FOREST RESTORATION RESEARCH UNIT

RESTORING TROPICAL FOREST ECOSYSTEMS ON LIMESTONE MINES

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Terrace in Phase-1 pit, SCG Lampang Mine, newly planted with saplings of native forest tree species.
Cover photo – Restoration plot at SCG :Lampang mine 1 year after planting framework tree species

Contents

Challenges of forest restoration on limestone mines

The physical, chemical and environmental conditions in open cast limestone mines present extreme challenges to the establishment of tree cover, and the eventual return of such sites to original forest ecosystems. Natural events, such as the eruption of Krakatoa in 1883, demonstrate that re-establishment of tropical forests is possible through natural succession, even under the harshest of conditions (Whittaker et al., 1989) but may take a hundred years or more. Forest restoration seeks to enhance, accelerate and direct such natural process, such that such “natural-looking” forests can be restored to limestone mines within reasonable timeframes acceptable to the legal requirement of mine companies to restore natural vegetation, once mining has ceased.

Limestone mines represent “Stage 5 Degradation”, the most extreme form, illustrated overleaf, with extremely poor substrate conditions and no natural sources of forest regeneration (i.e. seed bank, seedlings or live tree stumps) (Elliott et al., 2008). Plants are completely exposed to strong sunlight, causing desiccation and extreme temperature fluctuations between night and day. Since the substrate is largely impermeable, water accumulates on the surface during heavy rainfall events inundated plants. Drainage is impeded and oxygen supply to the roots is prevented. Furthermore, the substrate of limestone mines is highly alkaline, so that only trees evolved to grow under high pH conditions can grow there. This limits the number of tree species which can potential be planted under such conditions and require expensive substrate amelioration operations before tree planting can succeed.

However, most of the limestone mines operated by SCG differ from classic stage-5 degradation in that they are usually surrounded by natural forest, which acts as a reservoir for seed-dispersing animals. This means that once wildlife can be attracted into the restored sites, there is a high probability that they will disperse seeds of natural forest trees into the sites and thus bring about more rapid recovery of vegetation species richness than would usually occur with Stage 5 Degradation sites. Thus, the forest restoration approach on limestone mines can include the framework species method, specifically designed to attract seed-dispersing animals.

The definition of forest restoration used for this booklet is “directing and accelerating ecological succession towards an indigenous forest ecosystem of the maximum biomass, biodiversity, ecological functioning and structural complexity that are self-sustainable within prevailing climatic and soil limitations.”

Stage-5 Degradation

SITE CRITICAL THRESHOLDS		LANDSCAPE CRITICAL THRESHOLDS	
VEGETATION	No tree cover. Poor soil may limit growth of herbaceous weeds.	FOREST	Usually absent within seed dispersal distances of site
SOIL	Poor soil conditions limit tree establishment	SEED DISPERSERS	Mostly gone
SOURCES OF REGENERATION	Very few or none	FIRE RISK	Initially low (soil conditions limit plant growth); higher as the vegetation recovers

RECOMMENDED RESTORATION STRATEGY:

- Soil improvement e.g., green mulch, addition of compost/fertilizers and soil micro-organisms etc.…
- … followed by planting "nurse trees" – i.e., hardy nitrogen-fixing trees to further improve the soil (also known as "plantations as catalysts" (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 is recovered.
- Plantations of commercial tree species as nurse trees to generate revenue from thinning.
- Mechanisms to ensure that local people benefit harvesting of commercial tree species.
- Once the nurse tree crop is ready for thinning and modification, options for economic benefits include enrichment planting with economic species + sustainable harvesting of non-timber forest products and employment of local people on the restoration program.

Site amelioration and nurse plantations

On limestone mines, soil and micro-climatic conditions have deteriorated beyond the point, at which they can support tree seedling establishment. Site amelioration is a necessary precursor to forest restoration. Site amelioration can involve direct physical treatment of the substrate and/or establishing plantations of highly resilient tree species to improve the soil and modify the micro-climate – the so-called "nurse" plantation approach (Parrotta, 2000).

Top soil replacement and deep ripping are examples of the former.

Deep ripping, sometimes known as sub-soiling, involves slicing thin furrows through the soil, with strong, narrow tines, up to 90 cm deep, about 1 m apart, without inverting the soil. Deep ripping merely opens up soils that have become compacted (e.g. due to machinery or livestock trampling etc.) 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, so it is only possible on relatively flat and accessible sites and it is very expensive[1].

Mounding is another physical treatment, which can improve soil conditions, by aerating the soil and reducing the risk of water-logging.

Addition of organic materials such as straw and other organic waste materials improves soil structure, drainage, aeration and nutrient status and promotes 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

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

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 and sowing them 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.

Application of chemical fertilizers also improves soil nutrient status, but without the benefits to soil structure and fauna provided by organic materials. Several techniques can be employed to determine which particular 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 214-219). However, most of these techniques are expensive and require specialized expertise. If they are considered to be impractical or too expensive, application of a general-purpose fertilizer (NPK-15:15:15, 50-100 gm 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 gm of the dried pellets, mixed with the backfill or, in dry soils, two cupfuls of the hydrated gel. 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 the strains of micro-organisms required for high performance of the particular tree species being planted (particularly nitrogen-fixing, *Rhizobium* or *Frankia* bacteria, symbiotic with legumes, and mycorrhizal fungi, which improve nutrient absorption for most tropical tree species). Mixing a handful of soil, collected 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. Application of commercially produced inoculae of mycorrhizal fungi in tree-planting holes produced no noticeable benefits in N. Thailand (pers. obs.).

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. However, research suggests 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*, widely used for riparian forest restoration in Brazil, with *Rhizobia*, reduced the fertilizer 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 lab. The same is true of mycorrhizal fungi. Application of a commercially produced mix of "ubiquitous" mycorrhizal fungi species to forest tree seedlings, grown in a nursery in N. Thailand, failed to produce any benefits (Philachanh, 2003).

The planting of "nurse trees" (Lamb, 2011, pp340-41) 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, leading to the accumulation of humus and soil nutrients and, ultimately, much better conditions for subsequent seed germination and seedling establishment of less tolerant tree species (Parrotta et al, 1997)[2]. 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 a few fast-growing, pioneer species that are tolerant of the harsh soil and micro-climatic conditions prevalent on sites with stage-5 degradation, but which are also capable of improving the soil. Native tree species

[2] 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 "catalyze" 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.

are preferred, due to their ability to promote biodiversity recovery more than exotics (Parrotta, 1997). Study of the local tree flora will usually reveal indigenous pioneer tree species, which grow equally as well as any imported exotics.

However, exotic species 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, which 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, use of the exotic plantation tree, *Acacia mangium* in Indonesia is becoming a major problem for future forest restoration, since 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 S. America and tropical N. Australia. Seedlings of exotic species may be easier to obtain from commercial tree nurseries, but if you are unsure if the species being considered meets the above-listed criteria, it is better to search through the local tree flora for an indigenous alternative.

Plantation species should be light demanding, pioneers (commonly the case with commercial timber trees), extremely hardy and short-lived. In general, better results have been achieved with broad-leafed species than with conifers. Planting stock should be of the highest quality.

Legumes (Family, Leguminosae) and indigenous fig tree species (*Ficus* spp) nearly always make good nurse plantation species. Fig tree roots are capable of invading and breaking apart compacted soils and even rocks on the most degraded of sites, whilst 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 fertilizer.

Albizia lebbeck, hardy legume which grows quickly on limestone substrates and fixes nitrogen in the soil. This plant is just 5 months old..

When establishing a conventional tree plantation, it is tempting to follow conventional production forestry practices. However, the design and management of nurse plantations for forest restoration requires a more considered approach. Since canopy closure is the first objective of the plantation, the trees should be planted closer than is usual for commercial forestry. 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. That provides the planting distance necessary to close 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 growth of subsequently planted trees or prevent colonization 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 degradation sites, harsh conditions limit weed growth), then weeding is not necessary or it should cease as soon as the crowns of planted saplings have grown above the weed canopy. Where incoming seed dispersal may 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 framework 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 not to disturb the understory so that the accumulated biodiversity is not damaged. Hauling logs out from a plantation without damaging the undergrowth is, to say the least, not easy, but various "minimum impact" or "reduced-impact" logging (RIL) techniques are now being promoted (Putz et al., 2008).

Where seed-dispersal into a restoration site may still be possible, framework tree species should be planted to attract seed-dispersing birds and mammals.

The Framework Species Method

The framework species method involves planting the fewest trees necessary to shade out weeds (i.e. site "re-capture") and attract seed-dispersing animals. In order for it to work, remnants of the target forest type must survive within a few kilometres of the restoration site (as a seed source). Animals (mostly birds and bats), capable of dispersing seeds from remnant forest patches or isolated trees to restoration sites, must remain fairly common. The framework species method enhances this natural seed-dispersal service to achieve rapid tree species recruitment in restoration plots. Consequently, recovery of the biodiversity levels typical of climax forest ecosystems is attained without having to plant all 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 germination of tree seeds and seedling establishment. Since SCG's northern limestone mines are largely surrounded by relative undisturbed natural forest, which support a variety of seed dispersing animal, the framework species approach is appropriate as a guiding concept for the restoration of such areas.

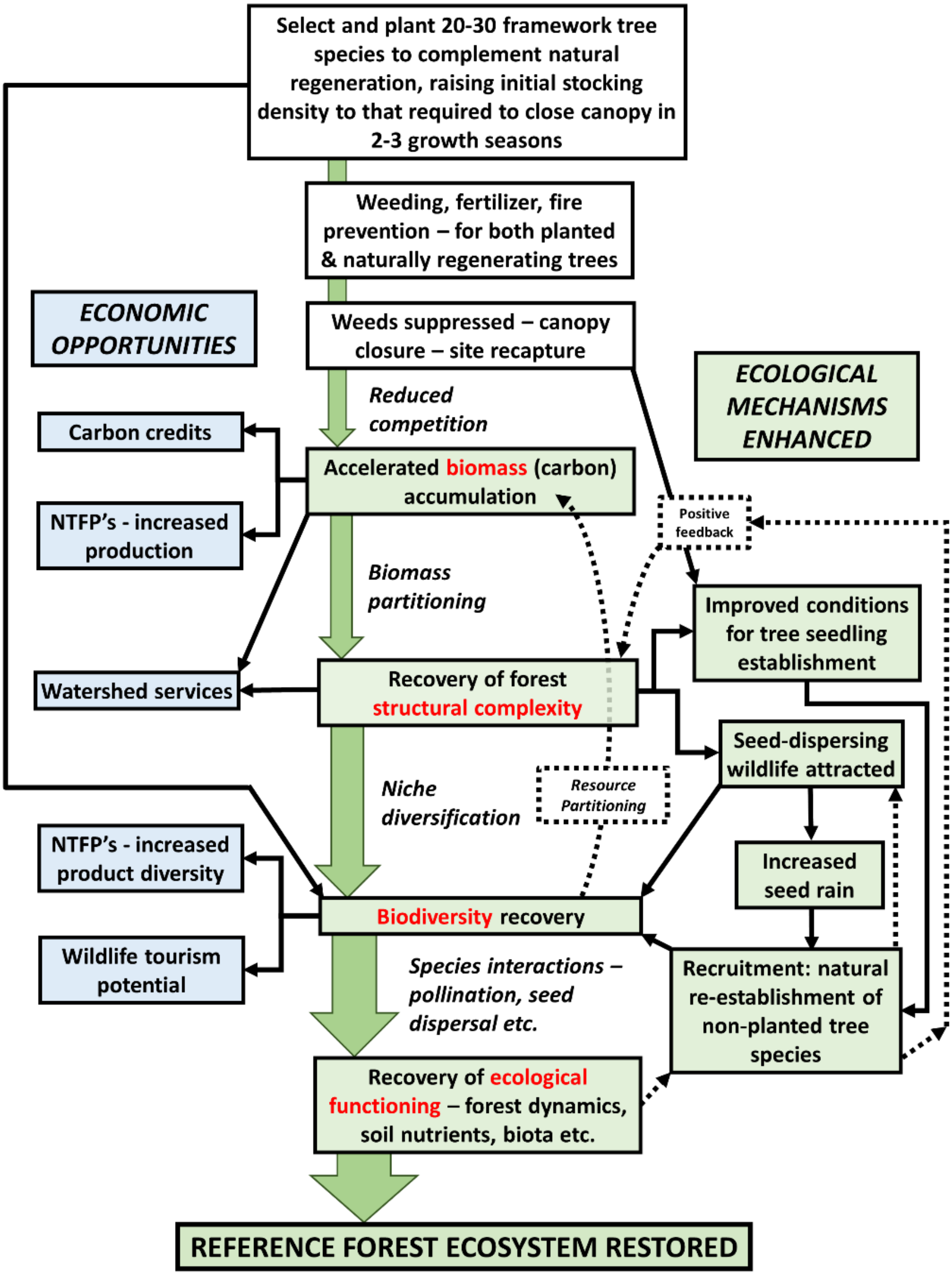
With seed-dispersing animals, such as this macaque monkey, living around SCG's Lampang Limestone Quarry, the framework species method should work well there, attracting such animals to deposit seeds into restoration sites, increasing tree species richness and promoting biodiversity recovery. Protection of such animals is essential for the technique to work

Box 1 - The origins of the framework species method

The framework species method of forest restoration originated in the Wet Tropics of Queensland, in Australia's tropical zone, where nearly 1 million hectares of tropical forest remain (some in fragments), collectively declared a UNESCO World Heritage Area in 1988. Restoring rain forest ecosystems to degraded areas began in the early 1980s, even before the area achieved World Heritage status. This challenging task was the responsibility of the Queensland Parks and Wildlife Service (QPWS) and much of the work was delegated to QPWS officer, Mr. Nigel Tucker and his small team, based at Lake Eacham National Park, where a tree nursery was set up to grow many of the area's native rain forest tree species. 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 water flow needed to maintain the swamp. The project aimed to restore the riparian vegetation along the stream which feeds into the swamp. A mix of native rainforest tree species was planted, including *Omalanthus novo-guineensis, Nauclea orientalis*, *Terminalia sericocarpa*, *Cardwellia sublimis* and others. The seedlings were planted among grasses and herbaceous weeds (without weeding for site preparation) and fertilizer was applied. After 3 years, initial results were disappointing. Canopy closure had not been achieved and the density of naturally established seedlings was lower than hoped for. However, the experiment resulted in the critical 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*).

From those early observations at Eubenangee Swamp, the idea of selecting tree species to attract seed-dispersing wildlife became established and, along with recognizing 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 rainforest tree species are recognized as framework tree species. The term first appeared in a booklet, "Repairing the Rain Forest"[3] published by the Wet Tropics Management Authority in 1995, which Nigel Tucker co-authored with QPWS colleague, Steve Goosem. The concept recognizes that where seed-dispersing wildlife remain, planting relatively few tree species, 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 approaches to restoring tropical forest ecosystems and the method has been adapted for restoring other forest types, well beyond the borders of Queensland.

[3] http://www.wettropics.gov.au/media/med_landholders.html



How the framework species method works – green arrows indicate progress with restoration objectives; black arrows – origin affects point; dotted arrows – positive feedback loops.

The framework species method involves planting mixtures of 20-30 indigenous forest tree species, which are typical of the target forest ecosystem, but which also share the following ecological characteristics: -

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

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 products and ecological services, rendered by each species, may be taken into account.

Species Selection

Few field trials have been carried out, to test which native forest tree species might function well as framework tree species on limestone mine sites. Furthermore, existing trials are still young, so it is not yet possible to definitively recommend species for planting. Table 1 lists trees, known to grow in limestone areas of N. Thailand, below 800 m. These tree species are recommended for trialling on limestone mines. Subsequent data collection from field trials will confirm the extent to which they meet the framework species criteria listed in the previous section. Abbreviations for the table are as follows: -

LOW/UPP= lowest/highest elevation at which the species has been observed in northern Thailand (m above seas level).

Habitat:	**rocks in**	**deciduous dipterocarp/oak**	**dof**
		pine dipterocarp	**do/pine**
	streams in	**bamboo/deciduous forest**	**bb/df**
		mixed deciduous/evergreen	**mxf**
	ponds in	**evergreen forest**	**egf**
		evergreen with pine	**eg/pine**
	wet areas in	**evergreen with bamboo**	**eg/bb**
		disturbed areas, roadsides	**da**
	cliffs	**secondary growth**	**sg**
		beaches	**be**

SEED COLL MONTH: Optimum seed collection month which yields maximum %germination.

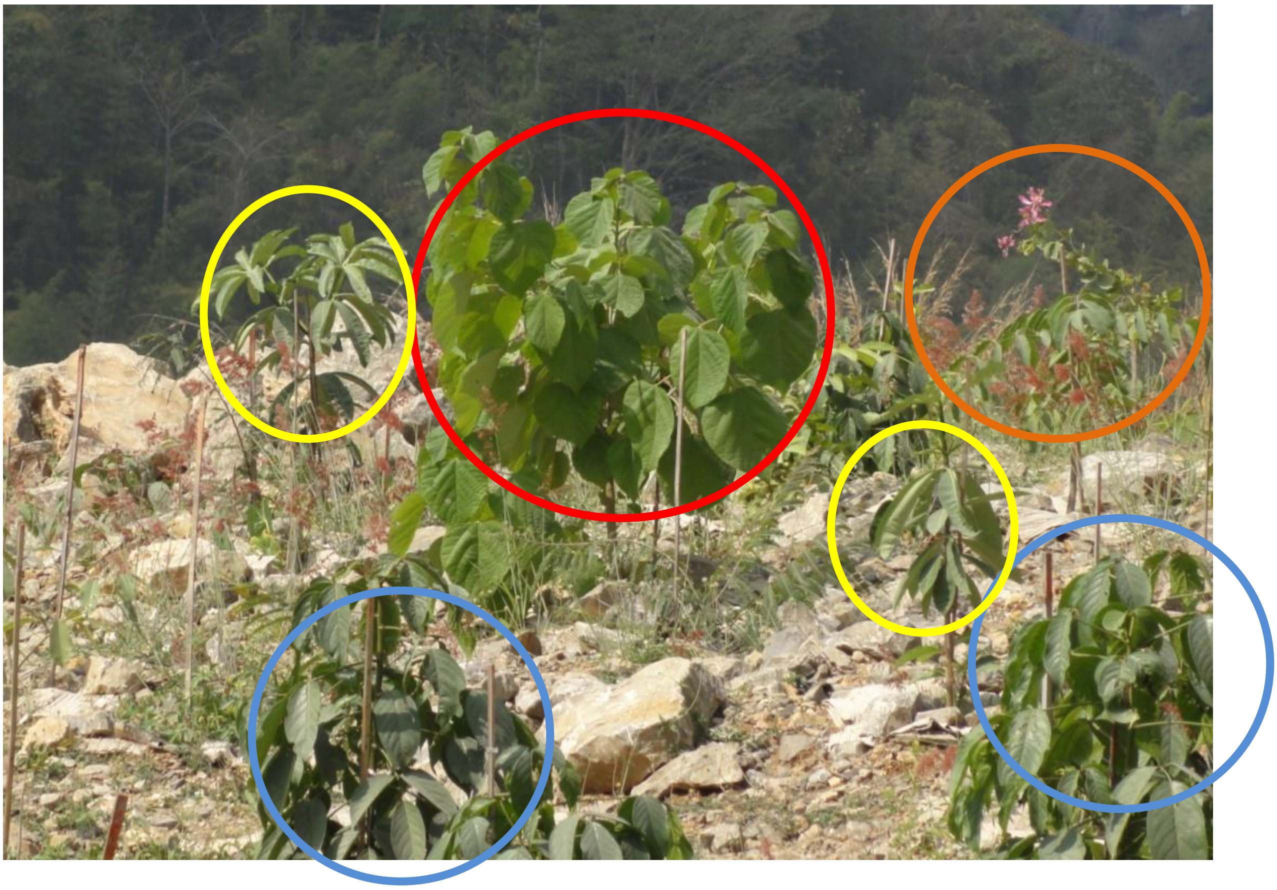
Table 1 – Species most likely to act as framework tree species for restoration of forest ecosystems to a limestone quarry in northern Thailand. Data are from CMU Herbarium Database and FORRU-CMU unpublished research data. Species highlighted in yellow can be recommended on the basis of field results from SCG's mine at Muang Poon. The other species are known to grow well on limestone substrates but require field trials to confirm if they are suitable for restoring mines. Ficus spp. (highlighted in blue) and Legumes (highlighted in green) should receive top priority for field trials.

Species	FAMILY	Low	Upp	Habitat	SEED COLL MONTH
Acrocarpus fraxinifolius Wight ex Arn.	Leguminosae C	500	1,250	bb/df (streams) mxf egf	APR
Albizia lebbeck (L.) Bth.	Leguminosae M	60	800	bb/df mxf eg/bb da sg	OCT
Alstonia scholaris (L.) R. Br. var. scholaris	Apocynaceae	60	1,200	streams in bb/df mxf egf	FEB
Anthocephalus chinensis (Lmk.) A. Rich.	Rubiaceae	400	1,050	mxf	OCT
Aporusa villosa (Lindl.) Baill.	Euphorbiaceae	60	1,500	dof mx/bb mx/pine bb/df do/pine mxf	MAY
Artocarpus lakoocha Roxb.	Moraceae	200	1,500	dof bb/df egf mxf da sg	JUN
Balakata baccata (Roxb.) Ess.	Euphorbiaceae	375	1,500	streams in mxf egf bb/df dof	JUL
Bauhinia purpurea L.	Leguminosae C	350	950	da	MAR
Bauhinia variegata L.	Leguminosae C	350	1,500	da sg in egf bb/df, limestone cliffs mxf	APR
Bischofia javanica Bl.	Euphorbiaceae	200	1,300	bb/df(streams) mxf da eg/pine eg/bb	JUL
Bombax ceiba L.	Bombacaceae	60	1,450	dof mxf da in eg/pine bb/df sg	APR
Bridelia glauca Bl. var. *glauca*	Euphorbiaceae	300	1,625	mxf egf da dof bb/df eg/pine do/pine	MAR
Canarium subulatum Guill.	Burseraceae	60	1,300	mxf dof bb/df egf da sg	SEP
Cassia fistula L.	Leguminosae C	60	1,050	bb/df dof mxf da sg	APR
Chukrasia tabularis A. Juss.	Meliaceae	60	1,240	bb/df mxf egf	MAR
Croton roxburghii N. P. Balakr.	Euphorbiaceae	200	950	bb/df mxf sg dof	APR
Cycas pectinata B.H.	Cycadaceae	60	1,750	dof eg/pine mxf do/pine da	APR
Erythrina subumbrans (Hassk.) Merr.	Leguminosae P	200	1,680	mxf egf bb/df	MAR

Species	FAMILY	Low	Upp	Habitat	SEED COLL MONTH
Eugenia fruticosa (DC.) Roxb.	Myrtaceae	350	1,515	eg/pine dof bb/df	MAY
Ficus auriculata Lour.	Moraceae	375	1,400	streams in mxf da in dof bb/df egf eg/pine	FEB
Ficus benjamina L. var. *benjamina*	Moraceae	60	1,400		FEB
Ficus callosa Willd.	Moraceae	500	1,100	streams in bb/df mxf egf	APR
Ficus capillipes Gagnep.	Moraceae	475	1,100	bb/df mxf streams	JUN
Ficus fistulosa Reinw. ex Bl. var. *fistulosa*	Moraceae	200	1,400	mxf da in eg/pine bb/df sg egf	JAN
Ficus glaberrima Bl. var. *glaberrima*	Moraceae	450	1,200	mxf egf streams in bb/df rocks	MAY
Ficus heteropleura Bl. var. *heteropleura*	Moraceae	350	1,200	bb/df mxf egf streams rocks	MAR
Ficus hirta Vahl var. *hirta*	Moraceae	60	1,550	mxf egf eg/pine da sg bb/df	JUN
Ficus hispida L. f. var. *hispida*	Moraceae	60	1,525	da sg mxf egf bb/df	APR
Ficus microcarpa L. f. var. *microcarpa* forma *microcarpa*	Moraceae	200	1,100	streams in dof bb/df mxf egf	DEC
Ficus racemosa L. var. *racemosa*	Moraceae	60	650	streams in dof bb/df mxf	JAN
Ficus rumphii Bl.	Moraceae	60	600	bb/df streams da sg	OCT
Ficus sarmentosa B.-H. ex J.E. Sm. var. *nipponica* (Fr. & Sav.) Corn.	Moraceae	550	1,400	egf eg/bb bb/df mxf	AUG
Ficus semicordata B.-H. ex J.E. Sm. var. *semicordata*	Moraceae	200	1,550	da sg in bb/df egf eg/pine	JAN
Ficus variegata Bl. var. *variegata*	Moraceae	300	1,250	streams in mxf egf bb/df	JUN
Ficus virens Ait. var. *sublanceolata* (Miq.) Corn.	Moraceae	525	1,250	rocks in bb/df mxf open egf	MAR
Glochidion kerrii Craib	Euphorbiaceae	550	1,600	egf eg/bb da eg/pine	FEB
Gochnatia decora (Kurz) Cabr.	Compositae	200	1,600	eg/pine often in da sg ls	MAR
Gmelina arborea Roxb.	Verbenaceae	350	1,475	dof bb/df mxf egf eg/pine	APR

Species	FAMILY	Low	Upp	Habitat	SEED COLL MONTH
Holarrhena pubescens (B.-H.) Wall. ex G. Don	Apocynaceae	200	1,050	mxf bb/df mxf dof da sg	FEB
Ilex umbellulata (Wall.) Loesn.	Aquifoliaceae	500	1,500	mxf egf bb/df eg/bb eg/pine	SEP
Lagerstroemia villosa Wall. ex Kurz	Lythraceae	300	1,150	da sg bb/df egf	NOV
Magnolia champaca L. var. champaca	Magnoliaceae	600	1,600	egf mxf	JUN
Mallotus philippensis (Lmk.) M.-A.	Euphorbiaceae	60	1,500	da bb/df mxf sg egf	FEB
Mangifera caloneura Kurz	Anacardiaceae	350	1,025	mxf bb/df egf streams	MAY
Markhamia stipulata (Wall.) Seem. ex K. Sch. var. *kerrii* Sprague	Bignoniaceae	60	1,550	bb/df sg mxf egf eg/pine da	MAR
Millingtonia hortensis L. f.	Bignoniaceae	60	800	bb/df mxf da sg cult cliffs	MAR
Morinda tomentosa Hey. ex Roth	Rubiaceae	60	850	dof bb/df mxf da sg	JUL
Oroxylum indicum (L.) Kurz	Bignoniaceae	60	1,450	bb/df da sg in mxf cult	FEB
Phoebe lanceolata (Nees) Nees	Lauraceae	550	1,600	egf streams in eg/pine da sg mxf	SEP
Spondias lakonensis Pierre	Anacardiaceae	450	850	mxf streams	DEC
Spondias pinnata (L. f.) Kurz	Anacardiaceae	60	1,200	bb/df mxf open egf dof	DEC
Sterculia villosa Roxb.	Sterculiaceae	200	1,600	dof bb/df mxf eg/pine da do/pine	APR
Streblus asper Lour. var. asper	Moraceae	60	900	streams in mxf da sg bb/df	APR
Tectona grandis L. f.	Verbenaceae	60	900	bb/df mxf da sg cult	MAR
Toona ciliata Roemer	Meliaceae	75	100	eg/bb	SEP
Tristaniopsis burmanica (Griff.) P.G. Wilson & T.Waterh.	Euphorbiaceae	600	800	mxf	JUL
Vitex canescens Kurz	Verbenaceae	60	900	bb/df mxf da sg	MAY
Vitex peduncularis Wall. ex Schauer	Verbenaceae	60	1,200	dof bb/df mxf da egf	AUG
Vitex quinata (Lour.) Will.	Verbenaceae	200	1,500	bb/df egf mxf da sg	JAN
Xylia xylocarpa (Roxb.) Taub. var. *kerrii*	Leguminosae M	60	1,000	dof bb/df mxf	MAR

Some of the more successful species beginning to display framework criteria at SCG's Muang Poon mine. Growth after 9 months. Planted 2012.



Bauhinia purpurea (already flowering) — *Gmelina arborea*

Bischofia javanica — *Alstonia scholaris*

As mentioned previously, *Ficus* species and those in the family Leguminosae should be considered first for planting trials, since the former can rapidly open out the substrate through root pressure and facilitate drainage and aeration and the latter can fix nitrogen and rapid improve substrate chemistry, thus ameliorating site conditions and facilitating establishment of other tree species.

Ficus species, known to thrive on limestone substrates, include *F. auriculata* Lour., *F. benjamin*a L. var. *benjamina*, F. *callosa* Willd., *F. capillipes* Gagnep., *F. fistulosa*, Reinw. ex Bl. var. *fistulosa*, *F. glaberrima* Bl. var. *glaberrima*, *F. heteropleura* Bl. var. *heteropleura*, *F. hirta* Vahl. var. *hirta*, *F. hispida* L. f. var. *hispida*, *F. microcarpa* L. f. var. *microcarpa* forma *microcarpa*, *F. racemosa* L. var. *racemosa*, *F. rumphii* Bl., *F. semicordata* B.-H. ex J.E. Sm. var. semicordata, F. *variegata* Bl. var. *variegata* and *F. virens* Ait. var. *sublanceolata* (Miq.) Corn.

Legumes worth testing include: *Acrocarpus fraxinifolius* Wight ex Arn., *Albizia lebbeck* (L.) Bth., *Bauhinia variegata* L., *B. purpurea*, *Cassia fistula* L., *Erythrina subumbrans* (Hassk.) Merr., *Xylia xylocarpa* (Roxb.) Taub. var. *kerrii* (Craib & Hutch.) Niels.

Gmelina arborea (9 months), *Bischofia javanica* (9 months) and *Morinda tomentosa* (fruiting after 18 months).

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