Forest Restoration and Sustainable Management

3-credit Undergraduate Course
(2h lecture and 3h practical /week x 18 weeks)

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FORRU

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CONTENTS

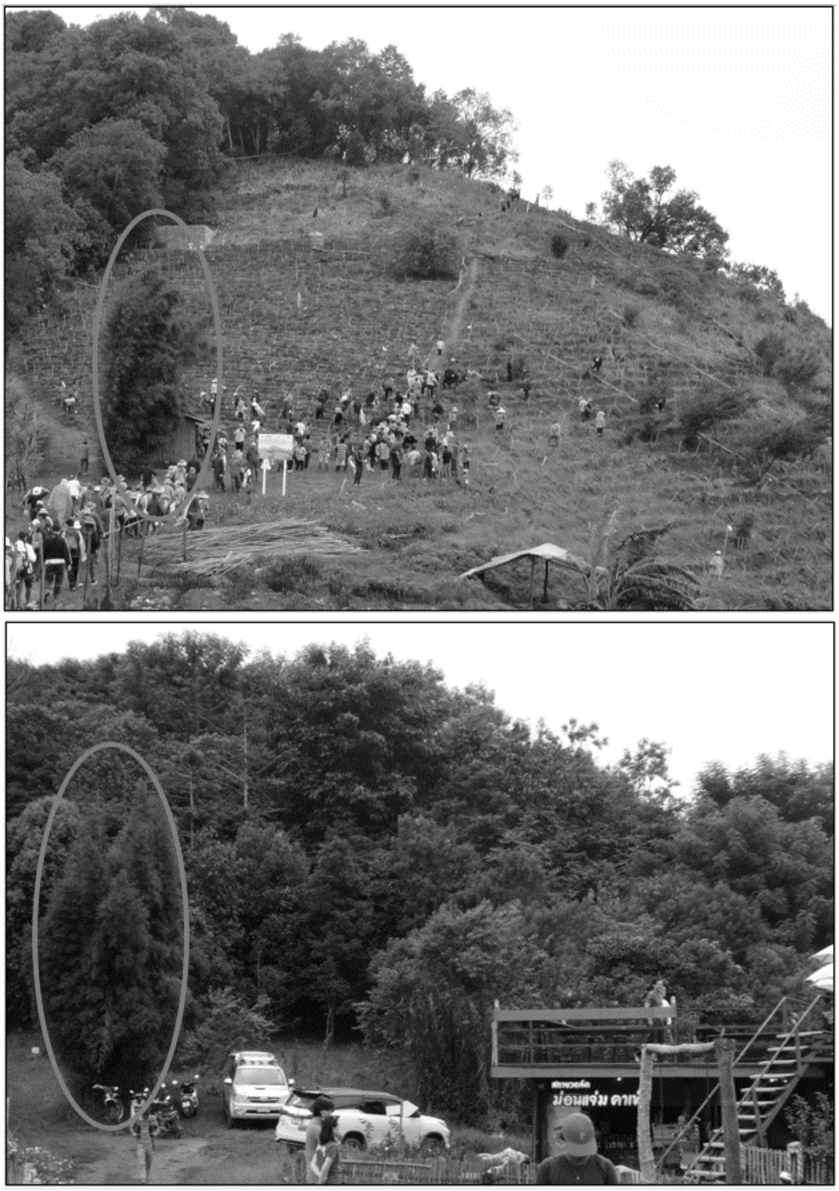
SYLLABUS

FOREST RESTORATION AND SUSTAINABLE MANAGEMENT

3-CREDIT UNDERGRADUATE COURSE
(2H LECTURE AND 3H PRACTICAL /WEEK X 18 WEEKS)

Week	Topic	Method	Hours	Location
	LECTURES			
1	Recognizing and understanding forest types	**Lecture**	**2**	**JC**
	Social Aspects			
2	The value of forest ecosystems	**Lecture**	**2**	**JC**
3	Traditional uses of forest products – economic and cultural	**Lecture**	**2**	**JC**
4	The drivers of deforestation	**Lecture**	**2**	**JC**
5	Incentivizing forest restoration and sustainable forest management	**Lecture**	**2**	**JC**
6	Ecological principles of community forestry and sustainable harvesting	**Lecture**	**2**	**JC**
7	Human rights and forest restoration/sustainable management	**Lecture**	**2**	**JC**
	Essential Ecological Science			
8	Phenology - seasonal cycles of flowering and fruiting	**Lecture**	**2**	**JC**
9	Seed dispersal	**Lecture**	**2**	**JC**
10	Seed predation, dormancy and germination	**Lecture**	**2**	**JC**
11	Barriers to tree seedling establishment – weeds, cattle and fire	**Lecture**	**2**	**JC**
12	The theory of ecological succession	**Lecture**	**2**	**JC**
	Forest Restoration Principles and Practices			
13	Forest restoration – matching techniques with degradation level	**Lecture**	**2**	**JC**
14	The framework species method of forest restoration	**Lecture**	**2**	**JC**
15	Seed collection, handling and storage	**Lecture**	**2**	**JC**
16	Tree nursery design and management - planting stock production	**Lecture**	**2**	**JC**
17	Field trial design and monitoring tree performance	**Lecture**	**2**	**JC**
18	Monitoring forest recovery	**Lecture**	**2**	**JC**
	TOTAL LECTURE HOURS		**36**	
Week	**PRACTICALS**		**Session***	
1-2	Reference Forest Survey - Defining Restoration Targets – Species Composition and Biomass	**Field exercise**	**2**	**Forest**
3-4	Rapid site assessment - determining degradation level	**Field exercise**	**2**	**Restoration site**
5	Designing an effective restoration strategy	**Practical**	**1**	**Lab**
6	Selecting tree species for forest ecosystem restoration	**Practical**	**1**	**Lab**
7-8	Forest phenology - data collection and seed collection	**Field exercise**	**2**	**Forest**
9-10	Tree nursery techniques - seed germination and seedling growth experiments	**Field exercise**	**2**	**Nursery**
11-12	Field trials - data collection	**Field exercise**	**2**	**Restoration site**
13-14	Biodiversity monitoring - bird diversity & vegetation surveys	**Field exercise**	**2**	**Restoration site**
15	Data analysis - germination tests, tree survival and growth	**Practical**	**1**	**Lab**
16	Data analysis - tree and bird species richness	**Practical**	**1**	**Lab**
17	Restoration planning logistics - timing, costing and labour	**Practical**	**2**	**Lab**
	TOTAL PRACTICAL SESSIONS*		**18**	

LECTURE NOTES



Forest restoration by the framework species method in northern `Thailand: Upper: Mon Cham site planted 2012; Lower: restored forest merging with original forest 2022

1. Recognizing and Understanding Forest Types

The reference ecosystem is a central concept of restoration science. It defines the target, at which restoration is aimed. International restoration guidelines define it as "… *the condition of the ecosystem as it would be had it not been degraded, adjusted as necessary to accommodate changed or predicted change in biotic or environmental conditions (e.g., climate change)"* (Gann et al., 2019). So, it's important to know which forest ecosystem type is indigenous to the restoration site

Know your reference forest type

Two broad categories of forest ecosystem dominate the region: deciduous forest types (from the lowlands up to about 1,000 m above sea level) and evergreen forest types (above about 1,000 m above sea level). For full descriptions of forest types see Chapter 3 of Forest Restoration Research Unit (2005) (https://www.forru.org/library/0000153) and Maxwell, J. F. & S. Elliott (2001) (https://www.forru.org/library/0000027).

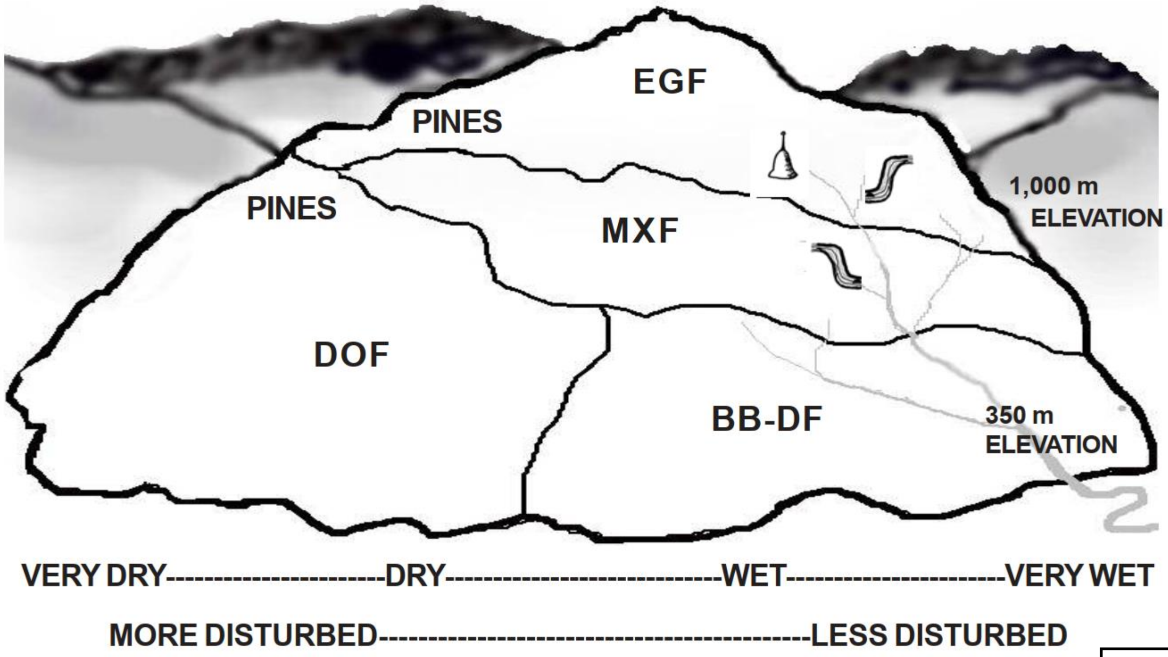
Figure 1.1 *- Diagramatic representation of the distribution of main forest types on a typical mountain EGF= Evergreen Forest; MXF = Mixed Evergreen-Deciduous Forest; BB-DF = Bamboo-Deciduous Forest (former Teak Forest); DOF = Deciduous Dipterocarp-Oak Forest*

Distinguishing characteristics of teak forest or bamboo-deciduous forest (BB-DF)

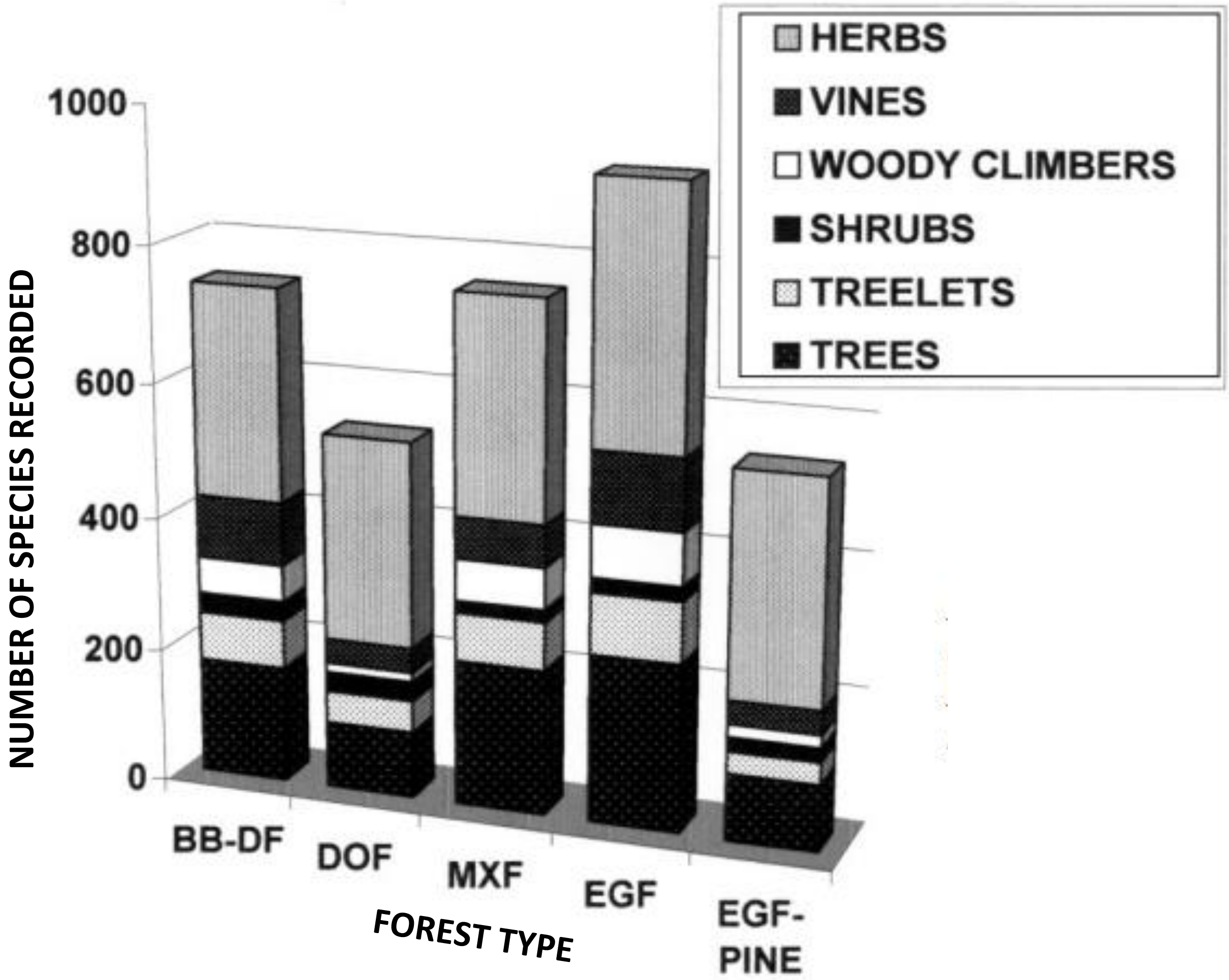
Most former teak forest have been replaced by bamboo-deciduous forest, following logging. Such forest grows on fertile soils from 300 to 900 m above sea level, with tall trees (20-30 m tall) producing a patchy canopy, becoming sparse in the dry season. Remnant teak trees and an understorey, dominated by bamboos are indicative. At least 180 tree species occur in such forest, of which more than 70 % are deciduous, but none approaches the former dominance of teak. Some of the more characteristic ones include valuable commercial tree species such as *Xylia xylocarpa*, *Dalbergia cultrata*, *Pterocarpus macrocarpus*, *Lagerstroemia cochinchinensis*, *Chukrasia tabularis* and *Afzelia xylocarpa*. Woody climbers (lianas), often quite large, are a notable feature of this forest type (*Millettia*, *Combretum, Congea* spp). Epiphytic orchids and ferns are common. A dense shrub layer is usually present, dominated by abundant bamboos, particularly in more disturbed areas e.g., *Bambusa* and *Dendro-calamus* species. The ground layer consists mostly of mixed herbs and grasses, the latter especially where fires occur. The ground is mostly bare during the dry season. The first herbs to appear are gingers (e.g., *Globba* and *Kaempferia* species, orchids and aroids (e.g., *Amorphophallus* species) which tend to flower in April before their leaves appear. As the rainy season starts, more species appear and flower e.g., *Curcuma parviflora, Geodorum recurvum, Habenaria thailandica and Peristylus constrictus*. By about July, ferns and their allies begin to proliferate, such that by August, the ground is covered with a diverse herbaceous vegetation, which dies back and later burns in the dry season.

Figure 1.2 *- Plant-species richness in each forest type for Doi Suthep-Pui National Park (northern Thailand) by plant habit.*

1.1


EGF
PINES
PINES
MXF
DOF
BB-DF
1,000 m ELEVATION
350 m ELEVATION
VERY DRY----------------------DRY---------------------------WET----------------------VERY WET
MORE DISTURBED--LESS DISTURBED

1.2


HERBS
VINES
WOODY CLIMBERS
SHRUBS
TREELETS
TREES
NUMBER OF SPECIES RECORDED
0
200
400
600
800
1000
BB-DF
DOF
MXF
EGF
EGF-PINE
FOREST TYPE

Distinguishing characteristics of teak forest or bamboo-deciduous forest (BB-DF)

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Factors limiting restoration of BB-DF?

Bamboos are aggressive competitors. Their dense root systems fully exploit the soil and, in the dry season, they smoother nearby tree seedlings with a dense layer of leaf litter. Consequently, trees planted near large bamboo clumps cannot compete and gradually fade away. Therefore, controlling the spread of bamboo is essential for the successful restoration of bamboo-deciduous forest. Luckily bamboo canes and bamboo shoots are useful local products, so local people can usually be encouraged to harvest them and help to give planted trees a better chance to survive. Bamboos and smaller grasses also constitute a serious fire hazard. Weeding, firebreaks and an effective fire prevention programme are therefore particularly important when restoring this forest type.

Distinguishing characteristics of deciduous dipterocarp-oak forest (DOF)

DOF grows in very dry or degraded areas, from the lowlands up to about 800-900 m elevation, along dry ridges with little or no top soil, alternating with BB-DF in the moister gullies. To recognize this forest type, look for short trees (rarely exceeding 20 m) forming an open or irregular canopy. A ground layer, dominated by grasses and sedges, is characteristic. Woody climbers are rare and the shrub layer consists mainly of the saplings of the common tree species. Large bamboos are absent. More than 80% of tree species are completely deciduous, shedding their leaves in the dry season and flushing green again, usually before the onset of the rainy season. With "only" around 100 tree species, of which 24 are common or abundant, deciduous dipterocarp-oak forest has a relatively low tree species richness compared with the other forest types.

With their huge leaves and massive winged fruits, the dipterocarps are easily recognized and are characteristic in this forest type (*Dipterocarpus tuberculatus*, *D. obtusifolius* etc.) Other common tree species of the Dipterocarpaceae include *Shorea* and *Hopea* species. Oaks and chestnuts, members of the family Fagaceae, are the next most easily recognized group of tree species, especially when they are in fruit, *Quercus, Lithocarpus* and *Castanopsis* spp*.* Where fires are frequent, oaks and chestnuts may be rare or absent, but if such areas are protected from fire from 30 years or more, they can slowly re-establish themselves, provided mature, seed-producing trees survive nearby. The small, fire-resistant palm *Phoenix loureiri*, so-called because it sprouts new leaves after fire from a woody stem, is an easily recognized indicator species of this forest type. Deciduous dipterocarp-oak forest supports only 14 species of woody climbers, but the deciduous species *Spatholobus parviflorus* and *Celastrus paniculatus* are characteristic as is the epiphytic vine *Dischidia major* (Asclepiadaceae), which supports ants' nests in its specialized bladder-like leaves. The ground layer is dominated by grasses and sedges which dry out in the hot season providing very combustible fuel materials for fires. Amongst the grasses species of the ginger family (Zingiberaceae) are quite common, including *Curcuma*, *Globba* and *Kaempferia* species*.* In burnt areas at the upper elevational limit of this forest type, pine (*Pinus kesiya*) sometimes grows amongst the dipterocarps.

Factors limiting restoration of DOF

Most DOF sites were originally disturbed by logging and have been subsequently degraded by decades of chopping for fire-wood, cattle browsing and frequent burning. The DOF sites that are currently available for restoration, are mostly those with soils too poor to have been completely cleared of trees and cultivated. They often retain some stunted trees or coppicing tree stumps of a few highly resilient (usually wind-dispersed) species. This means that the number of trees planted can be correspondingly reduced (often to as low as 1,250-1,875 per hectare) to compensate for the density of trees or stumps remaining. Restoration usually focusses on enrichment planting, to i) increase the diversity of tree species present; ii) re-introduce fleshy-fruited tree species, attractive to wildlife and iii) improve soil conditions (e.g., by planting legumes). In the lowlands, human population density is highest, so conflicts between forest restoration aims and human needs are intense. A high level of commitment from local communities is vital to cease disturbances that will endanger the planted trees. Education and public relations are, therefore, critical for successful restoration.

Dried grasses and leaf litter provide ideal fuel for fire. Therefore, fire prevention measures are particularly important at DOF sites. Soil conditions are very poor, with highly eroded, lateritic soils, with impeded drainage and low nutrient levels. Digging holes for tree planting in such soils is very hard work, so the labour costs for tree planting can be high. In the dry season, the upper soil layers quickly dry out, whilst in the rainy season, the soil becomes waterlogged due to poor drainage. This suffocates tree roots, killing the planted trees. Applying mulch or using polymer gels, when planting trees, can help reduce immediate post-planting mortality. Watering the trees immediately after planting can also help increase survival of planted trees. Hire a water tanker if the site is accessible by road. Frequent fertilizer application is mandatory and soil amelioration measures before planting, e.g., green manure, should be considered.

Distinguishing characteristics of mixed evergreen-deciduous forest (MXF)

In a narrow band at mid-elevations (about 800-1,000 m elevation or from 600 m in permanent stream valleys) a transitional zone between evergreen and deciduous forest types occurs. Mixed evergreen-deciduous forest consists of a diverse community of tree species from both evergreen and deciduous forest types, but it also supports many species, which do not occur in any of the other forest types. In general, canopy height varies from 20 to 30 m but emergent trees, exceeding 30 m, are common. Canopy cover is usually complete, though less dense than in evergreen forest. Woody climbers are a major feature. Epiphytes are common. Bamboos are present, but are less prevalent than in BB-DF. There is usually a dense ground layer of herbs and tree seedlings. Grasses rarely dominate the ground layer, except where fire has occurred.

More than 200 tree species grow in MXF, of which only about 43 % are deciduous. There are strong similarities between the tree floras of MXF and BB-DF. Of the 38 tree species that are common or abundant in the former, 21 (55 %) are shared with the latter.
The most easily recognized evergreen canopy tree species, characteristic of this forest type, are the tall, emergent, evergreen, dipterocarps: *Dipterocarpus costatus* and *D. turbinatus*, but these trees appear very different to the large-leaved dipterocarps of DOF. With their massive grey trunks, small leaves and dense, broad crowns they resemble giant sticks of broccoli.

Other tree species common in this habitat include *Duabanga grandiflora*, *Irvingia malayana*, *Mangifera caloneura* and *Eugenia albiflora*. Common deciduous canopy trees include *Lagerstroemia cochinchinensis* and *L. tomentosa*, *Spondias pinnata*, *Terminalia mucronata* and *Engelhardia serrata*. More than 60 species of woody climbers have been recorded in MXF, including *Combretum, Ventilago,* and *Tetrastigma* species. Epiphytes are also diverse, including fig trees, orchids, ferns, Gesneriaceae and Loranthaceae. The ground flora is also diverse and includes at least 278 herb species as well as seedlings and saplings of the trees and shrubs.

Factors limiting restoration of MXF

MXF sites are often located on steep slopes, so access to them can present problems. As with BB-DF, large bamboos can inhibit growth and survival of planted trees, so some control of them may be necessary to allow tree establishment. Most MXF sites are near permanent streams, so watering trees after planting is usually feasible. The large dipterocarps, characteristic of this forest type, have wind-dispersed seeds. Where remnant mature trees survive, there is usually no need to plant them. However, where they are absent, consider adding indigenous dipterocarp species to the mix of framework tree species planted, to maintain the distinctive structure of MXF. Dipterocarp seedlings grow very slowly in nurseries, so start collecting seeds at least 2 years in advance.

Distinguishing characteristics of evergreen forest (EGF)

Evergreen forest is quite distinct from the deciduous forest type. The main canopy is higher and denser, often exceeding 30 m in height. Emergent trees sometimes occur and, beneath the main canopy, there is usually a lower story, comprised of smaller trees, treelets and shrubs. Woody climbers are common. The high abundance of epiphytes is an obvious feature of evergreen forest. In addition to vascular plants, bryophytes and lichens often encrust tree trunks and branches. Tall bamboos are scarce. The ground flora is often dense and consists of tree seedlings and herbs, including several with a saprophytic or parasitic way of life. Grasses occur only in disturbed areas. Fires are less common in evergreen than in deciduous forests, but evergreen forest is less resilient of fire damage than deciduous forest. In particular, shrubs and the ground flora take many years to recover after burning. Evergreen forest supports more tree species than any other forest type, 250 have been recorded. Although no species or genus dominates, several families tend to be better represented there than in the deciduous forest types e.g., Lauraceae, Fagaceae, Theaceae, Moraceae, Magnoliaceae, etc. The understorey is denser than that of forests at lower elevations and is especially diverse in stream valleys. A high species richness of woody climbers (78 species) is a notable feature of evergreen forest from several families: Rutaceae, Moraceae, Combretaceae and Rubiaceae. Also common are several species of *Tetrastigma* (e.g., *T. laoticum* and *T. obovatum* (Vitaceae)) and *Mucuna macrocarpa* (Leguminosae, Papilionoideae), as well as rattans (Palmae) e.g., *Calamus kerrianus* and *Plectocomia kerrana*.

Epiphytes abound in evergreen forest. The 82 species recorded there include trees, shrubs, vines and herbs, including several species of "strangling" fig tree, which begin life as epiphytes e.g., *Ficus superba*.

The herbaceous ground flora (>300 species) is very diverse. Two of the most characteristic ferns of this forest type are *Brainea insignis* and *Dicranopteris linearis*, in open, fire-damaged places; whilst *Arachnoides henryi* and *Tectaria herpetocaulos*, *Thelypteris subelata* and *Diplazium dilatatum* grow in shaded, more pristine areas. Gingers and aroids are frequent. Parasitic or saprophytic members of the ground flora include several *Balanophora* species: *Sapria himalayana* and several rare orchids e.g., *Epipogium roseum.*

Factors limiting restoration of EGF

Because EGF supports more tree species than the other forest types, tree planting should aim to include as many species as possible, within practical limits, to kickstart biodiversity recovery. A large proportion of evergreen forest trees have large seeds, which are dispersed by large animals e.g., rhinos, elephants, wild cattle etc. Most such large animal species have been extirpated or remain only as tiny, isolated populations. Therefore, including tree species with large fleshy fruits amongst those planted can help to conserve such tree species, which now have very limited natural opportunities for seed dispersal. Deciduous trees, which grow in evergreen forest, often make the best framework species for accelerating biodiversity recovery after planting (e.g., *Acrocarpus fraxinifolius, Erythrina subumbrans, Gmelina arborea, Hovenia dulcis, Melia toosendan, Spondias axillaris* etc.). Their deciduous habit makes them resistant to drought-induced stress during the first hot-dry season after planting. Therefore, they usually have high survival rates. Soils at EGF sites are usually richer in nutrients than deciduous forest soils are, so less fertilizer may be required after tree planting. In contrast, weed growth tends to be more rapid. Weeding may, therefore, have to be carried out more frequently than in deciduous forest sites, with correspondingly higher labour costs. EGF sites at higher elevations may be above the spring line. This makes watering the trees after planting unfeasible, since access to the planting sites by water tankers is also likely to be difficult. Planting must therefore be delayed until rainfall is reliable.

Reading

Forest Restoration Research Unit, 2005. How to Plant a Forest: The Principles and Practice of Restoring Tropical Forests. Compiled by Elliott, S., D. Blakesley, J.F. Maxwell, S, Doust & S. Suwannaratana. Biology Department, Science Faculty, Chiang Mai University, Thailand, 200 pp. Chapter 3. https://www.forru.org/library/0000152

Gann, G.D., et al. (2019), International principles and standards for the practice of ecological restoration. Second edition. Restor Ecol, 27: S1-S46. https://doi.org/10.1111/rec.13035

Maxwell, J. F. & S. Elliott, 2001. Vegetation and Vascular Flora of Doi Sutep–Pui National Park, Chiang Mai Province, Thailand. Thai Studies in Biodiversity 5. Biodiversity Research & Training Programme, Bangkok. 205 pp. https://www.forru.org/library/0000027

2. The Value of Forest Ecosystems

Benefits

Benefits of forest ecosystem restoration can be grouped into 5 categories: forest products, watershed services, carbon sinks, biodiversity conservation and ecotourism.

Products

At least 150 non-timber forest products (NTFPs), including bamboos, nuts, essential oils and pharmaceuticals are traded internationally, contributing about US$ 4.7 billion/year to the global economy. Others are used for subsistence e.g., foods, fuel-wood, medicines and household products (e.g., glues, resins, rubber, oils, fibres etc.). Subsistence products are not bought or sold in markets; their value does not contribute towards GDP. However, their value is estimated as replacement value - the money that would be spent to replace them, if they were not gathered from forests. Harvesting NTFP's must be done sustainably. Standing crop and growth rate of each product are measured; annual harvest must not exceed annual production. This is achieved by setting quotas and issuing permits. The total harvest is recorded, as well as the harvest effort (number of permits issued or time spent by the collectors). If yield (quantity collected/effort) falls, quotas are reduced to prevent overharvesting. However, the costs of administering such systems can be higher than the value of the products collected. Therefore, the trend is to bring NTFP's into cultivation. This can actually encourage forest clearance, to provide land to cultivate the products.

Watershed Services

Restoration reduces water yield (as transpiration through tree crowns increases), but outflow becomes less seasonal. Forests enrich soils with organic matter, which increases their field capacity (gm water stored per gm dry soil). Such soils soak up water during the rainy season (reducing floods) and release it during the dry season (reducing droughts). Restoration reduces soil erosion. Infiltration is increased and runoff reduced, reducing floods, landslides and sedimentation of watercourses, including irrigation systems.

Carbon

Global climate change is caused by a build-up of greenhouse gases in the atmosphere, mostly emitted burning fossil fuels (coal and oil) to generate power, for transportation and industrial production (particularly the cement industry). Forests absorb atmospheric CO_2 during photosynthesis, but also emit some during respiration, decomposition and especially during forest fires. Globally, however, forests are net carbon sinks, absorbing about twice as much carbon as they emit, amounting to a net—7.6 billion metric tonnes of CO_2 per year (1.5 times more than the United States' annual emissions)[1]. Because of their high productivity, tropical forests constitute about 60% of the total carbon sink provided by all of Earth's terrestrial vegetation. During early growth of young trees, forest restoration results

[1] https://www.wri.org/insights/forests-absorb-twice-much-carbon-they-emit-each-year

in very rapid increase in CO_2 absorption rates. In fact, forest ecosystem restoration sequesters carbon 6 times faster than agroforestry does and 40 times faster than tree plantations (Lewis et al., 2019). Tropical forests store about 240 tC/ha in trees and soil; crop lands, about 80 tC/ha, mostly in soil. So, clearing 1 ha of tropical forest emits about 160 tC, as well as reducing subsequent sequestration rate. Agriculture also releases methane, which is 20 times more efficient at trapping heat than CO_2 is.

Carbon Credits

In response to obligations under international climate-change agreements, several nations limit carbon emissions from industries using "cap-and-trade" systems. This sets limits on how much CO_2 companies can emit. If a company emits more than the limit, they must reduce emissions, absorb emissions onsite or pay for activities that remove atmospheric CO_2 elsewhere, including tree planting, through the purchase of carbon credits. Thus, carbon credits can be used to turn the carbon-storage potential of forest ecosystem restoration into cash. Purchase of one carbon credit allows a company to emit 1 metric ton of CO_2. Money, paid for carbon credits, can then be used to finance forest restoration. Carbon credits are traded on international markets, like stocks and shares. If many companies need to buy them, the price goes up. If many tree projects seek carbon financing, the price falls—the balance between supply and demand. There are two kinds:

- Compliance credits are bought by corporations and governments in order to meet their obligations under national laws or international agreements and
- Voluntary credits bought to offset organizations' "carbon footprints".

The 'voluntary market' is much smaller than the compliance market and the credits are cheaper because the projects, supported by it, do not have to meet the stringent legal requirements compliance credits. REDD+, stands for 'reducing emissions from deforestation and forest degradation'. It is a set of policies and incentives, developed under the UN Framework Convention on Climate Change (UNFCCC), to reduce CO_2 emissions derived from clearing and burning tropical forests. It includes '*enhancement of carbon stocks*', i.e., forest restoration to increase CO_2 absorption. This international framework provides funding and monitoring mechanisms for forest restoration projects that enhance the global carbon sink, while also conserving biodiversity and benefiting local people. Funding comes from carbon credit markets and specially created international funds. The success of REDD+ will depend on improvements in forest governance, as well as capacity-building at all levels, from villagers to policy makers. Several pilot REDD+ projects are testing the concept.

Biodiversity – values

"Diversity" itself is difficult to monetarize. It can be viewed as the sum of the values of products/services from all species combined – with the added value of economic security. The latter arises from the fact that when harvesting a diversity range of forest products, villagers can switch from one product to another, in response to fluctuating market prices. This is difficult or costly with conventional mono-culture plantations (e.g., converting from rubber to oil palm). Mono-culture plantations are therefore high risk/high return systems, whereas diverse forests may offer lower returns but provide economic stability and security.

Pollination is one of the few environmental services that results directly from biodiversity. Crops, grown near to forest, often have high yields and are of high quality, due to the presence of a diverse community of pollinating animal species that depend on forest habitats to complete their life cycles (Ricketts et al., 2004).

Ecotourism

Ecotourism is another source of income that depends on the maintenance of biodiversity, provided that wildlife and scenery are the main attractions. Interactions between tourism and forests will be covered in detail in the next lecture.

Realizing total value

In 2009, The Economics of Ecosystems and Biodiversity initiative estimated that tropical forest ecosystem services are worth USD 6,120/ha/year (USD 7,732 today, after inflation), based on data from 109 studies (TEEB, 2009) (Figure 2.1). Such values depend on the two of the fundamental indicators of restoration: biomass accumulation and biodiversity recovery (Figure 2.2). Converting value into income requires good governance (e.g., peace, laws, land tenure, institutional support etc.), allowing local people to access diverse income streams that could potentially flow from restored forest ecosystem, whilst simultaneously regulating for sustainable management. Access to start-up capital is needed, as well as investment in human resources (particularly capacity building). Skillful marketing and advertising are also needed, to convince people to pay for products and services (e.g., flood prevention, water, carbon storage), which were formerly regarded as free or very low cost.

Reading

Lewis, L, C. Wheeler, E. Mitchard & A. Koch, 2019. Restoring natural forests is the best way to remove atmospheric carbon. Nature 568: 25-28

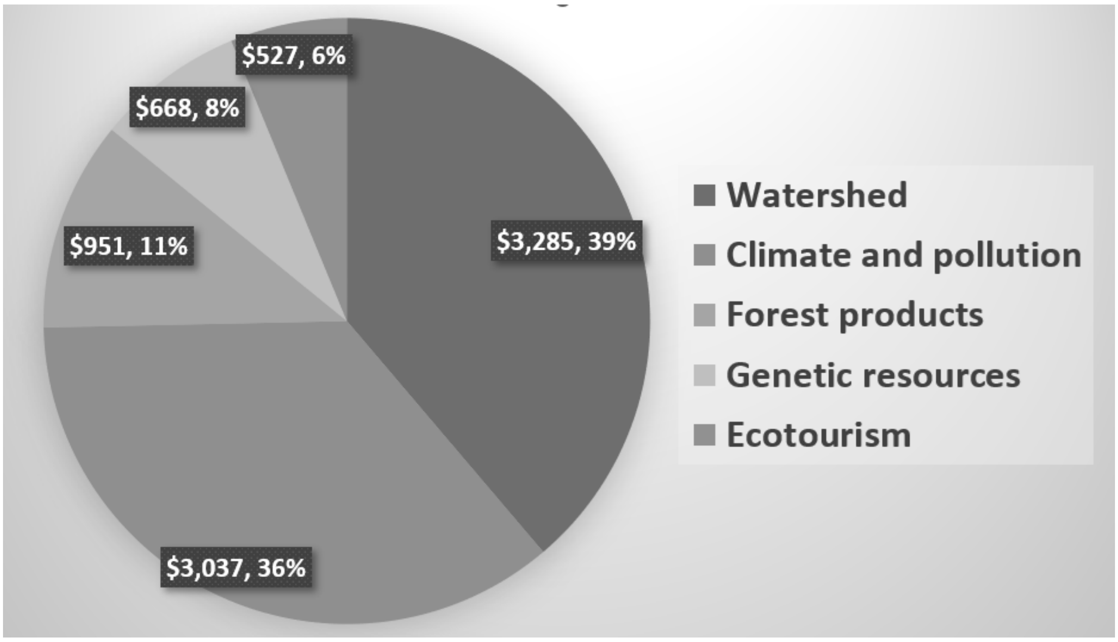
Ricketts, T., Daily, G., Ehrlich, P. & Michener, D., 2004. Economic value of tropical forest to coffee production. PNAS 101 (34) 12579-12582; DOI: 10.1073/pnas.0405147101

TEEB. (2009). TEEB climate issues update 2009. https://teebweb.org/publications/other/teeb-climate-issues/

Figure 2.1 *– Potential economic values of ecosystem products/services from 1 ha of tropical forest (US$/y) from the Economics of Ecosystems and Biodiversity https://teebweb.org/publications/other/teeb-climate-issues/*

Figure 2.2 *– Potential values of forest restoration are all based on two restoration goals – rapid recovery of both biomass and biosiversity.*

2.1



2.2

	DEPENDS ON	
ITEM	Biomass Accumulation	Biodiversity
Biomass Accumulation		Diverse forest ecosystems partition use of light, water & nutrients among species efficiently to reduce interspecific competition
Biodiversity	As biomass accumulates it becomes partitioned among a greater diversity of structures, creating a diversity of niches, which become occupied by a diversity of species	
Carbon	~47% of tree biomass is carbon	Via knock-on effects on biomass accumulation
Forest Products	Quantity	Variety of products - economic adaptability & security (buffering against fluctuating market prices)
Watershed Services I: *Flow regulation (flood/drought mitigation; irrigation for agriculture)*	Soil organic matter accumulation --> increasing soil moisture-holding capacity	Tree species diversity linked to increased interception, decreased runoff (flash floods) and improved infiltration
Watershed Services II: *Soils (erosion landslide mitigation)*	Below-ground root biomass --> reduces erosion/landslides	Different tree species root to different depths. Tree species diversity linked to decreased erosion.
Ecotourism	Knock-on effects on ecosystem structure, niches and biodiversity	Biodiversity-rich native forests are attractive to ecotourists

3. Traditional Uses of Forest Products – Economic and Cultural

Karen people, have a rich tradition of using plants and other forest products for food, medicine, and cultural purposes. Run a structured exploration and discussion session to encourage students to share their existing knowledge about their community's use of forest plants and animals both for utilitarian and cultural purposes. The goal is to come up with a value of such products, as a component of the overall value of forest restoration:

1. Introduction: introducing the topic of the traditional use of forest plants and animals. Explain that the goal is to put a value on community use of such non-timber forest products (NTPS) as one of the components of the overall value of forest restoration.
2. Group work: Divide students into small groups and assign each group a specific use-class of forest product e.g. foods, medicines, construction materials, household objects (utensils) and materials (glues, resins dyes etc.), ceremonial and cultural etc. Prepare a chart for each group with the headings - local and scientific names, plant/animal part used, description of use, seasonal availability, local market price and an estimate of approximately how much of the product might be harvestable from 1 ha of restored forest. The final column should be an estimate of the total value of the product per hectare per year. This information should come from the student's personal experience, but in case secondary information are needed to stimulate the discuss, some useful references are listed at the end.
3. For subsistence products, re-iterate the concept of "replacement value" from lesson 2 – how much would a family have to spend in the market to replace products gathered from the forest and used at home?
4. Presentation: Ask each group to present their findings to the class and encourage students to discuss the estimates of annual value per hectare of each product until a class consensus is reached.
5. Reflection: At the end of the activity, calculate the value of each sub-class of products and the overall value of all products. Ask the students consider the balance between subsistence use and marketed forest products. Ask them to consider how forest products could be marketed to attract customers and how they might be converted into value-added products such as preserved foods and processed medical remedies etc. What might be the impact of harvesting on the plant/animal populations in the forest and how could harvesting be implemented sustainably.
6. Finally, ask the students to consider how they can put a value on species of purely cultural significance.

Reading

Allen, D. E., Win, K. K., & Win, N. N. (2007). The Karen Medicinal Plant Compendium. Karen Environmental and Social Action Network.

Deverall, S. J., & van Andel, T. (2017). Karen Ethnobotany: Past, Present and Future. Royal Botanic Gardens, Kew.

Phonpadith, A., & Hongsanan, S. (2017). Plants Used by the Karen Hill Tribe in Northern Thailand. Chiang Mai University.

Sittivongkam, P., & Steinberg, M. K. (2012). Traditional Forest Knowledge of the Karen in Northern Thailand. Karen Environmental and Social Action Network.

4. THE DRIVERS OF DEFORESTATION

Primary Forest Loss

Deforestation is well-recognized as a major environmental problem worldwide. Since primary tropical forests, in particular, are home to more than half of the planet's terrestrial plant and animal species, their degradation or destruction constitute one of the most serious threats to global biodiversity. From 2001 to 2021, annual losses of primary tropical forests amounted to 2.5-6 million hectares per year (Figure 4.1). From 2002 to 2021, Myanmar lost 666,000 ha of humid primary forest, with annual loss rates accelerating markedly with time (Figure 4.2). In the Kawthoolei region, the increase in deforestation over the decade 2011-2021 has been dramatic (Figure 4.3), compared with the previous decade.

The obvious solution to this problem is to restore tropical forest ecosystems, to a condition similar to that of the original forest. This is termed forest **ecosystem restoration**. It is a specialized form of reforestation—a term, which refers broadly to the re-establishment of any kind of tree cover.

Before restoration commences, the reasons why the forest was originally destroyed must be identified and addressed—the so-called "drivers" of deforestation. Otherwise, restored forest will suffer the same fate as the original forest. Subsequently, incentives, to encourage sustainable management of restored forest must also be identified, along with how to deliver them. Then, stakeholders should be ready to start devising a restoration plan. This is best done through guided discuss groups, with students recording their opinions on post-its, which grouped and order on a board. The facilitator ensures all options are considered, and all students express their views. Group similar ideas together and re-arrange the post-its to produce an overall view of the drivers that need to be addressed before restoration can be successful and the incentives that could encourage restoration at the local level.

Drivers

Below are a few suggested deforestation drivers. The facilitator should ask stakeholders to consider whether they are relevant locally and if so, then assist stakeholders to identify reasons and mechanisms as to why and how each driver operates locally.

Logging—In most tropical countries, forest destruction usually begins with logging. Logging opens up forest areas with roads and, as the supply of timber trees becomes exhausted, the loggers are followed by landless rural people, looking for farmland. The facilitator should encourage students to consider the socio-economic reasons for logging and its legality.

Tree plantations—Forests are often replaced with tree plantations which can continue to meet demands for timber that was formerly harvested from forests. However, such plantations do little to conserve biodiversity and watershed services, nor supply the wide range of forest products, formerly provided by natural forest. The facilitator should encourage students to consider demand for tree plantation products and explore the potential to diversify tree plantations by inter-planting them with native forest tree species.

Agriculture—After logging, remaining trees are often replaced with small-scale agriculture. Small-holders may initially practice low-intensity, slash-and-burn agriculture, but as a growing population increases pressure on the land, more intensive agricultural systems tend to be adopted. As the land value increases, small-scale farmers often sell out to large agro-companies, moving on to clear forest elsewhere. In Asia, conversion of forest to small-scale farms, and replacement of shifting agriculture with more intensive agricultural practices, account for 13% and 23% of deforestation respectively, whilst industrial agriculture, particularly oil palm and rubber plantations, account for 29%. The facilitator should encourage students to consider the socio-economic factors creating the demand for the particular types of agriculture that are replacing forests locally.

Infrastructure development, especially, roads and dams, can also destroy tropical forests. Although such development impacts relatively small areas of forest, it opens up forest areas for settlement and fragments them, isolating small wildlife populations in ever-shrinking forest fragments. The facilitator should encourage students to consider the local political factors that may be operating to support infrastructure developments.

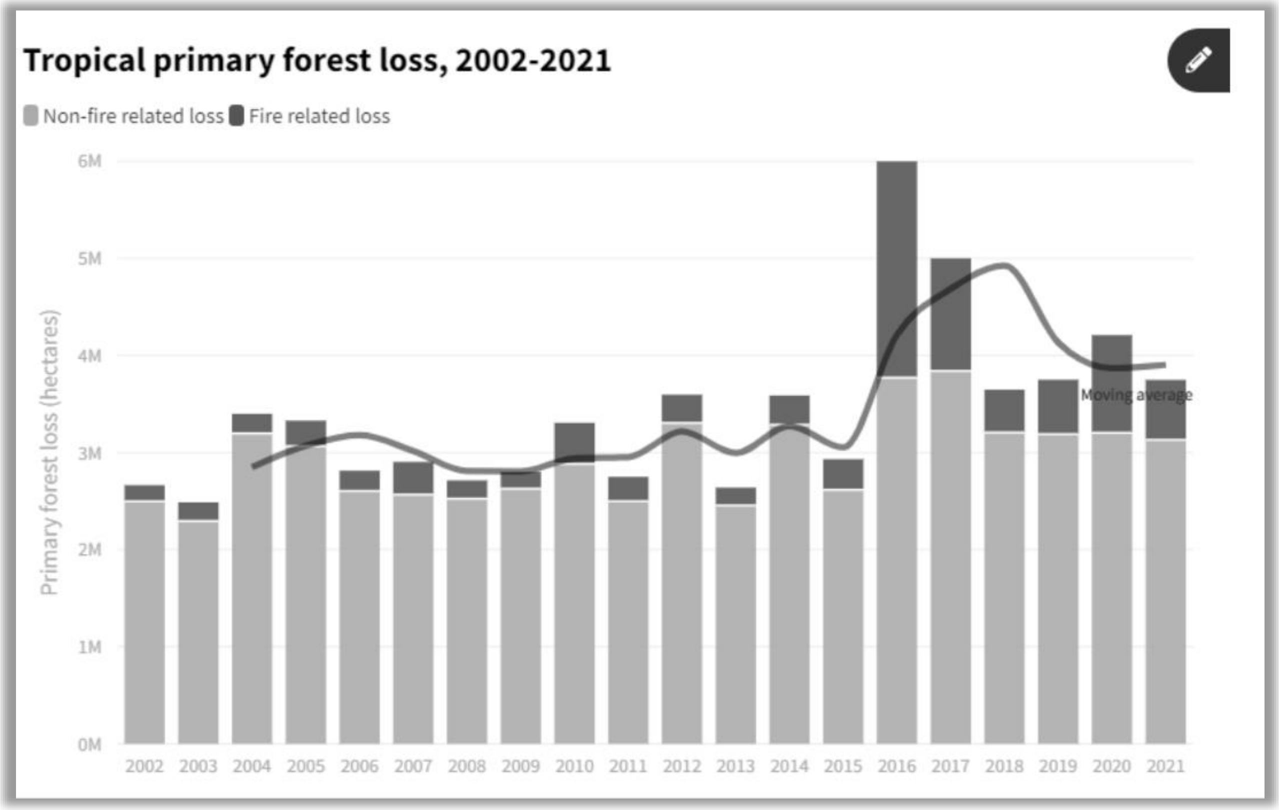
Poverty is a major driver of forest degradation, as poor folk are forced to exploit local forest resources unsustainably, to meet immediate needs. Addressing this driver usually involves developing alternative livelihoods and implementing sustainable harvesting systems.

Poor governance is a major factor that enables deforestation to occur. Although most countries have laws to control forest exploitation, forest departments often lack the authority and funding needed to enforce them. Consequently, more than half of the timber produced is extracted illegally. Forest officials are often poorly paid and are therefore easily corrupted. Local communities are marginalized in decision-making and thus lose their sense of forest stewardship. Consequently, strengthening governing institutions, as well as empowering local communities, is fundamental to successful forest ecosystem restoration.

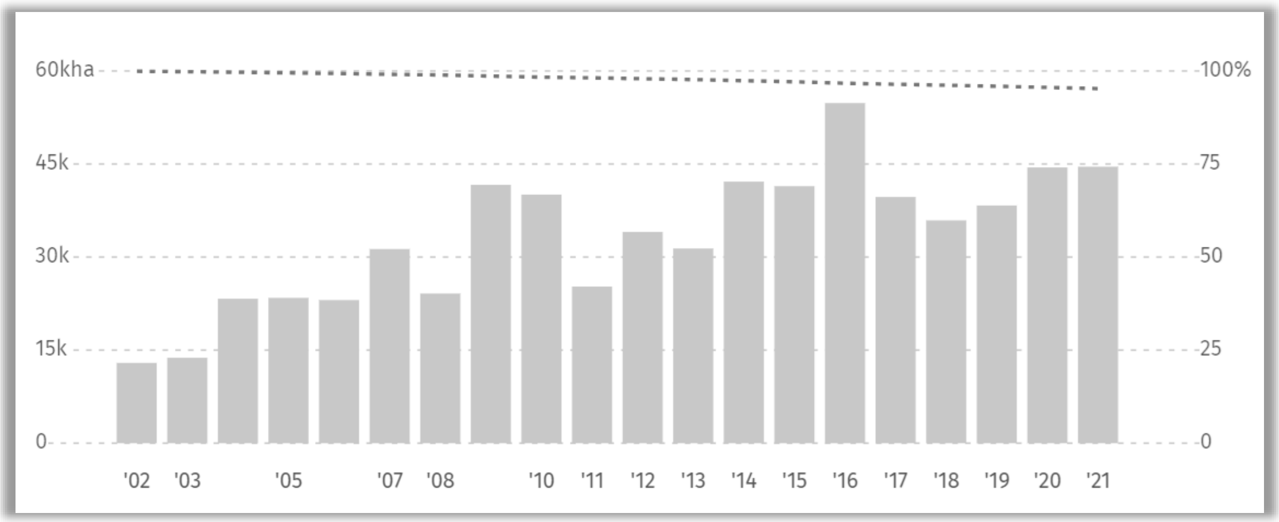
Population pressure—globally, the ultimate cause of tropical deforestation is too many people making too many demands on a finite supply of fertile land. The UN predicts that the global human population will surpass 9 billion by 2050; exceeding Earth's estimated carrying soon thereafter. The fate of tropical forests, ultimately depends on reducing human population growth and consumption. Locally, however, population trends may not follow the global trend. Students should consider local birth/death rates and immigration and out-migration, particularly of the younger generation moving out of rural areas into towns.

Figure 4.1*—Annual loss of primary tropical forests globally*
Figure 4.2*—Annual loss of primary tropical forests in Myanmar*
Figure 4.3 *— Forest loss in the Kawthoolei region. Forest loss (indicated by pink pixels) was fairly low in 2001-2011, but greatly increased in extent over the subsequent decade. Green areas are remaining primary forest.*

4.1


Tropical primary forest loss, 2002-2021
Non-fire related loss
Fire related loss
Primary forest loss (hectares)
6M
5M
4M
3M
2M
1M
0M
Moving average
2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021

4.2


60kha
45k
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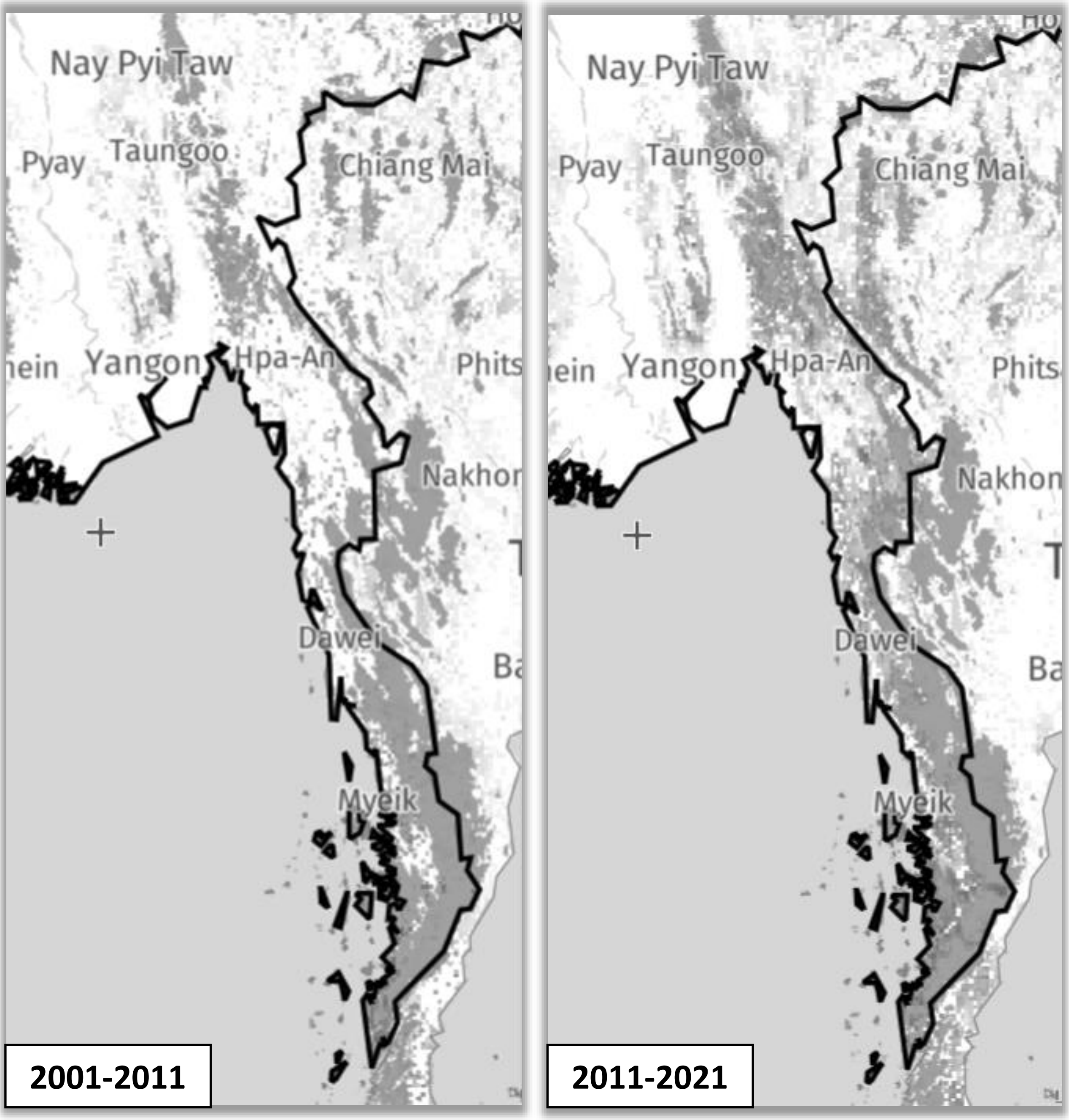
4.3


Nay Pyi Taw
Pyay
Taungoo
Chiang Mai
Yangon
Hpa-An
Phits
Nakhon
Dawei
Myeik
2001-2011
2011-2021

5. Incentivizing Forest Restoration and Sustainable Forest Management

Incentives

Incentives can be "tangible" (quantifiable as cash generated) and/or "intangible" (life-supporting but difficult to quantify). Students should consider which of the following possible incentives apply locally. Estimate annual income per family that could be generated from tangible incentives. For intangible incentives, describe the benefit. Group post-its of tangible and intangible incentives separately, with those that can be both in-between.

Tangible incentives – could include timber, fire-wood, foods (mushroom, honey, vegetables etc.), medicinal plants etc. Incentive value is the market price. If used directly from the forest, then value is the money that would have been spent buying the product in the market (replacement value). Carbon can have tangible value as carbon credits if traded on a carbon market. Potential income from ecotourism is also a tangible benefit.

Intangible incentives – are mostly environmental services provided to local communities and downstream by restarted forest e.g., watershed services such as prevention of soil erosion, landslides and flash floods and provision of water (particularly in the dry season) for irrigation of agriculture downstream. Pollination of crops by forest insects is also difficult to monetize and so could also be regarded as an intangible incentive.

Human aspects of forest restoration are equally as important as scientific aspects. These include the participation, motivation and resourcefulness of local people and the co-operation of government agencies.

Who are the "stakeholders"?

"Stake-holders" include individuals or groups that have any interest in the area of land to be restored or may influence the long-term success of restoration. They should all have some involvement in decision making and in project implementation e.g. government forestry departments, village headman or administrators elected by the community, supportive NGOs, funders and those providing technical support. Poor information flow among stakeholders can cause failure of restoration attempts. Visions of what a forest should be used for, and whose interest it serves may differ among stakeholders. Clear communication mechanisms among stakeholders should be established right from the start of a project.

Motivation is Fundamental

Motivation is the perceived or real benefit gained from any activity. For successful forest restoration, strong community motivation over many years is essential. Local people recognize a diverse range of incentives. Direct exploitation of forest resources for subsistence or income-generation is, perhaps, the most obvious one, but it may not be the primary motivation.

Economic Incentives

Communities may receive money through government departments, NGO's or private companies for their participation in restoration, e.g., as labour for tree planting, to maintain tree plots or prevent/suppress fires. In addition, eco-tourism may generate income. Extractive benefits, particularly in cash-poor communities, may provide significant incentives, provided access to forest resources is legal. In the future, payments for ecological services, including mitigation of climate change through carbon credit payments, might provide powerful financial incentives to restore and protect forest ecosystems. However, at present the legal and institutional mechanisms needed to make such payments are not yet in place.

Environmental motives

Most communities realize the environmental impacts of deforestation, particularly those that reduce agricultural productivity and lifestyle quality (e.g. watershed degradation). A community's motivation to restore forest ecosystems is often related to reducing such impacts. However, watershed protection is a "public good" – with downstream benefits far beyond the local community. So those restoring forests for watershed services should be rewarded from payment from national tax revenue.

Cultural motives

Forests and forest products are important in many cultural practices and often play significant roles in cultural ceremonies, or as components of spiritual belief. Many communities have tree ceremonies at the beginning of the New Year. Similarly, many forest products are still important in traditional medicine and ceremonies.

Political motives

Political considerations are sometimes the most compelling reason for the participation of communities in forest restoration – with the strengthening of land tenure rights being the primary incentive.

How can motivation be sustained?

Motivation at the community level can be sustained when stewardship of the project remains with the community. That is, the community is the lead interest-group in decision-making. Additionally, being publicly credited for the project success enhances community motivation. Communities that develop their own activities (such as, education programs) and enforce their own laws, to aid the sustainable use of their forest areas (e.g. restrictions on hunting and gathering activities), are more likely to sustain long-term project outcomes.

Collaboration is Crucial

Close collaboration ensures that resources are not wasted and prevents confusion and misunderstandings as to the roles of different organizations involved in the project.

How can collaboration be encouraged?

Different stakeholder groups come with different issues, however common goals can usually be identified and used to draw groups together to create joint working strategies. Each stakeholder group can maintain an individual role, but the roles must be clearly stated from the onset. Collaboration is enhanced if the interest groups are prepared to share their motives. Collaboration is maintained when the interest groups believe that their involvement is beneficial to the success of the restoration project and their capacity to direct the restoration project and achieve worthwhile outcomes is sustained. A neutral person or organization that is familiar with the stakeholders and who is not seen as authoritarian or gaining any direct benefit from their involvement can be influential in ensuring collaboration. This neutral authority can act as a 'go between' to diplomatically introduce or transfer ideas to a larger group forum, through sound facilitation techniques.

Local Skills and Resources are Invaluable

Use of existing community skills and resources saves time and money. Indigenous knowledge and skills should be identified and built upon. For example, cheap house-building techniques can be applied to nursery construction. Natural materials and implements, sourced locally, can be also be used as media etc. during nursery operations and tree planting. Many villagers may already have plant-propagation skills. Villagers may also have knowledge of where seed trees grow and the economic uses of proposed framework tree species. This knowledge might include optimum seed collection times and techniques. Fire prevention and control is also old knowledge in many communities that can be easily applied to protect young restoration sites.

… but not all local practices are beneficial to restoration

Some local practices are harmful to restoration, however. For example, a common mistake occurs when preparing a restoration site, when villagers completely clear a site of all vegetation (as they would for agriculture) – including regenerating trees. This reduces the potential for practicing ANR, increases the need for tree planting and greatly increases restoration costs.

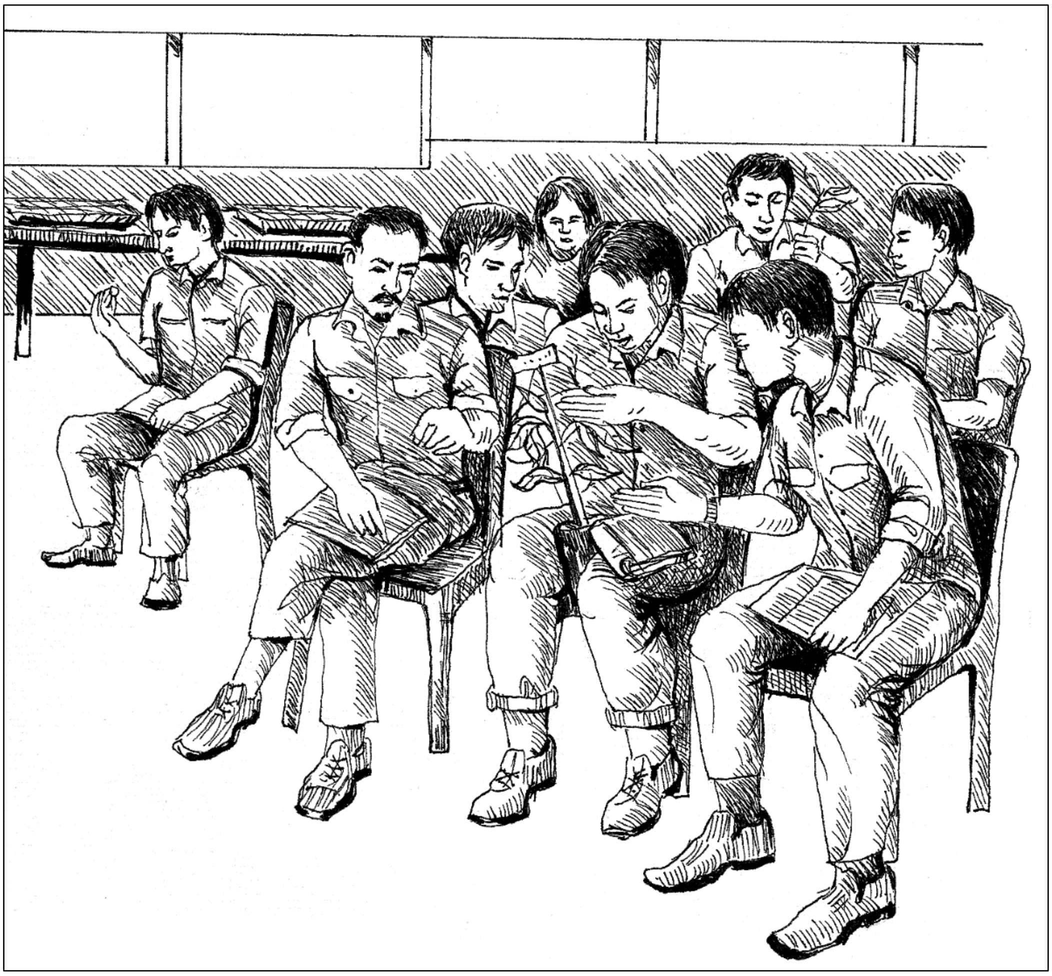
Discussion Groups – Role Play Stakeholders

1. Divide the class into discussion groups of 5-6 participants per group.
2. The members of each group then role-play as representatives of each of the stakeholder holder groups e.g. village committee members, forest officers, NGO officers, donor representatives etc.
3. Each stakeholder group must first identify and precisely define the incentives (economic, environmental, cultural, political etc.) that motivate their participation in the restoration project.
4. The stakeholder groups then self-identify the roles they will play in planning and implementing the project, taking into account the local resources (e.g. knowledge, materials and equipment etc.) that are available.
5. Any duplication in effort should be resolved by sharing responsibility for inputs.

6. Any conflicts among stakeholder groups should be resolved by agreeing to a benefit sharing plan.
7. Finally make a table showing how the work inputs and the benefits will be shared among all stakeholder groups.

Note: this exercise can be applied to a real project if a restoration site has been selected and the class includes representatives from all stakeholder groups. Otherwise it can be run as an imaginary role-playing game.

Online resource: https://www.forru.org/advice/socio-economic-aspects-restoration



6. Ecological Principles of Community Forestry and Sustainable Harvesting

Ecological principles of community forestry are the underlying principles that guide community forestry practices to ensure sustainable forest management. Some of the key ecological principles of community forestry include:

Biodiversity conservation

Community forestry practices aim to conserve and enhance biodiversity within the forest ecosystem. This involves maintaining forest biomass and structural complexity, as well as its species composition, and ecological functioning, including promoting natural forest regeneration and, where necessary, planting indigenous tree species.

Forest restoration

Where community forestry is being practiced on degraded areas, forest practices should focus on restoration. Since community forestry is often targeted at maximizing the production of forest products, there is the temptation to perform restoration by planting mostly economic species. This tends to reduce biodiversity within the forest and simplify forest structure. It can also reduce forest biomass and thus income from carbon credits and can reduce the diversity of forest products. Biodiversity is the key to ecological stability and economic sustainability and should be the top priority when planning forest restoration on degraded areas.

Sustainable harvesting

Community forestry practices aim to sustainably harvest forest resources while ensuring that natural regeneration rates are not adversely impacted. Ideally this involves knowing the standing stock (kg) and production rate (kg/y) of every product harvested from the forest. The annual production rate increases/declines with increasing/declining standing stock. If the harvest rate is lower than the production rate, then the standing stock will increase, and future harvesting rates can also be increased without endangering the species. However, if harvest rates exceed production rates, then both standing stock and production rates decreases, until eventually the species becomes locally extirpated. The opportunity for future harvests is lost. Local people will have to buy the product from the market instead of collecting it from the forest. The problem is that collecting data on standing stocks and production rates is complicated and usually involves hiring expensive outside expertise.

A simpler approach is to implement a quota system based on harvest rates. The harvest rate is the amount of product harvested per hour of searching effort. Each household is allocated a "quota" – the maximum allowable harvest each year (in kg). At first, such quotas are based on conservative estimates of the annual productivity of the forest products. As each family gathers their quota, they note the weight of the products collected and the time spent searching in the community forest.

Harvest rate = Weight /Time

An administrator calculates the total harvest rate over the first two years. If the harvest rate declines then quotas are reduced or even cancelled to all the plant/animal populations to recover. If the harvest rate increases, then quotas can be maintained or even cautiously increased. Quotas may be traded within the community. For example, a family who does not harvest mushrooms from the forest could sell their quota to their neighbor. For this approach to work, all community members must accurately report their search times and weight of gathered products. They must also agree to the quota plan and to the reduction of quotas when necessary. Finally, a trusted administrator must be employed to collate the data and calculate the allowable quota for each year. Usually administration costs are covered by a small fee, paid for the quota licenses.

Community participation

Sustainable harvesting of NTFPs and other community forestry practices must involve the participation of local stakeholders in decision-making. This ensures that community interests and needs are taken into account and that local knowledge and expertise are valued and fully utilized.

Forest protection

Community forestry practices aim to protect forest ecosystems from threats such as forest fires, illegal logging, and encroachment. This involves setting up community-based forest patrols, monitoring forest health, and implementing forest protection measures.

Landscape management

Community forestry practices aim to manage forest ecosystems in the context of the broader landscape. This involves considering the interactions between the forest ecosystem and other ecosystems within the landscape and incorporating landscape-level planning into forest management practices. The landscape approach has been formalized into the acronym "FLR" which stands for forest landscape restoration. It is defined as "a planned process, which aims to regain ecological integrity and enhance human well-being in deforested or degraded landscapes"2 (`Reitbergen-McCracken et al., 2007). It provides procedures whereby site-level restoration decisions conform to landscape-level objectives.

The goal of FLR is to achieve a compromise between meeting the needs of both humans and wildlife, by restoring a range of forest functions at the landscape level. It aims to strengthen the resilience and ecological integrity of landscapes and thereby keep future management

[2] A forested landscape is considered to be degraded when it is no longer able to maintain an adequate supply of forest products or ecological services for human well-being, ecosystem functioning and biodiversity conservation. Degradation can include declining biodiversity, water quality, soil fertility and supplies of forest products as well as increased carbon dioxide emissions.

options open. Local communities play a critical role in shaping the landscape, and they gain significant benefits from restored forest resources, so their participation is central to the process. Therefore, FLR is an inclusive, participatory process.

FLR combines several existing principles and techniques of development, conservation and natural resource management, such as landscape character assessment, participatory rural appraisal, adaptive management etc. within a clear and consistent evaluation and learning framework. Assisted natural regeneration (ANR) and tree planting are just two of many forestry practices that may be integrated into an FLR program. Others include protection and management of secondary and degraded primary forests, agro-forestry and even conventional tree plantations.

The achievements of FLR can include:

1. Identification of the root causes of forest degradation and prevention of further deforestation.
2. Positive engagement of people in the planning of forest restoration, resolution of land-use conflicts and agreement on benefit-sharing systems.
3. Compromises and land-use trade-offs that are acceptable to all stakeholders.
4. A repository of biological diversity of both local and global value.
5. Delivery of a range of utilitarian benefits to local communities including:
    - a reliable supply of clean water;
    - a sustainable supply of a diverse range of foods, medicines and other forest products;
    - income from ecotourism, carbon trading and from payments for other environmental services and
    - environmental protection (e.g. flood/drought mitigation and control of soil erosion).

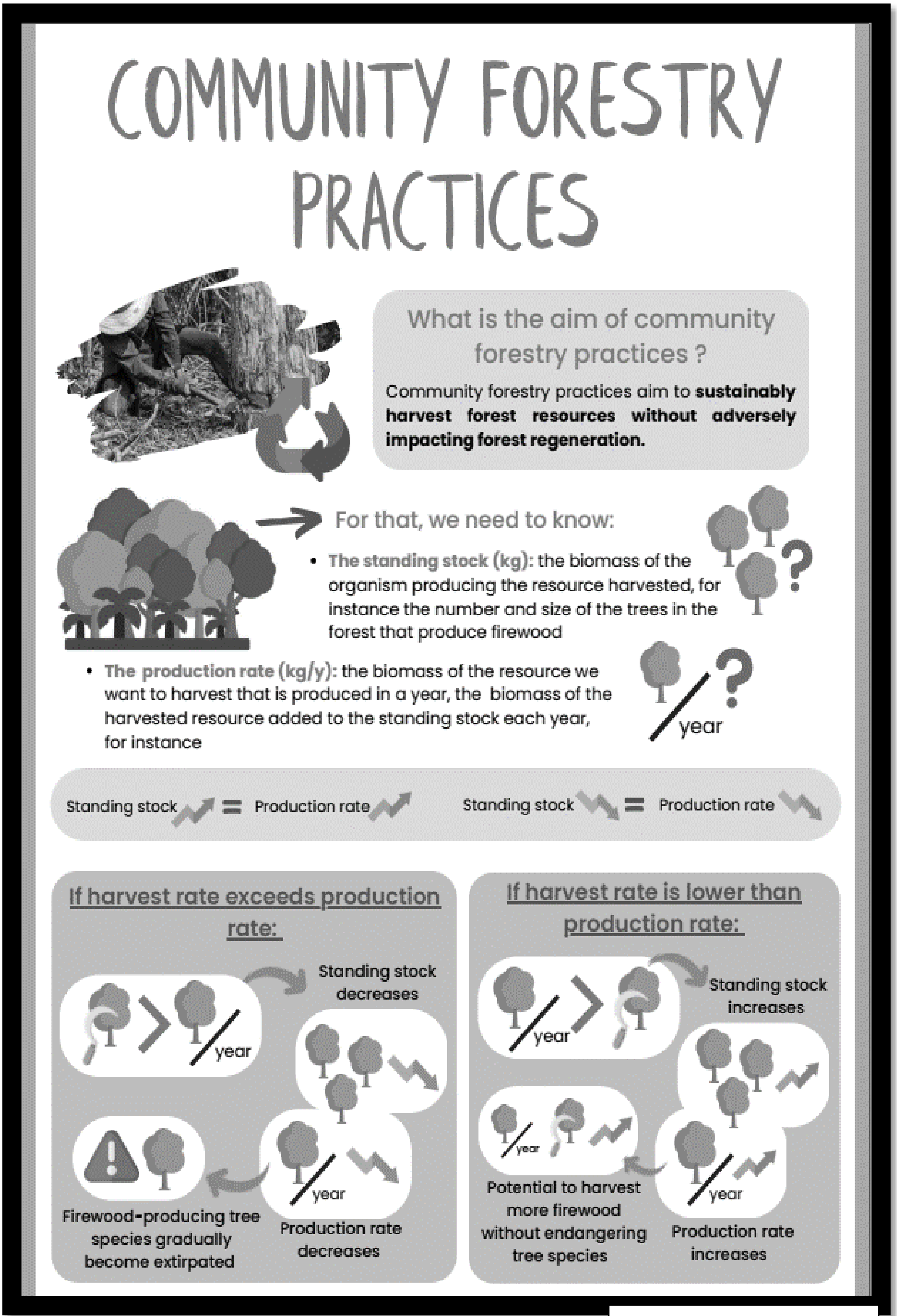
The concept of FLR is the result of collaboration among the world's leading conservation organizations including IUCN-The World Conservation Union, the World-Wide Fund for Nature (WWF) and the International Tropical Timber Organization; several comprehensive text books on the subject are available (e.g. Reitbergen-McCracken et al., 2007; Mansourian et al., 2005; Lamb, 2011).

Reading

Lamb, D., 2011. Regreening the Bare Hills. Springer, Dordecht.

Mansourian, S., D. Vallauri, and N. Dudley (eds.) (in co-operation with WWF International), 2005. Forest Restoration in Landscapes: Beyond Planting Trees. Springer, New York.

Reitbergen-McCraken, J., S. Maginnis and A. Sarre, 2007. The Forest Landscape Restoration Handbook. Earthscan, London.



Credit Mathilde Le LEvier

7. Human Rights Issues Associated with Forest Restoration

The restoration of tropical forest ecosystems and their sustainable management are associated with several human rights issues. The success of forest ecosystem restoration depends on the generation of benefits that are equitably shared among all stakeholders. Such benefit sharing provides incentives that enable and empower local people and other stakeholders to work together, firstly to implement restoration, and then to conserve the restored forest. Imbalance of power amongst the stakeholders, leading to abuse of human rights, creates jealously and discontent with restoration projects. This can manifest as protests that can result in forest destruction. Therefore, involving *all* stakeholders in planning and implementing restoration is essential for its long-term success, since it ensures that human rights issues are addressed right from the start.

Land and resource rights

Land tenure is the legal recognition and protection of a person's right to use and control a particular piece of land. It is crucial for forest restoration because most restoration occurs on land that is unofficially occupied or un-tenured. Such land is often public or common land and may be used by marginalized communities, who have little or no official recognition of their land tenure rights. This lack of recognition can lead to land conflicts and deprive communities of their livelihoods and cultural practices.

Stateless persons are particularly vulnerable in such circumstances, since, without legal recognition of their identity, they can have no land tenure. They may be excluded from initial discussions to plan forest restoration, and state agencies may not recognize their legitimacy to participate. NGOs can play a crucial role by advocating for such communities to be allowed to participate in restoration and share in its benefits.

“Customary tenure” usually refers to land controlled by a community due to long history of occupation, even though no land-rights documents may exist. Resources under customary tenure are mostly used to meet local livelihood needs: agricultural production, hunting, foraging, grazing, fishing, and spiritual purposes. Since customary land tenure arrangements existed before the creation of modern state structures or legal frameworks, they are usually not formally recognized or protected by governments.

For example, lack of legal recognition of customary land tenure systems in Myanmar has led to conflicts between communities and the government or private companies seeking to exploit the land. In the Tanintharyi Region of Myanmar, the Karen people have been living in and managing the forests for generations, but their customary land-tenure systems are not recognized under Myanmar's laws. Threats to land tenure security intensified, since the 2012 ceasefire, along with a mushrooming of investment in land-based industries such as logging, mining, and plantation agriculture. The military coup in 2021 increased the threat of destructive development. Consequently, the need to document and register the lands of Karen communities to assist them in defending their lands against confiscation and destruction is urgently needed. An NGO, KESAN, works on land and natural resource issues in collaboration with the Karen National Union’s (KNU) Karen Agriculture Department (KAD) and Karen Forestry Department (KFD). This work informs, encourages and empowers local community members and officials to secure land rights, by sustainably managing natural resources, and by implementing the KNU's inclusive land, agriculture and forest policies. KESAN works with communities to demarcate lands and to assist in land titling, by providing training on land and forest policies, community forestry, sustainable natural resource management principles, land demarcation with GPS and GIS mapping, and data management. The NGO advocates for the recognition of customary land tenure systems and supports Karen people to establish community forest management systems. These systems allow communities to manage and restore forests sustainably, while also benefiting from the forest products and services. For more information, see https://kesan.asia/land-forest-management/.

Thus, land tenure issues in Myanmar are closely connected with forest restoration efforts, particularly in conflict-affected areas. NGOs are playing a crucial role in advocating for the recognition of customary land tenure systems and supporting communities in establishing community forest management systems.

Indigenous rights

Indigenous rights include the right to continue to practice cultural and spiritual traditions, specific to particular ethnic groups, and to have the natural resources needed to do so. Indigenous peoples in tropical forest regions often rely on forest ecosystems for cultural purposes, as well as for subsistence. For communities with a strong spiritual connection to forest, restoration offers the prospect of maintaining such connections, but only if implemented with due respect for indigenous rights.

Restoration may also infringe upon the right to practice traditional agricultural systems such as shifting cultivation or slash-and-burn agriculture. Under such systems, the forest is cleared and burnt and the land used to grow crops for a few years, before invasion by weeds and losses of soil nutrients reduce productivity and increase the labour demand beyond that which families can meet. The field is then left "fallow". Natural forest regeneration starts to occur, whilst an adjacent forest patch is cleared. In areas of low population density and abundant land availability, fields may be left fallow for up to 20 years, before they are slashed and burnt once again. This creates a patchwork of forests at different ages, providing different habitats and niches for plant and animal species to occupy – thus supporting high biodiversity across the landscape as a whole. However, such practices are considered undesirable or are even illegal in several countries, especially where population pressure and declining land availability have reduced rotation periods to just a few years—not enough time for recovery of soil nutrients and forest ecosystems. Shifting-cultivation has been blamed as a cause of forest loss and as a source of smoke pollution (and thus a public health hazard). Governments have pushed for forest restoration on such areas, even though even aged restored forest would support less biodiversity than the patchwork of multi-aged fallow forests created by shifting cultivation. Greater scientific understand of the conservation value of traditional agricultural practice may help to resolve such issues (Wangpakapattanawong et al., 2010).

Restoration projects may involve significant changes to forest ecosystems, including the introduction of non-native species or the removal of certain trees and plants that are important to local cultures. Such alterations can disrupt indigenous knowledge systems and practices, leading to the loss of traditional knowledge and cultural heritage.

For example, Karen people in eastern Myanmar revere sacred bamboo (*Thyrsostachys siamensis*) for its spiritual significance. It is used in religious ceremonies, such as weddings and funerals, and is believed to have the power to ward off evil spirits. Since bamboos inhibit growth of planted trees, they are sometimes removed from forest restoration sites. Many spiritually significant plants grow in deforested open areas, such as betel leaf (*Piper betle*) used in traditional medicine and as offerings to deities and ancestors; ginger (*Zingiber officinale*) and holy basil: (*Ocimum tenuiflorum*) both used in religious ceremonies, for their spiritual and healing properties. Such plants may be shaded out and become scarce as forest recovery proceeds.

Furthermore, projects implemented without the free, prior, and informed consent of indigenous communities, violate their right to self-determination and participation in decision-making processes.

Such problems may be overcome by including indigenous people in the planning, implementation and monitoring of forest restoration programs, to ensure that species important for traditional cultural practices are re-introduced or conserved and sacred sites are respected. It also builds a sense of stewardship among local communities. Otherwise, restoration projects may reinforce historic patterns of exclusion and marginalization, further undermining the rights and livelihoods of indigenous peoples.

For example, Myanmar has been undergoing significant political and economic changes in recent years, including a push towards sustainable forest management and conservation. However, these initiatives have been criticized for neglecting the needs and rights of indigenous communities who rely on the forests for their livelihoods and cultural practices. Reports by the International Work Group for Indigenous Affairs (IWGIA) highlight the struggles of the Karen indigenous people in eastern Myanmar, who have been displaced and marginalized by projects that prioritize conservation over their rights and well-being (https://www.iwgia.org/en/myanmar.html).

Labor rights

The restoration and sustainable management of tropical forests is labour intensive. Large numbers of manual laborers are needed site preparation, tree planting maintenance and monitoring in the first 2-3 years of projects. Labour rights cover the right to work under humane conditions and to receive appropriate compensation for the labour provided.

Labour for forest restoration is usually paid for at the minimum daily rate and sometimes below that, since payments are usually in cash outside of the tax system. In extreme cases, local people may even by coerced into donating their labour as a “public duty”. Although such low costs make projects attractive to funders, they may also sow discontent among local stakeholders, as they feel exploited, thus endangering the project's long-term sustainability.

One approach to solve this problem is a specialized form of stakeholder participation known as "collaborative costing". Stakeholders are first involved in a rapid site assessment (LABS3-4), during which the amount of natural regeneration and the amount of tree planting needed are assessed. This defines the work effort required to meet project objectives. A meeting of all stakeholders is then convened, chaired by a neutral person. A spreadsheet of all project costs is then collaboratively compiled, with inputs from local people, donors, state agencies and NGO's, to determine costs of labour, transport, materials, equipment etc. arriving at an overall cost for the project (LAB 17-18). During this process, local people may negotiate a labour rate directly with project funders, whilst funders have an opportunity to explain funding limitations. The objective is to reach a consensus on whether the project is financially viable and to take further action if necessary, such as reaching out to secure additional funding.

Access to benefits

Restoration and sustainable management of tropical forests can provide benefits, such as carbon credit income, ecotourism revenue etc. However, there can be concerns about unequal distribution of these benefits, with communities that have contributed to the restoration and management efforts not receiving their fair share of the benefits.

Access to benefits is closely tied to the land tenure issues mentioned above. For example trading in carbon credits is only possible by those who actually own the land on which the trees are growing. Communities who restore forest on public land, therefore, cannot market carbon credits. Furthermore, access to benefits often depends on access to capital. Starting up an eco-tourism business, for example, requires capital to build accommodation and other facilities and to train staff. Thus wealthier community members or outside financiers may benefit from restoration more than poorer community members.

Inequitable distribution of benefits derived from forest restoration can lead to jealously and discontent among communities that can manifest as protest, including the setting of forest fires. Such pitfalls may be avoided by involving all stakeholders in the drafting of a clear benefit-sharing agreement, right from the start of restoration planning.

Tools for greater inclusion

To reiterate—most human rights issues related to forest restoration can be solved by inclusion of all stakeholders on an equal basis (regardless of land tenure, wealth and statehood) in the planning, implementation, maintenance and monitoring of projects and in the drafting of benefit sharing agreements. Each stakeholder group should contribute funding, labour, expertise, materials and other resources according to their ability and each should receive benefits according to their inputs and needs.

Various tools are available to assist with such negotiations. Perhaps the most widely used for forest restoration is ”Restoration Opportunities Assessment Methodology (ROAM)”, devised by the International Union for the Conservation of Nature available here:

www.wri.org/research/restoration-opportunities-assessment-methodology-roam

International Agreements

Myanmar signed the Universal Declaration of Human Rights (UDHR) on December 10, 1948. The document outlines the fundamental rights and freedoms that are inherent to all human beings, regardless of race, color, religion, sex, language, political or other opinion, national or social origin, property, birth or other status. Some of the rights listed that are relevant to forest restoration include:

- Right to work and to just and favourable conditions of work
- Right to free education, at least to elementary level, with technical and professional education being made generally available and higher education being equally accessible to all on the basis of merit.
- Right to an adequate standard of living, including adequate food, clothing, housing, and medical care
- Right to participate in cultural life and to enjoy the benefits of scientific progress and its applications

While signing the UDHR indicates a commitment to human rights, it is not a legally binding agreement. However, Myanmar is also a signatory to other legally binding international human rights treaties, including the International Covenant on Civil and Political Rights and the International Covenant on Economic, Social and Cultural Rights.

Despite these commitments, human rights abuses have been reported in Myanmar, including violations of freedom of expression, assembly, and association, as well as discrimination against ethnic and religious minorities.

Alignment with the UN SDGs

Closely linked to human right are the United Nations Sustainable Development Goals (SDGs). Funders of forest restoration now commonly demand to know how projects support the UN SDGs. Here are some of the ways that restoration aligns with the UN SDGs:

- SDG 1: No Poverty - Tropical forests are often located in regions where poverty is prevalent. Restoration of tropical forests can create job opportunities and generate income for local communities through sustainable forest management practices such as eco-tourism, agroforestry, and non-timber forest products.
- SDG 2: Zero Hunger - Restoration of tropical forests can contribute to food security by enhancing the productivity of forest landscapes and improving the livelihoods of forest-dependent communities. Sustainable forest management practices such as agroforestry and community forestry can help to increase the availability of food and other forest-based products.

- SDG 6: Clean Water and Sanitation - Tropical forests play a crucial role in regulating water resources, including maintaining water quality and regulating water flows. Restoration of tropical forests can help to protect watersheds, enhance water quality, and increase the availability of clean water.
- SDG 8: Decent Work and Economic Growth - Restoration of tropical forests can create employment opportunities in the forest sector, support sustainable forest-based livelihoods, and contribute to local economic development.
- SDG 13: Climate Action - Tropical forests are crucial for mitigating the effects of climate change as they act as carbon sinks, absorbing and storing carbon dioxide. Forest restoration can thus help to reduce buildup of atmospheric CO_2—one of the major causes of global warming.
- SDG 15: Life on Land – Forest restoration can create habitat for wildlife and thus recover and enhance biodiversity. Restoration of tropical forests is particularly effective in this respect since they are home to more than half of the terrestrial plant and animal species on Earth.

Learn more about the SDGs here: https://sdgs.un.org/goals

Reading

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8. Phenology - Seasonal Cycles Of Flowering And Fruiting

Phenology

Phenology is the study of the responses of living organisms to seasonal cycles in environmental conditions. In forestry, phenological studies are used to determine when to collect seeds and learn how forests function (particularly tree reproduction and forest dynamics), so that the same functionality can be replicated in restored forest. Understanding the phenology of tropical forest trees is important for the management of forest resources, the conservation of biodiversity, and the study of ecosystem processes.

The flowering and fruiting of many tropical trees are usually related to seasonal variations in moisture and insolation. Cycles in reproductive events are most marked in the seasonal tropics. Not all tropical trees reproduce seasonally. Some flower or fruit twice or several times per year, whilst others exhibit "masting" i.e. mass fruiting at intervals of several years.

In temperate regions phenological patterns are driven by alternation between summer and winter. In the seasonally dry tropics phenology is driven by alternation between wet and dry season. In equatorial regions, there is very little seasonal variation over a year and therefore phenology patterns are less pronounced.

Why study phenology?

Obtaining viable seeds is the first step for tree-planting projects, so it is worth the effort of carrying out phenology studies to determine optimal seed collection schedules.

Phenological studies can also enable the identification of "keystone" tree species; those which flower or fruit at times when other food resources for animals are in short supply. Keystone tree species, such as fig trees (*Ficus* spp), support whole communities of animal pollinators and seed dispersers; animals upon which other tree species rely for their reproduction. So, they are obvious candidates for testing as framework tree species.

During phenological studies, observations of pollination and seed dispersal mechanisms can also be made. Additional data on the leafing phenology of the trees is usually collected at the same time. This can help to predict optimal planting sites for individual tree species.

Understanding the timing of fruit production can be important for wildlife management, as many animals rely on fruits for food. Similarly, understanding the timing of leaf fall can be important for predicting the risk of forest fires, as dry leaves can provide fuel for fires.

How to study phenology?

Data collection must be performed monthly over several years to take into account inter-annual variations in weather conditions. At least 5 trees of each species are labelled and observed monthly for "phenophases" i.e. young leaves, mature leaves, flowers, fruits etc.

1. Ideally count every flower and fruit etc. on the tree —but that is impossible … so …
2. Record presence/absence data for each phonophase – this is rapid but not quantitative
3. Place litter traps randomly across the forest. Empty them monthly. Dry the contents and separate out leaves, flowers, fruits etc. This is very quantitative, but is also time- and labour-consuming. Litter traps sample only very small areas and can give highly skewed data. For example, if traps beneath fruiting trees catch a lot of fruit but those randomly placed in gaps capture nothing.
4. The crown density method – uses a rough score of 0 to 4 to represent each tree crown. The score (max 4) divided among phenophases. It is easy to learn, quick to implement and is semi-quantitative. However, the method does depend of subjective decisions which can vary among observers.

Environmental factors affecting phenology

Rainfall is one of the key factors that influences the phenology of tropical forest trees. In the dry season many trees drop their leaves (deciduous) to avoid excessive water loss. During the wet season, trees flush out with young leaves, flowers, and fruit. However, the timing and extent of these changes can vary depending on local conditions, such as soil type, topography, and elevation.

Although the changes in temperature in tropical forests are often more subtle than in temperate forests, they can still have a significant impact on tree growth and reproduction. For example, some species of trees may be more active during warmer periods, while others may be more active during cooler periods.

In addition to rainfall and temperature, other factors that can influence the phenology of tropical forest trees include day length, humidity, and soil nutrients. These factors can interact with each other in complex ways, creating a wide range of phenological patterns across different species and ecosystems.

Factors affecting timing of flowering

1. Seasonal presence of pollinating animals or seasonal variation in wind speeds.
2. Competition with other plant species for pollinators.
3. Physiological condition of plant – nutrient and water status.
4. Leafing phenology – many trees flower when leafless in the dry season. This maximizes visibility of the floral display, thus attracting more pollinators.
5. Time required for fruit development. The optimum time for fruit fall and seed dispersal is the beginning of the rainy season. This allows maximum time for roots to grow deep into the soil, so they can access soil moisture during the first dry season. Trees with long fruit development times must flower a long time before the rainy season. In contrast, those with rapidly developing small fruits can flower nearer to the start of the rainy season.

Factors affecting timing of fruiting

1. Timing of flowering and length of fruit development period.
2. Availability of fruit/seed dispersal agent.

3. Competition with other plant species for animal seed dispersers (although this has not been proven at the community level in tropical forests).
4. Presence of conditions favorable for seed germination.
5. Avoidance of seed predation.
6. Avoidance of fire and drought.

Types of fruiting phenologies

1. Monocarpy a single reproductive event at the end of the life of the plant – talipot palm, bananas, bamboos. Producing vast numbers of fruits satiates seed predator populations. They cannot eat all fruits and so many seeds survive to germinate.
2. Annual – one flowering and fruiting event, usually in the same season, every year – this is the most common pattern.
3. Biannual – two flowering or fruiting events per year.
4. Supra-annual – more than one year between flowering/fruiting events – "masting" e.g. some oaks, some dipterocarps etc.

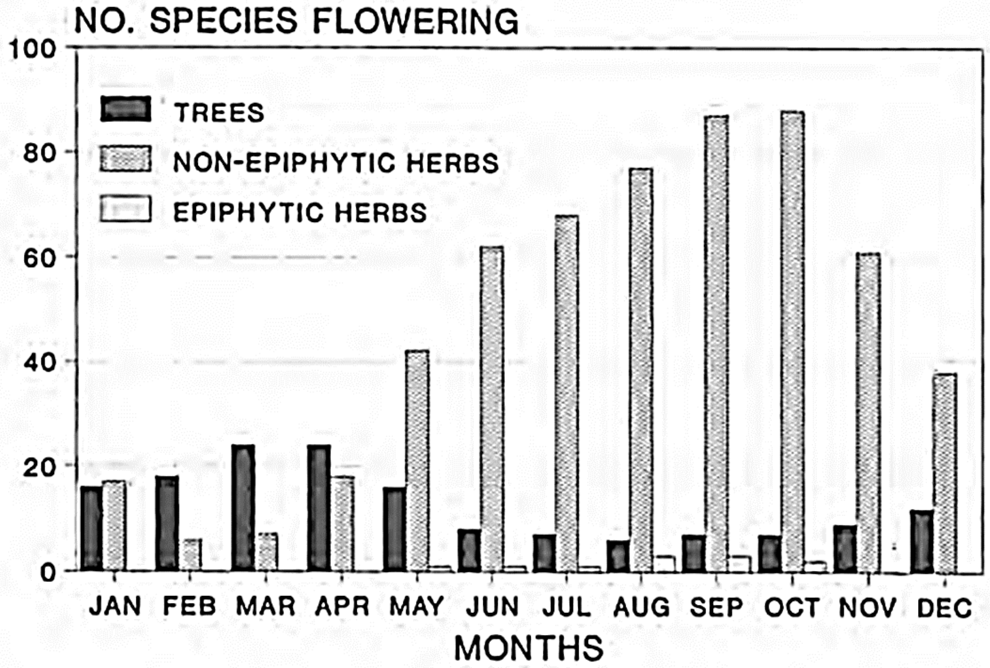
Community-level phenology patterns

In seasonally dry forest ecosystems, peaks in the number of species flowering or fruiting occur at distinct times each the year. The example in Figures 8.1 and 8.2 is from Doi Khuntan National Park in northern Thailand, with a rainy season from May to September, cool-dry season from October to January and hot-dry season from February to April. In both upland evergreen forest and lowland deciduous forest, flowering of trees peaks in March at the hottest, driest time of year and declines to a minimum in August in deciduous forest and in November in evergreen forest. Ground flora herbs reach their peak flowering in September to October (end rainy season). For trees in deciduous forest, a fairly constant but low number of tree species fruit in all months of the year, whereas in upland evergreen forest a board peak on fruiting occurred at the start of the rainy season. Tree seedlings germinating then have maximum time during the rainy season to grow roots long enough to reach moisture deep in the soil profile to sustain them through their first dry season. Fruiting amongst ground herbs peaked in October (end rainy season) in both habitats. This included many annual herbs, which survive as seeds through the dry season, to germinate at the start of the following rainy season. The conclusion is that tree-seed collection for forest restoration projects must be done in every month of the year, to grow a diversity of tree species in nurseries.

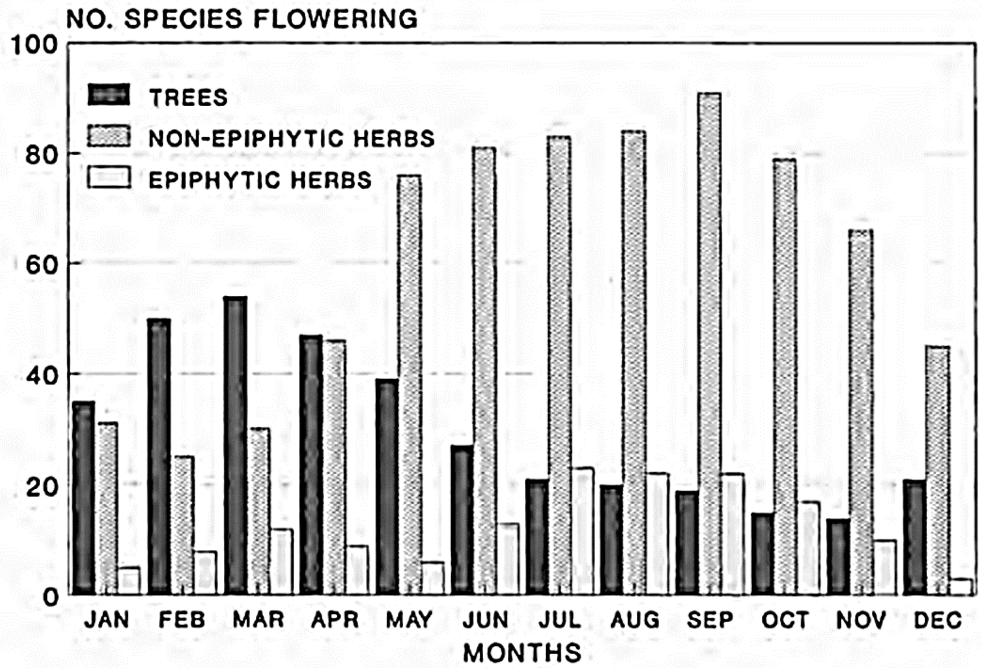
Figure 8.1 *– Number of plant species flowering in each month in lowland deciducous forest (above) and upkand evergreen forest (below)*
Figure 8.2 *– Number of plant species fruiting in each month in lowland deciducous forest (above) and upkand evergreen forest (below)*

Data from Doi Khuntan National Park in northern Thailand
https://www.forru.org/library/0000019

8.1

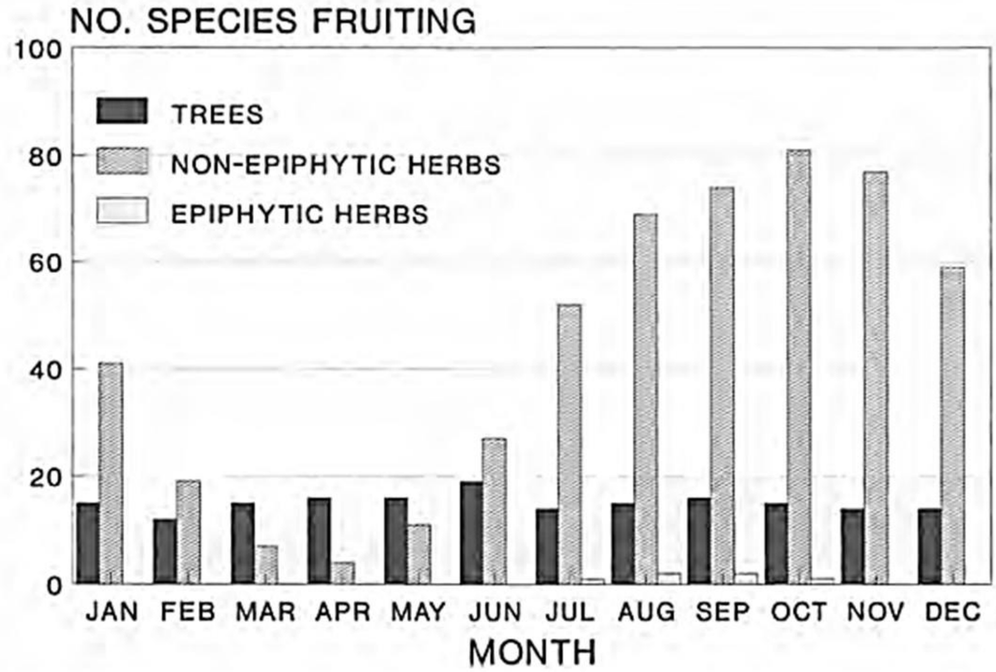


Flowering phenology deciduous dipterocarp-oak forest

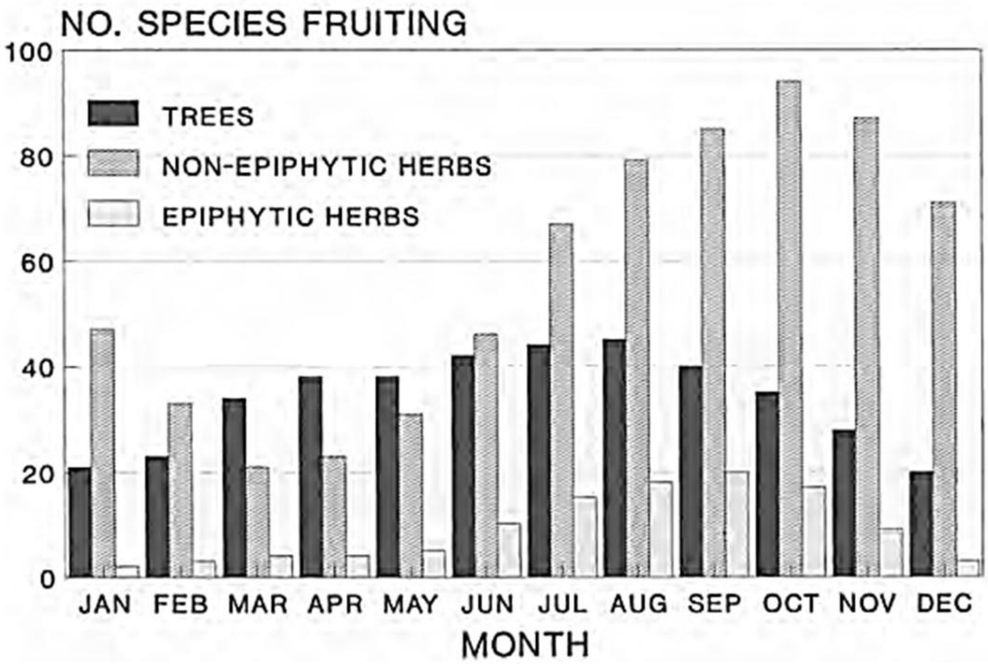


Flowering phenology upland evergreen forest

8.2



Fruiting phenology deciduous dipterocarp-oak forest



Fruiting phenology upland evergreen forest

9. Seed Dispersal

The function of any plant is to grow and eventually to reproduce itself. One of the most essential processes in plant reproduction is the production and dispersal of seeds.

What is the seed rain?

The seed rain consists of all seeds falling on to any particular area of land. It is often measured using seed traps, to capture seeds falling on to small, sample plots, of known area, and is expressed in terms of numbers of seeds, per metre squared, per month, often sub-divided by plant species, plant habit (tree, herb and so on) or dispersal mechanism. The density and species composition of the seed rain, on any deforested site, depends on the nearness of fruiting trees and on the efficiency of dispersal mechanisms. The seed rain is densest and contains more tree species near to intact forest and is sparser in the centre of large deforested areas.

Most tree seedlings, establishing on large, deforested sites, germinate from seed either blown on to such sites by the wind or carried there by birds, bats or other animals. A depleted seed rain is one of the major causes of lack of forest regeneration or low species richness among the tree communities colonizing such sites. Encouraging seed dispersal is therefore a vital element of forest restoration.

Why is seed dispersal necessary?

If a seed falls next to the parent plant, the seedling which germinates from it will be in direct competition for exactly the same resources and conditions, which are already being exploited by the parent plant. Since the parent plant already has a fully-grown shoot and root system, it is able to gain access to most of the resources and the seedling will eventually die.

In addition, if large numbers of seeds fail to be dispersed, they will accumulate around the parent plant. Such a large accumulation of food will attract seed predators, which can easily consume the entire seed crop. The density of the seed rain (or seed shadow) declines as distance from the parent plant increases. When a food resource is scarce, animals will tend to find other food to feed upon, rather than waste energy searching of sparse seeds. Therefore, seeds dispersed far away from the parent plant have an increased chance of escaping seed predators.

If seeds are dispersed too far away from the parent plant, however, it is likely that they will be deposited in an unsuitable habitat. Therefore, there is an optimum dispersal distance, not too far from, but not too near to the parent plant.

How are seeds dispersed?

Seeds can be dispersed by wind, by animals (both on the outside of animals and through ingestion), by gravity, by water and by "explosive" fruits.

Wind Dispersal

Wind-dispersed seeds are either very tiny and light (like orchid seeds) or they possess "wings" which slow their decent and enable the wind to carry them far away from the parent plant. A number of different arrangements of wings exist. *Dipterocarpus* spp. for example have two wings, whereas *Gluta usitata* has five or more arranged like the blades of a helicopter. Very light seeds can be dispersed at any time of the year, since they will float in the lightest of breezes. Large winged seeds, like *Dipterocarpus obtusifolius*, however, fall rapidly to the ground, despite their wings, since they are very heavy. They must therefore be produced when there are strong, gales in pre-monsoon storms.

Our study of seasonally dry forest on Doi Suthep, northern Thailand showed that dispersal of tree seeds by animals is more common than by wind. Of the 475 tree species studied, only 29 percent are wind dispersed. In deciduous dipterocarp-oak forest, 44 percent of tree species (approximately 62 percent of individual trees) rely on the wind for seed dispersal. In contrast, in evergreen forests, only 21 percent of tree species (approximately 11 percent of individual trees) are wind-dispersed.

Advantages of wind dispersal:

1. Small fruits – so many of them can be produced.
2. Long distance dispersal.
3. Wind is readily available, all year round.
4. Fairly even (non-clumped) dispersal.

Disadvantages of wind dispersal:

1. Non-specific – most seeds may be deposited in unsuitable habitats.
2. Small seeds cannot carry a large amount of endosperm.
3. Prevailing winds tend to blow in one direction – leading to one-way dispersal.
4. Wind has no effect on the seed to assist germination (e.g. effects of gastric acids, deposition with dung etc. as with animals).

Dispersal by Animals

Most tree species depend on animals to disperse their seeds. Some seeds become attached to fur or feathers and are transported on the outside of animals' bodies (termed "ecto-zoochorous" dispersal). More commonly, fruits are eaten and the seeds discarded or swallowed (dispersed whilst in the gut) and defaecated far away from the parent tree (termed "endo-zoochorous dispersal). The fruits of animal-dispersed seeds tend to be brightly coloured to attract animals, and fleshy, providing a reward of food to their animal dispersers.

Dispersal of seeds from forest into deforested sites, therefore, depends on animals that regularly move between the two habitats. Unfortunately, rather few forest animals venture out into open areas, for fear of exposing themselves to predators. Compared to wind, animals are rather inefficient seed dispersers. Apart from birds and bats, few animals travel very far between eating a fruit and defaecating the seed. Furthermore, many seeds are crushed by teeth or destroyed by digestive juices.

The maximum size of seeds dispersed by any animal species depends on the size of the animal's mouth. Whilst small animal species are still relatively common, larger ones, capable of swallowing large seeds whole, have been largely wiped out by hunting. Small seeds are therefore more easily dispersed into deforested areas by animals than large ones.

In the past, large herbivores were undoubtedly the most important dispersers of seeds from forest into deforested areas. Elephants, rhinos and wild cattle often consume fruit in the forest, emerging into open areas at night to graze. With their large mouths and long roaming distances, such animals could swallow the largest of seeds and transport them over long distances. The elimination of most of these large mammals, over much of their former ranges in recent decades is now preventing dispersal of many tree species with very large seeds.

Because they can fly, birds and bats disperse seeds over long distances. Amongst the birds, bulbuls are particularly important. They are common in evergreen forest and are frequent visitors to deforested sites, several kilometres from natural forest. They disperse seeds of a very wide range of plant species, up to 14 mm in diameter over long distances, since they retain seeds in their digestive tracts for up to 41 minutes. Other common bird species, which probably contribute to the seed rain of deforested areas, include mynahs, jays, magpies, thrushes, robins, chats, white-eyes, laughing thrushes and flowerpeckers. Many of these are insectivores, which also take fruit as part of their diet. Near to intact forest, green pigeons, Oriental Pied Hornbill and, at higher elevations, wood pigeons probably play a greater role in seed-dispersal.

Fruit bats are also important seed dispersers, since they fly over long distances and drop seeds in flight. However, unlike most birds, bats are nocturnal and cannot be identified using binoculars. Consequently, little research has been done on their role in forest regeneration. Research on bats is, therefore, a high priority for improvement of forest restoration techniques.

Non-flying mammal species that remain common and are likely to disperse seeds between forest and degraded areas include Common Wild Pig, Common Barking Deer, civets, and Hog Badger, but again, largely due to their nocturnal habits, very little information is available on the seed dispersing capabilities of these animals.

Seed dispersal by animals can be divided into 4 groups:

1. Passive-external – when fruits/seeds become attached to fur or feathers by special hooks or sticky substances and detached after the animal has moved some distance.
2. Passive-internal – when seeds are swallowed accidentally whilst the animal is feeding on some other part of the plant.
3. Active-external – when animals store seeds in stashes for eating later, then forget where they are or die before they can retrieve them OR when animals eat fruit pulp but discard the seeds without swallowing them.
4. Active-internal – when animals deliberately seek out fruit as part of their diet and swallow seeds, depositing them later when they defaecate.

Seeds dispersed internally must able to resist digestion in the gut, but they might benefit by having their seed coats abraded within the digestive tract of the animal. Seeds with a thick seed coat germinate more quickly after their seed coats are worn away, allowing water to enter the seed and trigger germination.

Advantages of animal dispersal:

1. Engaging a specific agent to deposit seeds in optimum sites for germination.
2. Heavy seeds can hold a lot of endosperm to help seedling establishment – but large seeds need large dispersers, which limits the number of disperser species.
3. Animals sometimes help seeds to germinate by scarifying them and depositing them with dung.

Disadvantages of animal dispersal:

1. Dispersal ceases with extirpation or extinction of disperser.
2. Sometimes clumped dispersal (especially with large vertebrates) leads to early seedling competition.
3. Animals don't travel as far as the wind – but they are less likely to leave the suitable habitat for the plant too.

Are relationships between seeds and their dispersers specific?

Not really. Kitamura et al (2002) showed that most seeds in tropical ecosystems are dispersed by a wide range of different animals, but bigger seeds are dispersed by fewer animal species. So, dispersal opportunities are limited for larger seeds. Therefore, tree species with larger seeds are more likely to be threatened with extirpation, if all large mammals disappear from a forest.

How far are seeds dispersed?

Most tree seeds fall within a few metres of the parent tree. The density of a single tree's "seed shadow" declines steeply with distance away from the tree. However, approximately 10 percent of the seeds are dispersed over much longer distances of 1 to 10 km. Little is known about the long-distance component of the seed rain, as it is difficult to measure. However, this component is essential for the regeneration of isolated sites.

Reading

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10. SEED PREDATION, DORMANCY AND GERMINATION

If seeds deposited in deforested areas are to germinate, they must avoid being killed by animals. A single tree produces vast numbers of seeds during its lifetime, although, to replace itself, it need produce only one that eventually grows into a reproductively mature adult. The need for such seemingly excessive seed crops is because most seeds are either deposited where conditions are unfavourable for germination or they are destroyed by animals. Because many seeds contain rich reserves of oils and carbohydrates, they often end up becoming nutritious meals for animals. Whilst some seeds may pass through the digestive tracts of animals intact, many others are crushed by teeth and digested.

What is seed predation?

Seed predation is the destruction of a seed's ability to germinate when an animal crushes or digests its embryo. It can occur whilst seeds are still attached to the parent tree (pre-dispersal predation). However, seed predators have a more direct impact on forest regeneration when they attack seeds that have already been dispersed into deforested areas (post-dispersal predation). Some ecologists also regard the killing of seeds by fungal infection as a form of seed predation.

What animals are seed predators in regenerating forest?

Small rodents and insects, particularly ants, probably kill more tree seeds in deforested areas than most other animals. In deforested areas of northern Thailand, rats and mice particularly *Mus pahari, M. cookie, Rattus bukit, R. koratensis, R. surifer* and *R. rattus* are the most prevalent mammalian seed predators. These animals are more common in open areas, dominated by herbs, than within closed forest. If forest regeneration progresses to the point of canopy closure, rodent populations decline markedly.

What levels of seed predation can be expected in deforested areas?

In the tropics, more than 90 percent of tree species have more than 50 percent of their seeds killed by animals or fungi. Seed predation has a significant effect on both the distribution and abundance of tree species. It is also a potent evolutionary force, compelling trees to evolve various morphological and chemical mechanisms to defend their seeds against animal attack e.g. distasteful or poisonous chemicals, tough seed coats and so on.

Levels of seed predation are highly unpredictable, varying from 0 to 100 percent, depending on species, vegetation, location, season and so on. In general, however, seed predation in deforested areas is usually severe enough to significantly reduce seed survival of most tree species.

What determines the susceptibility of seeds to predation?

Ecological theory suggests that the susceptibility of any particular tree species to seed predation should depend on the food value of its seed to animals. Animals should consume seeds that provide them with maximum nutriment, whilst expending the least effort to find them. Large seeds provide large food rewards to those seed predators that are capable of processing them. Animals may be able to locate large seeds easily, since they are more visible and emit more odour than small seeds, but small rodents have difficulty handling very large seeds. In contrast, small seeds have low food value and are easily overlooked.

The longer a seed lies on the ground before germinating, the higher is the probability that it will be discovered by a predator. Seed predators rarely attack seedlings (seedlings are subject to other hazards), so rapid germination reduces the period during which seed predation can occur.

The nature of the seed coat is also important in protecting seeds from predation. A tough, thick and smooth seed coat makes it very difficult for rodents to get to the nutritious seed contents. Low predation rates amongst seeds with thick or hard seed coats have been reported for many Asian forest tree species. However, there may be a trade-off between seed coat thickness and length of dormancy in their effects on susceptibility to seed predation. Seeds with thick seed coats may be resistant to animal attack, but a thick seed coat often causes prolonged dormancy, which prolongs the period during which seeds are available for attack by predators. Also, even the toughest, thickest seed coat must soften, just before germination, presenting a window of opportunity for seed predators.

Dispersal pattern may also affect likelihood of predation. Seeds that are scattered thinly over a large area (a pattern that often results from wind-dispersal) are hard to find by predators, whereas a clumped dispersal pattern (characteristic of animal-dispersal) means that once one seed has been discovered, the whole clump will probably be predated. Sporadic large fruit crops, such as those produced by masting or monocarpy (Section 2, this part) satiate seed predator populations. Seed predators cannot possibly eat all the seeds, so many seeds escape predation.

The effects of seed predation depend on complex interactions among many variables, including the nature of the environment, availability of alternative food sources and the individual preferences and seed handling capabilities of the particular seed predator species present. It is certainly a factor that must be considered in forest restoration projects that involve direct seeding, but its effects must be evaluated for each individual site.

What is seed dormancy?

Dormancy is defined as a period during which viable seeds delay germination, despite having conditions (moisture, light, temperature etc.) that are normally favourable for the later stages of germination and seedling establishment. Various authors have identified different types of dormancy. “Imposed” or “enforced” dormancy occurs when seeds remain viable but fail to germinate due to absence of one or more essential environmental conditions required for germination (e.g. optimal temperature, supply of moisture etc.). “Innate” dormancy refers to seeds which are released from the parent plant already in a dormant condition, in contrast to “induced” dormancy, which refers to seeds which are released in a non-dormant condition, but which become dormant in response to adverse conditions after dispersal.

Mechanisms of dormancy

Dormancy can originate in the embryo itself or in the tissues that surround the embryo (endosperm, testa or pericarp). The tissues surrounding the embryo can bring about dormancy by restricting the transport of water or oxygen into the seed, by mechanically restricting expansion of the embryo or by containing chemicals that metabolically inhibit the chemical changes necessary to initiate germination (most commonly abscisic acid). Dormancy mediated by the embryo can be due to a need for further embryo development and differentiation of tissues after detachment from the parent tree; so-called "after-ripening". Other forms of embryo dormancy include chemical blocks of nucleic acid and protein synthesis, failure to mobilize food reserves, deficiency of plant growth hormones and presence of chemical inhibitors. In most species, dormancy is brought about not by one but by a combination of several of these various mechanisms.

Length of Dormancy

Dormancy varies among seeds within a batch. Median length of dormancy (or MLD) is the number of days between seed sowing and germination of the median seed. For example, if 35 seeds germinate out of 100 sown, MLD would be the number of days between seed sowing and germination of the 17th seed. Seeds of some plant species can remain viable, but dormant, for several hundred years. However, most tree species in tropical forests have short dormancy. On Doi Suthep, 43% of tree species have dormancy periods of less than 30 days, whilst only 21% have MLD's > 100 days. At FORRU-CMU, the shortest MLD recorded in a survey of germination of a wide range of tree species was 7 days for *Albizia odoratissima* (L. f.) Bth., *Erythrina subumbrans* (Hassk.) Merr. and *Quercus lanata* Smith. The longest MLD recorded was 787 days for *Elaeocarpus bracteanus* Watt ex Cl., which has an extremely tough pyrene surrounding the seed.

The tendency of tropical forest trees to have short dormancy has implications for managing forest regeneration. When a forest is cleared, the contribution of the seed bank towards regeneration is short lived. Within 100 days, after the seed source trees have been felled, the viable seed bank will lose nearly 80% of tree species. Therefore, subsequent regeneration of the forest must depend almost entirely on the seed rain. For slash and burn areas that are cultivated for 2-3 years or longer, no seeds of the original seed bank will remain viable. Regeneration of such areas relies on new seeds being dispersed into the area and will most likely be colonized by small-seeded (especially wind-dispersed) species, with a consequent loss of large-seeded animal-dispersed tree species from the regenerating tree community.

Seed Germination

Seed germination and early seedling growth are the most crucial times in the life of a plant. At this time the plant is most vulnerable to: i) attack by herbivores; ii) sudden changes in environmental conditions and iii) competition from other plants, because it has: i) small overall size; ii) low reserves of energy and nutrients and iii) low photosynthetic capability and therefore low ability to recover from damage.

Therefore, plants must maximize their chances of survival at this critical time by timing germination for the optimal period. Although several factors might define the optimal period for germination (e.g. temperature, avoidance of seedling predators etc.), in seasonally dry tropical climates, with a dry season, soil moisture appears to be the overriding factor. The optimal time for germination of perennial plants is the start of the rainy season. This allows a maximally long growing season for the plant to grow its root system deep into the soil and to build up energy reserves. A deep root system allows the plant access to more moisture during the dry season and increases the chances of plants surviving through that first dry season.

Germination and dormancy of tree species – Doi Suthep Case Study

A study of seed dispersal and germination of 262 tree species collected in the forests of Doi Suthep-Pui National Park, (FORRU, original data, 2003) found that most seeds collected in the late dry and early wet seasons germinate rapidly (>90 percent had MLD's of <71 days). In contrast, of the seeds collected in the late wet and early dry seasons, only 48.5 percent and 54.8 percent of them, respectively, germinated rapidly (MLD <71 days). The others remained dormant for long periods. Consequently, the median seed of 75.8 percent of the species included in the study germinated in the late dry or early wet seasons. This maximizes seedling development before onset of the dry season and minimizes the period that seeds lie dormant on the forest floor, consuming energy by respiration and at risk from seed predators. Species were categorized according to dispersal time and dormancy syndromes. The 'rapid-wet group' comprised 171 species, which dispersed seeds late in the dry season and through the wet season, germinating rapidly in association with the prevailing rains. In contrast, 62 species comprised the 'delayed-wet group', which dispersed their seeds late in the wet season and early in the dry season and exhibited prolonged dormancy, resulting in germination in the subsequent wet season. In contrast, another distinct group, the 'rapid-dry group' of 34 species dispersed their seeds in the early dry season and germinated rapidly in the same season. The survival strategies of this latter group warrant further research.

What conditions are required for seed germination?

Seed germination depends on many factors, the most important of which are sufficient soil moisture and the light conditions, not only total light levels, but also the spectral quality of the light, particularly the ratio of red to far red light. In a gap within intact forest, which tree seed species germinate depends on the species composition of the seed rain and the microclimatic conditions within the gap. The latter depend on the size, shape and aspect of the gap and the density and height the trees that surround it. Temperatures vary more within gaps, compared to closed canopy forest and humidity levels may be lower. In a large deforested area, these fluctuations are greatly accentuated.

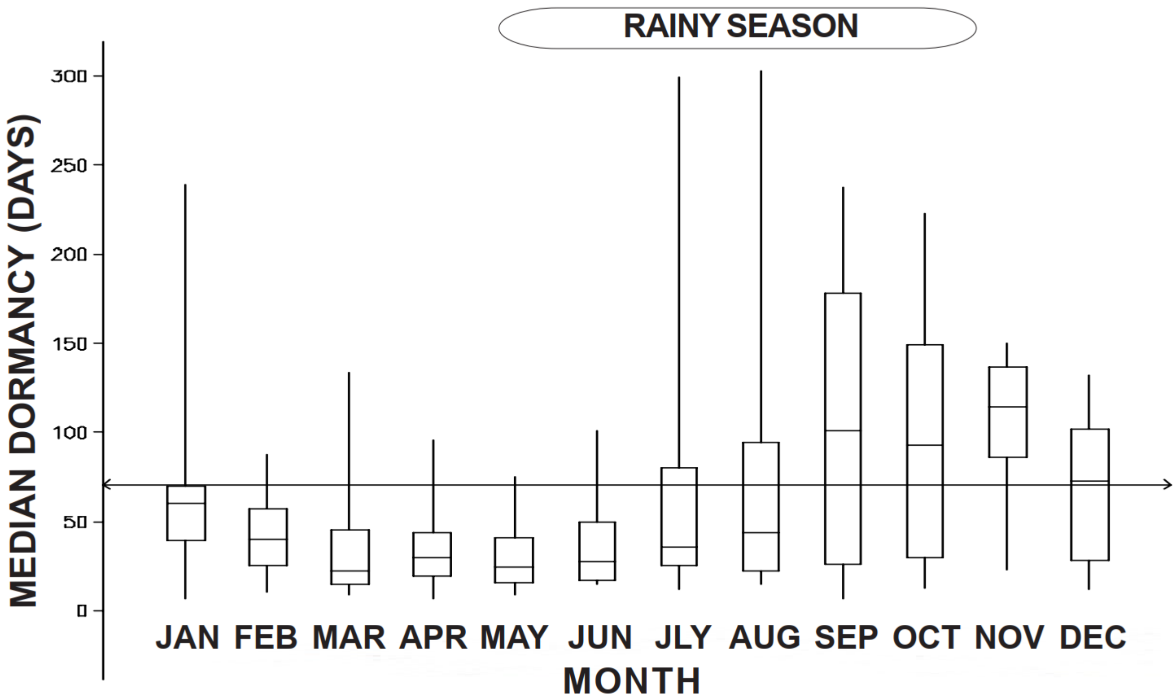
Table 10.1 *– Median lonegth of dromancy of seeds collected in different months*
Figure 10.1 *– The relationship between median length of dormancy (MLD) and the month of seed dispersal of forest tree species in Doi Suthep-Pui National Park. Each box represents 50 % of the number of tree species dispersed in each month. The horizontal line within each the box indicates the median value of MLD of all species dispersed in each month, whilst extreme values are indicated by the thin lines.*

Table 10.1

Species	Family	Seed Collection and Sowing	Median Seed Germination	MLD (days)	Germination class[1]
Albizia chinensis (Osb.) Merr.	Leguminosae	1-24-97	5-20-97	116	D
Dipterocarpus obtusifolius Teijsm. ex Miq. var. *obtusifolius*	Dipterocarpaceae	2-1-97	4-15-97	73	I
Gmelina arborea Roxb.	Verbenaceae	3-24-95	4-18-95	25	I
Erythrina subumbrans (Hassk.) Merr.	Leguminosae	4-22-97	4-29-97	7	R
Sterculia villosa Wall. ex Kurz	Sterculiaceae	5-17-97	5-27-97	10	R
Planchonella punctata Flet.	Sapotaceae	6-1-96	6-18-96	17	R
Casearia grewiifolia Vent. var. *grewiifolia*.	Flacourtiaceae	7-11-96	7-23-96	12	R
Antidesma montanum Bl.	Euphorbiaceae	7-19-95	5-7-96	293	D
Podocarpus neriifolius D. Don	Podocarpaceae	8-2-97	8-26-97	24	I
Microcos tomentosa Sm.	Teliaceae	8-14-97	5-12-98	271	D
Quercus vestita Rehd. & Wils.	Fagaceae	9-3-96	9-17-96	14	R
Lithocarpus polystachyus Rehd.	Fagaceae	9-24-96	5-20-97	238	D
Saurauia nepaulensis DC.	Saurauiaceae	10-1-98	10-22-98	21	R
Irvingia malayana Oliv. ex Benn.	Irvingiaceae	10-25-96	5-13-97	200	D
Euodia meliifolia (Hance) Bth.	Rutaceae	11-28-94	12-21-94	23	I
Melia toosendan Sieb. & Zucc.	Meliaceae	11-26-94	4-25-95	150	D
Macaranga denticulata (Bl.) M.-A.	Euphorbiaceae	12-1-94	12-13-94	12	R
Ficus capillipes Gagnep.	Moraceae	12-24-94	4-18-95	115	D

[1]D = delayed (MLD > 84 days; I = intermediate (MLD 22-84 days); R = rapid (MLD < 22 days)

Figure 10.1



Large, deforested sites that are dominated by dense weed growth present a hostile environment to tree seeds. Many seeds become trapped in the weed canopy, where they dry out and die, never to reach the soil. Even for seeds that fall through the weed canopy, weeds present another problem. A high ratio of red to far red light in the spectrum stimulates seed germination in many pioneer tree species, particularly those with small seeds (Pearson et al., 2003). By absorbing proportionately more red light than far red light, a dense green layer of weed leaves removes this vital stimulus.

Therefore, germination of most forest tree species depends on the presence of small areas where conditions are more favourable; so-called "germination micro-sites". These are generally small areas with reduced weed cover and sufficient soil moisture to induce seed germination. They can include decaying termite mounds, moss-covered rocks, exposed soil patches and especially rotting logs. The latter provide an excellent moist and nutrient-rich medium for seed germination and are usually weed free.

Do animals enhance germination?

Passage of seed through an animal's gut can affect both total germination percentage and the rate of germination. These properties can be enhanced, inhibited or unaffected. For most tropical trees, passage through an animal has no overall effect on germination, but for those species showing a response, germination is enhanced more often than it is inhibited. Travaset (1998) reported that ingestion by animals increased germination percentage of 36 percent of tree species tested, whilst it reduced germination percentage for only 7 percent. Seeds of 35 percent of tree species tested germinated more rapidly after passage through an animal's gut, compared with only 13 percent that had more delayed germination. Responses are highly variable. Seeds of species within the same genus, or even from different individual plants of the same species, can show different responses.

Reading

Traveset, A. (1998). Effect of seed passage through vertebrate frugivores' guts on germination: a review. Perspectives in Plant Ecology, Evolution and Systematics, 1(2), 151-190.

11. BARRIERS TO TREE SEEDLING ESTABLISHMENT – WEEDS, CATTLE AND FIRE

After a seed has germinated, the greatest threats to seedling survival in deforested areas are fire and competition with weeds.

Competition with weeds

Deforested areas are usually dominated by fire resilient, herbs and grasses. By soaking up most of the sunlight and draining the soil of moisture and nutrients, these rapidly growing weeds leave few resources for slower growing tree seedlings. However, tree seedlings may enlist the help of beneficial mycorrhizal fungi in their battle to survive and grow above the weed canopy.

Many weeds are introduced exotic species such as the shrubby-herbs *Eupatorium odoratum* and *E. adenophorum* (Compositae). Species in this family (the daisy family) are particularly successful at colonizing deforested sites. They produce tiny fruits (achenes) either topped with a parachute of fine hairs, for drifting on the breeze, or armed with hooks, which attach to the fur of passing animals (e.g. *Artemisia indica, Ageratum conyzoides, Bidens pilosa* var. *minor, Conyza sumatrensis* and so on). Found all round the world, the hardy bracken fern (*Pteridium aquilinum* ssp. *aquilinum* var. *wightianum* (Dennstaedtiaceae)) also dominates vast expanses of treeless hills.

Shrubs, such as *Boehmeria chiangmaiensis* (Urticaceae), *Clerodendrum fragrans* (Verbenaceae) and *Triumfetta pilosa* (Tiliaceae) represent more advanced regeneration, whilst evergreen vines e.g. *Shuteria involucrata* and *Clitoria mariana* and woody climbers e.g. *Millettia pachycarpa* (all Leguminosae, Papilionoideae) can inhibit forest regeneration by smothering tree seedlings.

How do weeds prevent forest regeneration?

Fast-growing, light-demanding, herbs can rapidly exploit the soil and develop a dense leafy canopy that absorbs almost all light available for photosynthesis. Amongst such voracious plants, a small tree seedling struggles to obtain sufficient light, soil moisture and nutrients for growth. Since trees have evolved to grow tall, they must expend considerable energy and carbon compounds producing the tough, woody substance, lignin, to support their future massive size against gravity. Free of the need to synthesis lignin, herbs can grow much faster than trees. Only when a tree's canopy overtops the weeds and its root system penetrates deeper into the soil than the shallower roots of the weeds does a tree gain an unbeatable advantage over the herbs. Unfortunately, most tree seedlings fade away in the shade of the weeds long before they reach that stage.

Weeds also prevent forest regeneration by providing fuel for fires in the dry season. Most herbaceous weeds survive fire as seeds, corms or tubers, buried in the soil, or they possess well-protected growing points (e.g. grasses, cycads, phoenix palms) that resprout after fire. In trees, the growing points are raised on the tips of branches. In a fire, therefore, the small seedlings or saplings of trees are usually completely incinerated by the blazing dried weeds surrounding them.

Does the structure of the weed community affect tree establishment?

The taller the weeds, the more difficult it is for trees to become established. Tree growth increases dramatically, once the tree crown emerges above the canopy of weeds. It also appears that some dominant weed species favour forest regeneration more than others. For example, sites dominated by the shrubby herb, *Eupatorium adenophorum*, support the highest density and diversity of forest tree seedlings and the tree seedlings established there survive better and grow faster than in sites dominated by grasses, such as *Imperata cylindrica* or bracken fern (*Pteridium aquilinum*). Weed communities dominated by bracken seemed particularly resistant to colonization by forest trees.

Do tree seedlings have predators?

In most areas, large herbivores like elephants and wild cattle, which could destroy a tree seedling with a single bite, are now so rare that they have no impact on forest regeneration at the landscape level. Domestic cattle, on the other hand can be a major impediment to natural forest regeneration. In most tropical countries, it is common to find cows or water buffaloes ranging freely across degraded forestland. The effects of domestic cattle on natural forest regeneration depend on their population density. A small herd might have no significant impact or might even be beneficial, in some areas but, where cattle populations are dense; their negative effects usually outweigh any positive effects.

One of the most beneficial effects of cattle can be weed reduction. By grazing on herbaceous weeds, cattle decrease competition for tree seedlings. In addition, domestic cattle can act as seed-dispersers, in the same way as wild cattle can, if they have access to fruits from nearby forest trees. Furthermore, their hoof prints can provide micro-sites for seed germination, where moisture and nutrients accumulate and weeds have been crushed.

The most obvious disadvantage of cattle is that they often browse on tree saplings. Cattle are very selective, often eating palatable tree species, whilst completely ignoring unpalatable ones. Distasteful or thorny tree species, therefore, become dominant, whilst edible species disappear completely from the regenerating forest. Cattle also trample young seedlings, indiscriminately and, where large herds follow regular paths, soil compaction can become a problem.

The balance between these positive and negative effects and their relationship with herd density are not fully understood. Furthermore, the effect of cattle on forest regeneration varies greatly with site conditions and vegetation type. Therefore, more research is required to develop models that might be able to predict the overall effects of cattle on forest regeneration at any particular site.

Fire

In the seasonally dry tropics, fires during the hot season are a major constraint to forest regeneration. By the end of the rainy season, weedy vegetation has often grown above head height and is practically impenetrable. In the hot season, this vegetation dies back, dries out and becomes highly flammable. Each time it burns, any tree seedlings that may have managed to gain a roothold amongst the weeds are usually killed, whereas the weeds survive, re-growing from root stocks or seeds protected beneath the soil. Therefore, the vegetation creates conditions conducive to fire and prevents establishment of trees that could shade out the weeds. Breaking this cycle is the key to seasonal forest restoration.

Is fire a natural occurrence in seasonally dry tropical forest?

Fires can be started naturally by lightning strikes, but such natural fires usually occur several years or decades apart. This allows plenty of time for trees to grow large enough to develop some resilience to burning. However, these days most fires are started by humans. Fires set to clear fields for cultivation escape into surrounding areas, burning young trees and preventing forest regeneration. Fires are also deliberately started to make mushrooms easier to find, and to encourage growth of grasses for livestock and to attract wild animals for hunting.

How do fires prevent forest regeneration?

Studies that compare areas frequently burnt with those protected from fire clearly show that fire prevention accelerates forest regeneration. Frequent fires reduce both the density and species richness of the tree seedling community. Frequent burns also reduce the seed rain (by killing seed-producing trees) and the accumulation of viable seeds in the soil seed bank. Fire burns off soil organic matter, leading to a reduction in the soil's moisture holding capacity. The drier the soil, the less favourable it is for germination of tree seeds.

Fire kills important soil micro-organisms, especially fungi that help re-cycle dead organic matter and mycorrhizal fungi. It also reduces soil nutrients. Calcium, potassium and magnesium are transported away as fine particles, while nitrogen, phosphorus and sulphur are lost as gases. By destroying the vegetation, fire increases soil erosion by 3-32 times.

Doesn't fire encourage seed germination?

In some ecosystems, fire stimulates seed release and germination, but this effect has not yet been found in seasonally dry tropical forests.

Does fire kill trees?

Most small tree seedlings and sapling are killed by fire, but the larger a tree becomes, the more likely it is to survive. Larger trees have thick bark, which insulates their vascular system (the cambium layer) from heat. Stored food reserves in the roots enable larger trees to grow back rapidly, even if their above-ground parts are burned away. The minimum size at which a tree can survive a wild fire varies among species, but as rough rule, a root collar diameter of 10 cm or more will guarantee survival of most tree species after a moderate burn.

To summarize; it is very difficult for most forest tree species to re-colonize large deforested areas that have become dominated by weeds. Lack of seed sources, disappearance of seed-dispersing animals, competition with hardy, often exotic, weeds and frequent fires all prevent enough tree species establishing at sufficiently high densities to restore the original forest ecosystem. However, a few tree species *can* overcome these constraints and some of the more common ones, found colonizing large deforested areas in SE Asia's seasonally dry forests are listed in the table below. Many are deciduous tree species, which grow over a wide range of elevations, and most have small seeds that are easily dispersed by small birds or wind. Where remnant, mature trees of these species survive in the landscape, there is usually no need to include them in tree planting projects; but wherever they have been eliminated, they are obviously very suitable for planting in degraded areas.

Table 11.1 – Tree species that establish in open deforested areas

Species	Family	Elevation (m)	Leafing Phenology[1]	Seed Size Class[2]	Seed dispersal[3]
Albizia odoratissima	Leguminosae(M)	350-1,525	D	M	W
Alstonia scholaris	Apocynaceae	350-1,150	D	M	W
Antidesma acidum	Euphorbiaceae	400-1,525	D	M	A
Aporusa dioica	Euphorbiaceae	475-900	D	M	A
Aporusa villosa	Euphorbiaceae	500-1,500	D	M	A
Aporusa wallichii	Euphorbiaceae	500-1,400	D	M	A
Dalbergia cultrata	Leguminosae(P)	350-700	D	L	W
Dalbergia stipulacea	Leguminosae(P)	500-1,400	D	L	W
Dillenia parviflora	Dilleniaceae	375-1,000	D	M	A
Engelhardia spicata	Juglandaceae	850-1,650	D	M	W
Eugenia albiflora	Myrtaceae	800-1,525	E	L	A
Ficus hirta	Moraceae	350-1,150	E	S	A
Ficus hispida	Moraceae	350-1,525	ED	S	A
Glochidion sphaerogynum	Euphorbiaceae	600-1,100	D	S	A
Litsea cubeba	Lauraceae	1,100-1,685	E	M	A
Markhamia stipulata	Bignoniaceae	950-1,550	D	M	W
Myrica esculenta	Myricaceae	1,300-1,500	E	S	A
Phoebe lanceolata	Lauraceae	550-1,550	E	L	A
Phyllanthus emblica	Euphorbiaceae	600-1,620	D	M	A
Pterocarpus macrocarpus	Leguminosae (P)	350-900	D	M	W
Schima wallichii	Theaceae	600-1,620	E	M	W
Sterculia villosa	Sterculiaceae	600-1,575	D	M	W
Stereospermum colais	Bignoniaceae	900-1275	D	S	W
Styrax benzoides	Styracaceae	600-1650	E	L	A
Trema orientalis	Ulmaceae	1,050-1500	ED	M	A

12. ECOLOGICAL SUCCESSION

Forests have immense capacity to self-regenerate in the absence of the human-caused barriers mentioned above. Ecological succession is **a series of predictable changes in ecosystem structure and composition, following disturbance, leading to a dynamically stable "climax" forest.** It is a technical term for natural forest regeneration. In the past, succession proceeded naturally, to re-establish forest ecosystems. However, as growing human populations have increased pressure on forestland, ecological succession is frequently blocked by human-caused factors. Therefore, the successfulness of restoration often depends on a clear understanding of the natural mechanisms of succession.

Once disturbance ceases, sequential changes in species composition occur due to interactions among plants, animals and the environment. Shrubs shade out herbs, light-demanding pioneer trees shade out shrubs, and much later, pioneer trees are themselves shaded out by shade-tolerant "climax" trees. These are called seral stages – temporary ecosystems in a successional series leading to a climax forest ecosystem. A climax forest is dynamically stable ecosystem with maximum biomass, structural complexity, biodiversity and ecologically functionality that can be supported by the prevailing climatic and soil conditions. Each seral stage changes the environment, making it more suitable for species of the next seral stage.

Even under the best of conditions, attainment of the climax condition may take 80–150 years; more often than not, continued human disturbance (cultivation, fire etc.) completely prevents it. Therefore, active restoration is needed, wherever a more rapid return to climax forest is desirable.

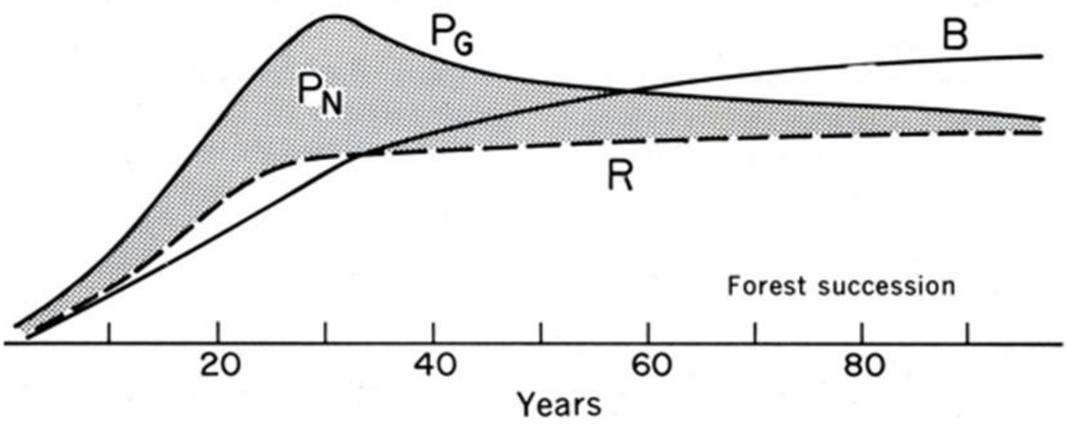
During the early stages of succession, community gross primary productivity (P) exceeds the rate of community respiration (R). Biomass (B) accumulates within the ecosystem. However, as B increases, a greater proportion of carbon and energy fixed by photosynthesis must be allocated towards maintenance and respiration, rather than growth. Therefore, the rate of biomass accumulation slows. In a climax forest, nearly all energy and carbon fixed by photosynthesis is used up in respiration and therefore biomass slows. Carbon continues to accumulate in the soil due to turnover - falling leaves and wood debris, being replaced, by new growth. However, no further increase in living tree biomass is possible. The ratio P/R tends towards 1.

The forest growth cycle consists of gap, building and mature phases. A forest consists of a mosaic of patches at different stages in the growth cycle. Small gaps are caused by trees dying of old age, lightning strikes and being blown over by the wind. Larger gaps are caused by landslides, earthquakes fires and large storms. Up to 10% of a mature tropical forest may consist of gaps. Anthropogenic gaps tend to be larger than natural gaps, and are caused by fire, shifting cultivation, industrial development projects and logging.

Figure 12.1 *– primary production, communityy repriration and biomass accumulation during ecological succession*
Figure 12.2 *– Successional guilds proposed by Ashton et al. (2001)*

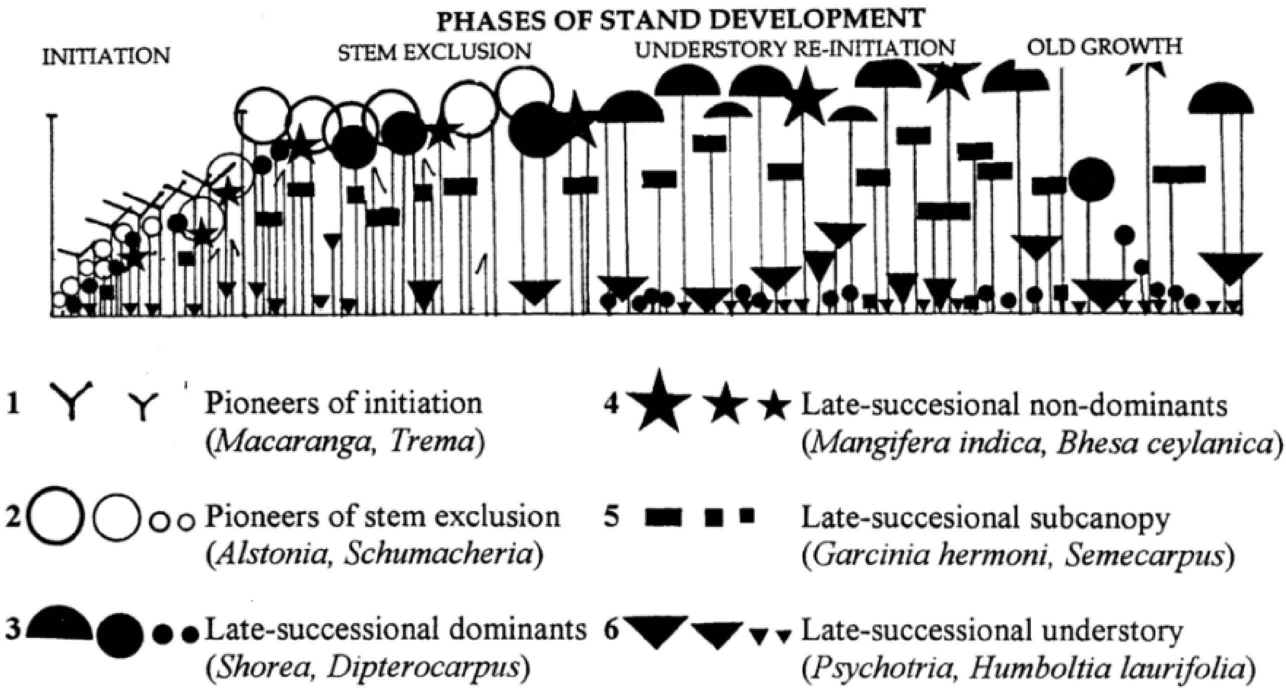
12.1

PG = gross primary productivity of the whole community, R = respiration of the whole community, PN = net primary productivity, B = community total biomass



Succession is marked by rapid increase in community productivity, initially well above community respiration. This leads to biomass accumulation and greater respiration costs. Eventually *all* energy fixed by plants is "used up" at the same rate by community respiration and there is none spare for further biomass accumulation. So biomass becomes stable.

12.2



Conditions in a gap are very different from those under the intact canopy. It is 10˚C hotter; relative humidity is up to 30% lower and there is 40 times more photosynthetically active radiation.

Regeneration may be from i) dormant seeds (SEED BANK), ii) seeds dispersed from other areas (SEED RAIN), iii) existing seedlings, iv) vegetative growth (SUCKERS) from mature trees nearby and v) COPPICING from tree stumps.

Large gaps are usually colonized first by tree species which are not present in the mature forest called PIONEER species. Over many years, the pioneer species decline in numbers and are replaced by CLIMAX tree species, those that are characteristic of the mature forest. The main distinctions between pioneer and climax species are that pioneer tree seeds can germinate only in canopy gaps which receive full sunlight and their seedlings cannot survive under the forest canopy, whilst climax tree seeds usually germinate below the canopy and their seedlings can survive for long periods of time in deep shade.

However, this binary classification of light-dependent pioneer trees and shade tolerant climax trees is rather too simplistic, since some species share characteristics of both pioneer and climax species. Many climax species thrive in open areas and not all climax species have large seeds

Ashton et al. (2001) proposed 6 successional tree “guilds”. Short-lived “pioneers of initiation” (=early pioneers) are the first to form a canopy that shades out weeds. “Pioneers of stem exclusion” (=late or persistent pioneers) rise to dominate the canopy later and live on, whilst late successional (=climax) canopy tree species grow up alongside them. Forest biomass increases and both the structure and tree species composition of the forest become more diverse. Seedlings of pioneers disappear, with development of an understorey marking a critical milestone in the progress of succession. Ashton *et al.* (2001) sub-divided late successional tree species into 4 groups, depending on the position of their crowns in the canopy: dominant (main canopy/emergent, abundant), non-dominant (main canopy, less abundant), sub-canopy and understory (Figure 12.2). They recognized 4 succession stages i) initiation, when incoming seeds of a wide range of species start to germinate and seedling grow up; ii) stem exclusion, when trees start to outcompete each other as they grow larger; iii) understorey development, as shade tolerant trees start to grow beneath the main canopy and finally “old growth” forest.

Reading

Ashton, M. S., C. V. S. Gunatilleke, B. M. P. Singhakurmara, I. A. U. N. Gunatilleke, 2001. Restoration path-ways for rain forest in southwest Sri Lanka a review of concepts and models. For. Ecol. Manag. 154:409-430

13. MATCHING RESTORATION TECHNIQUES WITH DEGRADATION LEVELS

Definition of forest-ecosystem restoration

*"Directing and accelerating ecological succession towards an indigenous **reference forest ecosystem** of the maximum **biomass**, structural **complexity**, **biodiversity** and **ecological functioning** that can be self-sustained within prevailing climatic and soil limitations."*

… where management aims include:

- delivery of long-term watershed services, such as a reliable supply of clean water and reduced risk of soil erosion, floods, landslides and droughts (since restoration aims for a persistent, self-sustaining ecosystem);
- carbon sequestration (since restoration maximizes biomass accumulation);
- wildlife conservation (since restoration maximizes biodiversity) and/or
- delivery of a diverse range of forest products and ecological services that benefit local communities and society.

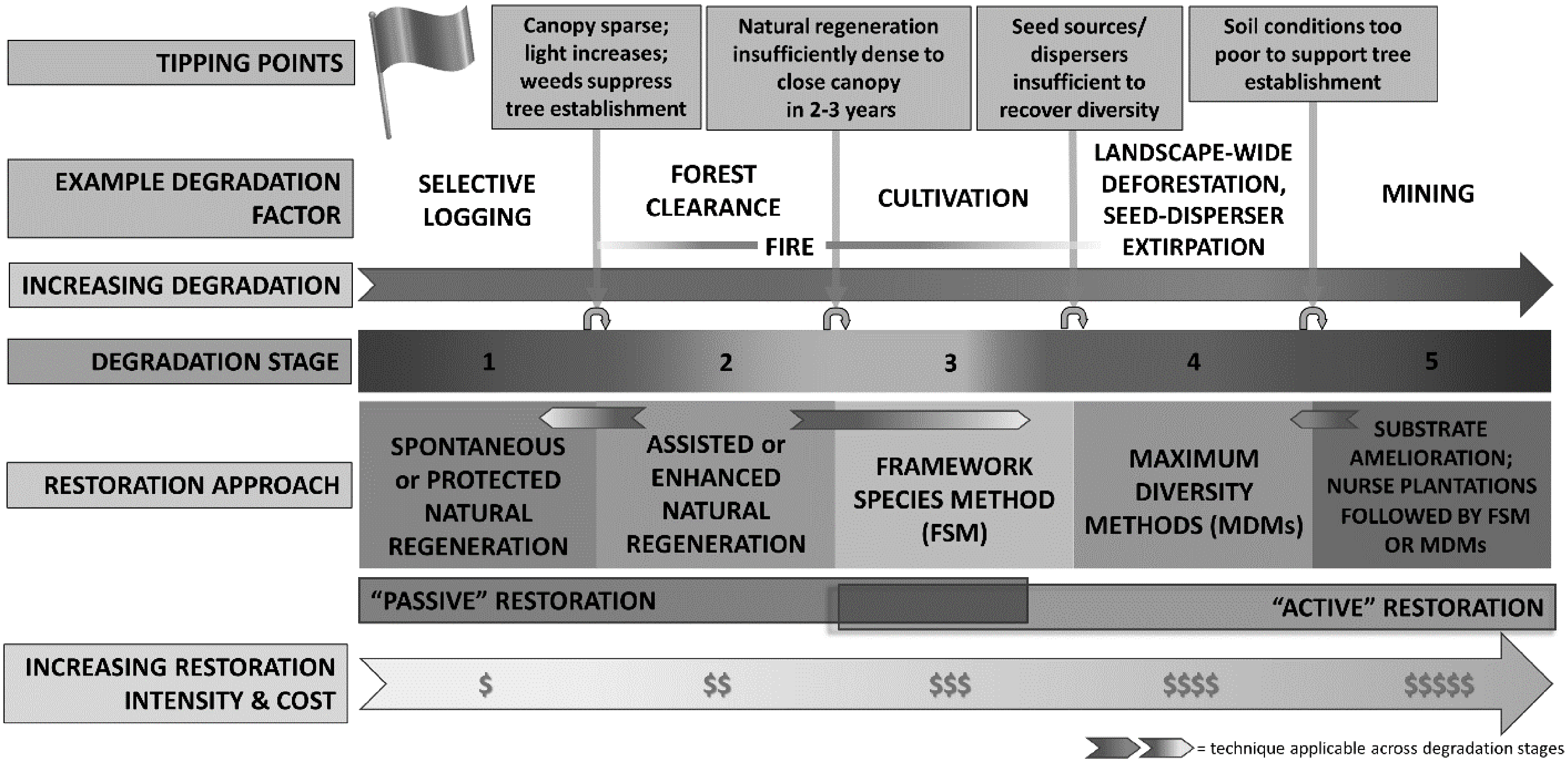
Five levels of forest degradation are distinguished, according to the intensity of the methods needed restore them to the climax-forest condition. Stage-1 is the least severe, requiring minimal intervention, other than protection. Stage-5 being the most severe, requiring most intensive restoration measures, such as substrate amelioration and tree planting.

Tipping points separate adjacent degradation stages, which, once reached, indicate the need for a substantial increase in the intensity of restoration actions to restore levels of biomass, structural complexity, biodiversity and ecological functioning, to those of the reference forest. Since higher levels of degradation require more intensive interventions, restoration costs increase with increasing original degradation level.

Degradation level is determined by i) landscape factors (particularly those related to seed dispersal from forest to restoration sites and fire risk) and ii) site factors (particularly those related to existing natural regeneration). Participatory stakeholder meetings and a rapid site survey are used to determine these factors and decide on the degradation level: a vital first step in planning forest ecosystem restoration.

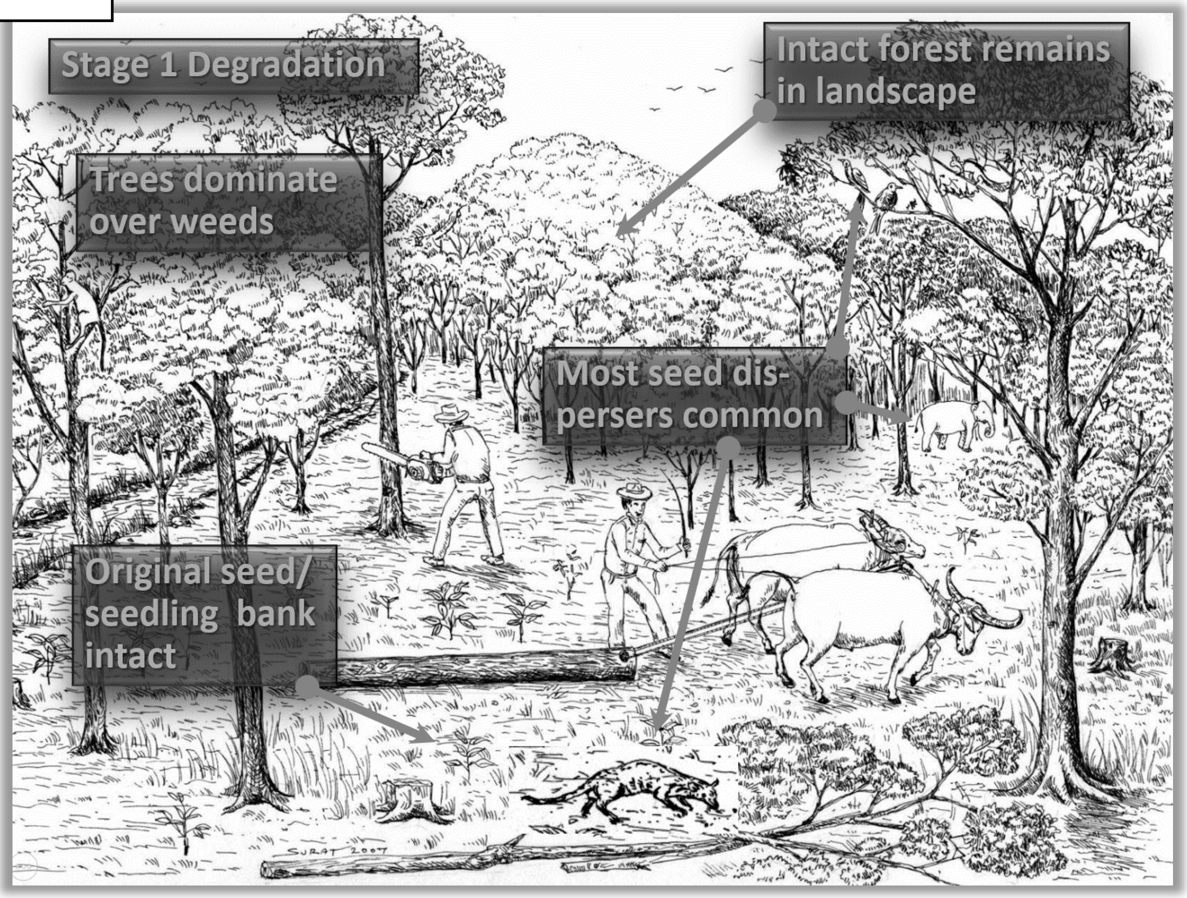
Figure 13.1 - *Summary overview of the five levels of forest degradation and the tipping points between them*
Online resource : https://www.forru.org/advice/forest-degradation

13.1

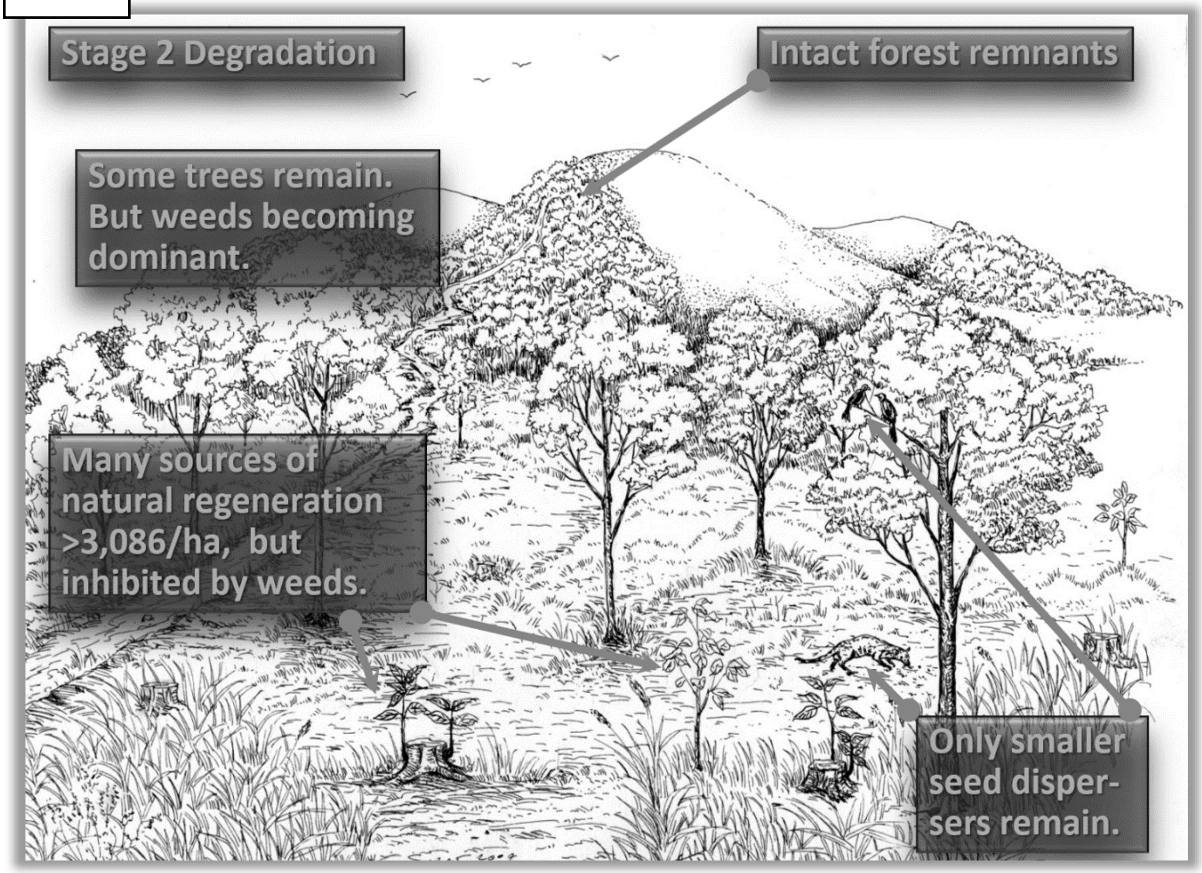


TIPPING POINTS
Canopy sparse; light increases; weeds suppress tree establishment
Natural regeneration insufficiently dense to close canopy in 2-3 years
Seed sources/ dispersers insufficient to recover diversity
Soil conditions too poor to support tree establishment
EXAMPLE DEGRADATION FACTOR
SELECTIVE LOGGING
FOREST CLEARANCE
CULTIVATION
LANDSCAPE-WIDE DEFORESTATION, SEED-DISPERSER EXTIRPATION
MINING
FIRE
INCREASING DEGRADATION
DEGRADATION STAGE
1
2
3
4
5
RESTORATION APPROACH
SPONTANEOUS or PROTECTED NATURAL REGENERATION
ASSISTED or ENHANCED NATURAL REGENERATION
FRAMEWORK SPECIES METHOD (FSM)
MAXIMUM DIVERSITY METHODS (MDMs)
SUBSTRATE AMELIORATION; NURSE PLANTATIONS FOLLOWED BY FSM OR MDMs
"PASSIVE" RESTORATION
"ACTIVE" RESTORATION
INCREASING RESTORATION INTENSITY & COST
$
$$
$$$
$$$$
$$$$$
= technique applicable across degradation stages

13.2


Stage 1 Degradation
Intact forest remains in landscape
Trees dominate over weeds
Most seed dispersers common
Original seed/ seedling bank intact
SURAT 2007

13.3


Stage 2 Degradation
Intact forest remnants
Some trees remain. But weeds becoming dominant.
Many sources of natural regeneration >3,086/ha, but inhibited by weeds.
Only smaller seed dispersers remain.

Stage-1 Degradation (Table 13.1, Figure 13.2)

Table 13.1 – Characteristics of Stage-1 Degradation

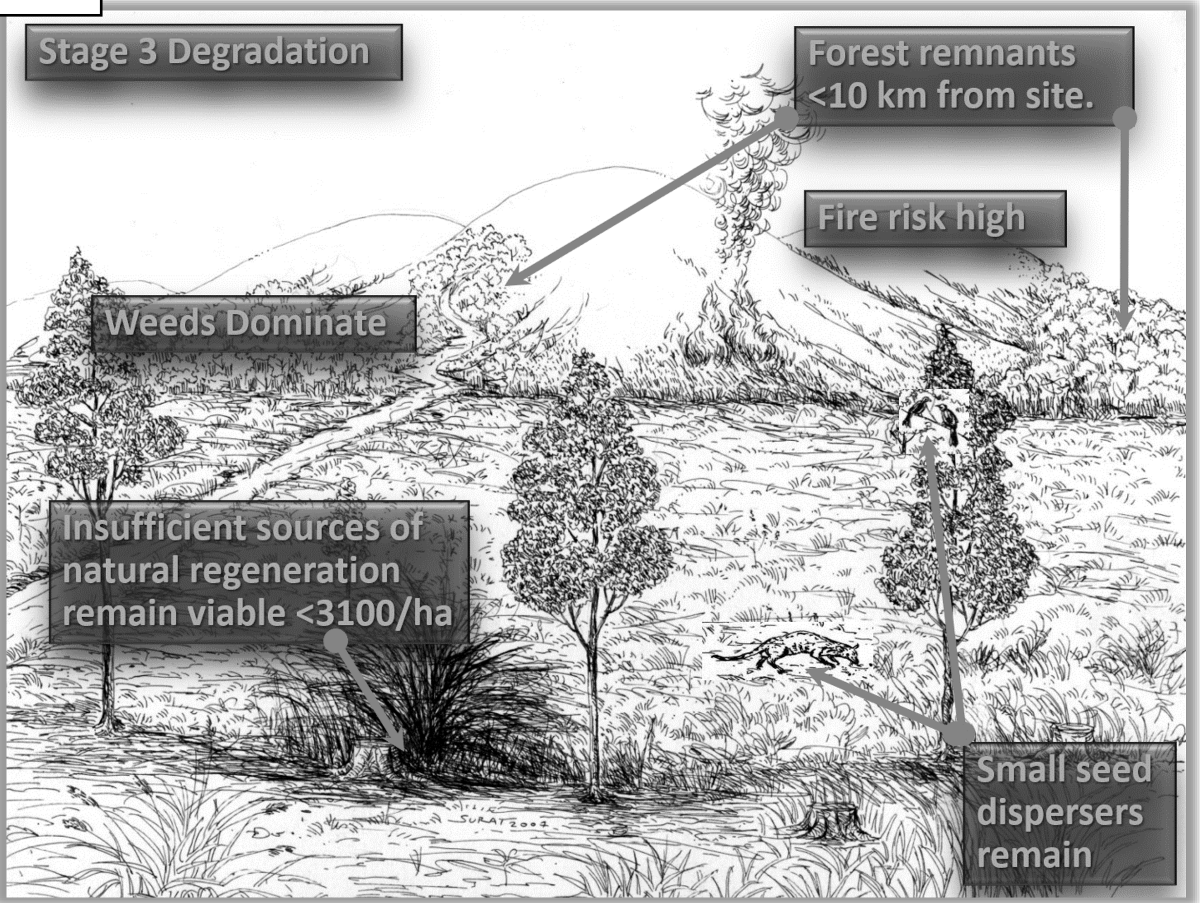
SITE CONDITIONS		LANDSCAPE CONDITIONS	
VEGETATION	TREES DOMINATE OVER HERBACEOUS WEEDS	FOREST	LARGE REMNANTS REMAIN AS SEED SOURCES
SOIL	LITTLE LOCALIZED DISTURBANCE; REMAINS MOSTLY FERTILE	SEED DISPERSERS	COMMON; BOTH LARGE AND SMALL SPECIES
SOURCES OF REGENERATION	PLENTIFUL: SOIL SEED BANK; DENSE SEEDLING BANK; DENSE SEED RAIN; LIVE TREE STUMPS	FIRE RISK	LOW TO MEDIUM
RECOMMENDED RESTORATION STRATEGY:			
• Protection from encroachment, cattle, fire and any other further disturbances and prevention of 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 (Table 13.2, Figure 13.3)

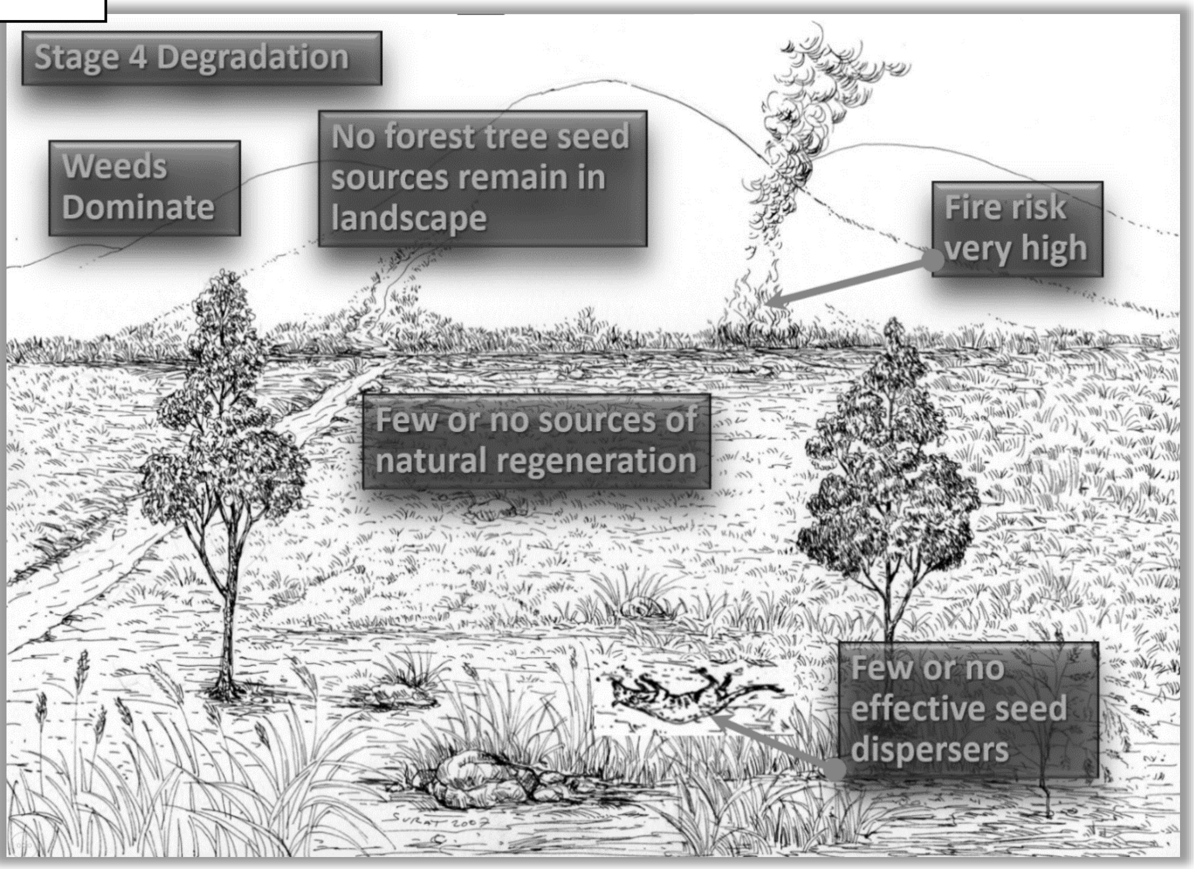
Table 13.2 – Characteristics of Stage-2 Degradation

SITE CONDITIONS		LANDSCAPE CONDITIONS	
VEGETATION	MIXED TREES AND HERBACEOUS WEEDS	FOREST	REMNANTS REMAIN AS SEED SOURCES
SOIL	REMAINS MOSTLY FERTILE; EROSION LOW	SEED DISPERSERS	LARGE SPECIES BECOMING RARE, BUT SMALL SPECIES STILL COMMON
SOURCES OF REGENERATION	SUFFICIENTLY DENSE TO CLOSE CANOPY IN 3 YEARS BUT SUPPRESSED BY WEED GROWTH	FIRE RISK	MEDIUM TO HIGH
RECOMMENDED RESTORATION STRATEGY:			
• Protection + accelerated natural regeneration (ANR) • Re-introduction of locally extirpated species			
OPTIONS TO INCREASE ECONOMIC BENEFITS:			
• Enrichment planting with economic species lost through unsustainable use • Establishment of extractive reserves to ensure sustainable use of forest products • Ecotourism			

13.4


Stage 3 Degradation
Forest remnants <10 km from site.
Fire risk high
Weeds Dominate
Insufficient sources of natural regeneration remain viable <3100/ha
Small seed dispersers remain
SURAT 2007

13.5


Stage 4 Degradation
Weeds Dominate
No forest tree seed sources remain in landscape
Fire risk very high
Few or no sources of natural regeneration
Few or no effective seed dispersers
SURAT 2007

Stage-3 Degradation (Table 13.3, Figure 13.4)

Table 13.3 – Characteristics of Stage-3 Degradation

SITE CONDITIONS		LANDSCAPE CONDITIONS	
VEGETATION	Herbaceous weeds dominate	**FOREST**	Remnants remain as seed sources
SOIL	Remains mostly fertile; erosion low	**SEED DISPERSERS**	Mostly small species dispersing small seeds
SOURCES OF REGENERATION	Mostly from incoming seed rain. Not dense enough to close canopy in 3 years	**FIRE RISK**	High

RECOMMENDED RESTORATION STRATEGY:

- Site protection + accelerated natural regeneration (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[3] or "Rainforestation" farming[4]

Stage-4 Degradation (Table 13.4, Figure 13.5)

Table 13.4 – Characteristics of Stage-4 Degradation

SITE CONDITIONS		LANDSCAPE CONDITIONS	
VEGETATION	Herbaceous weeds dominate	**FOREST**	Remnants too few or too distant to disperse tree seeds to site
SOIL	Erosion risk increasing	**SEED DISPERSERS**	Mostly gone
SOURCES OF REGENERATION	Few	**FIRE RISK**	High

RECOMMENDED RESTORATION STRATEGY

- Site protection + accelerated natural regeneration (ANR) + planting framework species + enrichment planting with climax species
- Maximum diversity methods

OPTIONS TO INCREASE ECONOMIC BENEFITS:

- Enrichment planting with economic species + sustainable harvesting of timber forest products.
- Employment of local people on the restoration program
- Analogue Forestry or "Rainforestation" farming

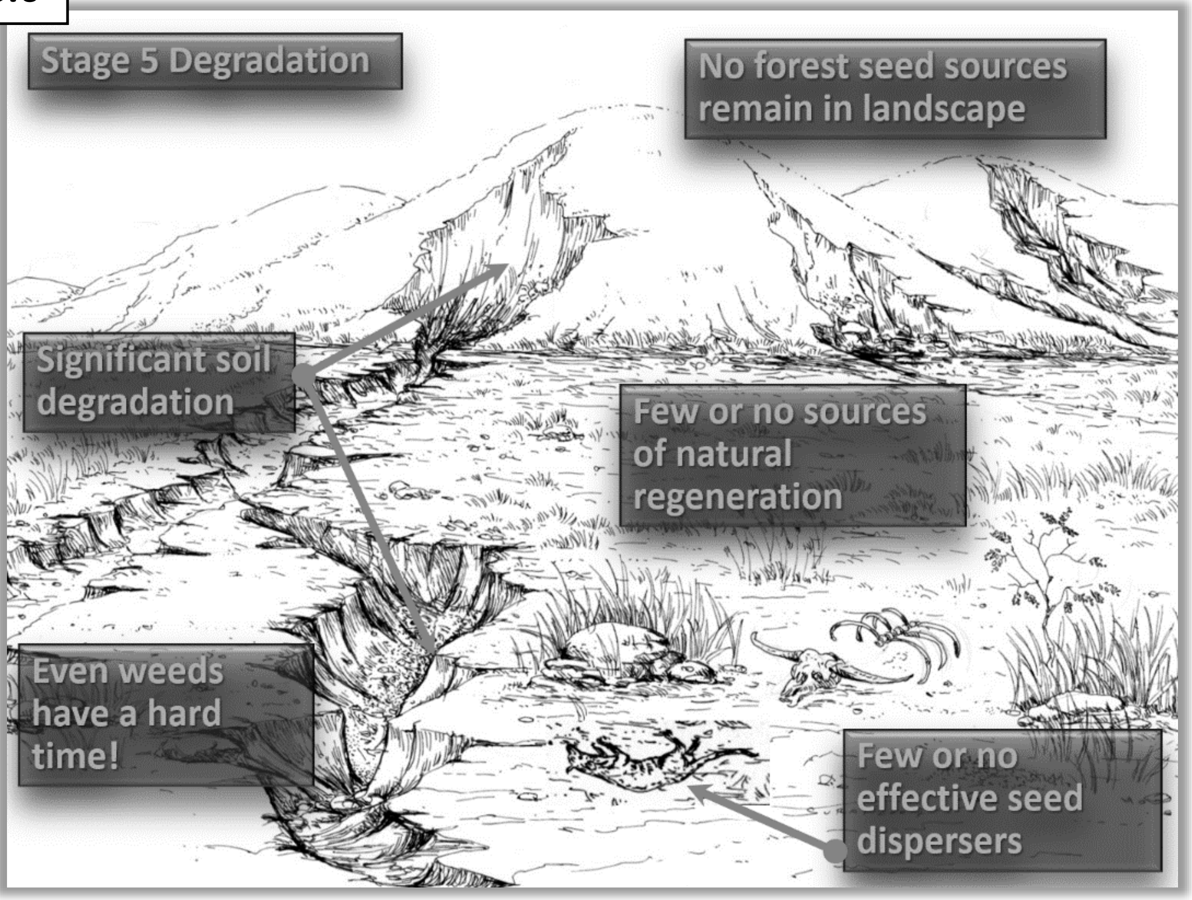
[3] en.wikipedia.org/wiki/Analog forestry ;
[4] www.rainforestation.ph/index.html

Stage-5 Degradation (Table 13.5, Figure 13.6)

Table 13.5 – Characteristics of Stage-5 Degradation

SITE CONDITIONS		LANDSCAPE CONDITIONS	
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, 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") • … and then planting a wide range of native forest tree species			
OPTIONS TO INCREASE ECONOMIC BENEFITS:			
• 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 are the same as for Stage 4			

13.6



14. The Framework Species Method (FSM) of Forest-Restoration

Tropical forest ecosystems typical comprise hundreds of tree species most of which have never been propagated in nurseries. Since it is impractical to attempt to grow them all, it is helpful to select those species with properties that enable them to prosper in degraded areas and accelerate forest regeneration – such species are known as "framework tree species". The framework species method of forest restoration is suitable for stage-3 degradation, where some natural regeneration is occurring and old-growth forest remains within seed-dispersal distance of the restoration site. Since stage-3 degradation is the most prevalent across SE Asia's upland areas, the framework species method is applicable over wide areas there.

Definitions

*The **framework species method** (FSM) is a technique for restoring forest ecosystems by densely planting open sites, close to natural forest, with a group of woody species, indigenous to the reference ecosystem and selected for their ability to accelerate ecological succession.*

***Framework tree species** are indigenous to the reference ecosystem, selected for restoration projects, for their tolerance of exposed conditions and their collective ability to inhibit herbaceous weeds and attract seed-dispersing animals, thus accelerating recovery of forest biomass, structure, biodiversity and ecological functioning.*

Selecting candidate framework tree species

Framework tree species are those that are more likely to accelerate natural forest regeneration than a random selection of reference-forest tree species. The various components that contribute towards this functionality are discussed here. Whilst the first two are essential, not all of the others need necessarily be maximal in *all* species planted; rather they should be strongly represented collectively by the mix of species planted.

(a) Indigenous to the reference forest ecosystem

By definition, framework species are indigenous to the reference forest ecosystem; exotic species are explicitly excluded. Therefore, where the local flora is not well known, selection of candidate species for field trials begins with a survey of remnant reference forest and its successional stages. Published accounts of the local flora and vegetation, as well as indigenous knowledge, are also invaluable for identifying such species.

(b) Tolerant of open conditions

All framework species must be able to persist with high survival and growth rates, in open, exposed conditions. This does not mean that only pioneer tree species are considered. Many tropical forest canopy tree species and some under-storey ones are phenotypically plastic, being tolerant of exposure to sunlight, despite growing as shade-tolerant seedlings in mature forest. For example, in northern Thailand, *Hovenia dulcis* displays rapid growth in open sites, whilst mature fruiting adults are confined to primary forest. Such plasticity makes such species ideal framework species.

(c) Attractive to seed-dispersing animals

For fostering biodiversity recovery, attractiveness to seed-dispersing animals within a few years after planting is crucial for framework-species selection. Seed-dispersing frugivores are attracted to tree species with fleshy fruits, but other foods such as nectar or high abundance of insects may attract omnivores, which may also incidentally disperse some seeds. Provision of structural features, which provide perches or nesting sites can also play an important role in attracting seed-dispersers. For example, *Melia azedarach*, planted in framework-species trials in northern Thailand, is highly attractive to birds, but not because of its fruits (which are large and woody). Its exceptionally high growth rate creates perching sites far above those of all other planted species, favoured by birds for territorial display.

However, attractiveness varies enormously among tree species, resulting in distinctive seedling communities establishing around each. Those that annually produce fleshy fruits or arillate seeds (preferably at a young age) of high nutritional value, are most likely to attract frugivores, particularly generalist birds (e.g., bulbuls (Pycnonotidae) on *Prunus cerasoides*, in northern Thailand).

(d) Ability to inhibit weeds

Framework species should inhibit weed growth beneath their crowns, by producing dense shade, or allelopathic chemicals. This is important because weeding is one of the most expensive components of the FSM. Selecting framework species with dense spreading crowns, (e.g., *Macaranga, Trema, , Gmelina, Choerospondias* etc.) and planting them close enough to initiate canopy closure in 2 years, shades out most light-demanding tropical weeds, except for some vines, which may require ongoing attention. Many tropical trees are allelopathic i.e., they release chemicals that inhibit germination and growth of nearby weeds (e.g., *Gmelina arborea*). Selection of such species is recognised as an effective tool for weed management, during forest restoration projects.

(e) Ease of propagation

Success of the FSM depends on nursery production of high-quality planting stock of the desired framework tree species: vigorous, disease-free, saplings 25-50 cm tall, weed-free, root-pruned and sun-hardened for at least six weeks before planting. Therefore, ease of propagation is also an important selection criterion. Framework species are commonly grown from seed, collected locally from many trees (to maintain genetic diversity). Most fleshy-fruited species can be germinated easily, particularly when seeds are fresh and the pericarp/mesocarp/aril are removed, prior to sowing. However, when seed germination is problematic, some species have been propagated from leafy cuttings. Nursery experiments, to develop efficient propagation techniques, are often helpful.

Implementing the FSM

Saplings are grown in a nursery from seeds, collected from multiple trees in the reference forest ecosystem or other local sources. Sapling of all selected species must be 30-50 cm tall by the optimum planting time (mid-June for eastern Myanmar).

A rapid site survey is performed to estimate the density and species richness of natural regenerants already on the restoration site. The number of trees needed to increase stocking density to about 3,100 is calculated and along with the number of species needed to increase species richness to at least 30 species. The appropriate number of trees and species is selected and planted following standard procedures. Weeding and fertilizer application are carried on both planted and naturally regenerating trees out least 3 times in the first and second rainy seasons and fire prevention procedures implemented. Further maintenance may be required in the 3rd year, but only in patches of the restoration site where canopy closure is failing to occur.

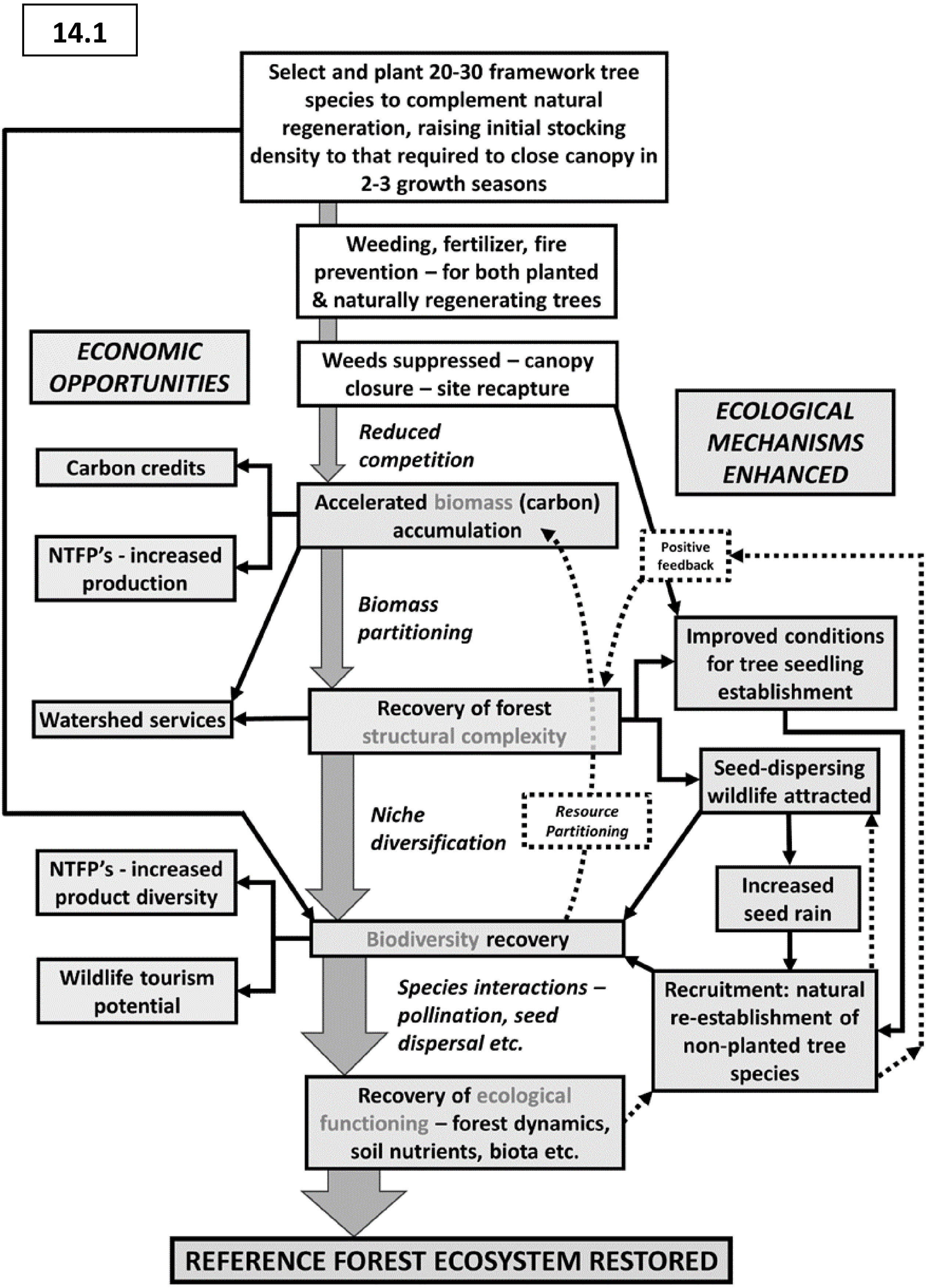
How the FSM works

Suitable species selection and maintenance procedures ensures that about 70-80 % of planted trees and natural regenerants survive into the 3rd and 4th year. Selecting species with high survival and growth rates and planting them at high densities (1.8 m apart) ensures rapid biomass accumulation. As forest biomass increases it becomes partitioned among more and more different components of forest structure (e.g. different types of tree trunks, large/small branches and roots etc.). This re-creates structural complexity and habitat diversity—ecological niches which can then become colonized by a diverse array of plant and animal species dispersing from nearby forest remnants. It also creates, cool shady and weed free conditions on the forest floor ideal for the germination of tree seeds coming in from remnant forest. As the incoming plant and animal species start to interact with one another, they increase the ecological functionality within the restored forest—insects pollinate flowers, birds disperse seeds, fungi decompose dead organic matter etc. The forest becomes self-sustaining and no further restoration interventions are needed.

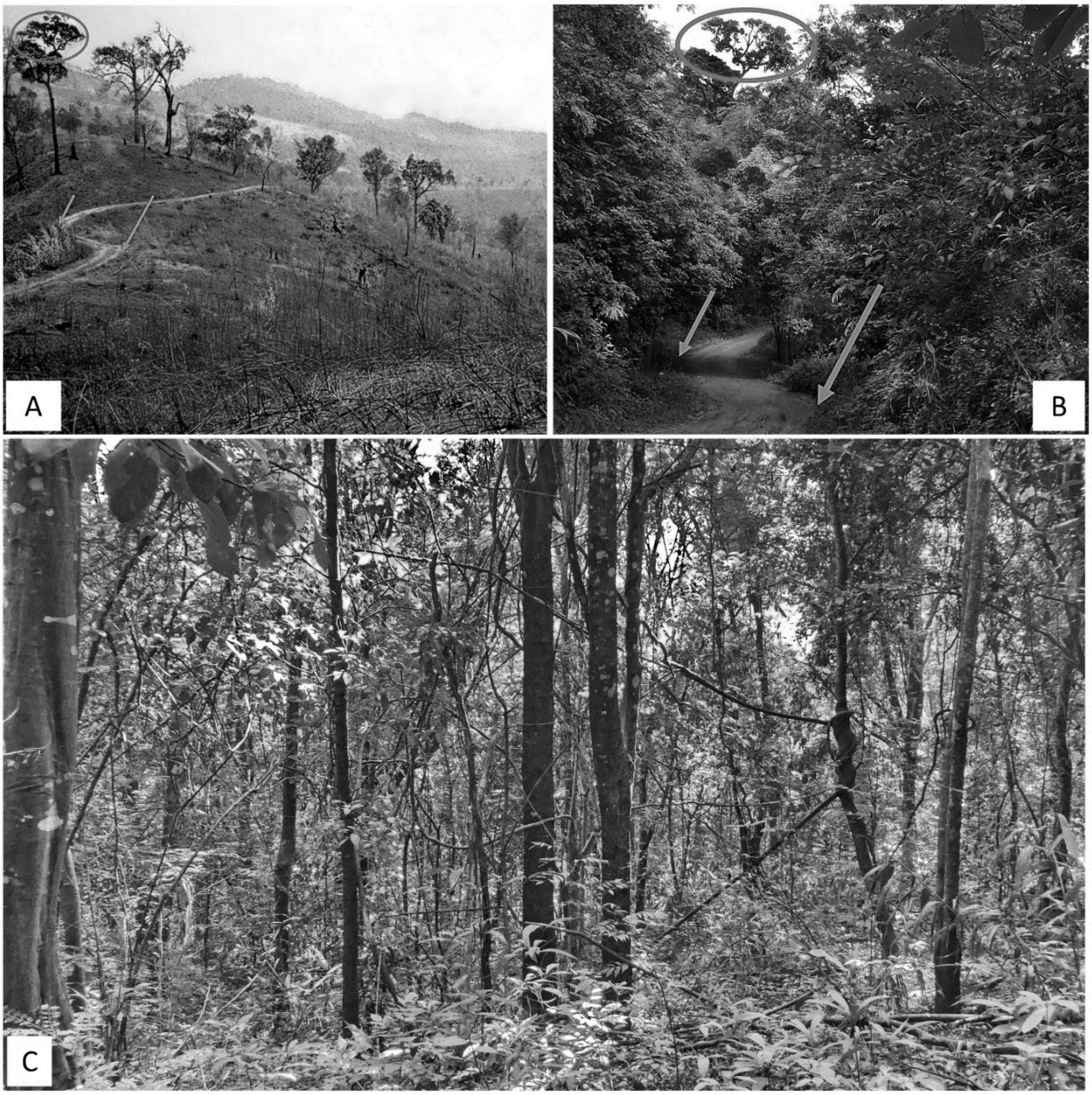
Reading

Elliott, S., N.I.J. Tucker, D. Shannon & P. Tiansawat, 2022. The framework species method—harnessing natural regeneration to restore tropical forest ecosystems. https://www.forru.org/library/0000229

Figure 14.1 *- How the framework species method works. Dotted lines indicate positive feedback loops, by which planted framework tree species intensify regeneration: weed suppression, the seed-rain, and creation of conditions conducive to the establishment of recruit tree species.*
Figure 14.2 *- [A] Upper Mae Sa Valley, northern Thailand May 1998; [B] same location after planting framework tree species (3,100 trees/ha), left of track, 15 years old (31 species); right, 9 years old, (76 species); [C] forest interior after 21 years—a dense understorey of recruit species (>70 measured in 0.46 ha) developed beneath the canopy. Structural diversity recovered (note woody climbers), and carbon-storage approached that of mature forest.*


14.1
Select and plant 20-30 framework tree species to complement natural regeneration, raising initial stocking density to that required to close canopy in 2-3 growth seasons
Weeding, fertilizer, fire prevention – for both planted & naturally regenerating trees
ECONOMIC OPPORTUNITIES
Weeds suppressed – canopy closure – site recapture
ECOLOGICAL MECHANISMS ENHANCED
Reduced competition
Carbon credits
Accelerated biomass (carbon) accumulation
NTFP's - increased production
Positive feedback
Biomass partitioning
Improved conditions for tree seedling establishment
Watershed services
Recovery of forest structural complexity
Seed-dispersing wildlife attracted
Niche diversification
Resource Partitioning
NTFP's - increased product diversity
Increased seed rain
Biodiversity recovery
Wildlife tourism potential
Species interactions – pollination, seed dispersal etc.
Recruitment: natural re-establishment of non-planted tree species
Recovery of ecological functioning – forest dynamics, soil nutrients, biota etc.
REFERENCE FOREST ECOSYSTEM RESTORED

14.2



15. Seed collection, Handling and storage

Seed Collection

What are fruits and seeds?

The structure sown in a germination tray is not always just the seed. Sometimes the whole fruit is sown e.g. the nuts of oaks and chestnuts (Fagaceae) or sometimes it is the pyrene. Pyrenes are one or several seeds enclosed by the hard-inner wall of the fruit (endocarp). For example, up to five seedlings can emerge from a single pyrene of *Choerospondias axillaris.* So, a basic understanding of the fruit and seed morphology can be helpful in deciding appropriate nursery procedures.

A seed develops from an egg cell (ovule) contained within the ovary of a flower, usually after pollination and fertilization. Being the products of sexual reproduction, combining the genes of two parents, seeds are essential in generating genetic diversity within tree populations. Seeds consist of three main parts: the covering part, the storage part and the embryo. The seed coat or testa protects seeds from harsh environmental conditions and plays an important role in dormancy. Food reserves, to sustain metabolism during and immediately after germination, are stored in the endosperm or the cotyledons. The embryo consists of a rudimentary shoot (plumule), a rudimentary root (radicle) and seed leaves (cotyledons). Fruits are derived from the ovary wall. They may be broadly classified as “simple” (from the ovary of a single flower); “aggregate” (from the ovary of a single flower, but several fruits fused into a larger structure) or “multiple” (from ovaries of several flowers fusing).

When should seeds be collected?

In the seasonally dry forests of northern Thailand, many tree species fruit in every month of the year, so at least one seed collection trip is needed every month. Fruiting peaks at the end of the dry season and at the end of the rainy season (see Fig 3.1), whereas a dearth of fruiting tree species in the early rainy season means that fewer seed collection trips are needed then. For northern Thailand, the fruiting months of individual tree species are can be found in Part 10 of this book and in Maxwell and Elliott (2001). For other regions, phenology studies are needed (see Part 9, Section 2).

Seeds must be collected before they are dispersed or consumed by animals. Seeds collected too early may be unripe and fail to germinate, whereas those collected too late may have lost viability. Seeds gathered from the ground must be collected before they start to germinate or rot. Therefore, the ideal time to collect seeds is just after the fruit matures, but just before fruit fall would occur naturally.

It is usually better to cut fruits from the tree branches rather than to pick them up from the ground. Climb the tree to cut down ripe fruit or use a cutter mounted on the end of a long pole. Fruits can also be dislodged by shaking the whole tree or some of the lower branches. However, for very tall trees, collecting fruits from the forest floor may be the only option. If so, make sure the seeds are not rotten, by cutting them open. The ideal time for picking up fruit from the forest floor is when the first truly ripe fruits are falling, or when animals and birds start to consume the fruit. This is a clear indication that seed dispersal has started.

Ripeness can be indicated by several factors, including;

1. the colour of the fruit (e.g. the fruits of *Prunus cerasoides* turn from green to red);
2. for dehiscent fruits, when they start to split open (e.g. *Erythrina subumbrans*) and
3. consumption by animals (e.g. *Hovenia dulcis*).

Cut open some seeds and look for a well-developed embryo, and/or a solid endosperm (if present).

Where should seeds be collected and from how many trees?

Genetic variability is essential to enable species to survive variable environmental conditions. Therefore, it is important to maintain a broad genetic base in tree planting programs, especially where biodiversity conservation is a major goal. The best way to ensure genetic variability among planted trees is to collect seeds from several parent trees. If seeds are collected from just one, or a few parent trees, genetic variability is reduced, resulting in inbreeding depression and decreased adaptability within the population. This is a particularly serious problem where trees are planted far from existing mature trees. These can provide pollen, which can restore genetic diversity in subsequent generations through cross pollination.

Various international organizations advise that, to maintain genetic diversity in tree planting programmes: 1) seeds should be collected from as many trees as is practicable (preferably 25-50), situated as close as possible to the planting site and 2) equal numbers of seeds from each seed tree should be mixed together prior to sowing to ensure equal representation of all the seed trees.

How many seeds should be collected?

The number of seeds collected depends on the number of seedlings required, seed germination percentage and seedling survival rates. Keeping accurate records will help determine the numbers required in future collections.

What precautions should be taken when collecting seeds?

Seed collection trips require planning and liaison with the people responsible for treating and sowing the seeds, because the seeds are vulnerable to desiccation and/or fungal attack, if they are not processed quickly. Use a cutter mounted on a pole or shake smaller trees to dislodge fruits. For very tall trees, collecting fruits from the forest floor may be the only option. If so, make sure the seeds are not rotten, by cutting them open and looking for a well-developed embryo, and/or a solid endosperm. Do not collect any fruits or seeds with signs of fungal infection, teeth marks or small holes made by insects.

How should fruit/seed be processed prior to planting?

Do not leave seeds in sun, where may dry and die, or in damp places where may rot. Sow them as soon as possible after collection. Seeds must be processed and cleaned to prepare them for sowing. The type of processing required depends on the fruit type.

Fleshy fruits: Remove as much flesh as possible with a knife and wash off any remaining flesh. Soak firm fruits, such as *Melia toosendan*, in water for 2-3 days to soften the pulp and ease seed extraction. In some species, removal of the pulp reveals a pyrene containing one or more seeds (e.g. *Prunus cerasoides* and *Melia toosendan* respectively). If seeds are to be planted immediately, the tough woody endocarp must be cracked open to allow water to penetrate into the seed and trigger germination. A vice, hammer or knife, can be used to gently crack open most pyrenes without damaging the seed(s) inside.

Dry dehiscent fruits: Dehiscent fruits, such as pods of trees in the Leguminosae family (e.g. *Erythrina subumbrans*), split open naturally as they mature. Dry, dehiscent fruits are therefore laid out in a dry, sunny place until they open naturally.

Dry indehiscent fruits: Dry fruits that do not split open naturally (e.g. *Cassia fistula*) must be cut open or prized apart with secateurs or other tools. Seeds of some indehiscent fruits, such as samaras and nuts, are not usually extracted. The whole fruit is placed in the germination tray. However, some appendages may be removed to aid subsequent handling, such as the wings of samaras (e.g. *Acer* spp). Similarly, the cupule of nuts should be removed e.g. of acorns or chestnuts (*Quercus* spp and *Castanopsis* spp, Family Fagaceae).

Why should seed be stored?

In general, storing seeds reduces their viability, so in most circumstances, sowing seeds immediately after collection is the best strategy. However, seed storage may become necessary for three main reasons:

1. Seed storage would allow seeds to be distributed to areas where seeds are not unavailable.
2. Secondly seed storage can shorten the length of time that fast-growing tree species need be kept in nurseries. The current practice of sowing seeds immediately after collection, results in seedlings of faster-growing trees reaching plantable size several months before the optimum planting time. Such seedlings must be pruned back to prevent them from outgrowing their containers and they must be stored in the nursery for several months, wasting space and resources. Storing the seeds of such species for a few months before sowing them would enable seedlings to be grown to optimum size just in time for the planting season.
3. Thirdly, some tee species produce large fruit crops in some years and no fruits in others (this is called masting) e.g. several species in the families Dipterocarpaceae and Fagaceae. Obviously, for such species, storing seeds collected during masting years for sowing in non-masting years would enable a steady supply of seedlings to be maintained.

What's the difference between orthodox and recalcitrant seeds?

Orthodox seed may be dried, without significantly reducing seed viability. They can also be stored at a few degrees above freezing. In contrast, seeds of recalcitrant species are killed by drying and chilling. The opportunity to store recalcitrant seeds is therefore very limited and usually requires technologies that are impractical in simple village tree nurseries. So, confirm from the literature that that seeds you want to store are orthodox.

How can orthodox seeds be stored?

Storage of dried seed at ambient temperatures should be sufficient to maintain viability for 12 - 24 months. Longer periods of storage may require low temperatures, but this is usually not necessary for most short-term forest restoration needs.

Slowly dry seeds in the sun, over several days, to at least 5-10% moisture content, but preferably lower. This reduces the metabolism of the seeds and prevents growth of fungi. To make sure that the required level of dryness has been reached, weigh a small sample of seeds and place them in an oven at 120-150°C for an hour. The weight of the seed sample, after it has been removed from the oven, should not have decreased by more than 10%. This sub-sample of seeds, used to confirm dryness, should be thrown away.

Immediately after the seeds have been dried, put them into airtight containers. Fill the containers to the top with seeds to minimize the volume of air (and moisture) inside them. Efficiently sealing the container is absolutely crucial, to prevent any moisture or fungal spores from entering. If containers are likely to be opened frequently, store seeds in small sealed packets within a larger container, to minimize exposure of the remaining seeds to air and moisture. Including a small sachet of silica gel within the containers can help maintain dryness.

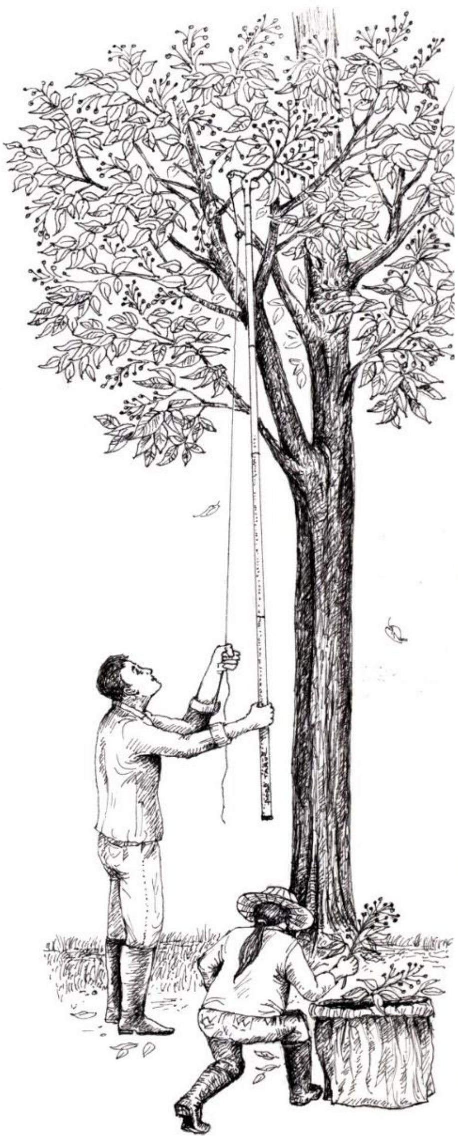
Reading

Schmidt, L., 2000. Guide to Handling of Tropical and Subtropical Forest Seed. The DANIDA Forest Seed Centre. https://www.dropbox.com/sh/5ajhd4ncn16quye/AACZ--vzE-Lf7VVDKW0Lw8coa?dl=0

Online resource: https://www.forru.org/advice/seed-collection-storage-banking

Figure 15.1 *– Collect seeds with a cutter mounted on a pole. Label the tree and measure its girth. Record relevant data on the record sheet and collect an herbarium specimen to confirm species identity.*
Figure 15.2 *– Basic fruit tyopes*

15.1



Species number: Batch number:

SEED COLLECTION RECORD SHEET

Family:

Species: Common name:

Date collected: Collector's name:

Tree label no.: Tree girth:

Collected from ground [ ] or from tree [ ]

Location: Elevation:

Forest type:

Approximate no. seeds collected:

Storage/transport details:

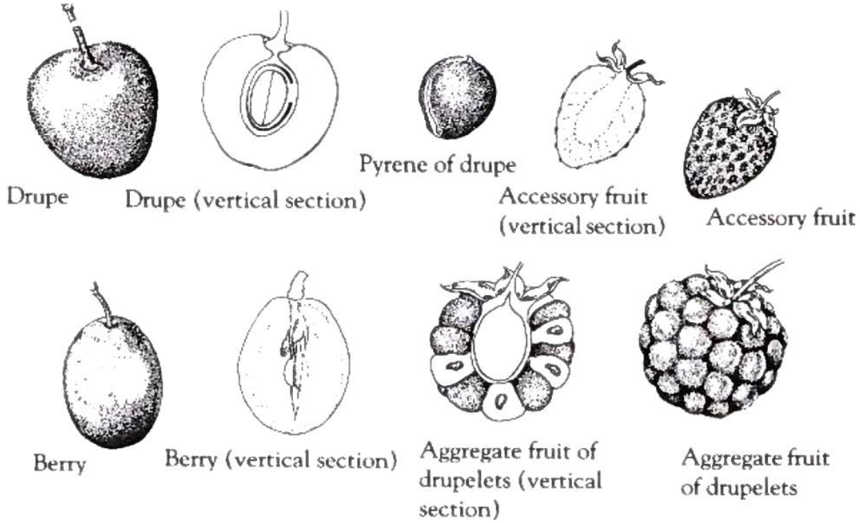
Pre-sowing treatment: Sowing date:

Voucher specimen collected [ ]

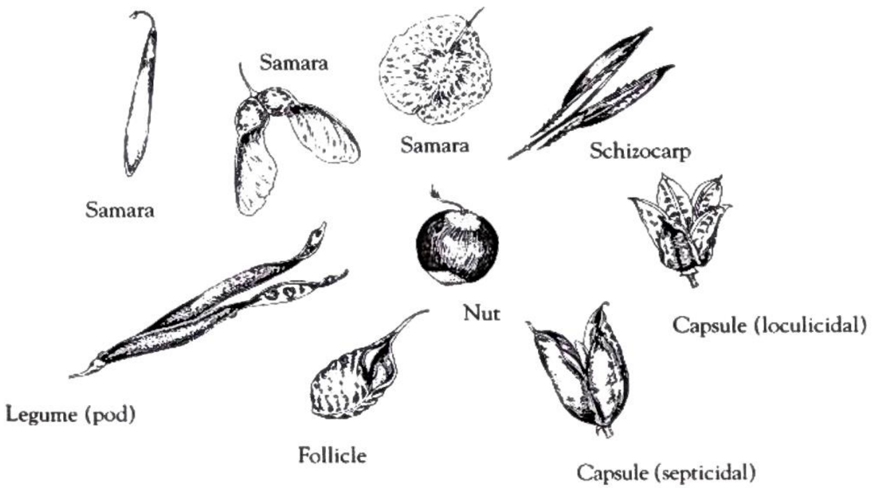
Notes for herbarium label

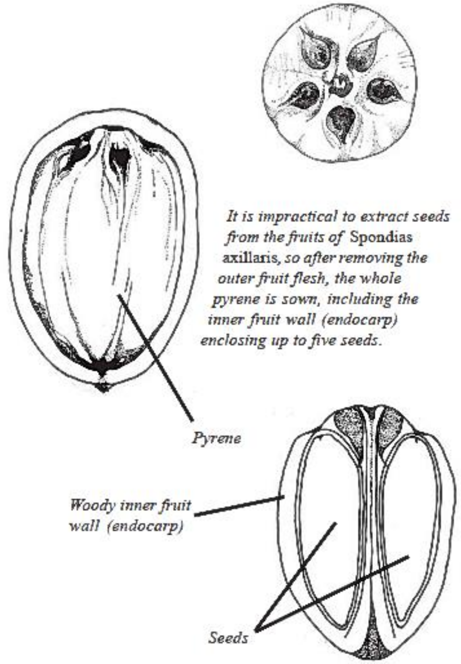
15.2

Fleshy Fruit Types

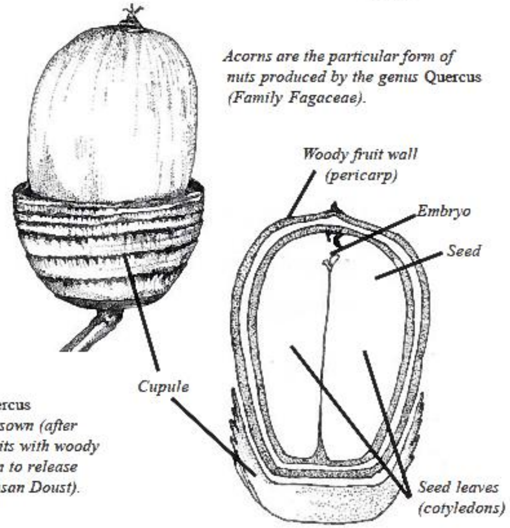


Dry Fruit Types





It is impractical to extract seeds from the fruits of Spondias axillaris, *so after removing the outer fruit flesh, the whole pyrene is sown, including the inner fruit wall (endocarp) enclosing up to five seeds.*



Acorns are the particular form of nuts produced by the genus Quercus *(Family Fagaceae).*

For growing oaks, such as this Quercus semiserrata, *the entire fruit (nut) is sown (after removing the cupule). Nuts are fruits with woody outer walls, which do not split open to release the single seed inside (drawn by Susan Doust).*

16. TREE NURSERY DESIGN & MANAGEMENT - PLANTING STOCK PRODUCTION

Building a nursery

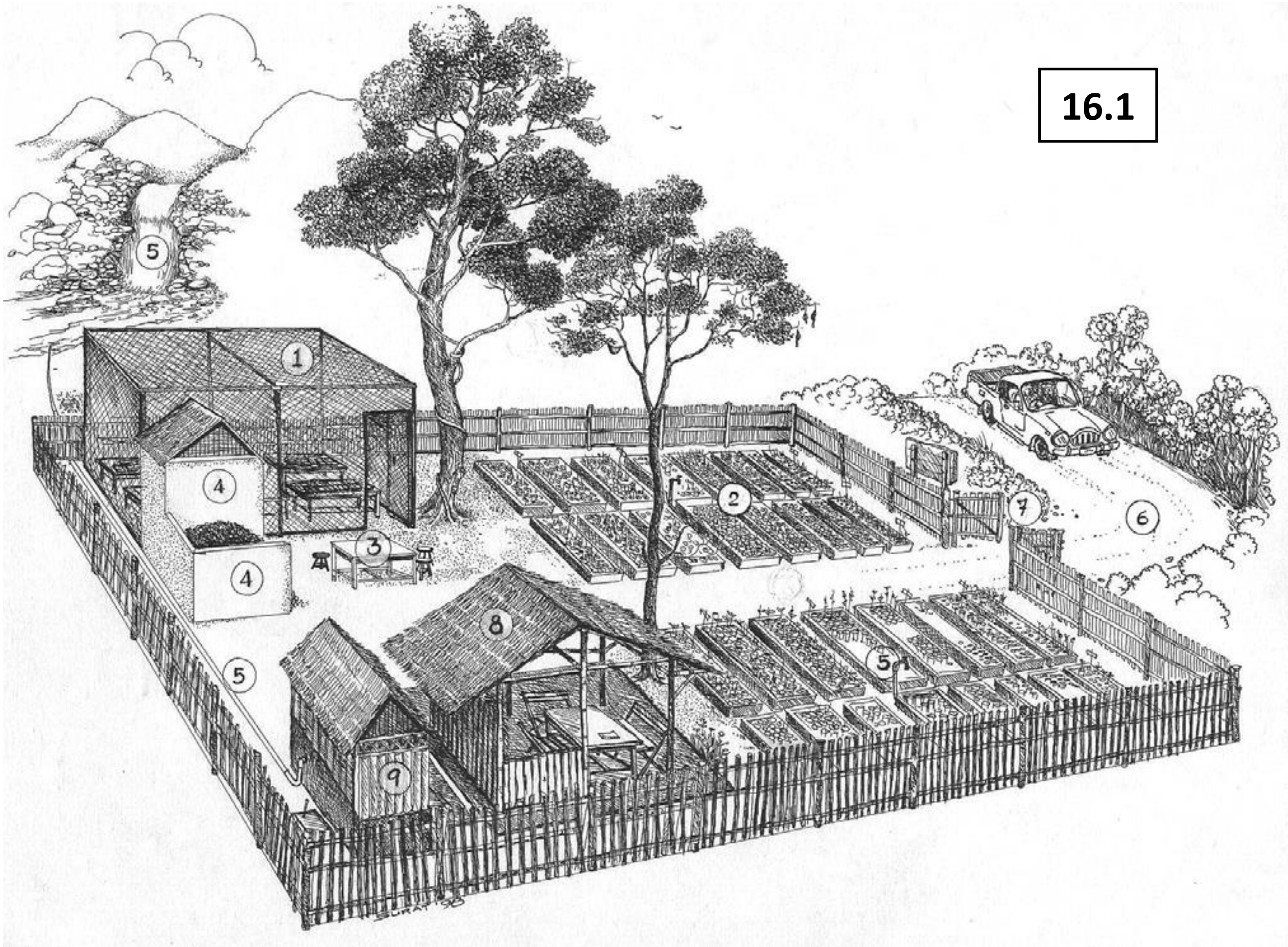
A nursery must provide ideal conditions for the growth of tree seedlings, whilst protecting them from stresses. It must also be a comfortable and safe place for nursery workers. It should be built on a flat or slightly sloping site, with good drainage (steeper slopes require terracing), close to a permanent supply of clean water (but free from the risk of flooding). The nursery should also be accessible by road and close to a supply of soil. The size of the nursery depends on the size of the area to be restored, which in turn determines how many trees must be produced each year. The table below relates the size of the area to be restored per year to the minimum size of the nursery required. These calculations refer to seeds germinated in trays and transplanted into containers, with relatively high survival rates. For example, if the area to be restored is one hectare per year, up to 3,100 trees will be needed, requiring a nursery of approximately 80 m^2.

Area to be restored (ha/yr.)	***Maximum Number of trees needed[1]***	***Seed germination area (sq m)***	***Standing-down area (sq m)***	***Storage, shelter, toilet etc. (m^2)***	***Total nursery area needed (m^2)***
0.25	775	3	11	15	29
0.5	1,550	6	22	15	43
1	3,100	13	44	15	72
5	15,500	63	220	15	298
10	31,000	125	440	15	580

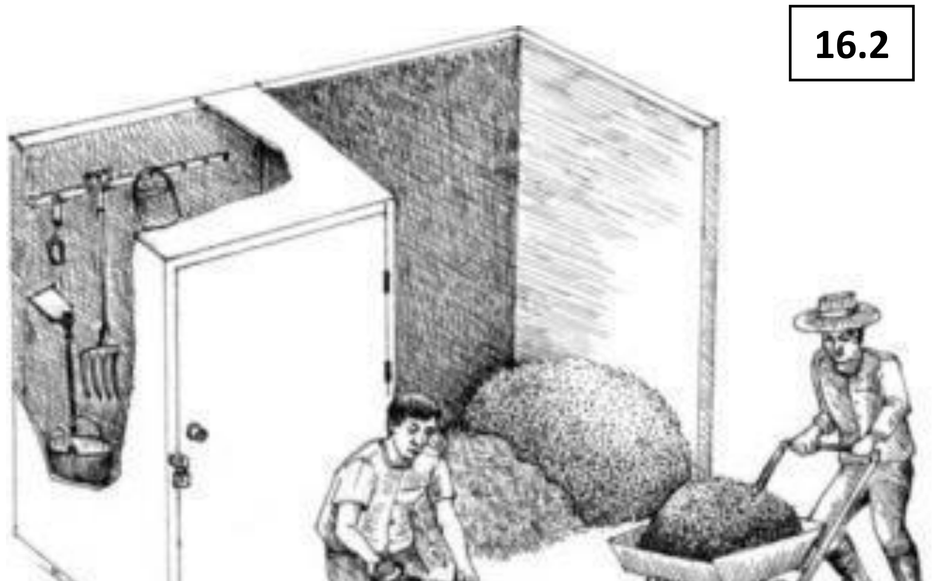
Locally available materials, such as recycled wood, bamboo and palm leaves can all be used to build a simple inexpensive nursery. The essential requirements include:

- a shaded area with benches for seed germination, protected from seed predators by wire mesh; shade may be provided by commercial materials, but alternatives include palm leaves, coarse grasses and bamboo slats,
- a shaded area where potted seedlings can be grown until ready for planting (shade should be removable if young trees are to be hardened *in situ* prior to planting),
- a work area for seed preparation, pricking-out etc.,
- a reliable water supply,
- a lockable store for materials and tools and
- a fence to keep out stray animals and a shelter and toilet for staff and visitors.

Figure 16.1 *- Nursery layout - (1) germination shelter, (2) standing-down area (shade removed), (3) potting work area, (4) media store and lockable equipment store, (5) water supply, (6) access, (7) fence to exclude animals, (8) shelter from the sun and rain and (9) toilet.*
Figure 16.2 - *A lockable store, to keep equipment safe, and a media store are essential parts of a tree nursery.*



16.1



16.2

16.3

Growing trees requires simple, inexpensive equipment. Many of the items illustrated in ***Figure 16.3*** *are readily available in an average agricultural community and could be borrowed for nursery work: shovel (1) and buckets (2) for collecting, moving and mixing potting media, trowels (3) or bamboo scoops (4) for filling containers with potting medium, a watering can (5) and hose, both with a fine rose, spatulas or spoons for pricking-out seedlings, a sieve (6) for preparing the potting medium, a wheelbarrow (7) for moving plants and materials around the nursery, hoes (8) for weeding and maintaining standing-down area, secateurs (9) for pruning seedlings, a ladder and basic construction tools for erecting shade netting etc.*

Overcoming seed dormancy

In nurseries, dormancy prolongs tree-production time. Therefore, various treatments are applied to break dormancy. A thick, impervious seed coat impeded penetration of water and oxygen to the embryo, so one of the simplest techniques to break dormancy is to cut away a small piece of the seed coat with a sharp knife or nail clippers. For smaller seeds, gently rubbing them with sandpaper can be equally effective. These techniques are called **scarification**. During scarification, take care not to damage the seed's embryo. Acid treatment is another form of breaking down seed covering, but since acid can kill the embryo, seeds must be soaked in acid only long enough to soften the seed coat, without penetrating to the embryo. When germination is inhibited by chemicals, soaking seeds in water to dissolve the chemical inhibiters can induce germination.

How should seeds be sown?

Sow seeds in germination trays, filled with a suitable medium, except for large seeds, which can be sown directly into plastic bags or other containers. Seed trays should be 6¬10 cm deep, with plenty of drainage holes in the bottom. The germination medium must have good aeration and drainage and provide support for germinating seedlings. Mix forest soil with coconut husk 2:1, or for very small seeds, forest soil:sand 1:1. Including forest soil in the medium provides a source of mycorrhizal fungi, required by most tropical forest tree species. Sow small to medium-sized seeds just below the surface of the medium, to a depth of approximately two to three times their diameter. If rats or squirrels are a problem, cover germination trays in wire mesh. Space the seeds at least 1-2 cm apart (more if the seeds are large) to prevent over-crowding. If seeds are sown too closely together, seedlings may be weakened and more susceptible to diseases such as damping off. Water the germination trays lightly, immediately after sowing the seeds and regularly thereafter. Use a spray bottle or a watering can with a fine rose to prevent compaction of the medium. Watering too frequently encourages damping off diseases.

Potting and Seedling Growth in Nurseries

Containers must be large enough to allow development of a good root system, and support adequate shoot growth. They must have sufficient holes to permit good drainage, be lightweight, inexpensive, durable and readily available. Plastic bags are most commonly used. The optimum size is 9 inches tall by 2½ inches wide (230 x 65 mm). This allows tap roots to grow fairly long, before they would reach the bottom of the bag and start spiraling.

A potting medium consists of coarse and fine soil particles with pores between them for aeration and drainage. The medium must provide growing trees with 1) support, 2) moisture, 3) oxygen, 4) nutrients and 5) symbiotic micro-organisms. Soil *alone* is unsuitable, because it is easily compacted and the container prevents free drainage. This causes water-logging, which suffocates roots. However, it is important to include some forest soil in the medium, since it carries the spores of soil micro-organisms (e.g. *Rhizobium* bacteria and mycorrhizal fungi), which help trees to grow. To prevent compaction, mix forest soil with bulky organic matter, to improve drainage and aeration. The materials you choose should be locally available throughout the year and cheap. A standard, medium consists of 50% forest top soil mixed with 25% fine organic matter and 25% coarse organic matter. To prevent the spread of diseases, never re-cycle the potting medium.

Potting (picking out)

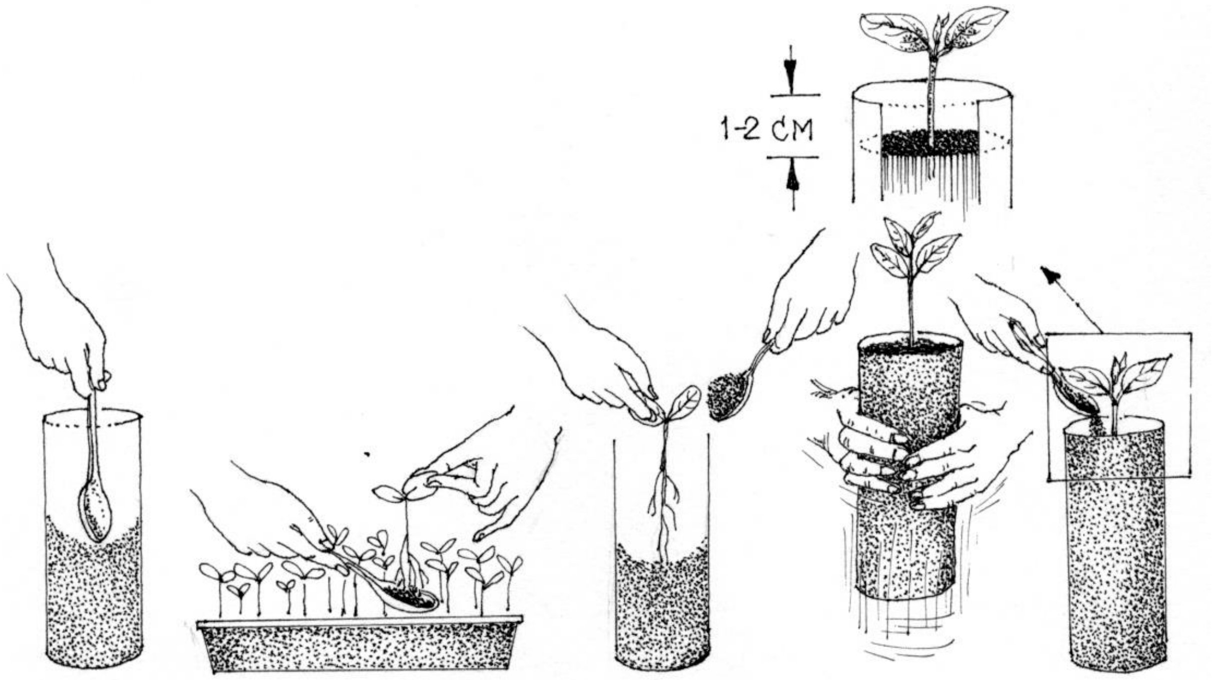
Fill containers with moist medium. Bang each container on the ground a few times to allow the medium to settle. Then, top up containers with more medium until they are full again. With plastic bags, check for correct consistency by firmly grasping the bag. The impression of your hand should remain after you let go and the bags should stand up straight, unsupported. Seedlings are ready for pricking out, when after the first 1-3 pairs of true leaves have fully expanded. Make a hole in the medium, big enough to take the seedling's roots without bending them. Gently grasp a leaf (not stem) of a seedling and slowly, prise it out of its germination tray with a spoon. Place the seedling's root into the hole in the potting medium and fill the hole with more medium. Bang the container on the ground to settle the medium. Top up with more medium, until the medium surface is 1-2 cm below the container's rim and the seedling's root collar (junction between root and shoot) is at the medium surface. Then, press the medium to make sure the plant is upright and centrally placed. Suspend larger plants in a partly filled container and add medium around the roots.

Caring for Seedlings in Nurseries

"**Standing-down**" refers to the time that containerized trees are kept in the nursery – from potting until transportation to the planting site. Place containers in shade area and water the seedlings as needed. The containers may be stood down on i) the ground, ii) on ground covered by various materials or iii) on raised wire grids. If containers are stood down on bare earth, tree roots can grow through holes in the base of the containers into the underlying soil. When the trees are lifted, the roots break; the plant goes into shock before it even reaches the planting site. Therefore, the containers must be lifted every few weeks, and **root pruning** performed. The ultimate solution is to stand down containers on raised wire grids. Roots growing out from containers are exposed to air and either stop growing or die. This is called **air pruning.** It encourages root branching within containers and the formation of a dense root ball, which increases survival after planting out.

Figure 16.4 - *Steps of pricking out*
Figure 16.5 - *Problems with potting (left to right from the top): 1. Medium has settled; bag rim of bag collapses, watering blocked; 2. Curled roots, adult trees susceptible to wind throw; 3. Seedling not central; 4. Medium too soft; 5. Medium compacted; 6. Excellent medium consistency 7. The perfectly potted seedling!*

16.4



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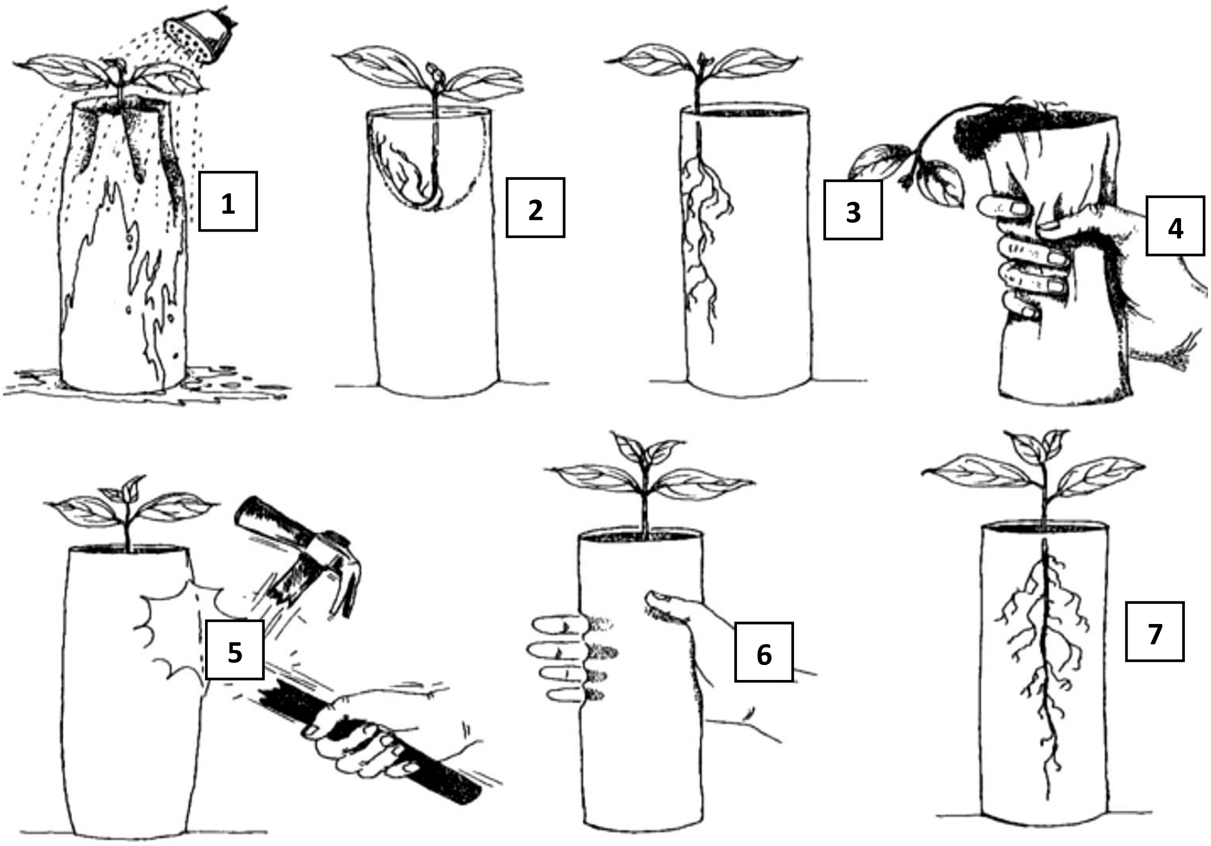


Water

Each container holds a relatively small amount of water, so seedlings can dry out rapidly if watering is interrupted for more than a day. In contrast, over-watering can saturate the potting medium, which suffocates the roots. Water the trees early in the morning and/or late in the afternoon. Judge watering frequency according to moistness of the medium.

Fertilizer

Trees require large amounts of nitrogen (N), phosphorus (P) and potassium (K), moderate amounts of magnesium, calcium and sulphur and trace amounts of iron, copper and boron and others. The potting medium may supply adequate quantities of these nutrients, but additional fertilizer application can accelerate growth. Plants with symptoms of nutrient deficiency, such as yellowing leaves, may be suffering from a nutrient shortage and should receive fertilizer. Fertilizer should also be applied when it is necessary to accelerate growth to produce plants large enough by planting time. Slow-release fertilizer granules such as Osmocote are recommended. Apply 10 granules of Osmocote NPK 14:14:14 (approx. 0.3 g) to the medium surface of each container every 3 months. Do not apply fertilizer i) to rapidly growing species that reach a plantable size before the optimal planting time (since they will outgrow their containers) ii) to species in the Family Leguminosae and iii) immediately prior to hardening-off (as new shoot growth should not be encouraged at that time).

Weeding

Weeds, around the nursery, can harbour pests and their seeds may spread into containers. Grasses, herbs and vines should all be removed from the nursery grounds before they can flower. Weeds that colonize containers compete with tree seedlings for water, nutrients and light. Use a blunt spatula to remove them while they are still small.

Disease

Diseases can occur even in the best-maintained nurseries. Three main causes are:

- **Fungi:** although some species are beneficial, others cause damping-off, root-rots and leaf-spots (blights and rusts);
- **Bacteria**: most are harmless, but some cause damping-off, canker and wilts and
- **Viruses**: most do not cause problems, but some cause leaf-spots

Prevention is better than cure, so keep containers, tools etc. clean using domestic bleach. Do not recycle plastic bags or medium. Make sure that the plants are not being over-watered, that drainage is adequate and that the plants are well-spaced to allow air movement around them and to prevent direct transfer of pathogens from individual seedlings to their neighbours. Remove infected leaves or dispose of diseased plants immediately. Routine spraying with chemicals should ***not*** be necessary. But sporadic use may be necessary to deal with a disease outbreak. **When using any pesticides, read the health warnings on the packet and follow all the protective precautions recommended.**

How can pests be controlled?

The most important pests include leaf-eaters such as caterpillars, weevils and crickets; shoot borers, particularly beetle and moth larvae; juice-suckers, such as aphids, mealy bugs and scale insects; root-eaters such as nematode worms; cutworms (larvae of certain moths) and termites (which also destroy nursery structures. Remove harmful animals or their eggs by hand, or spray the saplings with a mild disinfectant. If this fails to prevent infestation, then spray the saplings with an insecticide, observing all the health precautions on the packet.

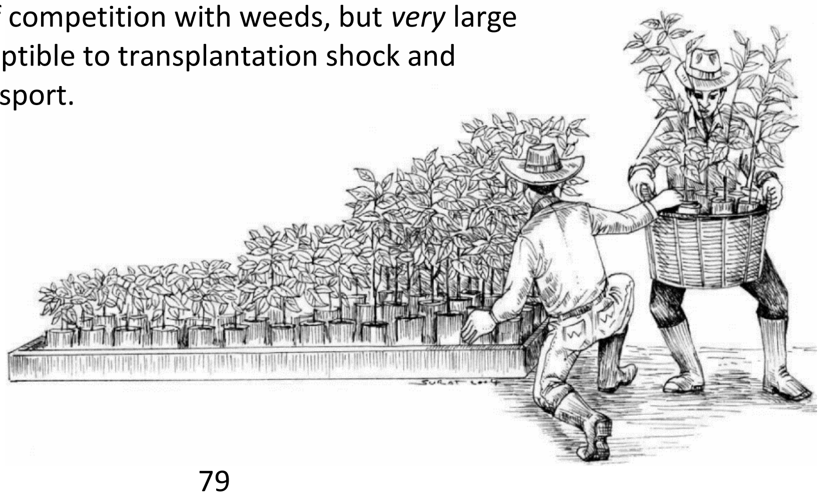
Grading for Quality Control

Grading is an effective method of quality control. It involves arranging the growing trees in order of size, whilst at the same time removing stunted, diseased or weak ones. In this way, only the most vigorous and healthy trees are selected for hardening-off and planting-out. This maximizes post-planting survival. Root pruning and disease inspection can be carried out at the same time. Wash hands, gloves and secateurs in disinfectant frequently to prevent spreading diseases from one block of plants to another. Dispose of poor-quality plants by burning them, well away from the nursery.

Figure 16.6 - Look out for problem plants:
1. *Unbalanced - the shoot is too long and thin. It may break during handling. Prune back well before planting time.*
2. *Malformed stem compromises future growth – dispose of it.*
3. *Attacked by insects - burn it and spray surviving plants with insecticide*
4. *Stunted growth – compared with other plants of same age – dispose of it.*
5. *This plant is losing its leaves, possibly as a result of disease – burn it.*
6. *This container was knocked over and spent some time lying on its side, resulting in a non-vertical stem – dispose of it.*
7. *The perfect plant – well balanced, disease free and straight – with adequate care and rigorous grading, all plants in your nursery should look like this.*

How tall should the saplings be at planting time?

Some fast-growing pioneer tree species can be planted when only about 30 cm tall. For *Ficus* spp, the recommended size is 20 cm tall, but for slower-growing climax forest tree species, it is better to plant trees around 40-60 cm tall. Small saplings have high post-planting mortality, because of competition with weeds, but *very* large saplings are much more susceptible to transplantation shock and they are more difficult to transport.



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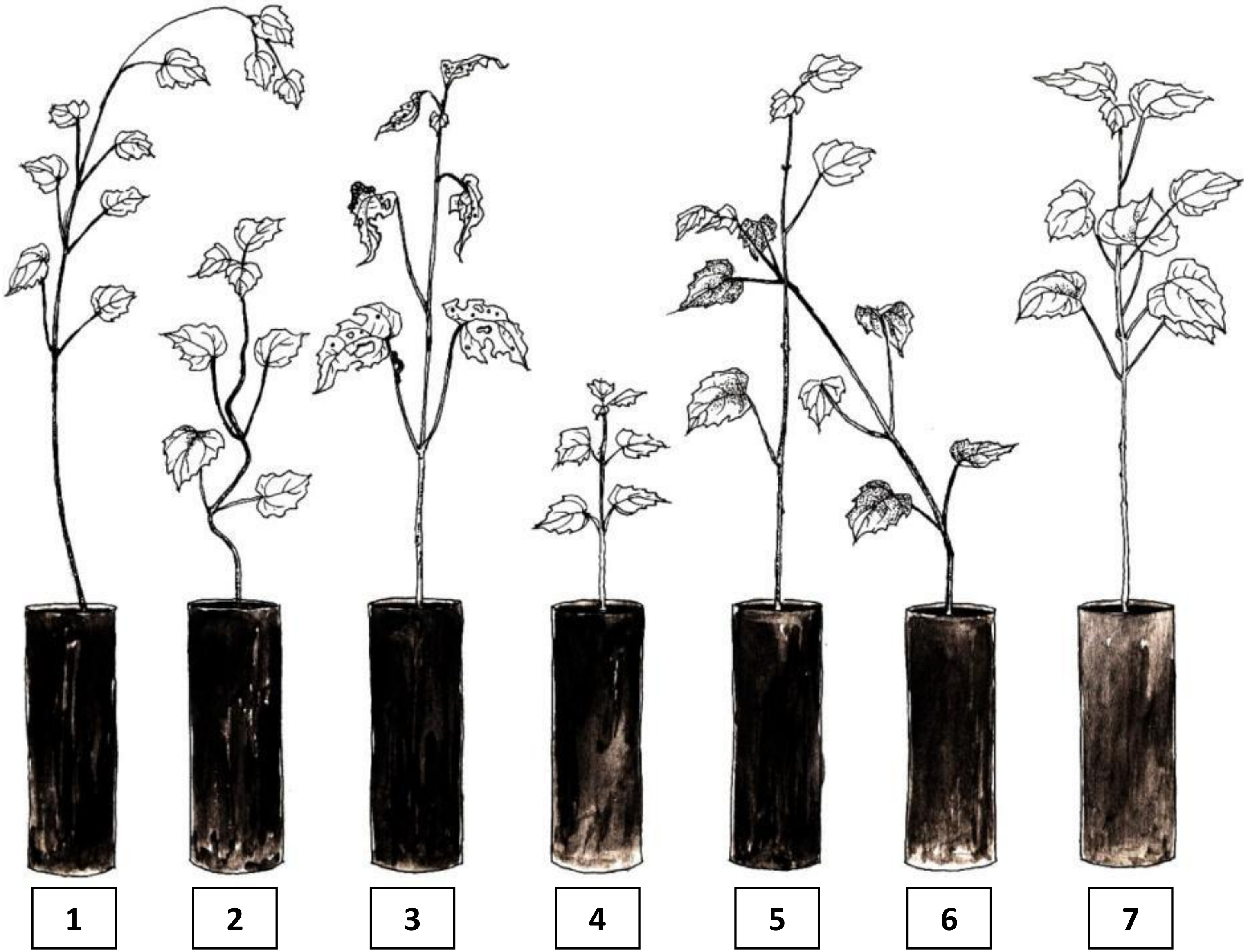
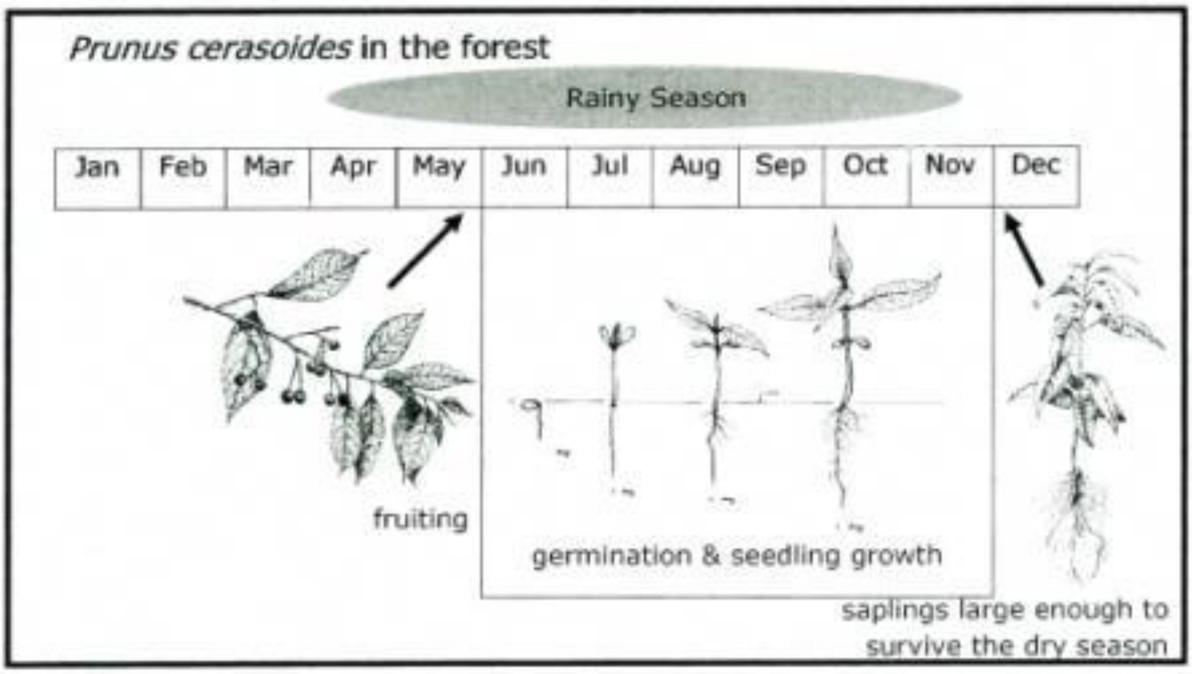
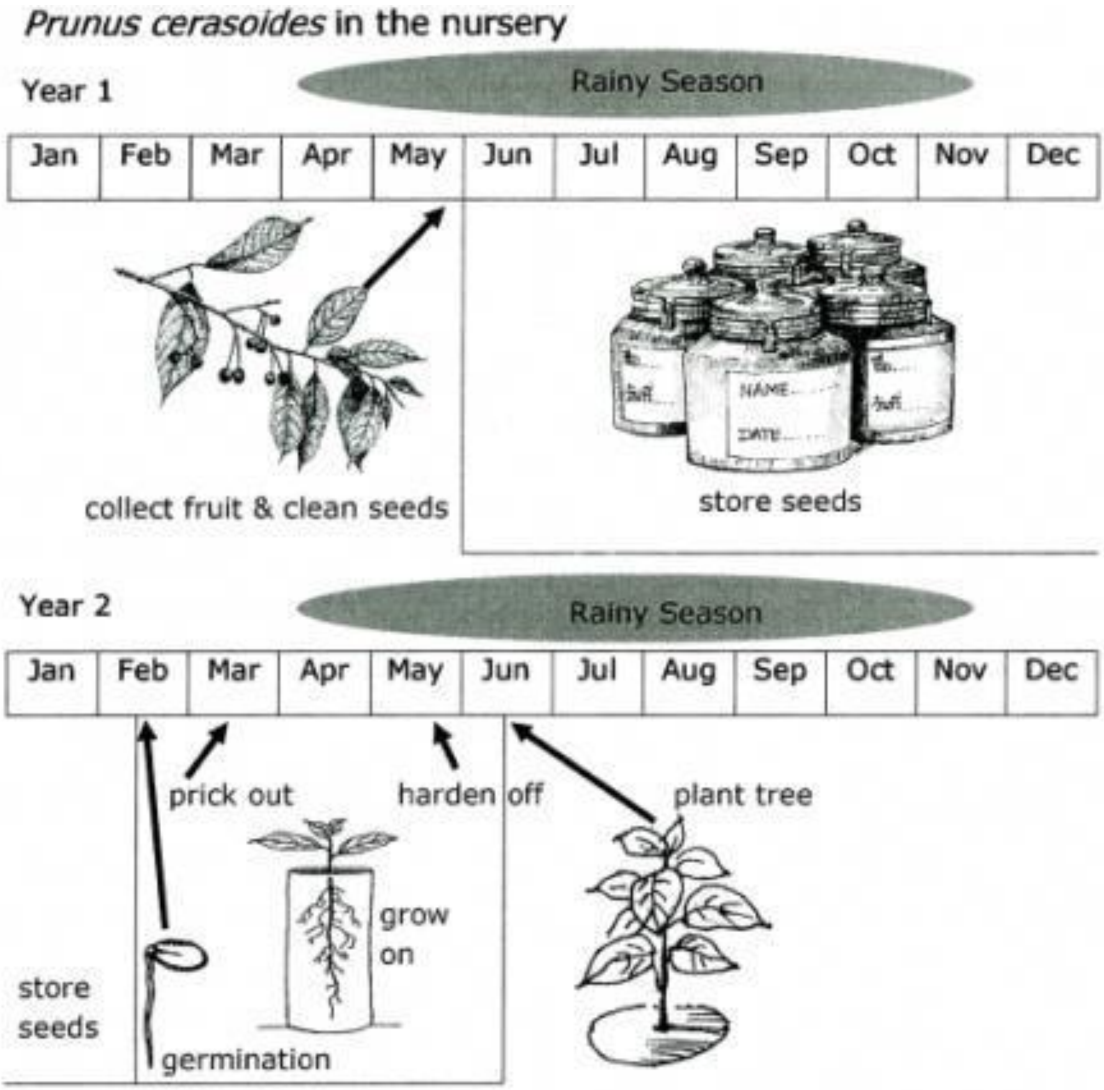


16.7


Prunus cerasoides in the forest
Rainy Season
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
fruiting
germination & seedling growth
saplings large enough to survive the dry season

16.8


Prunus cerasoides in the nursery
Year 1
Rainy Season
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
collect fruit & clean seeds
NAME
DATE
store seeds
Year 2
Rainy Season
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
prick out
harden off
plant tree
grow on
store seeds
germination

Example Production Schedule – Prunus cerasoides

Figure 16.7 *—In its natural habitat, this pioneer tree, fruits in April-May. Its seeds have short dormancy and seedlings grow rapidly, so that by December their roots have penetrated deep enough into the soil to supply the shoot with moisture during the dry season. In the nursery, saplings which reach a plantable size by December must be kept for a further 6 months before the following planting season (June) and out-grow their containers.*

Figure 16.8 *— a nursery production schedule, therefore, involves storing the sun-dried pyrenes at 5°C until January, when they are germinated. Plants grow to the optimum size just in time for hardening off and planting out in June. Development of this production schedule involved research on phenology, seed germination, seedling growth and seed storage.*

Hardening off

Weaning, or 'hardening-off', prepares saplings for transition from ideal nursery conditions to the harsh environment of deforested sites. Without hardening, planted trees suffer transplantation shock and mortality rates are high. About 2 months before planting, move saplings to be planted to a separate area and gradually reduce shade and the frequency of watering. Reduce watering by approximately 50%, to slow shoot growth, and encourage smaller new leaves. But do not reduce watering to the point at which leaves wilt, which weakens saplings. Water the saplings as soon as any wilting is observed.

Ultimate Aims

- >80% survival of saplings since pricking out.
- Mean sapling heights >30 cm for fast growing pioneer species (20 cm for *Ficus* spp) and >50 cm for slow-growing climax tree species at planting time.
- Sturdy stems, supporting mature, sun-adapted, leaves (not pale, expanding leaves) ("sturdiness quotient", height (cm)/RCD (mm) <10).
- Root:shoot ratio of between 1:1 and 1:2; with actively growing, densely branching root system, not spiraling at the base of the container.
- No signs of pests, diseases or nutrient deficiency.

Records

Label seed trays and plants in the nursery with species names, batch numbers and dates of seed collection and pricking-out. Record when and where each batch of seeds was collected, seed treatments applied, germination rates, growth rates, diseases observed and so on. Finally, record when and to where saplings are dispatched for planting.

Production schedules – the ultimate aim of nursery research

Growing a wide range of forest tree species is difficult to manage. Different species fruit in different months and have widely different rates of germination and seedling growth; yet all species must be ready for planting by the optimal planting time. Species production schedules make this daunting managerial task easier.

In seasonally dry tropical climates, the window of opportunity for tree planting is narrow, sometimes just a few weeks, usually at the beginning of the rainy season, whereas in less seasonal climates, there may be more latitude in the timing of tree planting. Either way, species production schedules are an excellent tool to ensure that the required species of trees are ready for planting when required.

What is a production schedule?

For each tree species being grown, the production schedule is a concise description of the procedures for producing planting stock of optimum size and quality from seed, wildlings or cutting by the optimum planting out time. It can be represented as an annotated time-line diagram which shows i) when each operation should be performed and ii) which treatments should be applied to manipulate seed germination and seedling/sapling growth.

What information is needed to prepare a production schedule?

The production schedule combines all available knowledge about the reproductive ecology and cultivation of a species. It is the ultimate interpretation of the results from all the experimental procedures described above, including:

- optimum seed collection date;
- germination time or natural length of seed dormancy;
- how seed dormancy can be manipulated with pre-sowing treatments or storage;
- length of time required from seed sowing to pricking out;
- length of standing-down time required to grow saplings to a plantable size and
- how plant growth and standing-down time can be manipulated with fertilizer application and other treatments.

All this information is available from nursery data sheets, if the procedures detailed above are followed. The production schedule is very much a working document. Draft the first version once the first batch of plants has been grown to a plantable size. This enables identification of areas requiring further research and appropriate treatments to test in subsequent experiments. As the results of experiments on each subsequent batch of plants, become available, the production schedule is gradually modified and optimized.

Online resource: https://www.forru.org/advice/nursery-techniques

17. Field Trial Design and Monitoring Tree Performance

Preparing to plant

When should trees be planted?

Trees should be planted early in the rainy season, once rainfall becomes reliable. This gives the trees maximum time to grow a root system deep enough into the soil, so that they can obtain sufficient water to survive the first dry season after planting.

Site preparation

Protect any existing, naturally-established trees, seedlings, saplings or live tree stumps (termed “natural regenerants”). Place a brightly coloured bamboo pole next to each regenerant and dig out weeds, using a hoe, in a 1.5 m diameter circle around each. This makes natural sources of forest regeneration more visible to workers, so they avoid damaging them during weeding or tree planting.

About 1-2 weeks before the planting date, clear the entire site of herbaceous weeds to both improve access and reduce competition between weeds and trees (both planted and natural). Slash weeds down to 30 cm or so. Then dig out their roots and leave them to dry out on the soil surface. Merely slashing weeds encourages them to re-sprout. As they do so, they absorb more water and nutrients from the soil than if they had never been cut in the first place. This intensifies root-competition with the planted trees. So, digging out the roots is essential, although the labour required to do so is considerable.

How many saplings should be delivered to the plots?

The final combined density of planted plus naturally established trees should be about 3,100 per ha, so the required number of saplings delivered should be based on this figure minus the estimated number of naturally established trees or live tree stumps determined during the site survey. This results in an average spacing of about 1.8 m between planted saplings or the same distance between planted saplings and naturally established trees (or live stumps). This is much closer than the spacing used in most commercial forestry plantations, because the objective is rapid canopy closure, to shade out weeds and minimize weeding costs. Shade is the most cost effective and environmentally friendly herbicide.

How many tree species should be planted?

With stage-3 degradation, deliver enough species to the restoration site to raise species richness to about 30 species or around 10% of the estimated species richness (if known) of the target forest type. With stage-4 degradation, plant as many species as possible of the target forest type. Nurse plantations (stage-5 degradation) may be mixtures of a few particularly hardy species (e.g. *Ficus* spp + Legumes).

How should saplings be transported to the planting plots?

Select the most vigorous saplings and label those included in the monitoring program. Then place them upright in sturdy baskets, water them and load them into a vehicle for transport to the site the day before planting. Make sure containers are packed upright to prevent spillage of potting mix. Do not stack containers on top of each other. If an open truck is used, cover saplings with a layer of shade netting and drive slowly. In the plots, place saplings upright beneath any available shade and, if possible, lightly water them again.

What materials should be delivered to the planting site?

Along with the saplings, transport planting materials to the plots. These include bamboo stakes and mulching material (if required) as well as fertilizer.

What else needs to be done before the big day?

A few days before the planting event, hold a meeting of all project organizers. Appoint a team leader for each group of planters. Make sure that all team leaders are familiar with the tree planting techniques and that they know which area they are responsible for. Use a planting rate of 10 trees per hour to calculate the number of people required to complete the planting event, within the desired time limit. Tell tree planters to bring gloves, box-cutters (to slash open plastic bags), buckets, hoes or small shovels (to fill in the planting holes) and cups for applying fertilizer. Team leaders should advise planters to carry a bottle of water, and wear a hat, sturdy footwear, a long-sleeved shirt and long trousers.

Make a final estimate of the number of people likely to participate in the planting event. Organize enough vehicles to take everyone to the plots and arrange enough food and drink to keep everyone well fed and hydrated. Make contingency plans in case of bad weather.

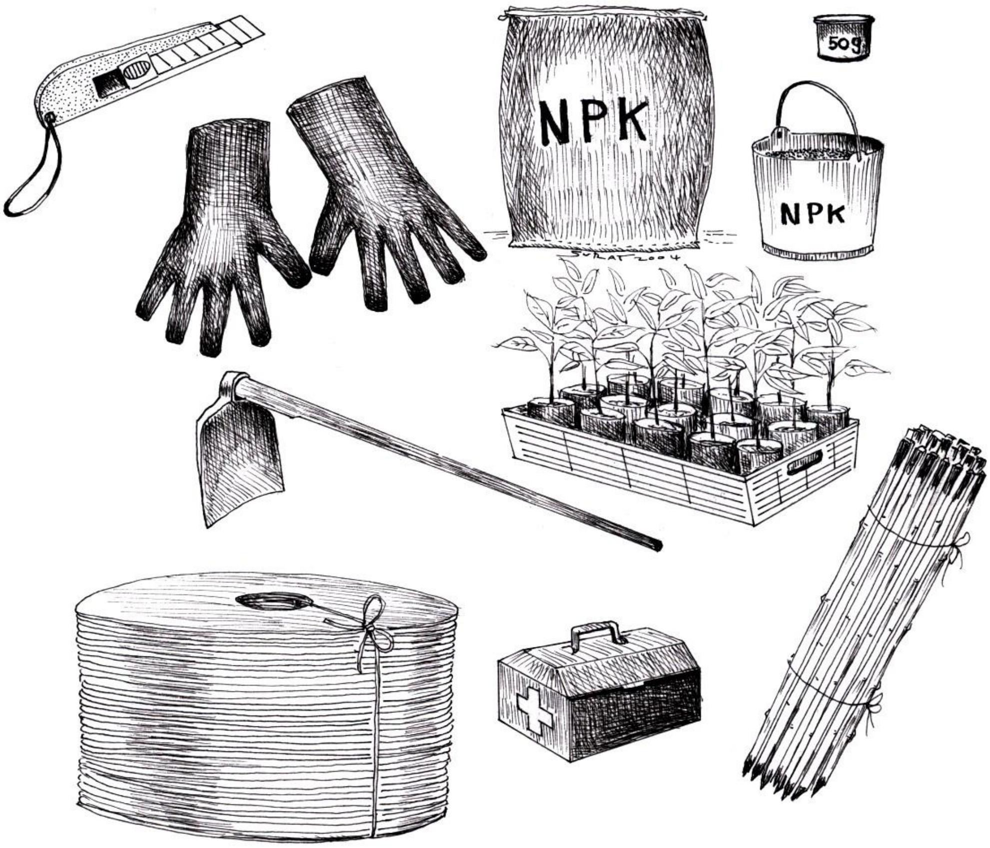
Planting

Take time at the beginning of the event to demonstrate the planting techniques to be used and make sure everyone understands the objectives of the forest restoration project. Also, take the opportunity to invite everyone to participate in follow-up operations, such as weeding, fertilizer application and fire prevention.

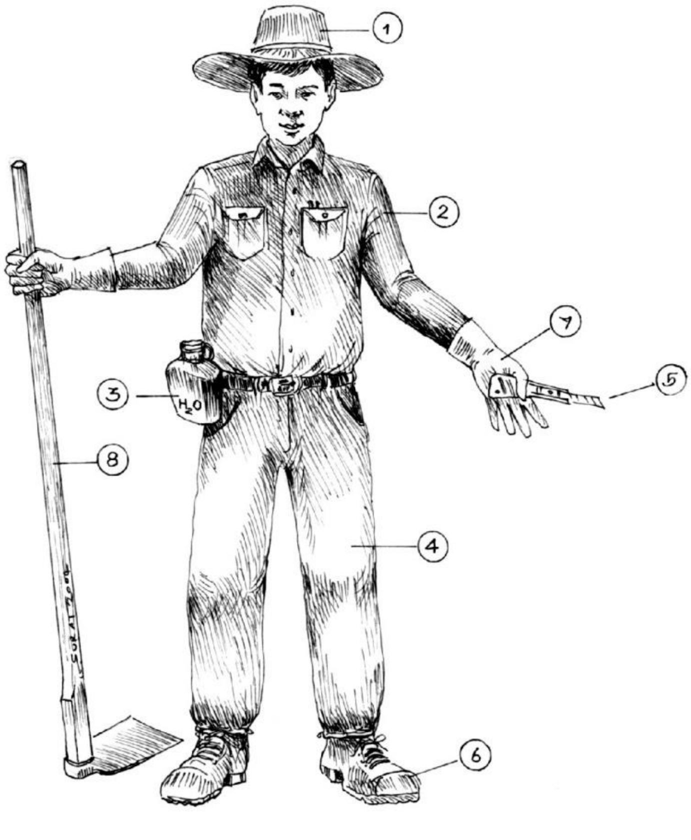
Figure 17.1 – *materials for planting day: box cutters to slice open plastic bags; gloves, fertilizer with buckets for distribution and small cups to measure out the dose required for each tree; saplings in baskets for distribution to planting spots; bamboo poles to mark planting spots, hoe for digging planting holes, cardboard mulch mats work well where soil conditions are poor but have little effect on fertile soils; first aid kit to deal with accidents*

Figure 17.2 - *The perfectly prepared planter, with hat (1) for sun protection; long-sleeved shirt (2); plenty of water to drink (3); long trousers (4); a box cutter (5) to slash open plastic bags; strong boots (6) to protect feet; gloves (7) and a hoe (8) to dig the planting holes.*

17.1



17.2



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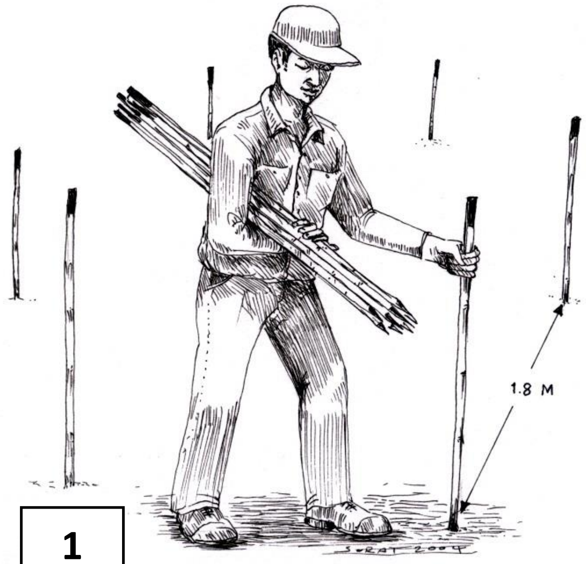

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2

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4

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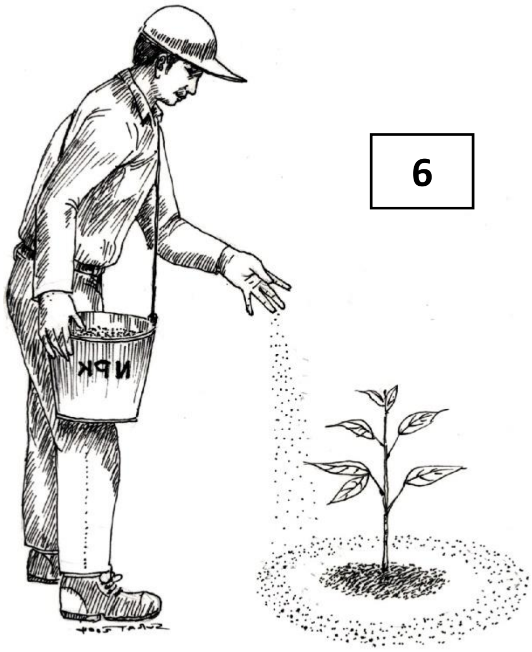


Figure 17.3 – *planting procedure. 1. Stake out planting spots randomly but averaging 1.8 m apar t(2 paces); 2. Dig planting hole about twice the size of the container; 3. Slice open the plastic bag; 4. Place sapling into the hole and back fill; 5. Firm down the soil; 6. Apply 50-100 g fertilizer in a ring 20 cm away from the tree stem.*

First mark where each tree will be planted with a 50-cm tall split-bamboo poles. Space the poles randomly about 2 paces apart, or the same distance away from naturally established trees. Use baskets to distribute one sapling to each of the poles. Mix up the species so that saplings of the same species are not planted next to each other. Beside each bamboo pole, use a hoe to dig a hole, at least twice the volume of the sapling's container. If saplings are in plastic bags, slash each bag up one side with a sharp blade, taking care not to damage the root ball inside. Gently peel away the plastic bag. Try to keep the medium around the root ball intact. Place the sapling upright in the hole and pack the space around the root ball with loose soil, making sure that the sapling's root collar is eventually positioned level with the soil surface. If the sapling has been labeled for monitoring, make sure that the label does not become buried. With the palms of your hands, press the soil around the sapling stem to make it firm. This helps to join pores in the nursery medium with those in the plot soil, thus rapidly re-establishing a supply of water and oxygen to sapling's roots.

Next, apply 50-100 g fertilizer in a ring on the soil surface, about 20 cm away from the sapling stem. If fertilizer contacts the stem, chemical burning can occur. Use pre-measured plastic cups to apply the correct dosage of fertilizer. Then (optionally) place a cardboard mulch mat, 40-50 cm in diameter around each planted sapling. Anchor the mulch mat in position by piercing it with the bamboo stake. Pile up dead weeds onto the cardboard mulch mat. At the end of the planting event, if there is a water supply nearby, water each planted sapling with at least 2-3 liters. A water tanker can be hired to deliver water to sites that are accessible by road but distant from natural water supplies. For inaccessible sites with no available water, schedule planting to take place when rain is forecast. The final task is to remove all plastic bags, spare poles or cardboard mulch mats, and garbage from the site. Team leaders should personally thank all those taking part in the planting. A social event to mark the occasion is also a good way to thank participants and build support for future events.

On lowland sites with poor lateritic soils, organic fertilizer seems to be more effective than chemical fertilizer, possibly because it breaks down and is leached from the soil more slowly than chemical fertilizer is. Thus, it delivers nutrients to the tree roots more evenly over a longer period. Organic fertilizers vary greatly in composition, but they are much cheaper than chemical fertilizers. So, find a reliable supply of an effective local brand or work with local communities to start producing fertilizer from animal waste.

Mulch is a material placed on the ground around a sapling, which can increase its survival and growth, particularly where soils are at risk of drying out immediately after planting. Mulching around planted saplings blocks out light and thus prevents weeds from re-growing. It also cools the soil, which reduces evaporation of soil moisture. Soil invertebrates are attracted by the cool, moist conditions beneath the mulch. They churn up the soil around planted saplings, improving drainage and aeration. Mulching is recommended when planting on highly degraded soils in drier areas. It has less effect on fertile upland soils or in the ever-wet tropics. Corrugated cardboard makes excellent mulch mats. It is widely available and relatively cheap. Cut the cardboard into 40-50 cm diameter circles. Cut a hole in the middle about 5 cm across and a narrow slit, from the circle perimeter to its centre. Open the circle along the slit and place the hole in the middle centrally around the tree stem. Make sure that the cardboard does not touch the stems of the planted tree, since it may abrade them, creating wounds, which can become infected by fungi. Drive a bamboo stake through the mat to keep it in place. In seasonal tropical forest, cardboard mats last one rainy season, gradually rotting down and adding organic matter to the soil. Replacing mats at the beginning of the second rainy season does not seem to result in additional beneficial effects.

Caring for planted trees

In deforested sites, planted trees are subjected to hot, dry, sunny conditions as well as competition from fast-growing weeds. Protective measures must be implemented to prevent fire and cattle from killing both planted trees and any natural regenerants present. Weeding and fertilizer application are also essential for at least 18-24 months after planting, to maximize tree growth and accelerate canopy closure, after which no further maintenance is necessary.

Fire prevention and excluding livestock

Cutting of fire breaks, organization of fire suppression teams and exclusion of livestock from restoration sites are essential to protect the planted trees.

Weeding

Weeding reduces competition between planted or naturally established trees and herbaceous plants. On nearly all tropical sites, it is essential to prevent high tree mortality in the first two years. After planting, weed around planted trees at 4 to 6-week intervals whilst the rains continue, for 2 rainy seasons after planting. Carry out weeding well before the weeds grow above the crowns of planted trees. It should not be necessary to weed during dry seasons. The labour force required for weeding varies with weed density but, as a guide, budget for 18-24 days labour per hectare.

In between the trees, use machetes or a “weed whacker” (mechanical hand held weed cutter), keeping well away from both planted and natural trees to prevent accidentally slashing them. Around the trees themselves, a more delicate approach is required. Wear a pair of gloves and gently pull out any weeds growing close to tree stems, including any

Figure 17.4 - *Weeding is essential to keep planted trees alive during the first few years after planting. A cardboard mulch mat can help keep weeds down to a minimum immediately around the tree stem (A). Pull out any weeds growing near the tree base by hand (wear gloves) to avoid damaging the tree roots (B). Try to keep the mulch mat intact. Next, use a hoe to root out weeds in a circle around the mulch mat (C) and lay the uprooted weeds on top of the mulch mat (D). Finally, apply fertilizer (50-100 g) in a circle around the mulch mat (E).*

17.4

growing through mulch. Try not to disturb the mulch. Around the mulch, use a hoe to dig out weeds by their roots. Lay uprooted weeds around the trees, on top of the existing mulch. This shades the soil surface, and inhibits germination of weed seeds, even as the organic mulch rots away. Apply fertilizer immediately after weeding around each tree.

How frequently should fertilizer be applied?

Even on fertile soils, most tree species benefit from application of additional fertilizer during the first two years after planting. It enables the trees to grow above the weeds rapidly and shade them out, thus reducing weeding costs. Apply 50-100 g fertilizer, at 4 to 6-week intervals, immediately after weeding, in a ring about 20 cm away from the tree stem. If a cardboard mulch mat has been laid, apply the fertilizer around the edge of the mulch mat. Chemical fertilizer (N:P:K 15:15:15) is recommended for upland sites, whilst organic pellets produces significantly better results on lateritic lowland soils. Weeding before fertilizer application ensures that the planted trees benefit from the nutrients and not the weeds.

Online resource: https://www.forru.org/advice/tree-planting-maintenance

18. MONITORING FOREST RECOVERY

The purpose of monitoring is to find out if tree planting actually results in the desired effects. For conservation projects, this means finding out whether or not planted trees survive and grow well and whether tree planting accelerates natural forest regeneration and biodiversity recovery, particularly, by enhancing the re-establishment of additional (non-planted) tree species. Monitoring can also help to identify problems with species selection, planting techniques and/or the methods used to care for planted trees. It stimulates further experiments to continuously improve forest restoration projects.

What are control plots and why are they important?

Control plots are sites which are not planted with trees, but which are as similar as possible to planted sites in all other ways e.g. altitude, slope, aspect, previous land use etc. Planted areas are compared with the controls to determine if planting results in a richer, denser forest than natural regeneration.

What is the simplest way to carry out monitoring?

One of the simplest ways to assess the effects of tree planting is to take plenty of photographs of both planted plots and the controls, from the same points every few months. Photographs are easier to understand than statistics of survival and growth rates. They immediately convey the overall effectiveness or otherwise of tree planting. However, if you want to know which species successfully act as framework tree species, sampled trees belonging to each species must be labelled and measured at regular intervals.

How should trees be sampled for monitoring?

When large numbers of trees are planted, it may be impossible to measure them all. The minimum requirement for adequate monitoring is a sample of at least 50 individuals of each of the species planted. The larger the sample is, the better. Randomly select the individual trees to include in the sample; label them in the nursery, before transporting them to the planting site. Plant them out randomly across the site, but make sure you can find them again easily. Place a coloured bamboo pole by each tree to be monitored; rewrite the identification number from the tree label onto the bamboo pole with a weather proof marker pen and draw a sketch map to help you find the sample trees in the future.

How should planted saplings be labelled?

Soft metal strips, used to bind electrical cables in the building industry, make excellent labels for small trees. They can easily be formed into rings around tree stems. Use metal number punchers or a sharp nail to engrave an identification number on each label and bend them into a ring around the stem, above the lowest branch (if present). This will prevent the label from being buried when the tree is planted.

Alternatively, drinks cans can be cut up to make excellent tree labels. Cut off the top and bottom of the cans and slice the cans' walls into strips. A tough ball point pen can be used to easily press an identification number into these soft metal foil strips (on the inside surface). The strips can be formed into loose rings around sapling stems.

Keeping labels in position, on rapidly growing, trees is difficult. As the trees grow, the expanding trunks gradually push the labels off. If monitoring is carried out frequently enough, you will be able to re-position or replace labels, before they are lost.

Once the trees have developed a girth of 10 cm or more, measured 1.3 m above the ground (girth at breast height or GBH), a more permanent label can be nailed to the trunk, marking the girth measuring point at 1.3 m. Use 5-cm-long, galvanized nails, with flat heads. Hammer only about 1/3 of the nail length into the trunk to allow room for tree growth. Metal foil from drinks cans, cut into large squares, so that the identification number can be read from a distance, make excellent labels for larger trees.

When should measurements be made?

Monitor planted trees about two weeks after planting, to provide base line data for growth calculations and to assess immediate mortality, due to transplantation shock and rough handling during the planting process. After that, monitor annually at the end of each rainy season. Additional monitoring at the end of the dry season can provide more detailed information about when and why trees die.

However, the most important monitoring event is at the end of the second rainy season after planting, when field performance data can be used to quantify how closely each species planted conforms to framework species standards (see Part 5 Section 3). Therefore, even if no other monitor can be carried out, at least monitor two weeks after planting and at the end of the second rainy season after planting.

To monitor tree performance, work in pairs, with one partner taking the measurements and the other recording the information on a prepared data sheet. One pair can collect data on up to 400 trees per day. Prepare data sheets in advance, including a list of the identification numbers of all labelled tree planted. Take along the sketch maps made when the labelled trees were planted, to help you find them. In addition, take a copy of the data collected during the previous monitoring session. This can also help you sort out tree identification problems in the field, especially for trees that may have lost their labels.

What measurements should be made?

Rapid monitoring can involve simple counts of surviving vs. dead trees. More detailed monitoring can include measurements of tree height and/or girth (for calculation of growth rate) and health.

In the first year or two after planting, the heights of the planted trees can be measured with 1.5-m tape measures mounted on rigid poles. Measure tree height from the ground, at the base of the trunk, to the highest living leaf. For taller trees, telescopic measuring poles can be used to measure trees up to 10 m tall. These poles are commercially manufactured but very difficult to obtain in Thailand, so try to make your own. If you want to continue monitoring the trees after they have grown tall, measurements of GBH are easier to make and can be used to calculate growth tree growth rates.

Using height measurements to calculate tree growth rate can be problematic, since sometimes the shoots can be damaged, resulting in negative growth rates, even though the tree may be growing vigorously. Consequently, measurements of root collar diameter (RCD) or GBH often provide a more stable assessment of tree growth. For smaller trees, use callipers with a vernier scale to measure the RCD at the widest point. Once a tree has grown tall enough to develop a girth at breast height of 10 cm, measure both the RCD and the GBH the first time and only GBH thereafter.

Suppression of weed growth, an important framework characteristic, can also be quantified important in determining whether or not a tree species qualifies as a framework species. Measuring canopy width and using a simple scoring system for weed cover can help determine to what extent each tree species planted conforms to this framework species characteristic. Use tape measures to measure the width of tree crowns at their widest point. Imagine a circle about 1 m in diameter around the base of the tree. Score 3 if weed cover is dense across the entire circle; 2 if weed cover and leaf litter cover are both moderate; 1 if only a few weeds are growing in a circle mostly covered by leaf litter and 0 for no weeds.

What about tree health?

Recording the health of the planted trees, each time they are inspected, can yield useful information about the vigorousness and resilience of each species planted to damaging factors such as fire or cattle browsing. For quantitative analysis, it is useful to assign a simple health score to each tree, but in addition detailed notes should be recorded on the particular health problem observed.

A simple scale of 0 to 3 is usually sufficient to record overall health. Score zero if the tree appears to be dead. Many framework tree species are deciduous, so don’t confuse a deciduous tree with no leaves in the dry season with a dead one. Do not stop monitoring trees just because they score zero on one occasion. Many trees that appear dead on the surface may still have living roots and may re-sprout shoots in the future. A score of 1 indicates a tree which is nearly dead; few leaves, most leaves discoloured, sever insect damage etc. A score of 2 indicates a tree showing some signs of damage but retaining some healthy foliage. Three indicates a tree in perfect or nearly perfect health.

How should other aspects of forest restoration be monitored?

To monitor the return of biodiversity, survey both planted and control sites for naturally establishing tree seedlings. Surveys of wildlife can also be done. Birds are perhaps the easiest group to work with and they are important dispersers of seeds. For a rapid bird survey technique see the MacKinnon method described in the lab notes.

LAB & FIELD INSTRUCTIONS

Monitoring forest restoration on a mine site

1-2. REFERENCE FOREST SURVEY - DEFINING RESTORATION TARGETS – SPECIES COMPOSITION AND BIOMASS (2 FIELD SESSIONS)

A **reference forest** is usually a remnant of the original forest ecosystem. The reference ecosystem is a central concept of restoration science. It defines the target, at which restoration is aimed. International restoration guidelines define it as "… *the condition of the ecosystem as it would be had it not been degraded, adjusted as necessary to accommodate changed or predicted change in biotic or environ-mental conditions (e.g., climate change)"* (Gann et al., 2019).

Restoration cannot recreate the original forest *exactly*, species by species, since the exact species composition for the original forest may not be known for any particular site. Instead, it aims to re-establish similar levels of biomass, structural complexity, biodiversity and ecological functionality as the reference forest.

Students should be taken to the reference forest and spend 1-2 days assessing these variables. Things to do when assessing the reference forest:

General random survey

During random walks through the forest the students note down the tree species they see and rank them subjectively as common to rare. The students should also take general notes on the condition of the forest: forest structure, understorey development, presence of climbers and epiphytes, accumulation of leaf litter etc. The notes are used to roughly estimate of species richness of the forest and to compile a species list, from which candidate framework species can be selected later for seed collection and testing in nursery and field trials.

Survey using circular plots

Follow the instructions in Lab Notes 11-12, to establish at least 10 circular sample units (SU) of 5 m radius across the reference forest. Record the species and girth at breast height (GBH (cm)) of the trees in the plots on Data Sheet LAB 11-2.3 – Trees. Work with local people to gather local tree names and use local floras to convert them to scientific names. Collect herbarium specimens from trees of unknown name and use a flora to identify them.

Estimate above-ground dry biomass (kg) of each tree as follows:

$$\text{Dry forest:} \quad 2.71828^{[-1.996 + (2.32 \times \ln(DBH))]}$$

$$\text{Moist forest:} \quad 2.71828^{[-2.134 + (2.53 \times \ln(DBH))]}$$

... where ln(DBH) in the natural logorithm of diameter at breast height (i.e. GBH/π). Dry forest means annual rainfall <1,500 mm with distinct dry season and moist forest means annual rainfall 1,500 – 4,000 mm, no or short dry season. To calculate the mass of roots of each tree, multiply the above-ground biomass by 0.37 for tropical evergreen forest or 0.56 for drier tropical forest. Sum the estimated total tree dry biomass (above-ground + roots in kilograms) within each SU.

An SU is 78.5 m^2. One hectare is 10,000 m^2. One metric ton is 1,000 kg. Therefore, an estimate of overall tree dry biomass of the reference forest in t/ha is:

$$\text{Mean SU total biomass} \times \frac{10{,}000}{78.5} \div 1{,}000$$

The carbon content of dry tropical wood varies considerably among species, but the average value is around 47%. Therefore, an estimate of tree carbon can be obtained by multiplying the above estimate by 0.47.

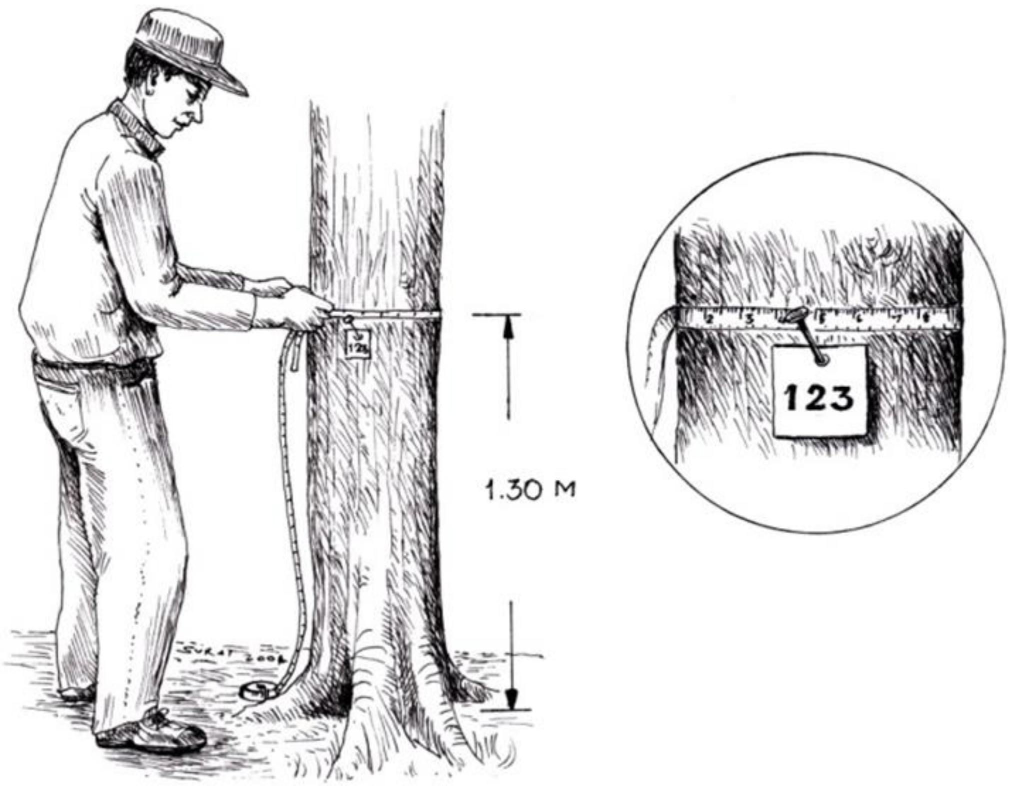
Reading

Basuki, T. M., P. E. van Laake, A. K. Skidmore and Y. A. Hussin, 2009. Allometric equations for estimating the above-ground biomass in tropical lowland Dipterocarp forests. Forest Ecology and Management 257 (2009) 1684–1694

Brown, S., 1997. Estimating biomass and biomass change of tropical forests: a primer. FAO. Forestry Paper 134, Rome, 87 pp.

Cairns, M. A., S. Brown, E. Helmer, G. A. Baumgardner, 1997. Root biomass allocation in the world's upland forests. Oecologia 111:1- 11.

Gann, G.D., et al. (2019), International principles and standards for the practice of ecological restoration. Second edition. Restor Ecol, 27: S1-S46. https://doi.org/10.1111/rec.13035



3-4. Rapid Site Assessment - Determining Degradation Level (2 Field Sessions)

A rapid site assessment determines existing potential for natural forest regeneration and identifies factors that may limit it. This helps to determine which restoration actions to implement and the intensity of the work required, thus contributing to a project plan.

Equipment: GPS (e.g., smartphone app GPS Test), compass (smartphone app "compass"), camera, plastic bags, a bamboo pole 2 m long, a piece of string marked exactly 5 m from the end and datasheets, clip board and pencil. Access to Google Earth.

All stake-holders should participate in the survey. Begin by recording the GPS co-ordinates of the corners of the site. Add them to Google Earth as "Placement Markers" (yellow pins), so you can assess gross forest cover across the site. Next, survey natural regeneration by placing sample points along a set compass bearing from one of the corners into the centre of the site. At the starting point, position a pole and use a piece of string 5 m long (attached to the central pole) to mark out a circular sample plot of radius 5 m. Record the following:

- presence of livestock (e.g., dung, hoof prints, etc.)— tick in the "livestock" column;
- likewise, for signs of fire (ash, or black marks at the base of woody vegetation);
- the extent of exposed soil in the circle (as a percentage of the area);
- soil condition (ask local people if they consider the soil good enough for crops);
- signs of soil erosion;
- estimated percentage cover and average height of weeds across the plot.
- land use history (ask local participants) and
- the number of regenerants: a) trees larger than 30 cm girth at breast height, b) saplings taller than 50 cm (but smaller than 30 cm GBH) and c) live tree stumps.

Place leaf samples from each of the tree species into plastic bags. Finally take photos, looking due north, south, east and west from the centre pole as in Lab Notes 11-12.

Repeat at a minimum of 10 sample points, spaced evenly across the site. If the site is large, position the sample points further apart and use more points (at least 5/ha). If the site is small, then use two or more lines. At the end of the survey, 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 provide local names for the species and try to determine if they are pioneer or climax species. Finally, calculate the number of 'regenerants' per circle adding a + b + c. Multiply the result by (10,000/78.5) to estimate the number per hectare. At the end of the survey, hold a short discussion session with all stakeholders to identify any other factors that may impede forest regeneration that have not already been recorded on the data sheets, especially activities of local people such as fuel-wood collection etc. Local people will probably know which seed dispersers remain common in the area. Try to determine if seed dispersers are threatened by hunting. Use the data gathered to determine the degradation level of the site (Lecture 13) and draft the restoration plan during Lab 5.

Rapid Site Assessment Data Sheet

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								
2								
3								
4								
5								
6								
7								
8								
9								
10								

Location, GPS **Recorder** **Date**				**Total**	
			(= total/10)	**Mean**	
			(= mean x 10,000/78)	**Average/ ha**	
Total Species of Regenerants	**Pioneers**	**Climax**	*(= 3100 – Average/ha)*	**No. of trees to plant per ha**	
Other Comments:					

Example - Rapid Site Assessment Data

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 Species of Regenerants 18	**Pioneers** 16 **Climax** 2	*(= 3100 – 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.

5. Designing an Effective Restoration Strategy (Classroom)

An overall strategy, to implement forest restoration effectively, is derived from analyzing the results from the rapid site assessment.

How to interpret the results of a rapid site assessment

Initial restoration activities should aim to:

- counteract the factors that impede forest regeneration (e.g., fire, cattle, hunting of seed dispersers etc.)
- maintain or increase the number of regenerants to about 3,100/ha and
- maintain or increase the number of common tree species represented by regenerants to a minimum of 10% of the tree species richness of the reference forest ecosystem.

Achieving a density of 3,100 regenerants per hectare results in an average spacing of 1.8 m between them; close enough to close canopy in 2-3 years. 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), which, for most tropical forest ecosystems, is usually sufficient to “kick start” biodiversity recovery. Compare the rapid site-assessment results with the guidelines in the table below, to confirm the degradation level of your restoration site. Then start to plan management tasks, including protective measures (e.g. livestock exclusion and/or fire prevention etc.), the balance between tree planting and assisting natural regeneration, the tree species to plant, the need for soil improvement etc.

Stage-1 Degradation

Survey results: The total number of regenerants averages more than 25 per circle, with more than 30 tree species 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 accelerated natural regeneration 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 and removal of livestock are necessary and/or measures to prevent hunting of seed-dispersing animals are necessary. If critical seed dispersing animals have been extirpated from the area, consider re-introducing them.

Landscape and site thresholds that help to determine restoration strategy

<table>
<tr><th colspan="3">LANDSCAPE CRITICAL THRESHOLDS</th><th>SUGGESTED RESTORATION STRATEGY</th><th colspan="3">SITE CRITICAL THRESHOLDS</th></tr>
<tr><th>Forest in landscape</th><th>Seed dispersal mechanisms</th><th>Fire risk</th><th></th><th>Vegetation cover</th><th>Natural regenerants</th><th>Soil</th></tr>
<tr><td rowspan="3">Remnant forest remains within a few km of the restoration site</td><td rowspan="3">Mostly intact - not limiting recovery of tree species richness</td><td>Low to medium</td><td>PROTECTION</td><td>Tree canopy cover exceeds herbaceous weed cover</td><td rowspan="2">Natural regenerants exceed 3,100/ha with more than 30[5] common tree species represented</td><td rowspan="4">Soil does not limit tree seedling establishment</td></tr>
<tr><td>Medium to high</td><td>PROTECTION + ANR</td><td>Tree crown cover insufficient to shade out herbaceous weeds</td></tr>
<tr><td rowspan="2">High</td><td>PROTECTION + ANR + PLANTING FRAMEWORK TREE SPECIES</td><td rowspan="2">Herbaceous weed cover greatly exceeds tree crown cover</td><td rowspan="3">Natural regenerants sparser than 3,100/ha with fewer than 30[5] common tree species represented</td></tr>
<tr><td rowspan="2">Remnant forest patches very sparse or absent in surrounding landscape</td><td rowspan="2">Seed-dispersing animals rare or absent such that tree species recruitment will be limited in restoration site</td><td>PROTECTION + ANR + MAXIMUM DIVERSITY TREE PLANTING</td></tr>
<tr><td>Initially low (soil conditions limit plant growth); higher as the vegetation recovers</td><td>SOIL AMELIORATION + NURSE TREE PLANTATION, FOLLOWED BY THINNING AND GRADUAL REPLACEMENT OF PLANTATION TREES BY MAXIMUM DIVERSITY TREE PLANTING</td><td>Herbaceous weed cover limited by poor soil conditions</td><td>Soil degradation limits tree seedling establishment</td></tr>
</table>

[5] *Or roughly 10% of estimated number of tree species in the reference forest, if known.*

Stage-2 Degradation

Survey results: The average number of regenerants remains higher than 25 per circle, with more than 30 tree species 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, with crown cover insufficient to shade out weeds. Therefore, herbs and grasses dominate, covering more than 50% the circle areas on average, although small tree seedlings may still be represented amongst the ground flora. Herbs and grasses overtop tree seedlings and often saplings and sprouts from tree stumps as well.

Strategy: Under these conditions, the protective measures described for stage-1 degradation must be complemented with additional measures to "assist" natural regeneration (ANR), 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 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, fertilizer application and/or mulching around natural regenerants. If certain climax forest species do not naturally colonize 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. 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 kilometers of the site and viable populations of seed-dispersing animals remain.

Strategy: Under these conditions, protection and ANR must be complemented with planting framework tree species. Prevention of encroachment and exclusion of livestock (if present) remain necessary and the importance of fire prevention increases, due to 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[6], minus the total number of species recorded during the site assessment. For example, according to the example site assessment data above, 433 trees of 12 species should be planted per hectare; mostly

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

climax tree species, since 18 pioneer species are already represented by surviving regenerants.

Select framework tree species to plant using the criteria defined in Lecture 14. They may include both pioneer and climax species, but should be different species to those recorded during the site assessment. Planting of framework species re-captures the site from invasive grasses and herbs and re-establishes seed dispersal mechanisms, which enhances re-colonization 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-colonize the site, they can be re-introduced in subsequent enrichment planting.

Stage-4 Degradation

Survey results: 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, they are no longer able to disperse seeds of climax tree species to the site in sufficient quantities. Re-colonization of the site by the vast majority of tree species, therefore, becomes impossible by natural means.

Strategy: Protective measures, ANR actions and 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, *full* recovery of the tree species composition of climax forest, can only be achieved by also manually establishing *all* the other tree species, that characterize the target climax forest, either by planting and/or by direct seeding. This is the maximum diversity approach (Goosem and Tucker, 1995, Lamb, 2011), which is technically challenging and costly to undertake.

Stage-5 Degradation

Survey results: The total number of regenerants falls below 2 per circle[7], with fewer than 3 tree species[8] 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, with signs of erosion recorded during the site assessment. Erosion gullies may be present, along with siltation of watercourses. The ground flora is limited by the poor soil conditions to less than 70% average cover 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 fertilizer 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 may be applied during tree

[7] Average spacing between regenerants > 6-7 m
[8] Or roughly 1% of estimated number of tree species in the reference forest, if known.

planting, such as adding compost, water absorbent polymers and/or mycorrhizal inocula to planting holes and mulching around planted trees.

Further improvements to site conditions may be achieved by first planting “nurse” trees (Lamb, 2011): tree species which are tolerant of the harsh soil conditions, but which are also capable of improving the soil. These should gradually be thinned out as site conditions improve, and be replaced by planting a wider range of native forest tree species. In most cases, to achieve full biodiversity recovery, the maximum diversity approach must be used, but where forest and seed dispersers remain in the landscape, planting a smaller range of framework tree species may suffice.

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

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

Classwork – Write a restoration plan

Divide the class into groups of 4-5 students and ask them to draft a restoration plan for the site surveyed in Labs 3-4. The plan should clearly state the objectives of restoration, and outline the techniques and tasks required to restore a forest similar to the reference forest ecosystem (Labs 1-2), enriched with economic species if necessary. The structure of the plan should include:

- Title
- Introduction – background and why the project is needed
- Objectives
- Site description – topography, existing vegetation access and map
- Basic methods – tree planting, direct seeding, ANR etc.
- Tree species selected and number of trees of each species needed
- Tree planting event plan
- Maintenance – weeding, fertilizer application, fires prevention etc.
- Monitoring plan
- Schedule and budget will be dealt with in the final lab (LAB 17-18)
- Appendices – results of the rapid site assessment, results of reference forest survey

Online resource: https://www.forru.org/advice/restoration-strategies

6. Selecting Tree Species For Forest Ecosystem Restoration (Classroom)

There are two stages to the selection of tree species to plant in forest restoration projects i) preliminary screening, based on current knowledge, to identify “candidate” species for testing and ii) nursery and field experiments to confirm suitability. 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 reference forest survey. However, as the results of field trials accumulate, the list of acceptable framework tree species can be refined. Sources of information for preliminary screening include: i) floras, ii) results of the reference forest survey, iii) indigenous local knowledge and iv) scientific papers and/or project reports, describing any previous work in the area.

Floras can provide basic taxonomic data on species under consideration as well as their suitability to the reference forest type being restored, elevation range etc. They also indicate if the species produce fleshy fruits or nectar-rich flowers likely to attract wildlife. The reference forest survey provides a great deal of original information that is useful for selection of candidate framework tree species including, a list of indigenous tree species from which species can be selected, as well as which species have nectar-rich flowers, fleshy fruits and dense spreading crowns capable of shading out weeds. Phenology studies yield information on which trees 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 colonize fallow fields and grow fast and which tree species attract wildlife.

Forestry departments and protected areas authorities often carry out biodiversity surveys, although the results may remain in unpublished reports. Finally, there’s always the internet. Simply typing the name of your project site into a search engine may reveal major additional sources of information.

Lists of tested framework tree species exist for Thailand (www.forru.org). Trees species in the same genera as those listed for Thailand may also perform well in your country.
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 via symbiotic bacteria, resulting in rapid improvement of soil conditions.

	INFORMATION SOURCE			
Species characteristics	**Floras**	**Reference Forest Survey**	**Indigenous Knowledge**	**Papers and Previous Project Reports**
Indigenous, non-domesticated, suited to habitat/elevation	Often indicated in plant descriptions in botanical literature.	List of tree species from reference forest survey	Unreliable: villagers often fail to distinguish between native and exotic species.	EIA's 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.
Dense broad crown shades out weeds	Few texts cover tree crown structure.	Observe crown structure of trees in the reference forest.	-	-
Attractive to wildlife	Fleshy fruits or nectar-rich flowers indicated in taxonomic descriptions.	Observe fruit type and animals eating fruits or flowers in reference forest.	Villagers often know which tree species attract birds.	-
Resilient to fire	-	Survey trees in recently burnt areas.	Villagers often know which tree species recover after burning in fallow fields.	-
Easy to propagate	-	-	-	Unlikely - except for economic species in forestry projects.
Climax/large seed	Often indicated in plant descriptions in botanical literature.	Observe fruits & seeds of trees in reference forest.	-	-

Class exercise – selecting species

Work in groups of 3-4 students

- Start with the list of tree species, compiled when surveying the reference forest.
- Use personal experience and the information sources listed above to score the species for each desirable characteristic on a scale of 1-3. Add new columns to the table to score new characteristics or cut out existing ones, if you consider them unimportant, according to the objectives of the forest restoration project.
- You can weight the more important factors by multiplying them with a weighting factor: x1.5, x2.0 etc. according to the group consensus of their importance.
- Next, consider if economic species should be added and score them appropriately.
- Select 20-30 of the highest scoring species. Then consider where seeds of such species can be collected. Plan a monthly seed-collection program and a phenology study. So, you can start growing saplings of them in a nursery.

Online Resources: ***The Forest Trees of Northern Thailand***:
www.forru.org/library/0000227

Selecting species support materials: www.forru.org/advice/species-selection

Edit column headings according to experience and project objectives

Species characteristic	Indigenous to the Reference Forest	High survival and growth	Dense, broad crown to shade out weeds	Attractive to seed-dispersing animals	Easy to propagate	Climax/large seed	TOTAL SCORE x weight
Species Name	Weight [x ....]	Weight [x ....]	Weight [x ....]	Weight [x ....]	Weight [x ....]	Weight [x ....]	
Reference Forest-Tree Species Name							
Added Economic Tree Species Name							

7-8. Forest Phenology - Data Collection (2 Field Sessions)

How should phenological studies be established?

Phenology trails are set up as part of the reference forest survey. Label at least five individuals of each tree species that characterize the reference forest type. Collect voucher specimens, from each labeled tree and get a botanist to identify them. Write a brief note, describing where each tree is located in relation to the trail (e.g. “10 m to the left”; “right 20 m by rocky overhang” etc.). As you repeat the observations month by month, you will soon be able to remember where each individual tree is located.

A semi-quantitative scoring system for monitoring tree phenology

For recording tree phenology, we recommend the “crown density” method, originally devised by Koelmeyer (1959). This semi-quantitative method uses a linear scale of 0-4 with 4 representing the maximum intensity of reproductive structures (flower buds (FB), open flowers (FL) and fruits (FR)) in the crown of a single tree. Values of 3, 2 and 1 represent approximately three quarters, half and one quarter of the maximum intensity respectively. The “maximum intensity” of flowering/ fruiting events varies among species and judgments of it are bound to be subjective at first, but they improve with experience.

The same approach can be used to score leafing. For individual tree crowns, estimate scores between 0 to 4 for i) bare branches, ii) young leaves, iii) mature leaves and iv) senescent leaves. The sum of these four scores should always equal 4 (which represents the entire tree crown). Scores for flowers + fruits are always less than 4, except when flowering/fruiting is occurring at the maximum intensity, typical of that species.

The crown density method is rapid and it allows quantitative analytical techniques to be applied to the data. However, at the beginning of a study, it is important, to train all data collectors to be consistent in their scoring, to minimize the subjectivity of the technique.

How should phenology data be presented and analyzed?

Once the study trees have been selected and labeled, prepare a data sheet, as shown below. List the trees in the order in which they are encountered along the phenology trail. In the field, carry the previous month’s data sheets with you, as well as blank sheets for recording the current month’s data. Month by month, accumulate all data into a single Excel spreadsheet. **Do not** store each month’s data on separate spreadsheets. Always enter new data at the bottom of the spreadsheet (rather than to the right). After each data-collection session, paste a copy of the blank data record sheet at the bottom of the spreadsheet and then add the newly collected data.

To analyze the data, first select the entire spreadsheet (by clicking on the grey, blank rectangle between the column headings and row numbers in the top left-hand corner of the spreadsheet). Next click on “Data” in the top menu bar and select “Sort”. In the dialogue box, sort first by “SPECIES”, then by “LABEL” and finally by “DATE”. This arranges the data in chronological order, for each individual tree of each species

Then use the MS Excel graph wizard to construct a visual phenological profile as shown below. Start by making a profile for each individual tree of each species. This indicates variability of phenological behaviour within each species population and will enable you to assess the synchrony of phenological events and calculate several of the indices defined below. The graph wizard can then be used easily to create a graphical phenological profile of each tree. Only after that should you calculate mean score values across all individuals for each species population and construct an "average" profile for each species.

When analyzing flower/fruit data, the most important point to look for is the period during which fruit scores decline for each species. This indicates the optimal seed-collection month, when natural seed dispersal is occurring. The example here shows that the optimum seed collection time for *Acrocarpus fraxinifolius* is from late June to early July, when maximum seed dispersal occurs. The fruit/seed maturation period is from February to June. After the study has continued for several years, various useful indices of seed production may be calculated by extracting data from the spreadsheets:

- **Duration** – the mean length of flowering/fruiting episodes (in weeks or months) for each individual tree and averaged across all trees in a species sample.
- **Frequency** – the total number of flowering/fruiting episodes recorded for each individual divided by the number of years the study has run: then averaged across all individuals of the same species.
- **Intensity** – mean of the maximum flower/fruit scores (for each flowering/fruiting episode) recorded for each individual tree: then averaged for all flowering/fruiting individuals in the species sample.
- **Prevalence** – number of individual trees that flowered/fruited in each year, expressed as a percentage of the total number of individual trees in each species sample, averaged across the total duration of the study (in years).
- **Fruit set index** – for each flowering/fruiting episode, the maximum fruit score observed expressed as a percentage of the maximum flower score: averaged for all flowering/fruiting episodes for all individuals in the species sample.

Reading

Koelmeyer, K., 1959. The periodicity of leaf change and flowering in the principle forest communities of Ceylon. Ceylon For. 4: 157-189

Lab 7-8.1 *- Phenology record sheet.*
Lab 7-8.2 *– Examples of scoring reporductive phenology: flwoers fruits etc. Total score should not exceed 4, but can be less than four*
Lab 7-8.3 *– Examples of leafing phenology scores. The total score should always add up to 4.*
Lab 7-8.4 *– Typical species phenological profile showing that the best time to collect fruits and seeds is in November, that this species is only very marginally deciduous and that flowering co-incides with leaf fall at the and of the dry season.*

LAB 7-8.1

Order in which the trees are encountered along the phenology trail

Date of observation

Scientific name

Flower/fruit scores:-

FB = flower buds

FL = open flowers

FT = fruits

The sum of these scores should never exceed 4 but can be <4

Notes of the location of each tree. R12 = 12 m right of the trail. L2 = 2 m left of the trail and so on.

ORDER	LABEL	DATE	S. No.	SPECIES	GBH	FB	FL	FT	BA	YL	ML	SL	LOCATION
1	1667.1	04/01/95	34	DUABANGA GRANDIFLO	102	3.5	0.5		0.5		3	0.5	R 12. LARGE PINNATE LEAVES. .
2	1667.2	04/01/95	54	ALSTONIA SCHOLARIS	54		1	3			4		R 18. JUST BEFORE 1667
3	1667	04/01/95	23	SCHIMA WALLICHII	230			4			4		R 1
4	1667.3	04/01/95	34	CASTANOPSIS TRIBULO	24					3	1		R 20. 3 BIG STEMS
5	1668	04/01/95	54	ALSTONIA SCHOLARIS	100				4				R 5 BRANCH NEAR BASE
6	1669	04/01/95	34	DUABANGA GRANDIFLO	288				1		2	0.5	L 4. BRANCHING V.NEAR BASE
7	1670	04/01/95	56	EURYA NITIDA	54						3.5	0.5	R 4
8	1671	04/01/95	67	CINNAMOMUM INERS	85						3.5	0.5	L 0
9	1672	04/01/95	34	DUABANGA GRANDIFLO	150			4			4		JUST BEHIND 1671
10	1673	04/01/95	54	DIOSPYROS GLANDULO	70				0.5		3.5		R 2
11	1674	04/01/95	56	EURYA NITIDA	53					0.5	3	0.5	L 2. FORWARD 35M
12	1675	04/01/95	43	WENDLANDIA PANICULA	95				1	1.5	1	0.5	L 0
13	1676	04/01/95	32	SAPIUM BACCATUM	168								L 6
14	1677	04/01/95	21	PHYLLANTHUS KERRII	25				0.5	1	2.5		L 0
15	1678	04/01/95	98	STEREOSPERMUM COL	160				1		2	1	R 2
16	1679	04/01/95	23	SCHIMA WALLICHII	150			4			3.5	0.5	R 2
17	1680	04/01/95	97	CASTANOPSIS DIVERSIF	65			0.5			2.5	1.5	R 2. 3 STEMS
18	1681	04/01/95	23	SCHIMA WALLICHII	77					1	2.5	0.5	L 0
19	1682	04/01/95	56	EURYA NITIDA	43				0.5	0.5	[illegible]		R 3. 2 STEMS
20	[illegible]	04/01[illegible]	[illegible]	SCHIMA [illegible]CHII	24				1				R 20

Identification number on label attached to each individual tree

Species number

Girth at breast height (cm)

Leaf scores:-

BA = bare branches

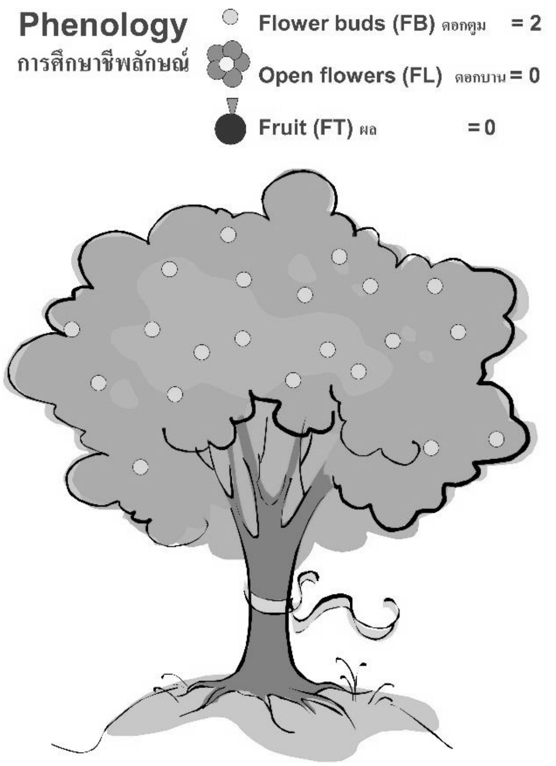
YL = young leaves

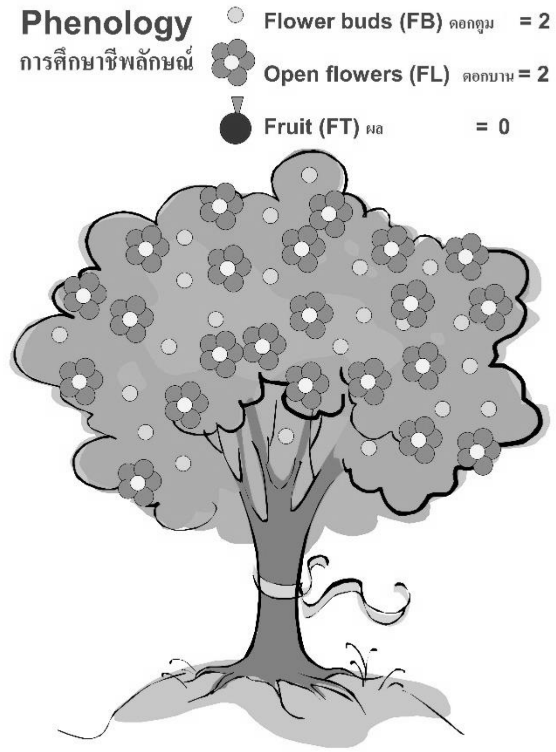
ML = mature leaves

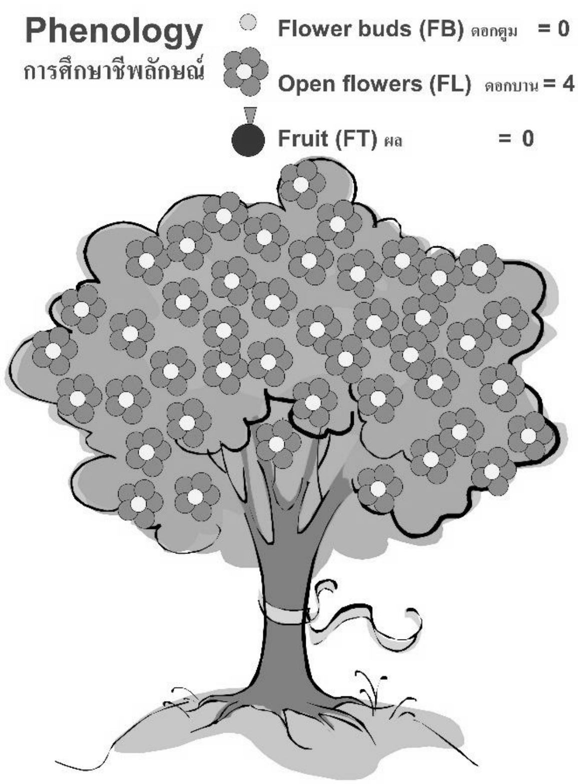
SL = senescent leaves

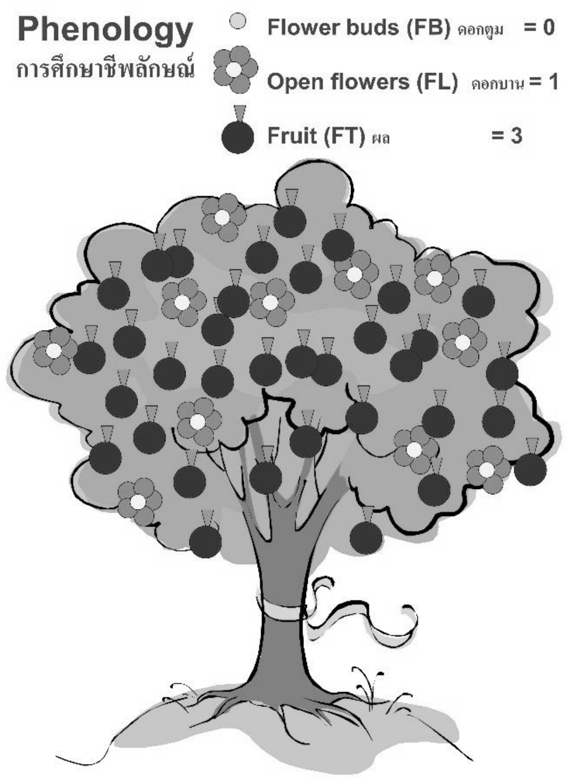
The sum of these scores should always equal 4

LAB 7-8.2


Phenology
การศึกษาชีพลักษณ์
Flower buds (FB) ดอกตูม = 2
Open flowers (FL) ดอกบาน = 0
Fruit (FT) ผล = 0

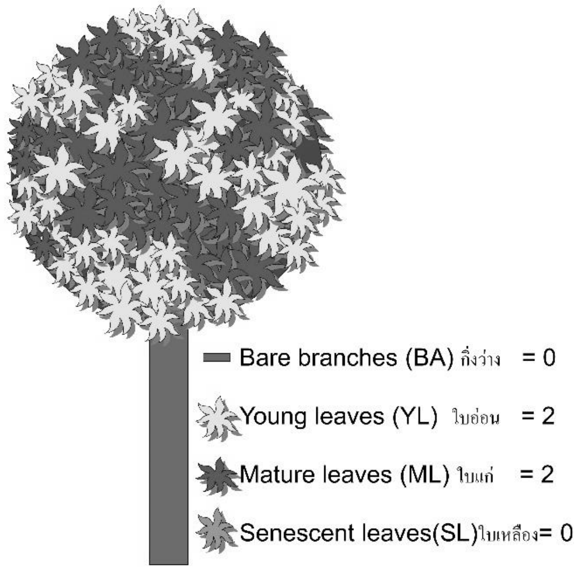

Phenology
การศึกษาชีพลักษณ์
Flower buds (FB) ดอกตูม = 2
Open flowers (FL) ดอกบาน = 2
Fruit (FT) ผล = 0


Phenology
การศึกษาชีพลักษณ์
Flower buds (FB) ดอกตูม = 0
Open flowers (FL) ดอกบาน = 4
Fruit (FT) ผล = 0

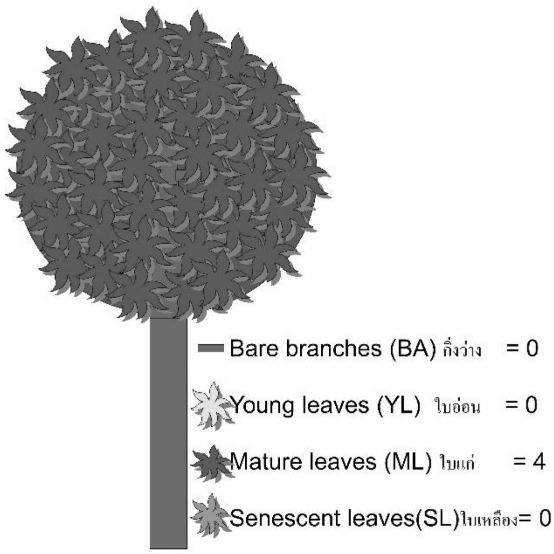

Phenology
การศึกษาชีพลักษณ์
Flower buds (FB) ดอกตูม = 0
Open flowers (FL) ดอกบาน = 1
Fruit (FT) ผล = 3

LAB 7-8.3

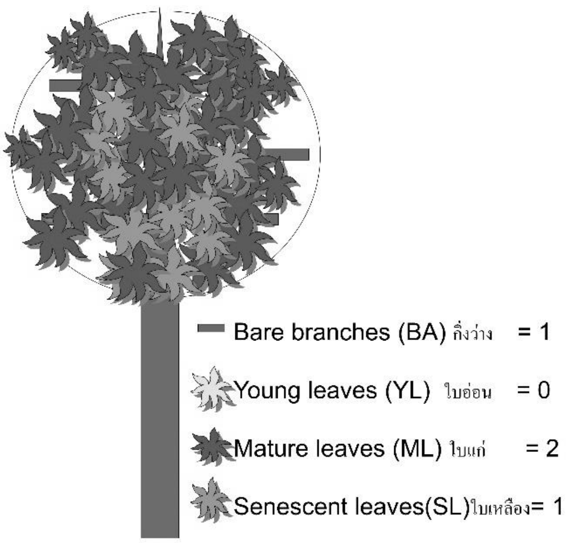
Phenology
การศึกษาชีพลักษณ์



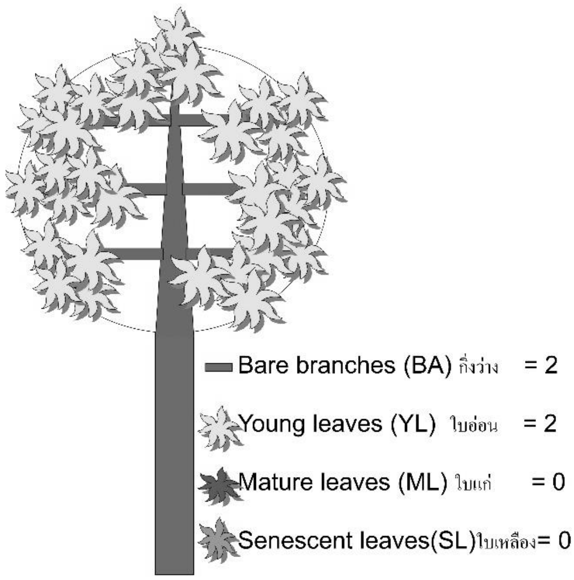
Phenology
การศึกษาชีพลักษณ์



Phenology
การศึกษาชีพลักษณ์

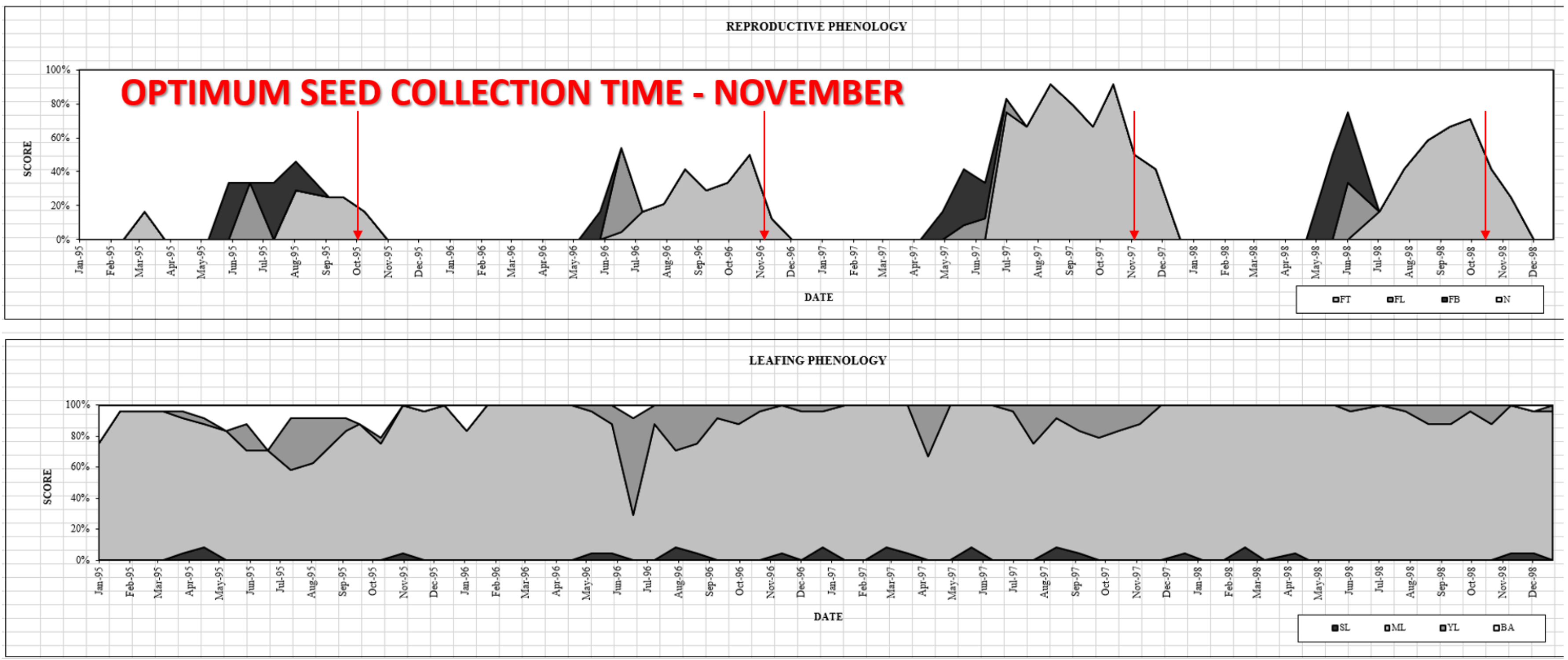


Phenology
การศึกษาชีพลักษณ์



LAB 7-8.4

Species (*Styrax benzoides*) – Phenology Profile



9-10. Tree Nursery Experiments - Germination & Seedling Growth (2 Sessions)

Germination comprises three overlapping processes. Water absorption swells the seed, which splits the seed coat. Food reserves are mobilized and transported to the embryonic root (**radicle**) and shoot (**plumule**), which begin to grow. The final stage (and the most precise definition of germination) is **emergence of the radicle** through the seed coat. In germination trials, this can be difficult to observe for buried seeds, so emergence of the plumule can also be used to indicate germination.

Setting up seed germination experiments in the nursery

Collect fruits when they are fully. Label each seed tree with a unique number and fill in a seed collection data sheet (Figure 15.1). Germination trials can answer two basic questions: i) how many seeds germinate (per cent germination) and ii) how quickly they germinate. Both of these variables can be manipulated to grow tree saplings for a specific planting time.

To accelerate and maximize germination, seed treatments should aim to overcome dormancy by e.g. scarification, acid treatment, soaking etc. Design treatments that change only one factor, although this can be difficult to achieve in practice. For example, putting seeds into hot water has two simultaneous effects i.e. soaking and heating.

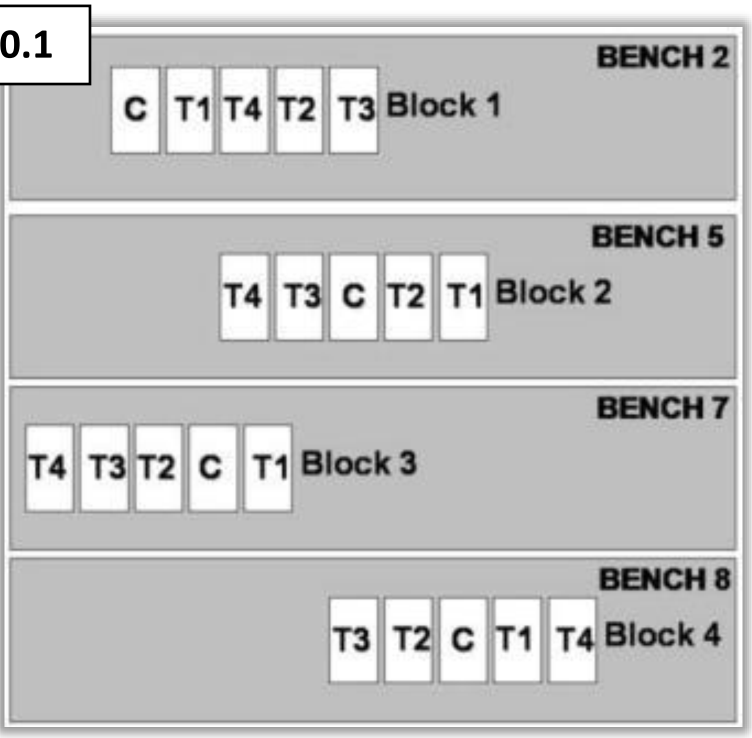
Experimental Design

Use a **randomized complete block design** (RCBD) (LAB 9-10.1) to test different treatments or to compare germination among species. Place a control germination tray (with seeds prepared in a standard way) and several treatment trays (each one containing seeds subjected to a different pre-sowing treatment) adjacent to each other on a nursery bench as one “block”. Replicate the blocks several times on different benches and represent each treatment equally in every block (i.e. the same number of seeds subjected to each of the treatments and in the control tray). Within each block, allocate the positions of the control and the treatment replicates randomly. Fill modular germination trays with the regular germination medium used in the nursery. Then, sow a single seed into each module. Clearly label the trays with the species number and treatment. A similar design can be used to compare among species replace T1, T2 etc. with Species 1, Species 2, etc.

LAB 9-10.1 – *Example of a randomized complete block design (RCBD) germination trial with 4 blocks and 4 treatments + control. Each block of 5 modular germination trays is placed on a different bench, where environmental conditions may differ slightly.*

LAB 9-10.2 – *Typical germination-trial-data sheet with 3 blocks (or replicates R)and 2 treatments + control, with 24 seeds being used of each replicate ”R”. At least once a week (more frequently if germination is rapid) record the number of seeds germinating in each block (R1, R2 etc.) and for each treatment (T1, T2 etc.) and the number of modules where a seedling has died. ANOVA can then be used on these data to separate the effects of block positioning and the treatments.*

LAB 9-10.1



LAB 9-10.2

Species Number: 133 Batch Number: 10

SEED GERMINATION DATA COLLECTION SHEET

Species Name: *Afzelia xylocarpa (Kurz) Craib* **Family:** Leguminosae (Caesalpinioideae)

Date Seeds Collected: 20/8/2010 **Date Seeds Sown** 24/11/2010 **No. Seeds Sown Per Replicate:** 24

Description of standard seed preparation procedures applied to all seeds:

	TREATMENT DESCRIPTIONS
T1	Control
T2	Scarification
T3	Soaking in water for 1 night

	BLOCK 1						BLOCK 2						BLOCK 3							
	T1R1		T2R1		T3R1		T1R2		T2R2		T3R2		T1R3		T2R3		T3R3			
Date	G	GD	G	GD	G	GD	G	GD	G	GD	G	GD	G	GD	G	GD	G	GD	Total germibated	Total died
1/12/2010	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8/12/2010	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15/12/2010	0	0	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	3	0
22/12/2010	0	0	5	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	6	0
29/12/2010	0	0	6	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	7	0
5/1/2011	0	0	9	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	10	0
12/1/2011	0	0	9	0	0	0	0	0	3	0	0	0	0	0	5	0	0	0	17	0
19/1/2011	0	0	12	0	0	0	0	0	5	0	0	0	0	0	6	0	0	0	23	0
26/1/2011	0	0	17	1	0	0	0	0	7	0	0	0	0	0	7	0	0	0	31	1
2/2/2011	0	0	17	1	0	0	0	0	7	0	0	0	0	0	7	0	0	0	31	1
9/2/2011	0	0	19	1	0	0	0	0	8	0	0	0	0	0	9	0	0	0	36	1
16/2/2011	0	0	22	1	0	0	0	0	12	1	0	0	0	0	9	0	0	0	43	2
23/2/2011	0	0	22	2	0	0	0	0	15	1	0	0	0	0	11	0	0	0	48	3
2/3/2011	0	0	22	2	0	0	0	0	17	1	0	0	0	0	15	1	0	0	54	4
9/3/2011	0	0	22	2	0	0	0	0	17	1	0	0	0	0	19	1	0	0	58	4

Data Collection

Inspect all seed germination trays at least once per week. For each seed that has germinated, use a white marker pen to place a waterproof white dot on the rim of the module. Count the total number of white dots and record the result on the data sheet. Recording early seedling mortality is also a useful to help to calculate the number of trees that can be generated from a given number of seeds collected. Count the number modules with white dots, but containing no live seedling.

Data analysis will be performed in Lab 15.

Seedling growth and survival

Monitoring the performance of tree species in nurseries enables calculation of the time needed to grow trees, of each selected species, to a plantable size by the planting-out date.

Tree species that grow well in nurseries usually perform well in the field. So, one of the simplest nursery experiments is to compare survival and growth among species. Adopt a standard production method for all species and use a RCB experimental design to compare performance among species. In this case, there are no “control” and “treatment” replicates. A “block” consists of one replicate (at least 16 containers) of each species.

Subsequent experiments can test different techniques to manipulate growth rates in order to grow saplings to a suitable size. Treatments to test include:

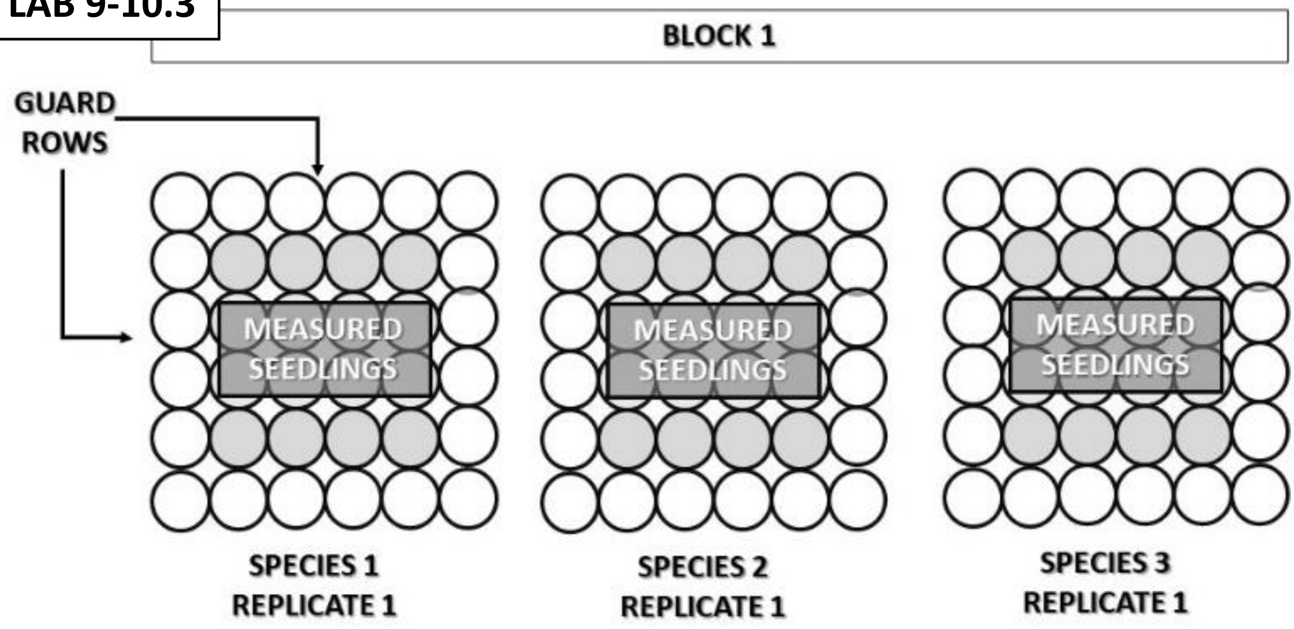
- **Container type** - compare plastic bags with other container types such as rigid plastic cells or tubes, which exert more control over root form, with or without air-pruning
- **Media and fertilizer regime** – vary the potting media composition, such using different forms of organic matter (coconut husk, rice husk, peanut husk etc.) or adding nutrient rich materials such as cattle dung. For slow-growing species, try accelerating growth by experimenting with different fertilizer treatments.
- **Pruning** - If trees start to out-grow their containers before planting-out time, experiment with shoot pruning treatments. Compare different shoot pruning intensities, timing and frequencies.

To test treatments, use a randomized complete block design. Decide on the treatments that can be applied. Then, for each block, select a minimum of 16 plants (more is better) to constitute one “replicate” for each treatment and the same for the control. Make sure that all treatments (and a control) are represented by the same number of plants in all blocks.

LAB 9-10.3 – *Seedling growth experiment design: containerized seedlings are arranged in 4x4 blocks pot-thick, surrounded by guard rows. This ensures all seedlings are completely surrounded by others on all sides and experience similar conditions. Data are collected only from the inner seedlings.*

LAB 9-10.4 – *Typical seedling growth monitoring data sheet.There shoul dbe one sheet for each species and each block.*

LAB 9-10.3



LAB 9-10.4

Species												S.# b.#							
Potting date:					Block #:							Treatment:							
HEIGHT (cm)		SEEDLING NUMBER																	
DATE	DAYS SINCE POTTING	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	MEAN	STDEV
RCD (mm)		SEEDLING NUMBER																	
DATE	DAYS SINCE POTTING	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	MEAN	STDEV
HEALTH SCORE (0-3)		SEEDLING NUMBER																	
DATE	DAYS SINCE POTTING	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	MEAN	STDEV

Place each block, consisting of one replicate of each treatment + control, in a different bed in the standing down area of the nursery. Within each block, position treatment and control replicates randomly. Select uniform plants for experiments. Plants at the edge of a block experience no competition from neighbours on one side and they may be affected by people brushing up against them. Reduce these “edge effects” by surrounding each replicate with a “guard row” of plants that are not included in the experiment.

Data Collection

Collect data immediately after the experiment is set up and at intervals of approximately 45 days, thereafter. Measure the height of each sapling (from root collar to apical meristem) with a ruler. Measure RCD (root collar diameter), at the widest point, with Vernier scale callipers (Box 7.3). Use a simple scoring system to record plant survival and health (0=dead, 1=severe damage or disease; 2=some damage/disease but otherwise healthy; 3= good health). Also, record descriptions of any pests and diseases observed, as well as any signs of nutrient deficiency.

Data analysis will be performed in Lab 15.

Reading

The Forest Restoration Research Unit, 2008. Research for Restoring Tropical Forest Ecosystems: A Practical Guide. Chiang Mai University, Forest Restoration Research Unit, Thailand. 144 pp.

11-12. FIELD TRIALS - DATA COLLECTION (2 FIELD SESSIONS)

Monitoring Forest Restoration

To determine the effectiveness of forest restoration treatments, restoration plots should be paired with “control” plot nearby, where no restoration treatments are applied. The same sampling effort should be expended at both the restoration sites and the control sites and the measurements made in both should also be identical. Control sites should be close and as similar as possible to the restoration sites, in terms of original vegetation, elevation, slope, aspect, etc. Delineate the boundaries of both control and restoration sites with wrought iron metal poles, placed every 100 m. Wrap coloured sticky tape around the tops of the poles and write an identification number on each pole with an indelible pen. Record the GPS location of each pole and take a photograph looking towards the centre of the study site from each pole. Record site details on Data Sheet LAB 11-12.1.

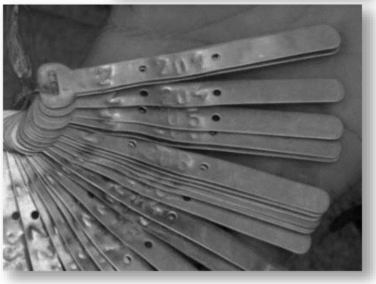
Circular sample units (SU’s) of 5 m radius have become the international standard for monitoring vegetation recovery as a result of restoration activities. Position SU’s evenly across both the control and restoration sites. A minimum of 10 SU’s should be positioned across the restoration site and 10 more across the control site. Use a wrought iron pole (which will survive fire) to mark the centre of each circular SU and a 5-m-long piece of string (tied to the centre pole) to delineate the SU circumference. Use coloured tape and an indelible pen to apply an identification number to each pole. Record the GPS location of each pole. Record SU details on Data Sheet LAB 11-12.2 and perform photo-monitoring as described in Box LAB 11-12.1

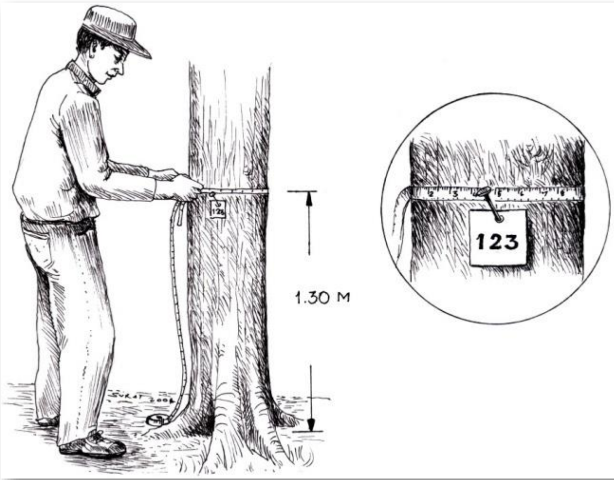
Box LAB 11-12.1 - Photo monitoring procedure

Take photos of the vegetation at all boundary and SU centre poles. At boundary poles, take photos looking towards the centre of the study site. At sample-unit poles, take 4 photos, looking out from the pole roughly N, W, S and E (in that order). Set the camera to the widest possible zoom setting and the highest resolution. Frame each picture to include the top of the pole (showing the pole i.d. number) in the lower right-hand corner. Use a compass to record the direction of the photo. Keeping the top of the pole in the lower right-hand corner of the picture, gradually tilt the camera down to minimized the amount of sky in the shot, so the horizon should be near the top edge of the picture. Repeat photo-monitoring in the mid dry and wet seasons and at annual intervals. Use the same camera with the same zoom and resolution settings for all photos. Transfer photos to a computer as soon as possible and rename the files as follows: pole reference number_date (yymmdd) e.g. B08E_120315 (boundary pole 8, facing east, taken on 15th March 2012).

Box LAB 11-12.2 - Labelling

For seedlings and saplings use soft aluminium strips, used to bind electrical cables, available from builders' supply stores. They can be easily formed into rings around tree stems. Use metal number punchers or a sharp nail to engrave an identification number on each label and bend them into a ring around the stem, above the lowest branch (if present) to prevent labels from becoming buried. For larger trees and stumps, use square labels made from drinks cans. Cut off the top and bottom of the cans and slice up the length of the can to open out the metal foil sheet. Cut the sheet horizontally into 2-3 strips and then vertically to make squares. Place the labels on a pad of paper or rubber mat and then use a tough ball-point pen or nail to press identification numbers into these soft metal foil squares (on the inside can surface). On trees of girth 5 cm or more, nail labels to the trunk so that the upper edge of the label is at exactly 1.3 m above the ground, where girth at breast height (GBH) will be measured. Use 5 cm long, galvanized nails, with flat heads. Hammer only about 1/3 of the nail length into the trunk to allow plenty of room for tree growth.





Measurements

Equipment: metal labels, permanent marker or metal stylus, wire, nails, tape measures (1.5 m), Vernier calipers, Data Sheet #3, pencil, clip board, tree height measuring poles.

Within each SU, label every tree sapling taller than 50 cm and every live tree stump and then use Data Sheet 3 to record i) the label number, ii) the species name (both local name and scientific name), iii) height, iv) for small saplings, root collar diameter (RCD mm) or for larger trees (if girth at breast height (GBH) is more than 5 cm), record the GBH (cm), v) health score, vi) crown width and vii) for tree stumps, the number of coppicing stems. Ask local people for the name of each tree in the vernacular. Work with a botanist to obtain scientific names on-site, or collect specimens for identification at an herbarium later.

Use tape measures to measure the heights of small saplings (taller than 50 cm) (e.g. 1.5 m tape measures mounted on rigid PVC poles). Measure the tree height, from the root collar to the highest meristem (shoot tip). For taller trees, telescopic measuring poles can be used to measure trees up to 10 m tall. For small trees, measure RCD at the widest point with Vernier calipers. Once a tree has grown tall enough to develop a GBH of 5 cm or larger, measure both the RCD and the GBH (1.3 m from the ground), the first time and only GBH thereafter.

Data Sheet LAB 11-12.1 - Site Information

	Date:				**Recorder:**			
	Restoration				**Control**			
Name								
Location (Province District etc.)								
Elevation range								
Average slope								
Average aspect								
FACTORS AFFECTING REGENERATION								
Fire History								
Livestock usage								
Erosion/landslides								
BOUNDARY POLES	**POLE ID #**	**GPS**	**PHOTO FILE I.D.**	**PHOTO DIRECTION (DEGREES)**	**POLE ID #**	**GPS**	**PHOTO FILE I.D.**	**PHOTO DIRECTION (DEGREES)**
Etc. (add lines as needed)								

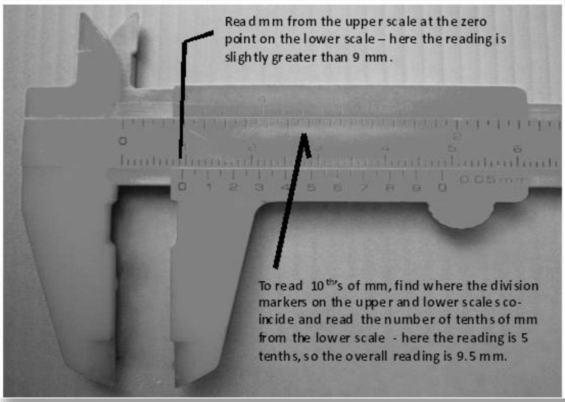
Data Sheet LAB 11-12.2 – Sample Unit Details

DATE:	RECORDER:	Sample Unit I.D. #:
STUDY SITE:		restoration or Control:
Slope:	Aspect:	Elevation:
GPS:	N	E
Signs of Fire:		
Signs of livestock impact:		
Signs of erosion:		
Any other distinguishing features:		
Photos	Compass direction (degrees)	Photo File I.D. #
N		
E		
S		
W		

Data Sheet LAB 11-2.3 – Trees

SAMPLE UNIT ID #:		RECORDER:			restoration OR CONTROL			DATE:
Within 5 m radius circle								
Label	Tree Species	Height (cm)	RCD (mm)	GBH (cm) if >5 cm	Health Score 0-3	Crown Width (cm)	No. Coppicing Shoots (for tree stumps)	Notes
	Local Sci.							
	Local Sci.							
	Local Sci.							
	Local Sci.							
	Local Sci.							
	Local Sci.							
	Local Sci.							
	Local Sci.							
	Local Sci.							

Box LAB 11-12.3 - Using Vernier Callipers
Vernier scale callipers are available from most stationary stores. At the zero mark on the lower sliding scale, read number of millimetres diameter from the upper scale. For the decimal point, look for the point at which the division marks on the lower scale are exactly aligned with the division marks on the upper scale. Then, read the decimal point off the lower scale.

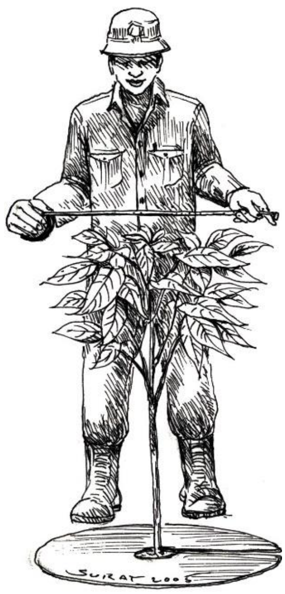


Assign a simple health score (0-3) to each tree and record descriptive notes about any particular health problems observed. Score zero if the tree appears to be dead. For deciduous tree species, don't confuse a tree with no leaves in a dry season with a dead one. Do not stop monitoring trees just because they score zero on one occasion. Many trees, which appear dead above ground, may still have living roots, from which they may subsequently re-sprout new shoots. Score 1 if a tree is in poor condition (few leaves, most leaves discoloured, severe insect damage etc.). Score 2 for trees showing some signs of damage but retaining some healthy foliage. Score 3 for trees in perfect or nearly perfect health.

Measure the width of the tree crown (cm) at the widest part with a tape measure. Any tree seedlings or saplings shorter than 50 cm can be considered as part of the ground flora and need not be individually measured.

If restoration treatments are effective, the number/unit area of trees > 50 cm tall and their growth rates should increase more in the restoration site than in the control site over successive monitoring events.

Online resource: https://www.forru.org/advice/field-performance-planted-trees



13-14. Biodiversity Monitoring Using Birds as Indicators (2 Field Sessions)

Birds

Birds provide a very convenient indicator group for evaluation of biodiversity because: -

i) they are relatively easy to see and to identify;
ii) many excellent identification books are available;
iii) most species are active by day;
iv) birds occupy every trophic level – herbivores, insectivores, carnivores etc.
v) a high diversity of birds usually indicates a high diversity of plants and prey species, especially insects.

Field work

The McKinnon's curve technique uses "the list" as a unit of effort to determine how many bird species are seen with increasing number of lists. It works well and is independent of area covered, time length and expertise of the bird watcher. It can be done sitting in one place or walking around. Bird watching can be stopped at any time and continued later. The technique simply involves recording every bird seen in order of time. The best time to go bird watching is early morning. Use binoculars to spot the birds and a bird guide book to identify them. Record all bird observation on the standard data collection sheet. Work in pairs with one person spotting the birds and the other recording the data. Interchange these roles every 30 mins. It is important to write down every bird that is seen and the time it is seen, regardless of whether it is the same species seen multiple times or not. You may also record a bird by hearing its song. To analyse the results follow instructions in Chapter 9.2.

Bird Survey Record Sheet

File Name: Restoration Plot 6 years old

Date: 17.12.05 Weather: sunny, cool Recorder/s: LM, MT, CT

Block Number: G1 Plot Number: EG-05

Start time: 7.47am Finish time: 10.30 am

TIME	SPECIES(COMMON NAME)	SONG OR SIGHT	NO. OF INDIVIDUALS	DISTANCE FROM POINT (M)	TREE (SPECIES/ LABEL)	POSITION (CROWN/ TRUNK ETC.)	ACTIVITY (FEEDING, PERCHING, DISPLAYING ETC.)
7.47	Black-crested Bulbul	sight	1	20	Eyrthrina stricta	crown	feeding and flying
7.52	Bar-winged Flycatcher-shrike	sight	5	30	Ficus altissima	crown	feeding and flying
8.06	Hill Blue Flycatcher	song	1	50	Betula alnoides	tree trunk	flying
8.08	Sooty-headed Bulbul	song	1	25	Gmelina arborea	crown	flying
8.15	Puff-throated Babbler	sight	2	15	Spondias axillaris	tree trunk	flying
8.23	White-rumped Shama (male)	sight	1	10	near Prunus cerasoides	ground	perching

15. DATA ANALYSIS – NURSERY GERMINATION AND SEEDLING GROWTH EXPERIMENTS (CLASSROOM)

Dormancy is a period during which viable seeds, under favourable conditions, fail to germinate. It can originate in the embryo or in the tissues that surround it (endosperm, testa or pericarp). Embryo dormancy can be due to i) a need for further development (after-ripening); ii) chemical inhibition; iv) blocked mobilization of food reserves or v) lack of plant- hormones. Dormancy, due to seed coverings, can be caused by i) water or oxygen not reaching the embryo; ii) physical restriction of embryo expansion or iii) chemical inhibitors.

Germination curves

Use the data from Datasheet 9-10.2 to Plot cumulative total number of seeds that germinate as a per cent of the number sown on the vertical axis and time in weeks on the horizontal axis. This can be done first individually for each replicate with curves for all replicate plotted on the same axes. Look at variability among the replicates. Next combine data across all replicates of the same species/treatment and plot an average curve. The germination curve combines all germination parameters into a single graphic, including length of dormancy period, rate and synchronicity of germination, as well as final percent germination LAB 15.1.

How is dormancy measured?

Dormancy varies among individual seeds within a batch. Median length of dormancy (MLD) for a seed batch is the length of time between sowing and germination of half the seeds that eventually germinate. For example, in LAB 15.2, MLD is the time between sowing and germination of the 28th seed, i.e. 13 weeks.

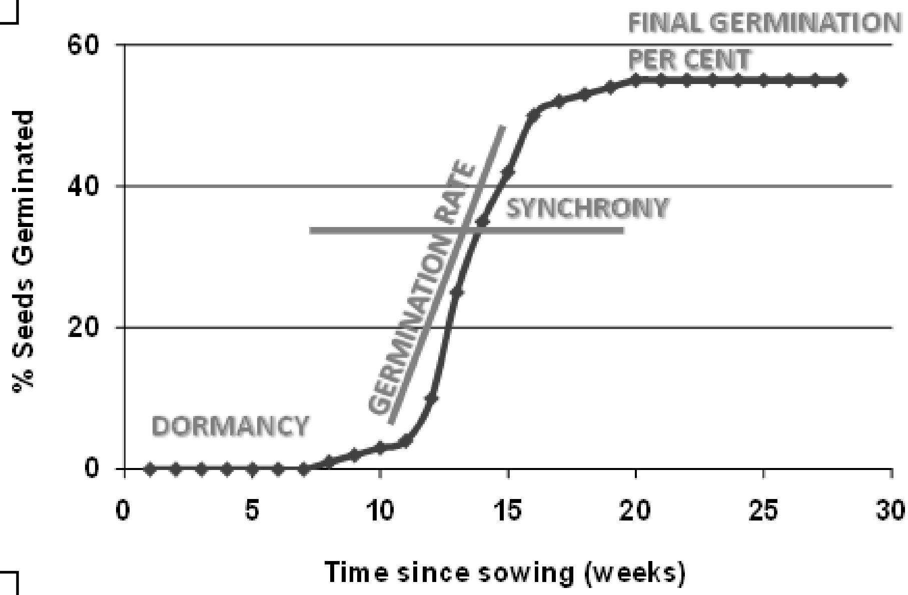
Decisions can be made even without complex statistical tests. In the example in LAB 15.3, a pre-sowing seed treatment accelerates germination but reduces the germination per cent, compared with the control. Faster germination may mean the difference between achieving a crop of saplings ready to plant by the first rainy season after seed collection or having to maintain saplings in the nursery until the second rainy season after seed collection.

More advanced analysis ANOVA and t-tests

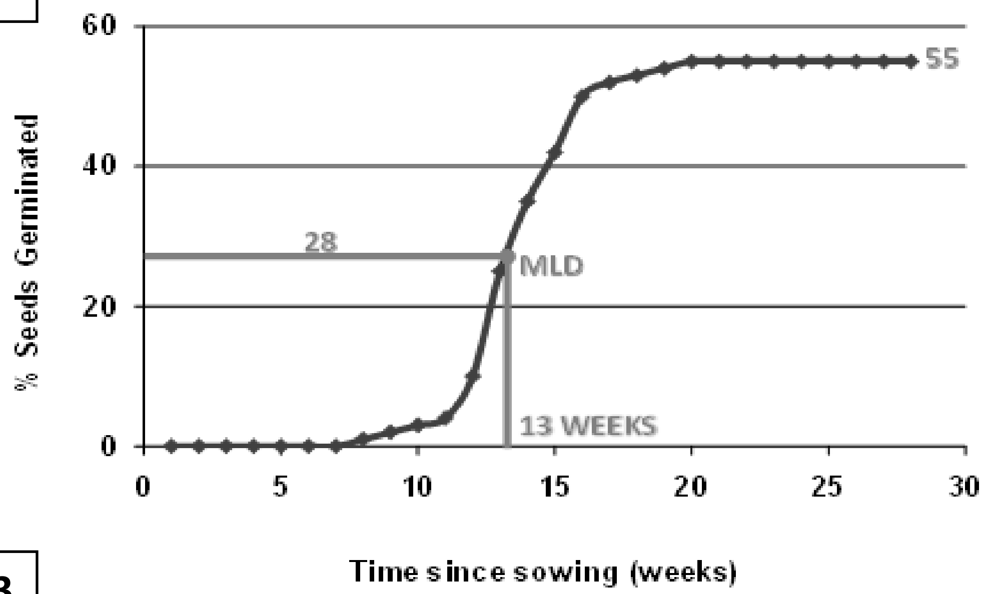
A "two-way ANOVA (without replication)" can be used to test for significant differences among treatments and blocks. If the ANOVA shows significant differences, then perform pair-wise comparisons between each treatment mean and the control mean, to determine which treatments increase or decrease germination and/or dormancy. Use the Data Analysis Tool Pak of MS Excel (see Elliott et al., 2013; Appendix 2)

LAB 15.1 –*Germination curves show dormancy, germination rate, synchronicity and final germination per cent at a glance.*
LAB 15.2 – *Median length of dormancy is time taken for germination of half the seeds that finally germinate.*
LAB 15.3 – *Germination curves allow rapid evaluation of the effectiveness of treatments.*

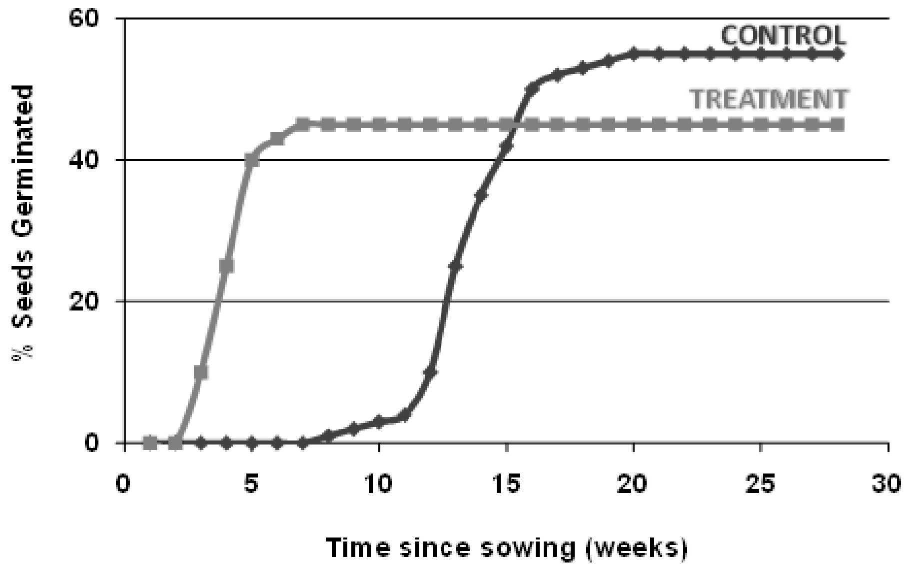
LAB 15.1



LAB 15.2



LAB 15.3



Nursery seedling growth experiments

Set up seedling growth experiments as described in LAB 9-10, monitor them every 45 days until the plants are 30-50 cm tall. Use Data Sheet LAB 9-10.4 to record the data.

First count the number of seedlings that have died each time data are collected. Plot a graph of cumulative mortality vs. date. Compare mortality among species and treatments. Optionally use and use a Chi-square test to determine if differences are statistically significant (see page 236 of Elliot et al., 2013)

Next, represent sapling growth graphically by constructing a growth curve. Plot mean sapling height (or mean RCD) vs. date averaged across blocks, for each treatment (vertical axis). By extrapolation, such curves can be used to roughly estimate how long saplings must be kept in the nursery to grow to the optimum planting size (30-50 cm tall by mid-June). They can also be used to compare growth among species and to determine the effects of treatments.

Growth can also be represented by a single number called "relative growth rate" of RGR, which removes the effects of differences in the original sizes of seedlings/saplings, immediately after potting, on subsequent growth. Consequently, it can be used to compare plants that were larger at the beginning of the experiment with those that were smaller. It is defined as the ratio of growth of a plant to its mean size over the period of measurement, according to the equation below…

$$\textbf{RGR (\% per yr)} = \frac{(\ln FS - \ln IS) \times 36{,}500}{\text{No. days between measurements}}$$

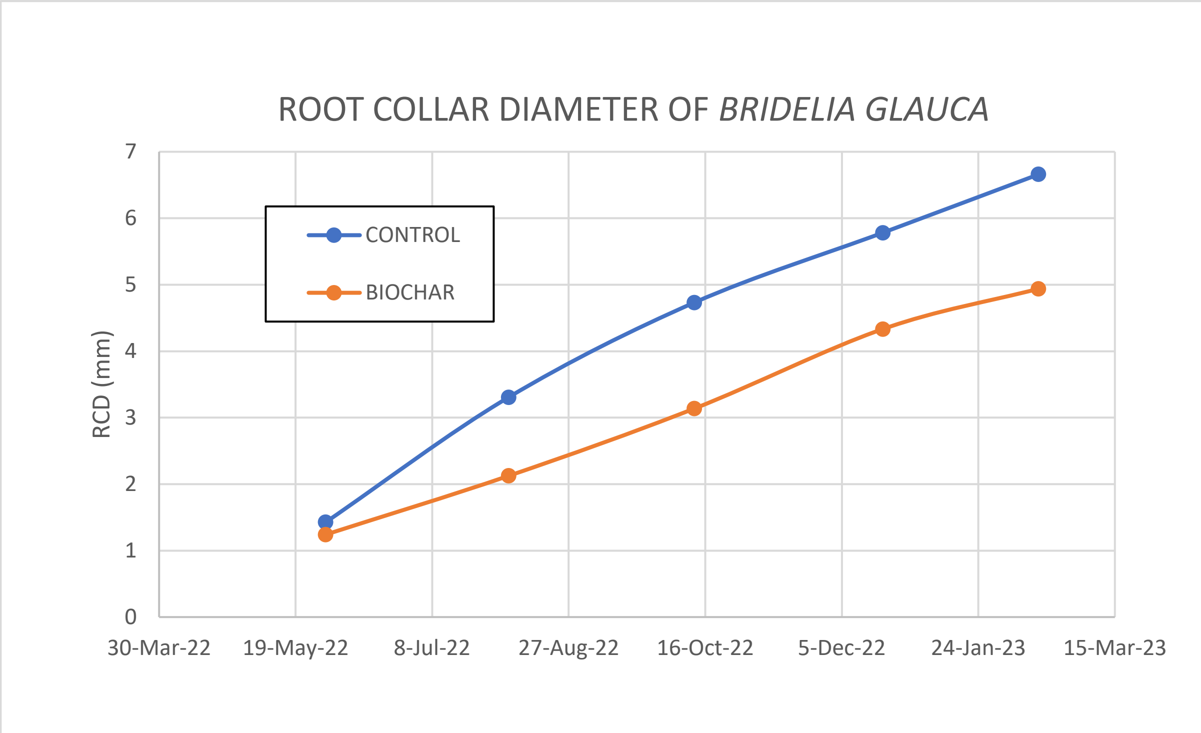
…where ln FS = natural logarithm of final size (height or RCD) and ln IS – natural logarithm of initial size.

Reading

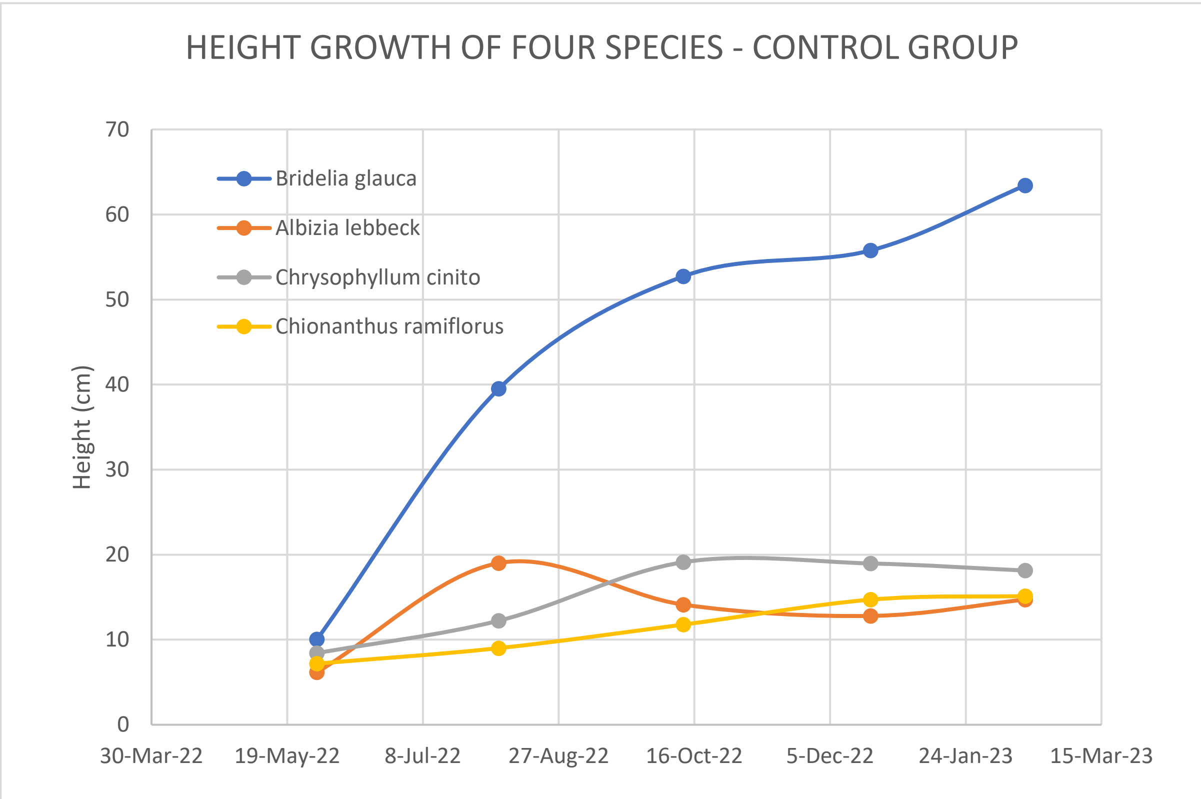
Elliott, S.D., D. Blakesley & K. Hardwick, 2013. Restoring Tropical Forests: A Practical Guide. Royal Botanic Gardens, Kew; 344 pp. https://www.forru.org/library/0000152

LAB 15.4 –*This experiment tested the effects of adding biochar to the potting medium on seedling growth in a nursery, measure as increasing root collar diamter Three replicates of 16 seedlings each – both for the control (regular potting medium) and the treatment (20 % biochar added to medium) The graph shows that biochar reduced seedling grwoht by about 25%.*
LAB 15.5 – *This experiment compared growth of 4 potential framework tree species in the nursery, using standard techniques (controls). The graph shows that only Bridelia glauca will be ready for planting out by June 2023. The trees should be at least 30 cm tall by mid-June.*

LAB 15.4



LAB 15.5



16. Data Analysis - Tree And Bird Species Richness (Classroom)

After finishing the bird watching field work (LABS 13-14) arrange the data sheets in order of time and then make a list of the first 10 **DIFFERENT** bird species seen down the left-hand column on a table. Continue scanning the data sheets and in the second column of the table make a second list of 10 species, just as before. If you recorded a species already recorded in the first list, place a cross against its name in column 2. If you saw a species not already recorded in the first list, then add its name to the bottom of the species list. Repeat this process until you have ten lists. On any one list, each species occurs only once, but a single species may occur on more than one list or even on all of them. You need to have collected enough field data to compile about 10 lists. The total number of bird species seen (by making ten lists) can be used as a reliable index of the bird community species richness.

McKinnon Bird Species List - 6 year old Restoration Plot

		List Number 1	2	3	4	5	6	7	8	9	10	No. of lists on which the species occurs
1	Black-crested Bulbul	√			√	√	√		√	√		6
2	Bar-winged Flycatcher-shrike	√	√						√			3
3	Hill Blue Flycatcher	√		√	√	√		√		√	√	7
4	Sooty-headed Bulbul	√				√	√					3
5	Puff-throated Babbler	√	√	√								3
6	White-rumped Shama	√							√	√	√	4
7	Yellow-browed Warbler	√			√		√	√	√			5
8	Golden Spectacled Warbler	√	√	√	√		√	√		√	√	8
9	Golden-fronted Leafbird	√										1
10	Verditer Flycatcher	√				√					√	3
11	Lesser Necklaced Laughing thrush		√									1
12	Long-tailed Minivet		√	√		√		√		√		5
13	Green-billed Malkoha		√						√			2
38	Grey-headed Flycatcher							√			√	2
39	Scarlet Minivet								√			1
40	Sulphur-breasted Warbler								√			1
41	Buff-throated Warbler								√			1
42	Pin-tailed Pigeon									√		1
43	Eastern Crowned Warbler									√		1
44	Brown-breasted Bulbul									√		1
45	Flavescent Bulbul										√	1
46	Lanceolated Warbler										√	1
	Number of New Species	10	7	5	5	4	4	3	3	3	2	
	Cummulative Species	10	17	22	27	31	35	38	41	44	46	

- Count the numbers of new species found in each list and fill in the row marked "NO. OF NEW SPECIES".
- Accumulate the no. of new species in the bottom row of the table, e.g. the value for list no. 3 would be no. new species in list 3 + no. new species in list 2 + no. of new species in list 1. Plot a graph of cumulative no. of new species along the y axis and no. of lists along the x axis.
- Fill in the far-right column on the data sheet marked "NO. OF LISTS ON WHICH SPECIES OCCURS" and fill in the table below:

NO. OF LISTS ON WHICH SPECIES OCCURS	1	2	3	4	5	6	7	8	9	10
NO. OF SPECIES OCCURRING ON THAT NO. OF LISTS (FREQUENCY)										
LOG$_{10}$ FREQUENCY										

- Plot a graph of log frequency along the y axis and no. of lists on which species occur along the x axis.
- Extrapolate the line back to zero. Where the line crosses the y axis gives an estimate of the log no. of species not seen during the survey. Convert this log value into a number (antilog). Add the result to the total number of species seen, to obtain an estimate of the total number of birds in the community.

Repeat bird surveys and estimate bird species richness like this annually i) in the restoration site, ii) in a control site (degraded area where restoration was not done) and iii) in a remnant of the reference forest type. If restoration increases biodiversity, you should see that bird-species richness increases over time in the restoration site faster than in the control site and that it begins to approach that of the reference forest.

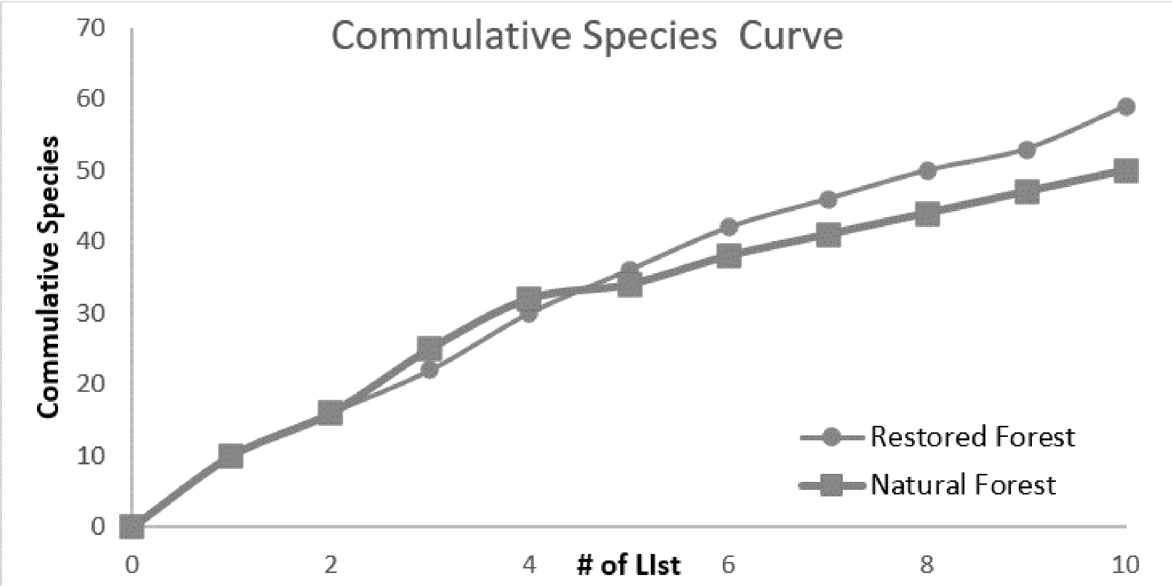
Also examine the species composition of the three areas. Bird species in the control site should be mainly those that thrive in open areas e.g. those that feed on grass seed and insects. In the restoration site, such species should become rarer and be gradually replaced by those more typical of the reference forest. In this way you can determine if restoration increases biodiversity, by using birds as an indicator-species group.

Online resource: https://www.forru.org/advice/biodiversity

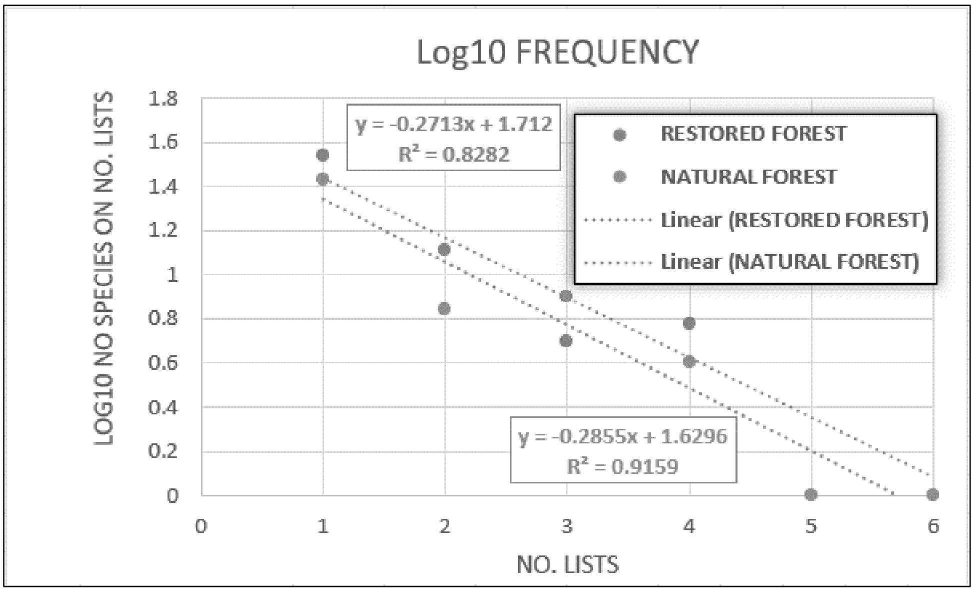
LAB 16.1 *Example results. Nine more bird species were recorded in 10 year old restored forest (59) than in natural forest (50). The number of birds not seen (i.e. occurring on zero lists) was estimated to be 52 (antilog 1.712) for restored forest and 43 (antilog 1.6296) for natural forest, supporting the hypothesis that restoration recovers bird species richness.*

LAB 16.1

Summary of accumulative number of Species in both restored and Natural Forest												
# species in each list		0	10	10	10	10	10	10	10	10	10	10
NO of lists		0	1	2	3	4	5	6	7	8	9	10
No of ***new*** Species	Restored forest	0	10	6	6	8	6	6	4	4	3	6
	Natural Forest	0	10	6	9	7	2	4	3	3	3	3
Cumulative number	Restored forest	0	10	16	22	30	36	42	46	50	53	59
	Natural Forest	0	10	16	25	32	34	38	41	44	47	50



Frequency, log of frequency and projected unseen species											
No. lists on which species occurs		1	2	3	4	5	6	7	8	9	10
Frequency	Restored forest	35	13	5	6						
	Natural Forest	27	7	8	4	1	1	0	0	0	0
$\log_{10}$ Frequency	Restored forest	1.544	1.114	0.699	0.778			0	0	0	0
	Natural Forest	1.431	0.845	0.903	0.602	0	0	0	0	0	0
Expected # of Species remained		Restored Forest					52				
		Natural Forest					43				



17-18. RESTORATION PLANNING LOGISTICS - TIMING, COSTING & LABOUR (CLASSROOM)

Work to complete the restoration plan started in LAB 5 by adding the logistics of implementation: scheduling activities, calculating labour requirements and finally performing a collaborative costing exercise.

Scheduling restoration tasks

Examine the example schedule in table LAB 17-18.1. Consider which tasks to retain and which may not be needed. Add any other tasks that you feel may need to be performed. Next identify your ideal tree planting date. Place the optimum planting date on a GANNT chart and then arrange the other tasks either side of it. Add who will be responsible for organizing and implementing each task and finally start to consider how many person-days (or hours) may be need to complete each task. each task.

Time	YEAR:												YEAR:												RESPONSIBLE GROUP	PERSON-DAYS WORK REQUIRED
Task*	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D		
Stakeholder meetings																										
Build nursery																										
Etc.																										
Etc.																										
Etc.																										
Tree planting						X																				
Clean site and quality check																										
Baseline monitoring																										
Etc.																										
Etc.																										

**select tasks from example schedule LAB 17-18.1 - add tasks as needed*

Labour

Forest restoration is hard work, but, sharing the work amongst many people, lightens the load, turns a chore into a social event and develops a collective sense of "stewardship". The amount of labour available is the critical factor that determines the maximum area that can be restored each year. It is better to plant small areas annually over many years, than to plant large areas and risk the trees dying due to lack of labour for maintenance. Tree planting and aftercare, including fire prevention, are usually organized as community activities. The maximum area of land that can be planted each year therefore depends on the number of households in the village. As community size increases, an "economy of scale" comes into effect, meaning that a larger area can be planted with fewer days work required from each household.

LAB 17-18.1 *A list of restoration tasks and when they should be perfromed relative to the tree-planting date.*

Time relative to first planting event	Action
2 years before	Achieve consensus amongst stakeholders on project aims
	Establish nursery
12-18 months before	Agree on location and extent of restoration plots and decide on a production schedule for desired tree species.
12 months before	Start seed collection and seedling production.
6 months before	Perform rapid site assessment and prepare restoration plan. Check nursery for numbers of seedlings ready for planting. If necessary, obtain more seedlings, from other local nurseries.
2 months before	Begin hardening off seedlings to be planted and contacting volunteer planters.
6 weeks before	Demarcate the boundaries of the plots to be planted. Clearly mark naturally established trees, saplings and seedlings and slash weeds down to ground level.
1 month before	Start labeling seedlings to be monitored, preparing planting materials (poles, mulch, fertilizer etc.).
	Clear the site of herbaceous weeds
1 day before	Transport seedlings and all planting equipment and materials to planting site; brief planting team leaders
	Planting event early rainy season (June for northern Thailand)
1-2 days after	Check quality of planting; remove any garbage from the planting site.
1-2 weeks after	Collect baseline data on seedlings to be monitored (health, height diameter etc.) – carbon and biodiversity.
During first rainy season after planting	Weeding and fertilizer application every 4-6 weeks, as required.
End of first rainy season	Monitor growth and survival of planted trees.
Beginning of first dry season after planting	Cut fire breaks; organize and implement fire patrols until the rainy season begins.
End of dry season	Monitor growth and performance of planted trees. Weeding and fertilizer application. Replace mulch. Assess the need for maintenance planting.
1 year after	Maintenance planting – if needed.
2nd rainy season after	Continue weeding, fertilizer application, as required and
End 2nd rainy season after	Monitor growth and survival of planted trees. Monitoring at this time provides the best prediction of likely overall success.
Subsequent years	Continue weeding until canopy closure is complete. Monitor recovery of biodiversity and continue monitoring planted trees as needed.

Although the labour required for most tasks is area-dependent (i.e. the greater the area planted, the more workers required), fire prevention is a notable exception. Teams of 8 or so fire watchers are necessary to prevent fires approaching the areas planted, regardless of the size of the plot (from 1 to 50 ha). Since fire prevention and suppression requires more labour than all other activities combined, the sharing of fire prevention duties amongst larger numbers of households greatly reduce the labour required from each household. The example detailed below shows how the labour required to replant each hectare of forest declines with increasing total area replanted.

At the outset of any forest-restoration project, participants must be aware of the labour required both to plant the trees and to care for them until canopy closure occurs and no further maintenance is required. Project planners must also address the crucial issue of whether labour will be donated voluntarily or whether daily rates for casual labour must be paid. If the latter, then labour costs will dominate the budget. If villagers understand and appreciate the benefits of forest restoration and have a clear benefit sharing agreement with other stakeholders, then they may be motivated to work on restoration voluntarily in exchange for a share in the benefits.

		Person-days labour per ha (2 years)						
				Total labour required for				
Area Dependent work		**Year 1**	**Year 2**	**1 ha**	**5 ha**	**10 ha**	**25 ha**	**50 ha**
Site preparation	24 people/ha	24	0	24	120	240	600	1,200
Planting	10 trees per person per hour over 6-h working day	50*	0	50	250	500	1,250	2,500
Weeding and fertiliser application	18 people/ha 4 times in Y1 & 3 in Y2	72	54	126	630	1,260	3,150	6,300
Fire break establishment	2 people/100 m firebreak	8	8	16	36	50	80	112
Monitoring	10 people/ha, twice in Y1 and once in Y2	20	10	30	150	300	750	1,500
Area Independent work			*Subtotal*	*246*	*1,186*	*2,350*	*5,830*	*11,612*
Fire prevention /fighting teams.	90 days; 8 people per day; taking care of up to 50 ha	720	720	1,440	1,440	1,440	1,440	1,440
Administration, reporting and accounting								
**Assuming zero natural regeneration i.e. planting 3,000 trees per ha*				1,686	2,626	3,790	7,270	13,052

Apply such considerations to your particular local situation and calculate the project's labour needs. Next apply the local acceptable payment rate for labour, bearing in mind that different types of jobs may be paid at different rates. Now you are ready for the final step—calculation of costs.

Costs

Restoration costs depend primarily on the balance between assisted natural regeneration (ANR) (cheap) and tree planting (expensive). To determine this balance, first perform a participatory rapid site assessment (RSA) (LAB3-4), and then download the budget-calculation spreadsheet, to perform "collaborative costing", involving all stakeholders, particularly the funder. Project the spreadsheet on a screen, so all stakeholders can comment on the numbers being added (transparency).

This is the link for the spreadsheet:
https://www.dropbox.com/s/66i94xaa4scriyf/PLANTING%20COST%20CALCULATION%20SPREADSHEET%20THB%20AND%20USD%20to%20RECOFTC.xlsx?dl=0

First be aware that the spreadsheet is currently in Thai Baht and the land unit is hectares. Change to local currency and land-measurement units.

In the local cost parameters section, enter the number of regenerants recorded per hectare from the RSA. The number of trees that must be planted will automatically appear. Next enter the distance from base to the planting site, cost of gasoline, labour costs (per day) and salary costs of advisors etc. (per month). Change currency to your local currency. Adjust the cost parameters to local rates (according to feedback from stakeholders) and enter the area to be planted. Next take the whole group through the budget line. They are arranged in the order in which tasks are performed: site survey, site prep, planting, maintenance and monitoring and fire prevention. Delete any items irrelevant to your project. Add new items if necessary.

Discuss estimates of the units required and the cost/unit of each budget line with the group. Reach a consensus and enter the data accordingly. Once you have completely overwritten the example data with your own data, the total cost of the project will appear on the TOTAL line.

What if the bottom line exceeds the amount the funder wants to pay? There are 4 options to consider:-

1) Ask the funder to increasing funding – this is risky since the funder might withdraw from the project altogether. On the other hand the funder may very well be able to find extra funds, since the transparent process of collaborative costing shows exactly why the extra funds are needed.
2) Look for ways to adjust the budget. In some cases local stakeholders may be willing to reduce their labour rate if they are offered a greater share in future benefits.
3) Look for additional funding
4) Plan to plant a smaller area – reduce the area planted in the spreadsheet until the bottom line is within the funders' capability. The funder must be persuaded to accept a smaller area restored for the same budget, with the option to continue the project in the future when more funds may become available.

Now you are ready to implement your forest ecosystem restoration project!