depth of 20 cm or b) added only to the hole in which the sapling was planted.
3. A further study looked at the effects of distance to natural forests as a source for regeneration.
4. Native species with or without exotic species (including *Eucalyptus robusta* and *Acacia mangium*) were planted as shade trees in an attempt to promote succession.
5. In accordance to the results of studies of forest succession, forest tree species were assigned into one of three classes: pioneer (sun-loving), intermediate and late successional (climax or shade-loving).
6. The influences of ectomycorrhiza, nitrogen fixation and unknown microbial associations upon succession were also considered.

Lessons learned

The demineralisation of sandy soils as during mining (i.e. the removal of the heavy minerals, such as ilmenite ($FeTiO_2$) and zircon) did not have any measurable effect on the survival rates of trees. These minerals are stable and do not seem to be taken up by plants, which need the ions to be in water solution for assimilation. Several trees that were planted on demineralised soils produced flowers and fruits; hence, demineralisation did not seem to affect the reproductive state of the plants.

Native trees that were planted in combination with the exotic species *Eucalyptus robusta* and *Acacia mangium* had a very low survival rate or were totally overtaken by the exotic species. Within five years, the exotic species reached heights of at least 5 m. Only a few shade-tolerant species such as *Apodytes bebile*, *Astrotrichilia elliotii* and *Poupartia chapelieri* survived under these conditions. It is unclear, however, whether the low survival rate of the native species is due to competition for light or to allelochemical interactions with products from the exotic trees. In the experimental plots without exotic tree species, native species from the sun-loving/pioneer and intermediate classes survived well. These plants will probably be important for the first stage of the restoration of native littoral forest after mining.

Saplings that were close to the edge of the natural forest grew more rapidly than those further away from the forest edge. In addition, trees growing in small isolated patches of forest (i.e. groups of trees growing in an open landscape) were generally much smaller than those in the larger blocks of forest. These observations support the idea that restoration activities should commence by enlarging existing forest blocks rather than by starting with isolated plantations.

The addition of topsoil has a major impact on the growth of the saplings. Saplings planted with a 20 cm layer of topsoil concentrated around them grew at the same rate as those planted in an area covered with a continuous 10 cm layer of topsoil. In Mandena, the supply of topsoil has become a significant management issue because most of the natural forests outside the conservation zone were destroyed. It is therefore important that the remaining topsoil is used as efficiently as possible.

The idea of using exotic trees to provide shade and a suitable microclimate for the saplings of native trees needs to be abandoned. Competition for light and growth-enabling components make exotic species unsuitable pioneer plants for the restoration of native littoral forests.

One further consideration that is of paramount importance for the growth and survival of trees is the ubiquitous association of trees with nitrogen-fixing bacteria and mycorrhiza. Specific fungi can penetrate the root cells of their symbiotic partners forming endomycorrhiza, or remain in close association with the roots without penetrating the cell, forming ectomycorrhiza. Ectomycorrhiza form mixed mycelium-root structures that effectively increase the resorptive surface of the tree and facilitate the uptake of nutrients. Furthermore, the fungi also seem to be able to mobilise essential plant nutrients directly from minerals. This could be important for forest restoration as it might enable ectomycorrhizal plants to extract essential nutrients from insoluble mineral sources through the excretion of organic acids.

Ectomycorrhizal symbioses are known for less than 5% of terrestrial plant species and are more common in temperate zones than in the tropics. Follow-up research on the ectomycorrhizal associations of the Sarcolaenaceae, a tree family that is endemic to Madagascar and has eight species that occur in the littoral forest, is recommended. Whether ectomycorrhizal associations provide an advantage over the formation of endomycorrhiza for plants growing on nutrient-poor sand remains to be studied in more detail. The importance of either form of mycorrhiza to the tree species of the littoral forests of south-eastern Madagascar is unknown. It has been observed, however, that saplings planted on demineralised soil hardly grew for several years and then suddenly increased in height. This might indicate that the plants first had to acquire their mycorrhizal fungi or nitrogen-fixing bacteria before they could start growing. Species with ectomycorrhiza or nitrogen-fixing bacteria seem to have enhanced growth on demineralised soil, growing about three times faster than other species. Under normal conditions, this advantage was not as obvious. Thus, knowledge of microbial symbioses and their species specificities could facilitate forest restoration programmes.

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