Best Practices for Restoring Forest Ecosystems

A 10-day training course to build capacity among Kawthoolei Forestry Department (KFD) officers

Stephen Elliott

FORRU

January 2023

The curriculum and teaching notes for this course were developed under the project: "A Capacity-Building Curriculum on Forest Management And Restoration for Kawthoolei Forestry Department (KFD) Staff", by Chiang Mai University's Forest Restoration Research Unit.

CONTENTS

Syllabus

BEST PRACTICES FOR RESTORING FOREST ECOSYSTEMS

A 10-DAY TRAINING COURSE TO BUILD CAPACITY AMONG KAWTHOOLEI FORESTRY DEPARTMENT (KFD) OFFICERS

Day	Time	Topic	Method	Location	ITEM #
1	am	Forest loss and ecological succession Forest-ecosystem restoration defined	Lecture	Classroom	1
	pm	Costs and benefits of forest ecosystem restoration	Lecture	Classroom	2
	pm	Drivers of deforestation and incentives for forest ecosystem restoration	Guided discussion	Classroom	3
2	All Day	Rapid site assessment - determining degradation level	Hands-on field exercise	Deforested site	4
3	All Day	Reference forest survey - defining restoration targets - biomass and tree species (profile diagram)	Hands-on field exercise	Undisturbed forest	5
4	am	Tree species selection for forest ecosystem restoration - general principles	Lecture and class exercise	Classroom	6
	pm	Designing an effective restoration strategy	Classroom exercise	Classroom	7
5	All Day	Forest phenology and seed collection	Hands-on field exercise	Undisturbed forest	8
6	All Day	Tree nursery techniques - nursery design, seed germination/dormancy, growing planting stock, production scheduling	Hands-on field exercise	Tree nursery	9
7	All Day	Tree planting, maintenance and monitoring	Hands-on field exercise	Restoration site	10
8	All Day	Biodiversity monitoring - bird diversity	Hands-on field exercise	Restoration site	11
9	am	Data analysis - germination tests, tree survival and growth	Hands-on class exercise	Classroom	12
	pm	Data analysis - bird species richness	Hands-on class exercise	Classroom	13
10	am	Restoration planning logistics - timing, costing and labour	Lecture and class exercise	Classroom	14
	pm	Working with stakeholders Exam & course evaluation	Group discussion	Classroom	15

1.1 - Forest Loss and Ecological Succession Forest-Ecosystem Restoration Defined

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 1.1). From 2002 to 2021, Myanmar lost 666,000 ha of humid primary forest, with annual loss rates accelerating markedly with time (Figure 1.2). In the Kawthoolei region, figure 1.3 shows a dramatic increase in deforestation over the decade 2011-2021, compared with the previous decade 2001-2011.

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.

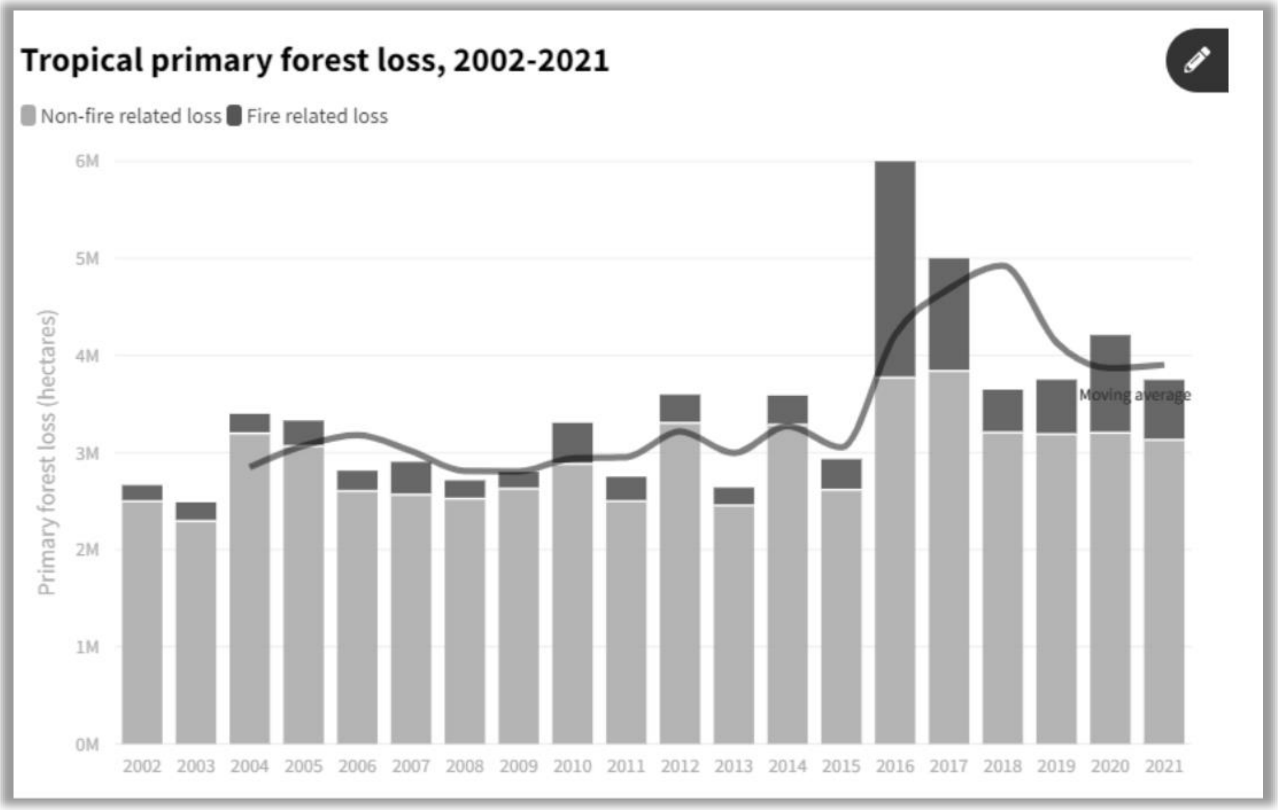
Ecological Succession

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. A climax forest is an ever-changing mosaic of differently sized tree-fall gaps, regenerating open patches and closed-canopy old growth, with species composition varying according to micro-habitat, disturbance history, seed dispersal limitations and chance events. 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.

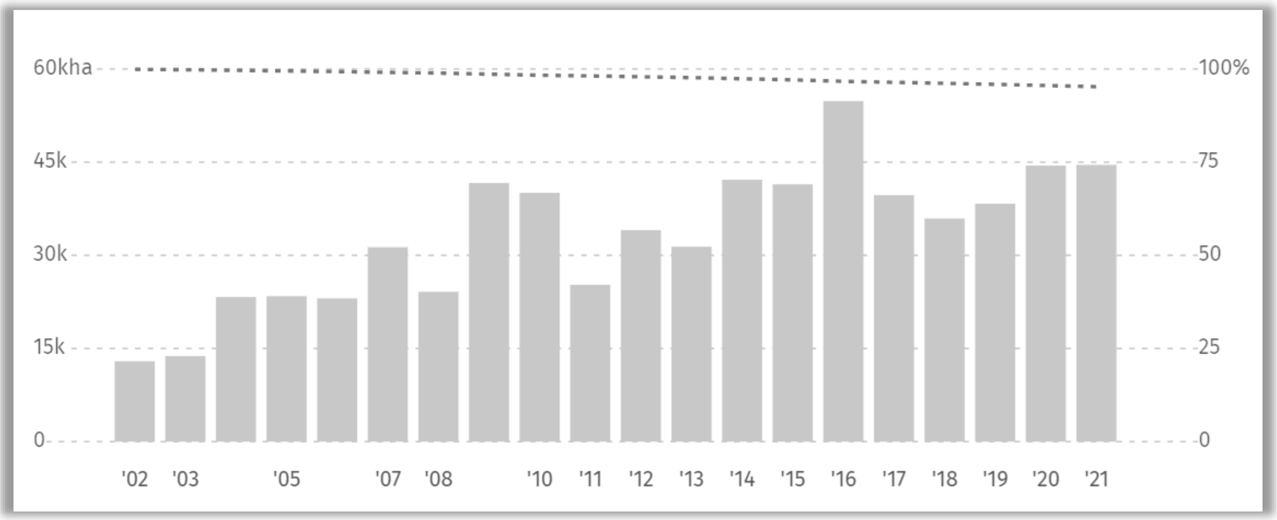
Figure 1.1.1—Annual loss of primary tropical forests globally
Figure 1.1.2—Annual loss of primary tropical forests in Myanmar

1.1.1



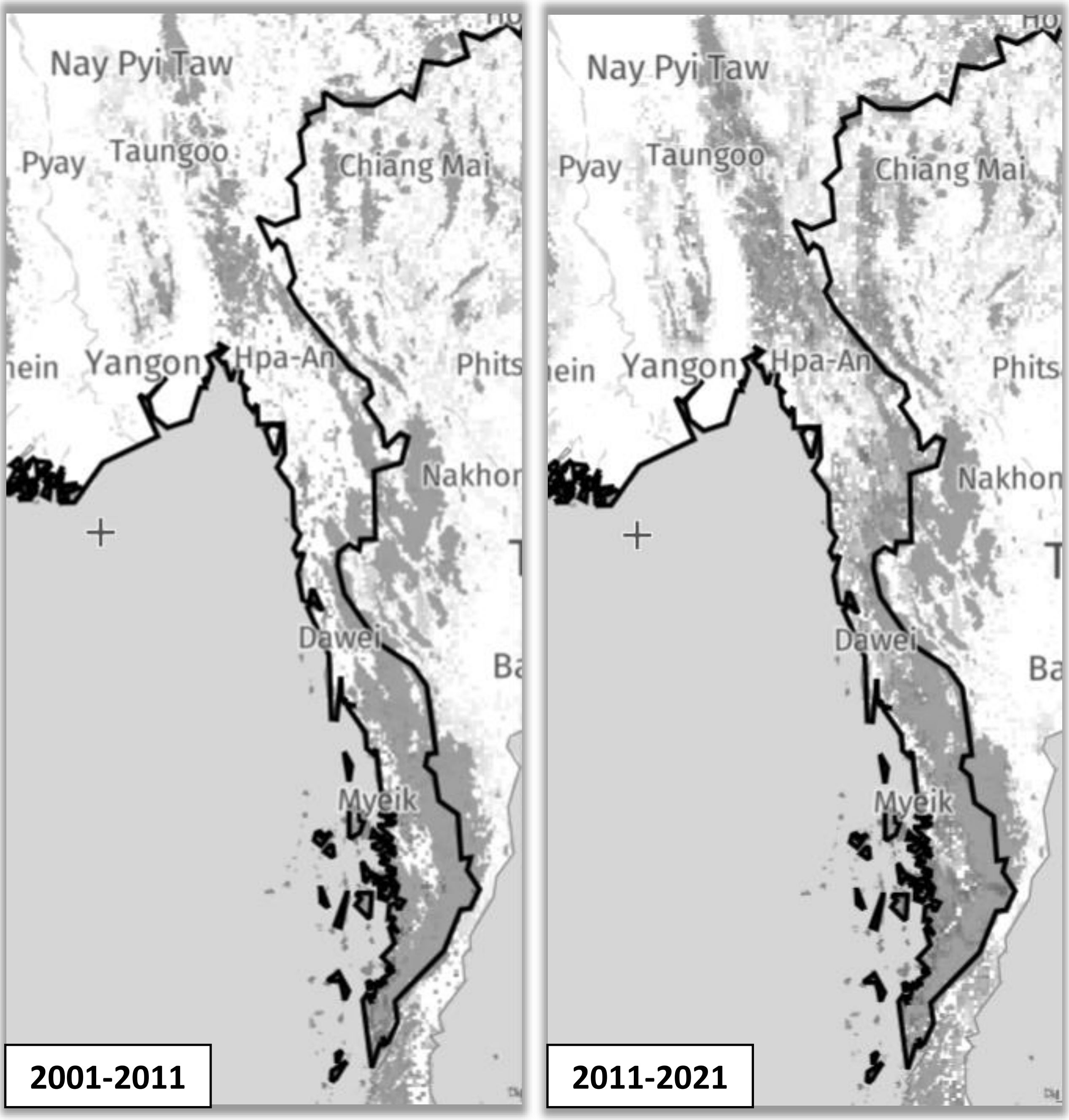
Tropical primary forest loss, 2002-2021
Non-fire related loss
Fire related loss
Primary forest loss (hectares)
6M
5M
4M
3M
2M
1M
0M
Moving average
2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021

1.1.2



60kha
45k
30k
15k
0
100%
75
50
25
0
'02 '03 '05 '07 '08 '10 '11 '12 '13 '14 '15 '16 '17 '18 '19 '20 '21

1.1.3


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

Seeds of pioneer trees can germinate only in full sunlight and their seedlings cannot grow in shade, whereas those of climax trees can germinate in shade and their seedlings are shade-tolerant. The seeds of pioneer trees can lie dormant in the soil, germinating when a gap is formed and light intensity increases. Once the forest canopy closes, however, no more seedlings of pioneer species can grow to maturity. Therefore, pioneer trees grow rapidly and usually produce large numbers of small fruits and seeds at a young age. These are dispersed over long distances by wind or small birds, thereby finding new disturbed areas to colonize. Climax tree species grow slowly, gradually consolidating their position in the forest before flowering and fruiting. They tend to produce large, animal-dispersed seeds with low (or no) capacity for dormancy and large food reserves that can sustain seedlings in shaded conditions. Hence, climax tree species can regenerate beneath their own shade, giving rise to the relatively stable species composition of climax forest. They may live for hundreds of years.

Dormant buds around the root collar of a tree stump can sprout spontaneously, often generating several new shoots. This is called coppicing. The presence of such “living dead” trees can accelerate canopy closure and enhance tree-species diversity in early successional forests. However most natural regeneration originates from incoming seeds.

When a forest is cut down, many seeds remain in the soil (the **seed bank**). However, seeds of the vast majority of tropical tree species are viable for only short periods. So, if a forest is cleared and the site is then burnt and cultivated for more than a year or so, most seeds from the original climax forest seed bank die, because they lack dormancy. Consequently, forest regeneration depends almost entirely on seeds being dispersed into deforested sites from surviving forest remnants—the **seed rain**.

The seed rain consists of all seeds falling on to any particular site, either blown there by the wind or deposited by animals. The seed rain is most dense and contains most tree species near to intact forest and is sparse in the centre of large deforested areas.

In seasonally dry climates, 40-50% of tree species are **wind**-dispersed in deciduous forest, whilst in evergreen forests about 20% of species are wind-dispersed. Wind-dispersed seeds tend to be small, light and have wings. Many wind-dispersed, tree species fruit at the end of the dry season, when mean maximum wind gust speeds are at their highest. Consequently, wind-dispersed tree species can colonize deforested sites up to 5–10 km from seed sources.

Most tropical tree species depend on **animals** for seed-dispersal. Dispersal of seeds from forest into deforested sites, therefore depends heavily on animal species that move between the two habitats. Unfortunately, few forest animals venture out into open areas for fear of exposing themselves to predators. Apart from birds and bats, few animals travel far between eating a fruit and depositing the seed. The maximum size of seeds that can be dispersed by an animal depends on the size of the animal’s mouth. Small seed-dispersing animals are still relatively common, but most of the larger ones have become extirpated,

Figure 1.1.3—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.

e.g., elephants, rhinos, wild cattle etc. Because birds and bats can fly, they can disperse seeds over long distances. The most important dispersers of seed from forest to deforested sites are therefore bulbuls, barbets, pigeons, fruit bats, wild pigs, monkeys, deer, civets and badgers (FORRU, 2005).

Seed predation is the destruction of a seed's potential to germinate, when an animal crushes or digests its embryo. It can seriously limit natural forest regeneration. Seed predation levels vary enormously depending on tree species, vegetation, location, season and so on, but levels usually decline as canopy closure is achieved. Small rodents and insects, particularly ants, are the most abundant seed predators, capable of affecting forest regeneration.

Seed **dormancy** is the length of time, during which a mature seed fails to germinate under favourable conditions. It enables seeds to be dispersed at the optimal time, survive the rigors of dispersal (such as being swallowed by an animal) and then germinate when conditions are favourable for seedling establishment. Dormancy is more frequent among deciduous trees than evergreen ones. Physical dormancy (caused by impermeable seed coverings that restrict moisture absorption and gaseous exchange) is most prevalent among deciduous and savanna forest tree species.

The transition from seed to seedling is a dangerous time in a tree's life. **Germination** occurs when water and oxygen penetrate the embryo and trigger emergence of an embryonic root (radicle) and shoot (plumule). Because of small size, low energy reserves and low photosynthetic capability, seedlings are vulnerable to changes in environmental conditions, competition from other plants and attack by herbivores. In deforested sites, temperatures fluctuate dramatically between night and day. Humidity is lower, wind speeds are higher and soil conditions are much harsher than those in a forest. Therefore, germination of many forest tree species depends on the presence of so-called '**germination micro-sites**', where weed cover is reduced and there is sufficient soil moisture to induce seed germination. They include decaying termite mounds, moss-covered rocks and rotting logs.

In the seasonal tropics, the optimal time for tree seed germination is shortly after the start of the rainy season. Seedlings, establishing during this period, have the full length of the rainy season to build up energy reserves and grow their roots deep into the soil, enabling them to access enough moisture to resist the desiccating heat of their first dry season.

After germination, the greatest threats to seedling survival are competition with **weeds**, **seedling predators** and **fire**.

The **weeds** that are most capable of suppressing forest regeneration are nearly always invasive, exotic species mostly from South America. They tend to be rapidly growing perennials that flower and fruit at a very young age, produce very large numbers of dormant seeds (or spores), are resilient after burning and produce allelo-chemicals that inhibit other plant species. The most important groups are grasses (e.g., *Imperata*, *Pennisetum*, *Andropogon*, *Panicum*, *Phragmites*, *Saccharum*, etc.) bracken fern, vines (*Mikania micrantha*), herb/shrubs (*Eupatorium* species), thorny shrubs (*Lantana camara, Mimosa pigra*), and shrub/trees (e.g., *Leucaena leucocephala*).

Cattle are the most destructive **predators of tree seedlings and saplings**. They can be very selective, often eating the foliage of palatable tree species whilst ignoring that of unpalatable ones. Dominance of distasteful or thorny trees in regenerating forest is therefore a sign that too many cattle present. In contrast, cattle can help to control weed growth, thus reducing the fire-fuel load and releasing tree seedlings from competition. They may also replace extirpated large wild ungulates as dispersers of large seeds into deforested site. Cattle hoof prints can become germination microsites. Further research is needed on the balance between the positive and negative effects of cattle on forest succession.

Fires are a major constraint to forest regeneration, particularly in the seasonally dry tropics. Infrequent, low-intensity fires may slow succession and alter the composition and structure of regenerating vegetation, but frequent burns can completely prevent it, leading to the persistence of grasslands where forests would otherwise grow. Dried vegetation (particularly grasses) provides the main fuel for fires in the hot season. Each time it burns, tree seedlings established amongst the weeds are killed, whereas the weeds and grasses rapidly regrow. Thus, weedy vegetation creates conditions for fire and in doing so prevents the establishment of trees that could shade out the weeds. Breaking this cycle is a vital component of forest restoration in seasonally dry areas.

These days, most fires are started by humans to clear land for cultivation. They are also started to stimulate the growth of grasses for livestock and to attract wild animals for hunting. In addition to causing ecological damage, fires are a major health hazard. Smoke pollution causes respiratory, cardiovascular and eye problems in hundreds of thousands of people every year.

Human-caused fires are increasing throughout the tropics, both in frequency and intensity. The underlying cause is a growing human population that requires clearance of ever more agricultural land. This results in the fragmentation of forest areas, which exposes more forest edge into which fires can spread from surrounding areas. Within forests fragments, degradation creates more fire-prone conditions by opening up the forest canopy. This allows light-loving and highly flammable grasses and other weeds to invade and dead wood to accumulate. Furthermore, global climate change is resulting in hotter, drier conditions that favour fire in many tropical regions, particularly in the dry season.

Frequent fires reduce both the density and species richness of the tree seedling and sapling communities. Burning reduces the seed rain (by killing seed-producing trees) and the accumulation of viable seeds in the soil seed bank. It favours the establishment of wind-borne, light-demanding pioneer tree species at the expense of shade-tolerant climax species. Direct exposure to fire kills seeds of the vast majority of tropical tree species or significantly reduces their germination. 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 tree seed germination). It also reduces soil nutrients. Calcium, potassium and magnesium are lost as fine particles in smoke, while nitrogen, phosphorus and sulphur are lost as gases. By destroying vegetation cover, fire increases soil erosion. It also kills beneficial soil micro-organisms, especially mycorrhizal fungi and microbes that break down dead organic matter and recycle nutrients.

Is forest ecosystem restoration necessary?

Some people take the view that deforested sites should be left to recover naturally and that forest restoration is “unnecessary interference with nature”. This view fails to recognize that humans have not merely destroyed the forest; we have also destroyed the natural mechanisms of forest regeneration. All of the barriers to forest regeneration, described above, are caused by humans. Forest restoration is merely an attempt to remove or overcome these “unnatural” barriers to forest regeneration.

Definition of forest-ecosystem restoration

Forest ecosystem restoration is therefore defined as:

> *“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.

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 ecological conditions to those of the reference forest. The definition lists the four most important criteria by which restoration success is judged.

Firstly, **biomass** should return to levels similar to those the reference forest. Since just under half of forest biomass is carbon, this is a particularly important where carbon credits are used to finance restoration. As biomass accumulates, it can be partitioned among more different kinds of structure: tree trunks, branches, roots and leaves of different sizes and shapes, climbers, epiphytes etc., resulting in **structural diversity**.

Development of structural diversity leads to habitat diversity, as various different structures provide opportunities for various different plant and animal species to fill their niche requirements. Thus, structural diversity leads to **biodiversity**. As an increasing diversity of plant and animal species interact with each other, essential **ecological functions,** necessary to self-sustain forest dynamics are performed. Animals pollinate flowers and disperse seeds, whilst micro-organisms form the essential symbiotic partnerships necessary to increase survival and growth of tree seedlings; nutrient cycles are re-established etc.

Although restoration aims to maximize these four interrelated indicators of ecological recovery, the amount by which they can be increased is limited by soil and climate. For example, forests in dry areas accumulate far less biomass than those in wetter areas. So, the last part of the definition "… *self-sustained within prevailing climatic and soil limitations" …* is important, in that it allows restoration goals to be adjusted in response to changes in climate and soil.

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

1.2 - Costs and Benefits of Forest-Ecosystem Restoration

Costs

Costs include time and money. Stakeholders must sacrifice time that could be spent on agriculture, for meetings to plan and manage restoration including. Financial costs can include legal/admin fees, survey costs and costs of tree production, planting, maintenance and monitoring. Another cost is income forgone from *not* converting forest to agricultural land. Implementation costs depend on site conditions and local labour rates.

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 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.

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

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.

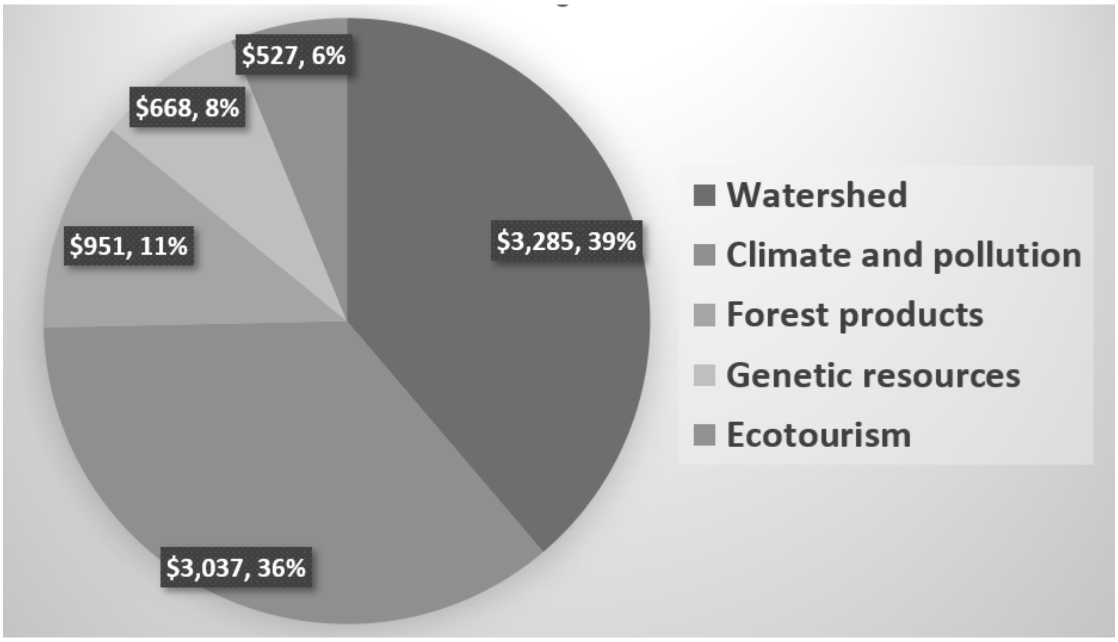
Reading

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 1.2.1 *– 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 1.2.2 *– Potential values of forest restoration are all based on two restoration goals – rapid recovery of both biomass and biosiversity.*



1.2.1

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

1.3 - DRIVERS OF DEFORESTATION AND INCENTIVES FOR FOREST RESTORATION (GUIDED DISCUSSION)

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.

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.

2. - Rapid Site Assessment - Degradation Level (Notes For Field Trip)

Five levels of forest degradation are distinguished, according to the intensity of the methods needed restore them to the climax forest condition – from stage-1 being the least severe, requiring minimal intervention to stage-5 being the most severe, requiring most intensive restoration measures. Adjacent stages of degradation are separated by tipping points, 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 typical of the reference forest. Since higher levels of degradation require more intensive interventions, the restoration costs increase along with the original degradation level of the restoration site. 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 the extent of 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 2.1 - Summary overview of the five levels of forest degradation and the tipping points between them
Online resource : https://www.forru.org/advice/forest-degradation

Stage-1 Degradation (Table 2.1, Figure 2.2)

Table 2.1 – 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

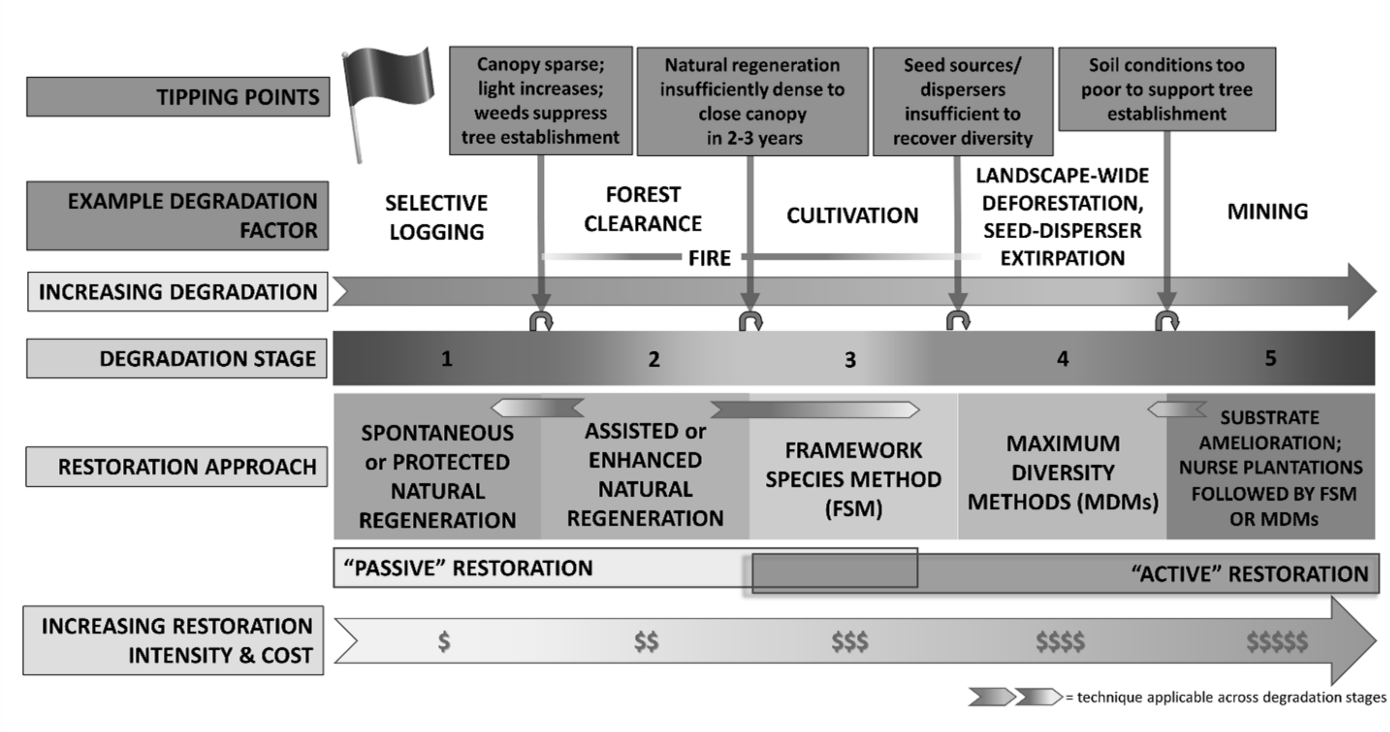
RECOMMENDED RESTORATION STRATEGY:

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

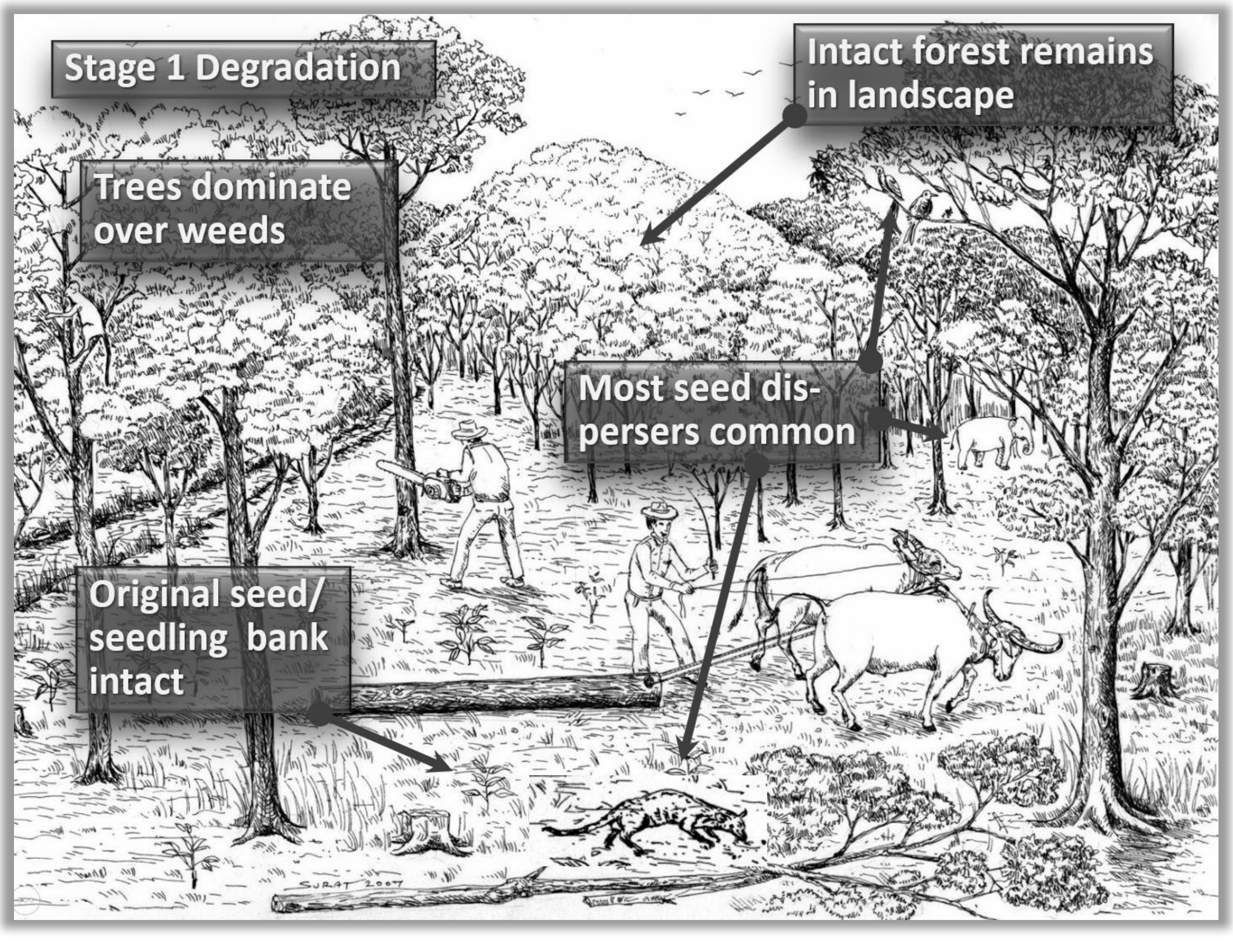
OPTIONS TO INCREASE ECONOMIC BENEFITS:

- Extractive reserves for sustainable use of forest products
- Ecotourism

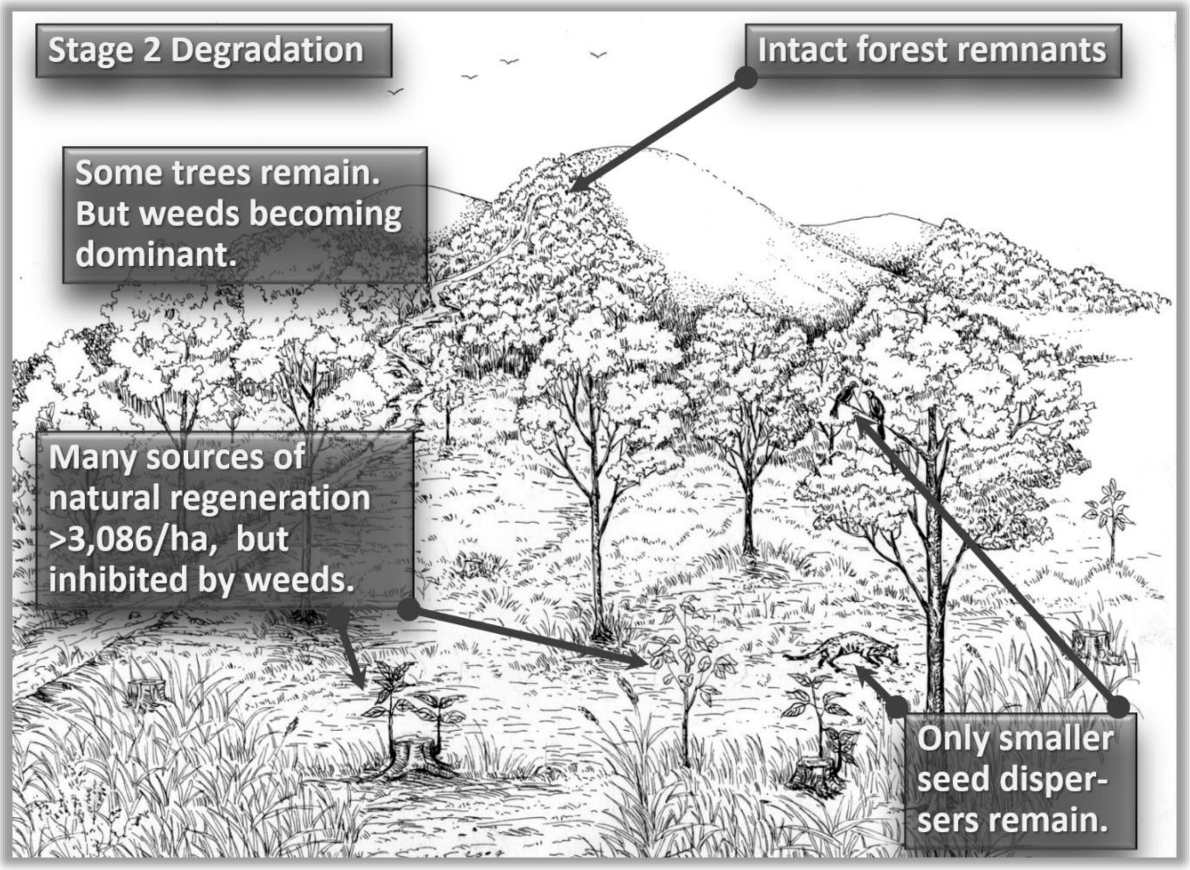
2.1


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
FIRE
CULTIVATION
LANDSCAPE-WIDE DEFORESTATION, SEED-DISPERSER EXTIRPATION
MINING
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

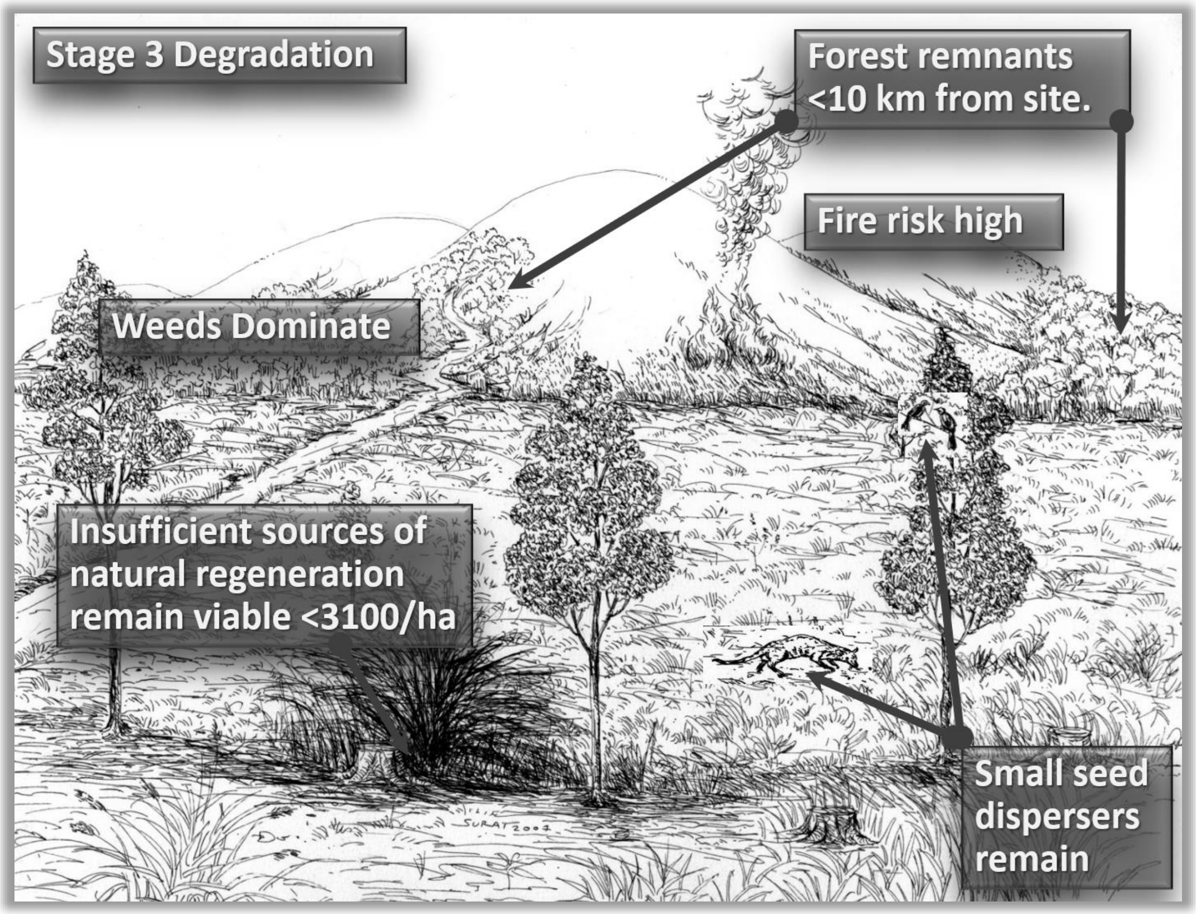
2.2


Stage 1 Degradation
Intact forest remains in landscape
Trees dominate over weeds
Most seed dis- persers common
Original seed/ seedling bank intact

2.3


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 dispers-sers remain.

2.4


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

Stage 2 degradation (Table 2.2, Figure 2.3)

Table 2.2 – 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			

Stage-3 Degradation (Table 2.3, Figure 2.4)

Table 2.3 – 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[2] or "Rainforestation" farming[3]			

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

Stage-4 Degradation (Table 2.4, Figure 2.5)

Table 2.4 – 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

Stage-5 Degradation (Table 2.5, Figure 2.6)

Table 2.5 – 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

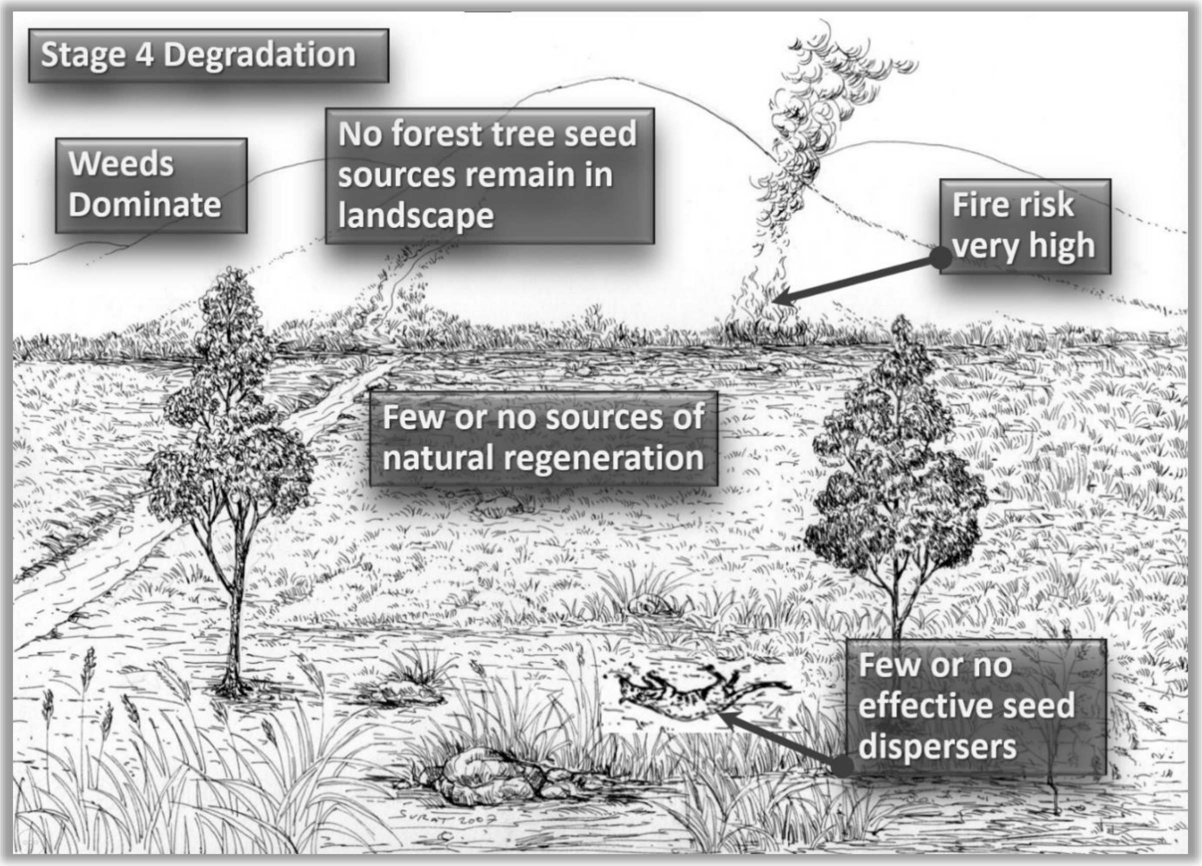
RECOMMENDED RESTORATION STRATEGY:

- 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

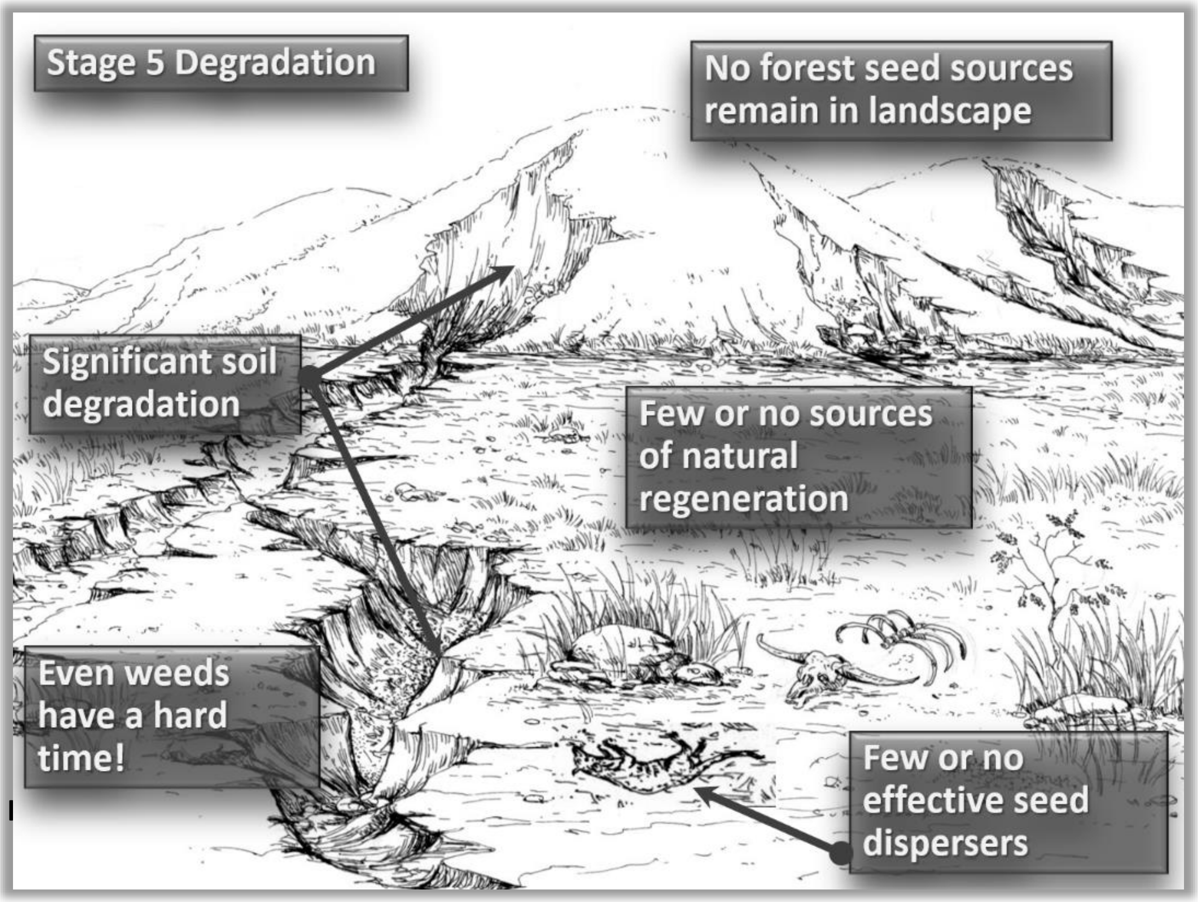
OPTIONS TO INCREASE ECONOMIC BENEFITS:

- 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

2.5


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

2.6


Stage 5 Degradation
No forest seed sources remain in landscape
Significant soil degradation
Few or no sources of natural regeneration
Even weeds have a hard time!
Few or no effective seed dispersers

A rapid site assessment determines existing potential for natural forest regeneration and identifies factors that may limit it. This helps to determine which restores activities 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, bite marks on vegetation 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);
- gross 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, which include: 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 (with green shoots).

Place leaf samples from each of the tree species you find into plastic bags. Finally take photos, looking due north, south, east and west from the centre pole – this is baseline photo monitoring.

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. Once you have decided on a compass bearing for the transect heading and a distance between sample points for each line, stick strictly to these parameters. 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.

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								
2								
3								
4								
5								
6								
7								
8								
9								
10								

Location, GPS				**Total**	
Recorder			*(= total/10)*	**Mean**	
Date			*(= 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:

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.

3. - REFERENCE FOREST

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).

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).

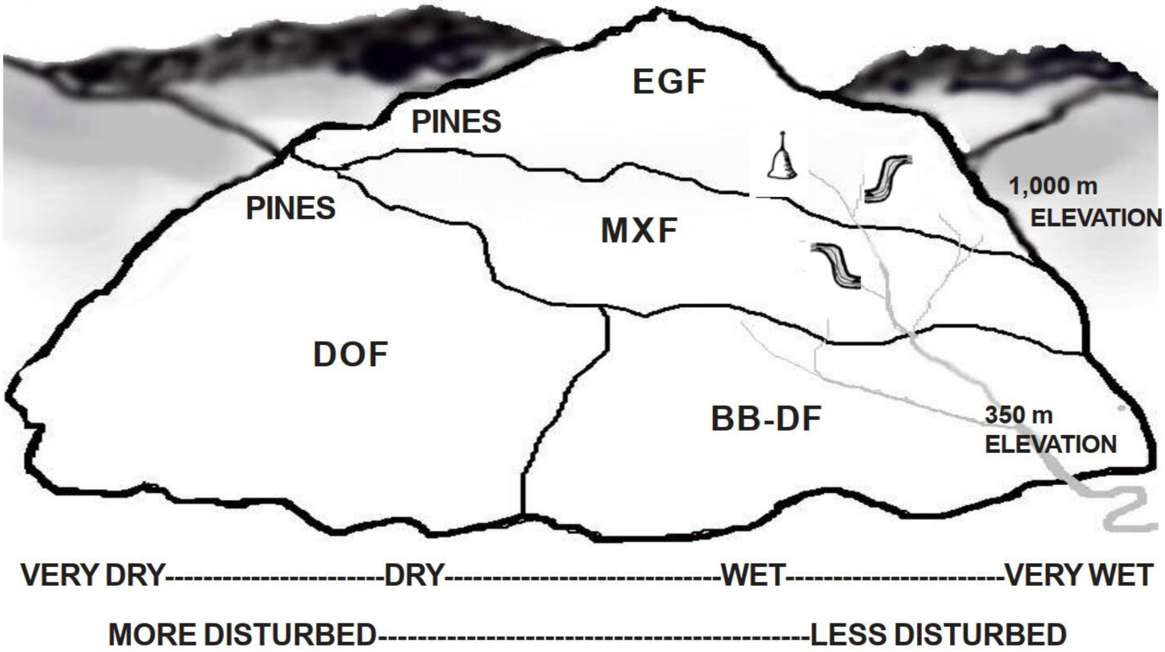
Figure 3.1 - Diagramatic representation of the distribution of main forest types on a typical mountain EGF= Evergreen Forest; MXF = Mixed Evergreen-Deciduous Forest; BB-DF = Bamboo-Deciduous Forest (former Teak Forest); DOF = Deciduous Dipterocarp-Oak Forest

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 *Dendrocalamus* 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.

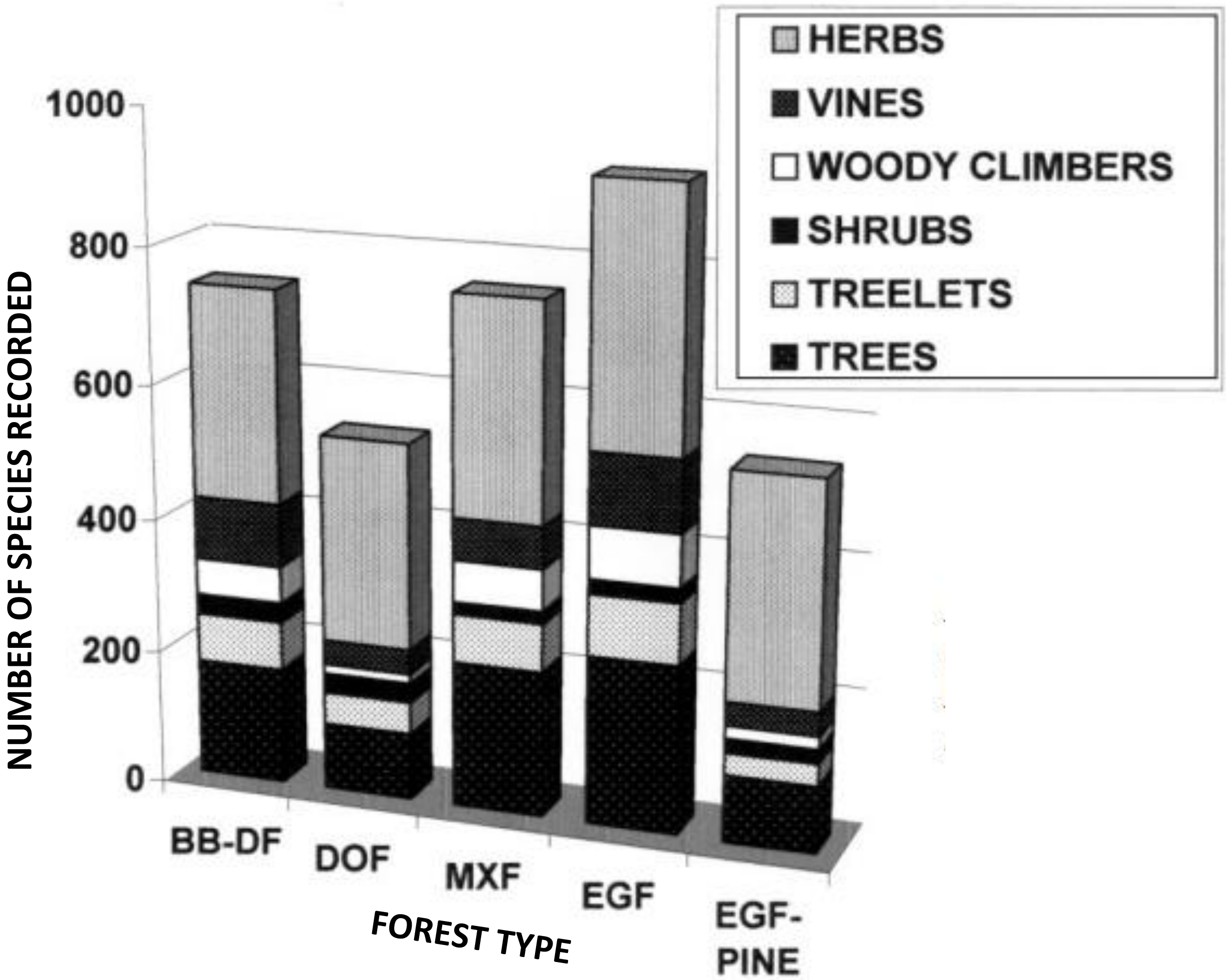
Figure 3.2 - Plant species richness in each forest type for Doi Suthep-Pui National Park (northern Thailand) by plant habit.

3.1



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

3.2



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

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 *Dendrocalamus* 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.

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.

Things to do when assessing your reference forest

- Make a list of all the different tree species recognized during a visit to the reference forest type
- Lay out circular sample plots as described in module 2. Measure the GBH of trees within the plots for which GBH is greater than 20 cm
- Ask local people what wildlife species have been seen in the area, particularly seed-dispersing animals.

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

4.1 - Tree Species Selection for Forest Ecosystem Restoration - General Principles

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 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 stud. 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							

4.2 - DESIGNING AN EFFECTIVE RESTORATION STRATEGY

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[4] 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[1] 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>

[4] *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[5], 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

[5] 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 section 5.3. 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[6], with fewer than 3 tree species[7] 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

[6] Average spacing between regenerants > 6-7 m.
[7] 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. This is known as the “plantations as catalysts” or “foster ecosystem” approach (Parrotta, 2000).

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.

Homework – Write a restoration plan

At this stage trainees should be ready to compose a concise plan listing objective and techniques and tasks required to restore a forest similar to the reference forest ecosystem, 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 of events showing when each task will be performed and who is responsible for each action.
- Budget
- Appendices – results of the rapid site assessment, results of reference forest survey

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

5. - FOREST PHENOLOGY AND SEED COLLECTION

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.

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.

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.

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 will give you some idea of the 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.

Figure 5.1 *- Phenology record sheet.*
Figure 5.2 *– Examples of scoring reporductive phenology: flwoers fruits etc. Total score should not exceed 4 but can be less than four*
Figure 5.3 *– Examples of leafing phenology scores. The total score should always add up to 4.*
Figure 5.4 *– Typical species phenological profile showing that the best time to collect fruits and seeds is in Novembe, that this species is only very marginally deciduous and that flowering co-incides with leaf fall at thee and of the dry season.*

5.1

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 PANICUL/	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]2.1	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

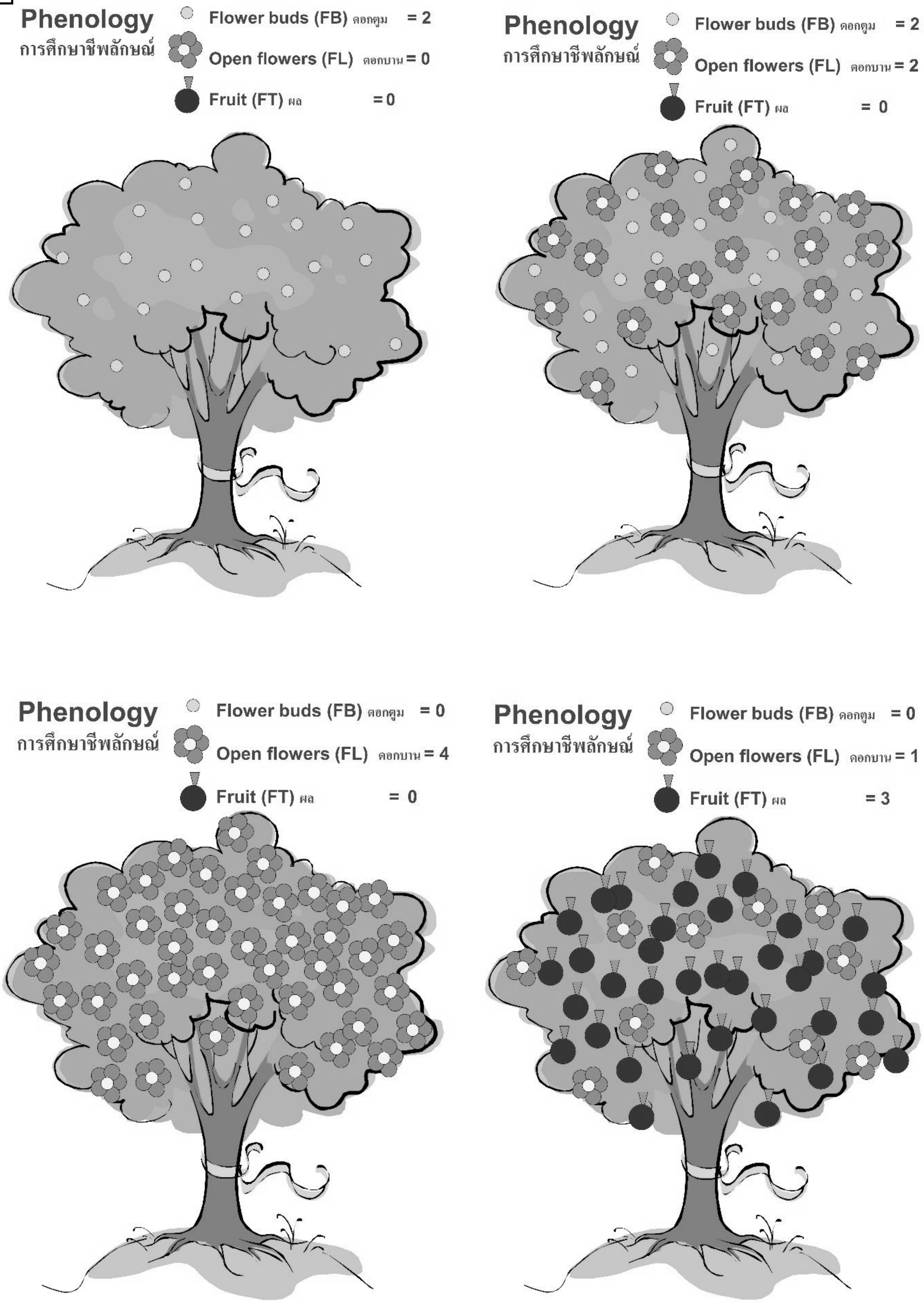
YL = young leaves

ML = mature leaves

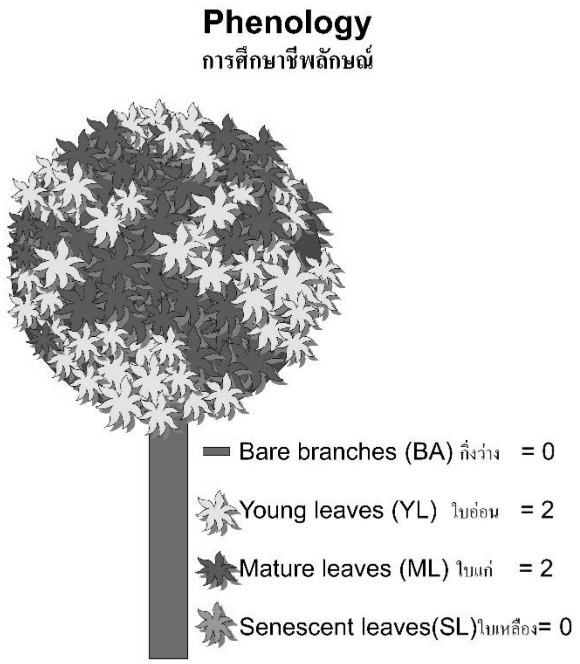
SL = senescent leaves

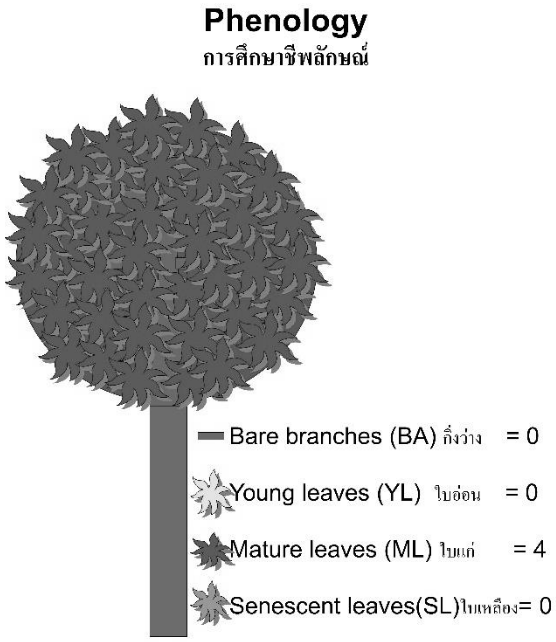
The sum of these scores should always equal 4

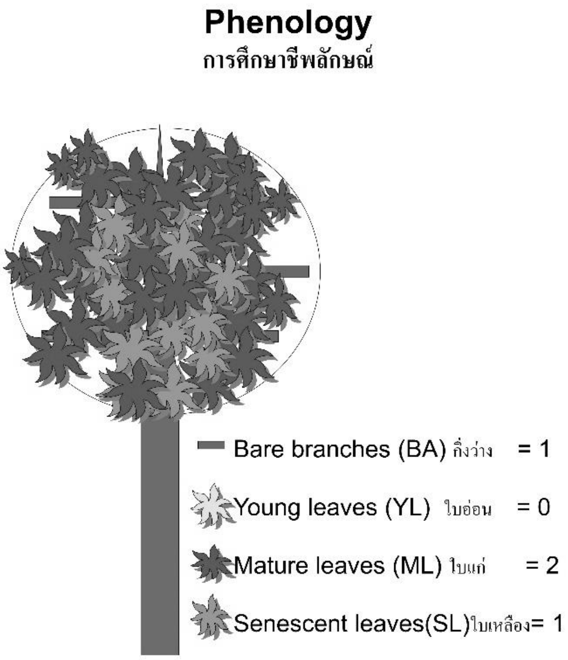
5.2

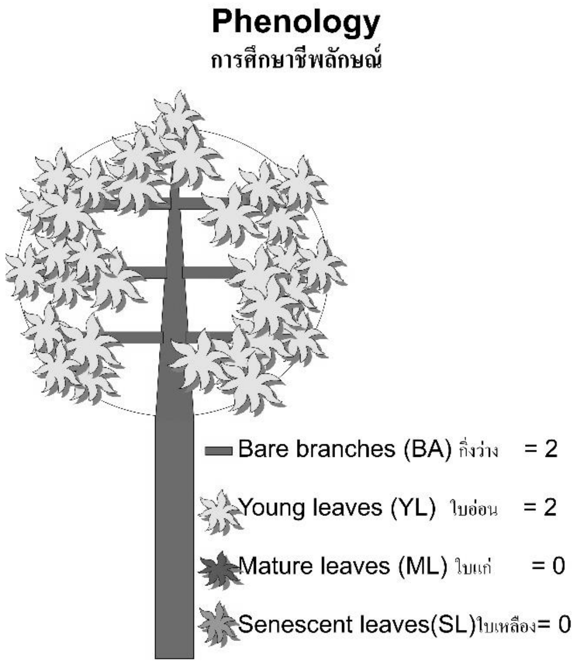

Phenology
การศึกษาชีพลักษณ์
Flower buds (FB) ดอกตูม = 2
Open flowers (FL) ดอกบาน = 0
Fruit (FT) ผล = 0
Phenology
การศึกษาชีพลักษณ์
Flower buds (FB) ดอกตูม = 2
Open flowers (FL) ดอกบาน = 2
Fruit (FT) ผล = 0
Phenology
การศึกษาชีพลักษณ์
Flower buds (FB) ดอกตูม = 0
Open flowers (FL) ดอกบาน = 4
Fruit (FT) ผล = 0
Phenology
การศึกษาชีพลักษณ์
Flower buds (FB) ดอกตูม = 0
Open flowers (FL) ดอกบาน = 1
Fruit (FT) ผล = 3

5.3


Phenology
การศึกษาชีพลักษณ์
Bare branches (BA) กิ่งว่าง = 0
Young leaves (YL) ใบอ่อน = 2
Mature leaves (ML) ใบแก่ = 2
Senescent leaves(SL)ใบเหลือง= 0

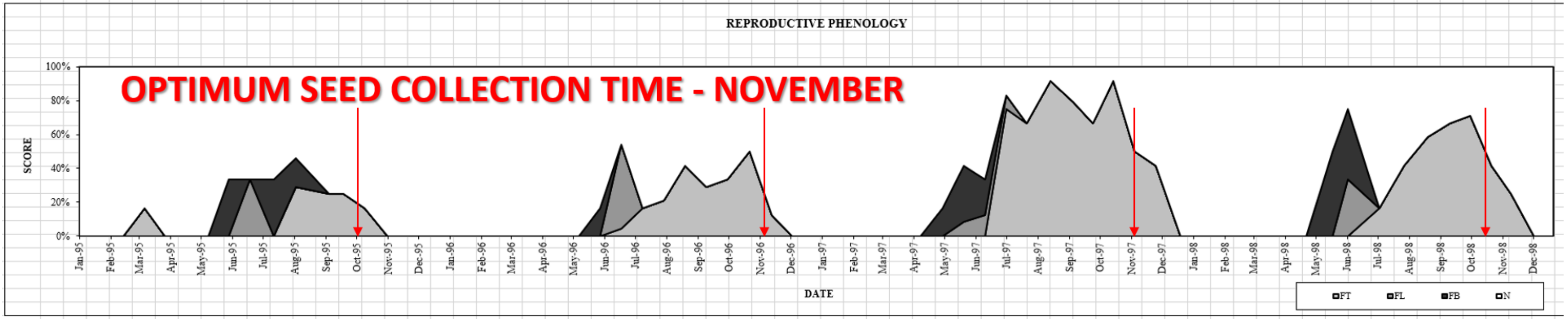

Phenology
การศึกษาชีพลักษณ์
Bare branches (BA) กิ่งว่าง = 0
Young leaves (YL) ใบอ่อน = 0
Mature leaves (ML) ใบแก่ = 4
Senescent leaves(SL)ใบเหลือง= 0

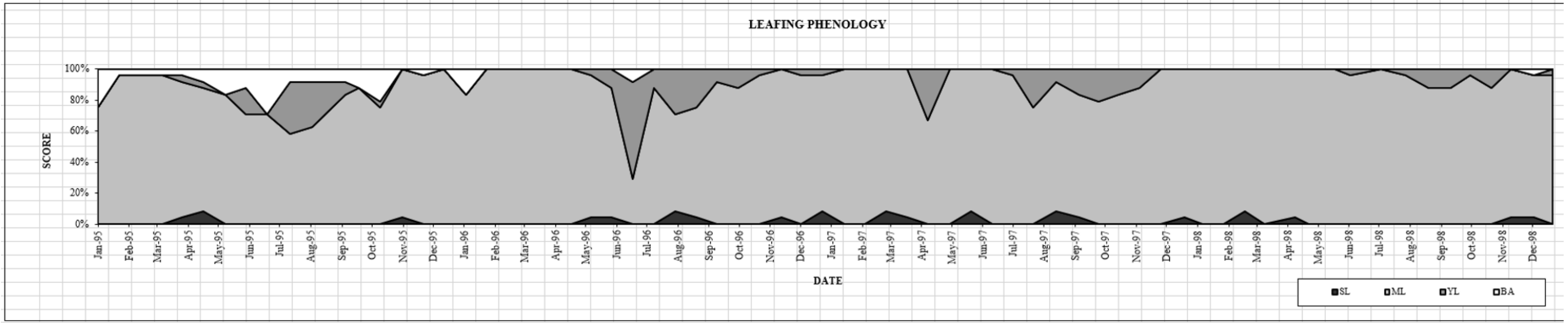

Phenology
การศึกษาชีพลักษณ์
Bare branches (BA) กิ่งว่าง = 1
Young leaves (YL) ใบอ่อน = 0
Mature leaves (ML) ใบแก่ = 2
Senescent leaves(SL)ใบเหลือง= 1


Phenology
การศึกษาชีพลักษณ์
Bare branches (BA) กิ่งว่าง = 2
Young leaves (YL) ใบอ่อน = 2
Mature leaves (ML) ใบแก่ = 0
Senescent leaves(SL)ใบเหลือง= 0

5.4

Species (*Styrax benzoides*) – Phenology Profile





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.

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 or sometimes it is the pyrene. Pyrenes consist of one or several seeds enclosed within the hard, inner wall of the fruit (endocarp). The pyrene wall can delay water penetrating the seed embryo.

When should seeds be collected?

In all tropical forests, different tree species fruit in every month of the year, so at least one seed collection trip is needed every month. In seasonally dry tropical forests, fruiting peaks at the end of the dry season and at the end of the rainy season, whereas reduced numbers of fruiting tree species in the early rainy season means that fewer seed collection trips are needed then. Collect fruits once they are fully ripe, but just before they are dispersed or consumed by animals. Seeds collected too early will be undeveloped and fail to germinate, whereas those collected too late may have lost viability. For fleshy fruits, ripeness is usually indicated by a change in the colour of the fruit, usually from green to a brighter colour, to attract seed-dispersing animals. If animals are seen eating the fruits, it is a sure sign that the seeds are ready for collection. For dehiscent fruits such as some legumes, ripeness occurs when they start to split open. It is usually better to cut fruits from the tree branches rather than to pick them up from the ground.

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.

Where should seeds be collected and from how many trees?

Genetic variability is essential to enable species to survive in changeable environments. The best way to maintain it is to collect seeds from at least 25 to 50 trees. Mix equal numbers of seeds from each tree.

How many seeds should be collected?

The number of seeds collected depends on the number of trees required, seed germination percentage and seedling survival rates. Keep accurate records to determine the numbers required in future collections.

What precautions should be taken when collecting seeds?

Sow seeds as soon as possible after collection. Do not leave them in sun, where they may dry out nor in damp places, where they may rot or germinate prematurely.

What information should be recorded when collecting seeds?

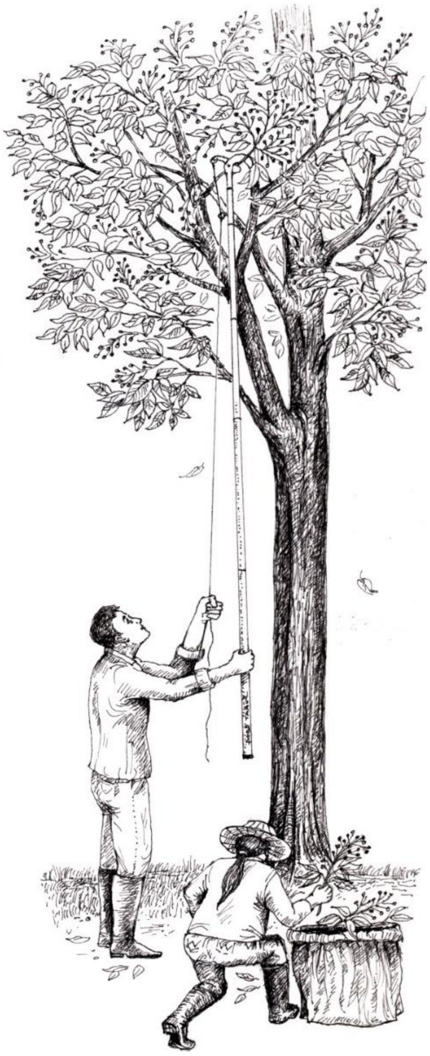
Each time you collect seeds from a new species, give that species a unique species number. Nail a numbered, metal tag on to the tree, so that you can find it again. Collect a specimen of leaves and fruits for species identification. Place the specimen in a plant press, dry it and ask a botanist to identify the species. Use a pencil to write the species name (if known), date and species number on a label and place the label inside the bag with the seeds. Record essential details about the seed batches collected and what happens to them from collection time until they are sown in germination trays. This information will help to determine why some seed batches germinate well, whilst others fail and thus improve seed collection methods in the future.

Figure 5.5 – *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.*

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



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:

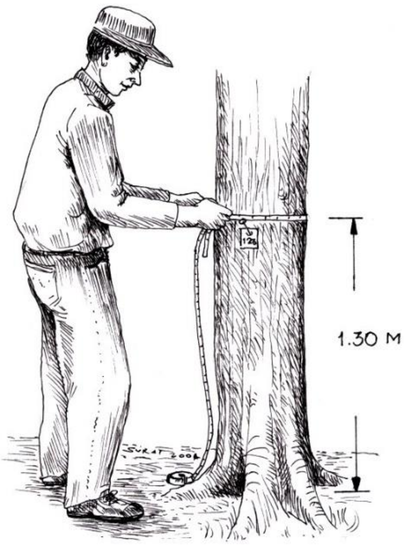
Approximate no. seeds collected:

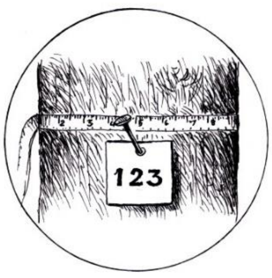
Storage/transport details:

Pre-sowing treatment: Sowing date:

Voucher specimen collected [ ]

Notes for herbarium label





6. - Tree Nursery Techniques

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.

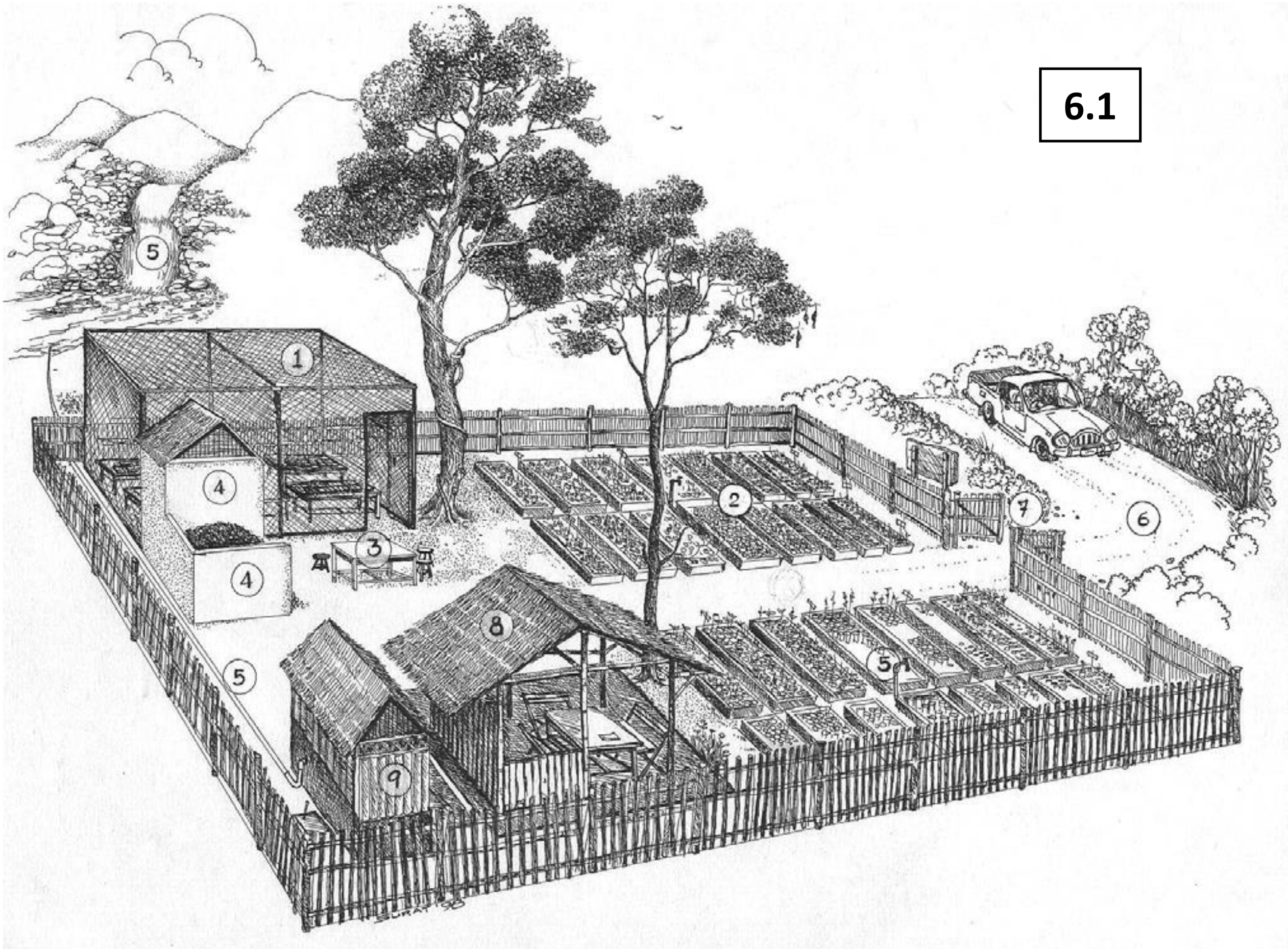
Area to be restored (ha/yr)	***Maximum Number of trees needed[1]***	***Seed germination area (sq m)***	***Standing-down area (sq m)***	***Storage, shelter, toilet etc. (m^2)***	***Total nursery area needed (m^2)***
0.25	775	3	11	15	29
0.5	1,550	6	22	15	43
1	3,100	13	44	15	72
5	15,500	63	220	15	298
10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

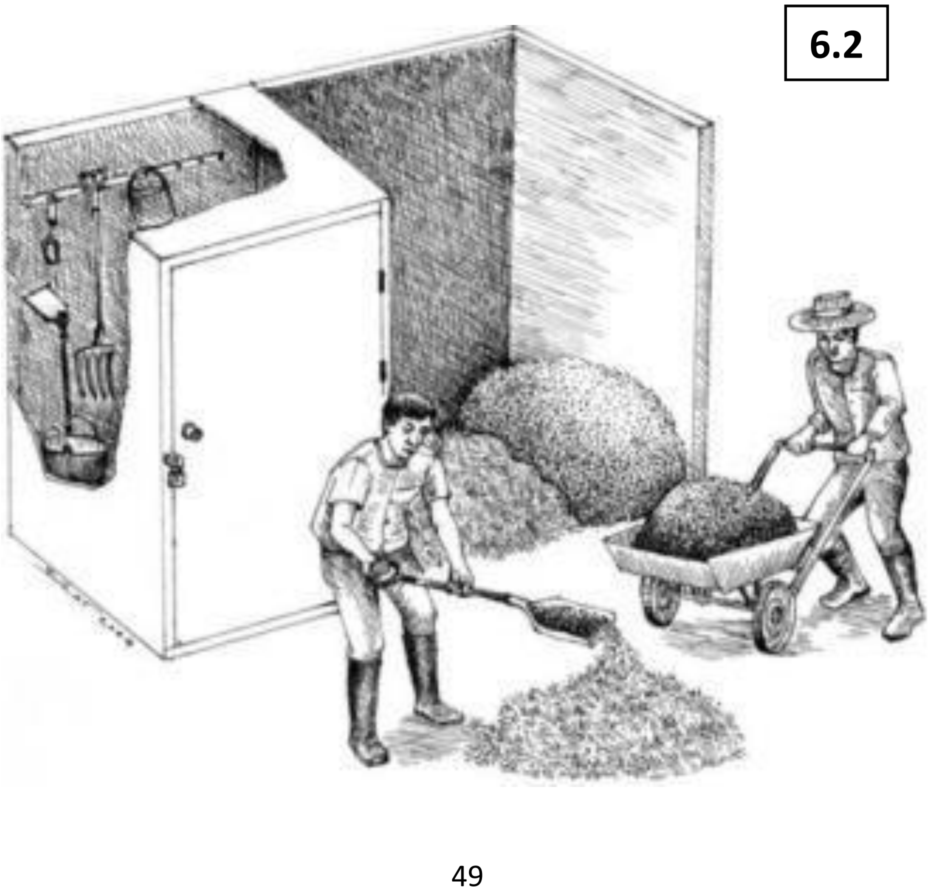
- a shaded area with benches for seed germination, protected from seed predators by wire mesh; shade may be provided by commercial materials, but alternatives include palm leaves, coarse grasses and bamboo slats,
- a shaded area where potted seedlings can be grown until ready for planting (shade should 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 6.1 *- 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 6.2 - *A lockable store, to keep equipment safe, and a media store are essential parts of a tree nursery.*

6.1



6.2



6.3

Growing trees requires simple, inexpensive equipment. Many of the items illustrated in **Figure 6.3** 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 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 organic matter, to improve drainage and aeration. Materials 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)

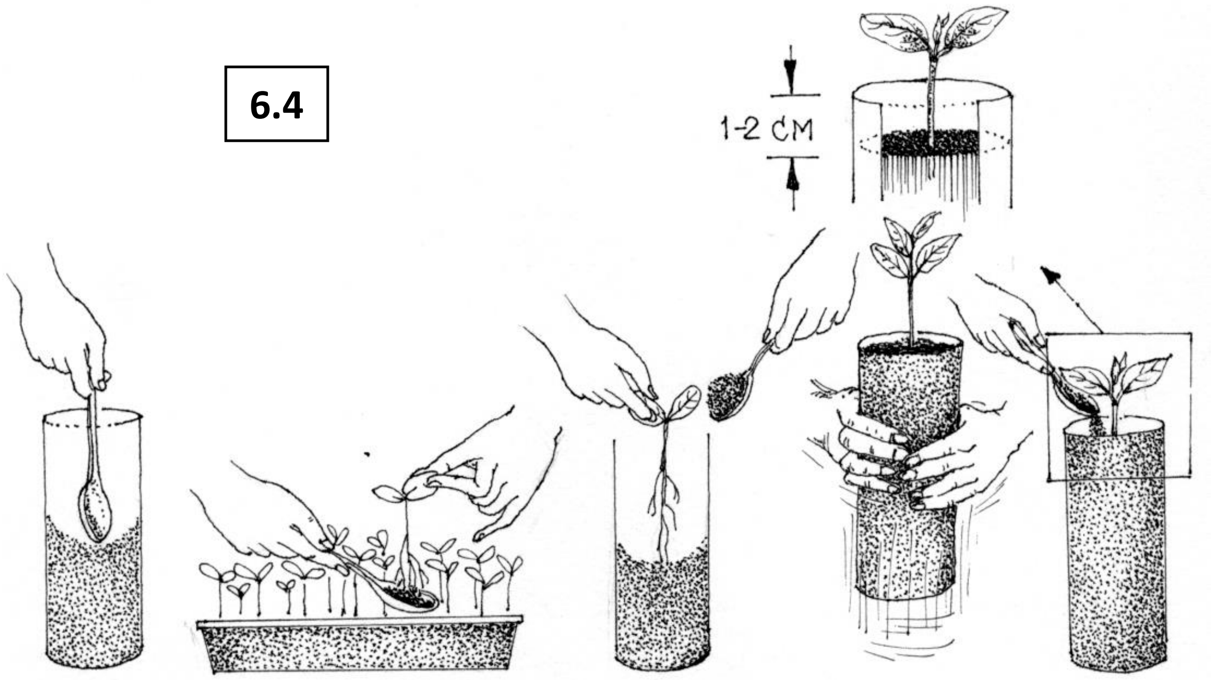
Fill containers with moist medium. Bang each container on the ground a few times to settle the medium. Then, top up containers with more medium until they are full again. With plastic bags, check for consistency by firmly grasping the bag. The impression of your hand should remain after you let go and the bags should stand up straight, unsupported. Seedlings are ready for pricking out, 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 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 (root-shoot junction) is at the medium surface. Press the medium to make sure the plant is upright and centrally placed.

Figure 6.4 - *Steps of pricking out*
Figure 6.5 - *Problems with potting (left to right from the top): 1. Medium has settled; rim of plastic bag collapses, blocking watering; 2. Curled roots will make the adult tree susceptible to wind throw; 3. Seedling not placed centrally; 4. Medium too soft; 5. Medium compacted; 6. Excellent medium consistency 7. The perfectly potted seedling!*

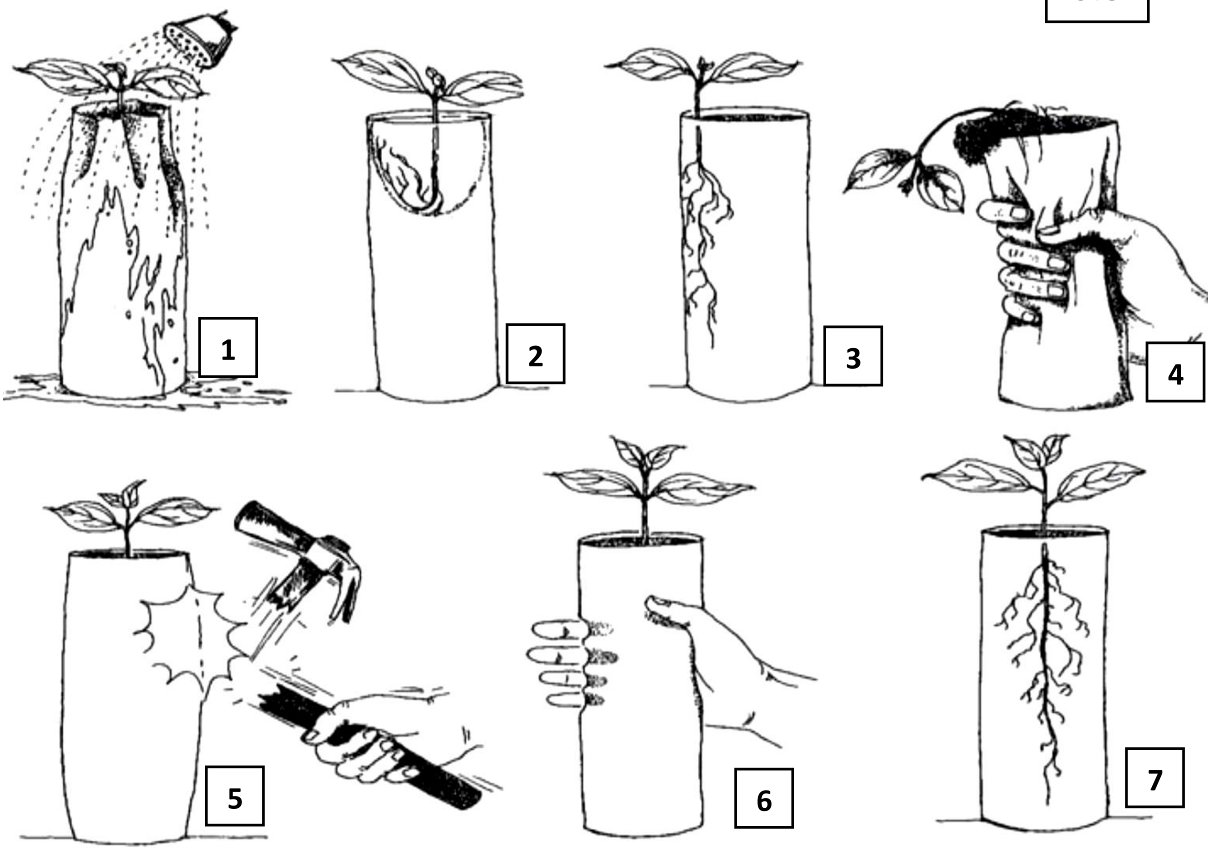
Caring for Seedlings in Nurseries

"**Standing-down**" is the time 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 for planting, 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.

6.4



6.5



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.

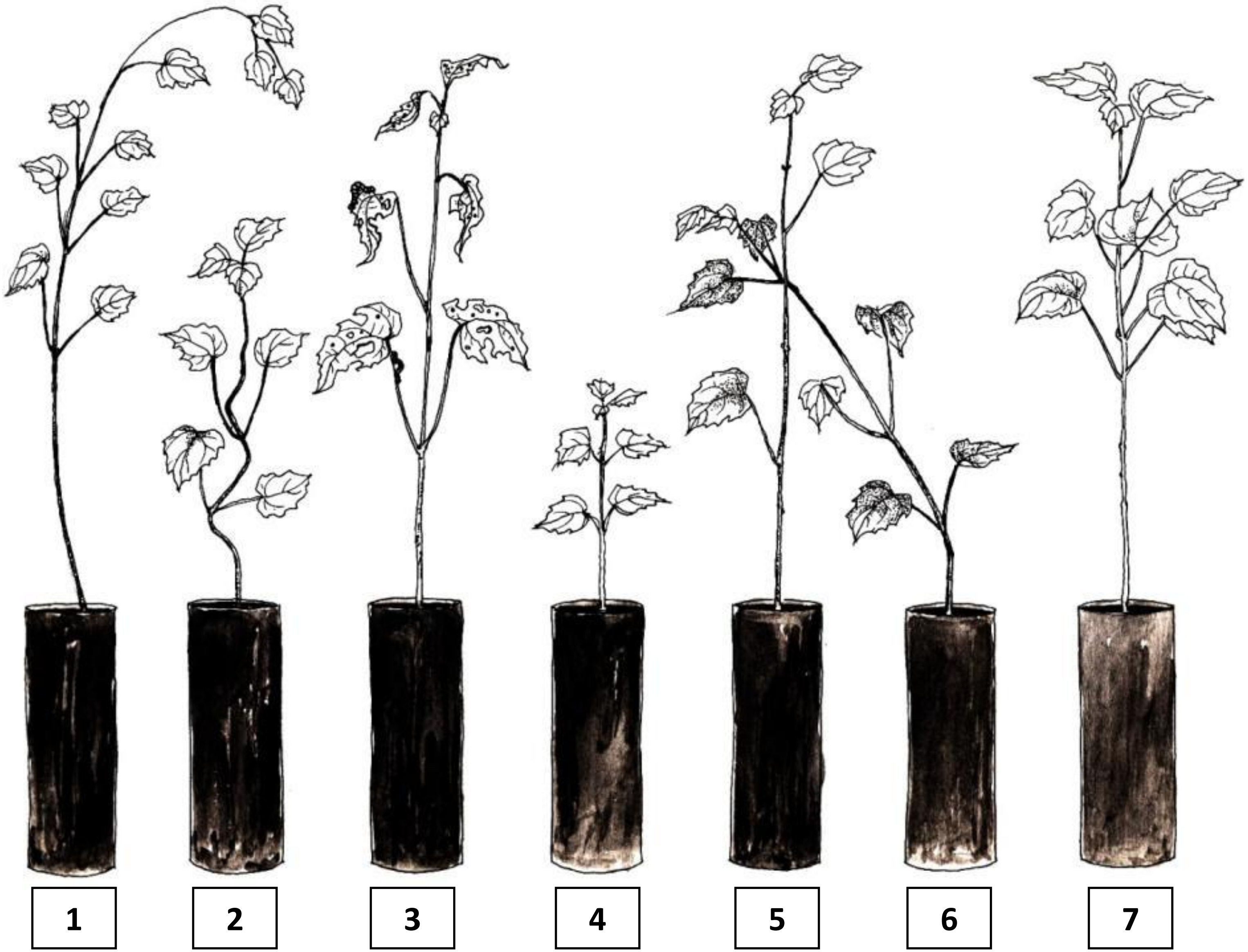
Figure 6.6 - Look out for problem plants:

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.*

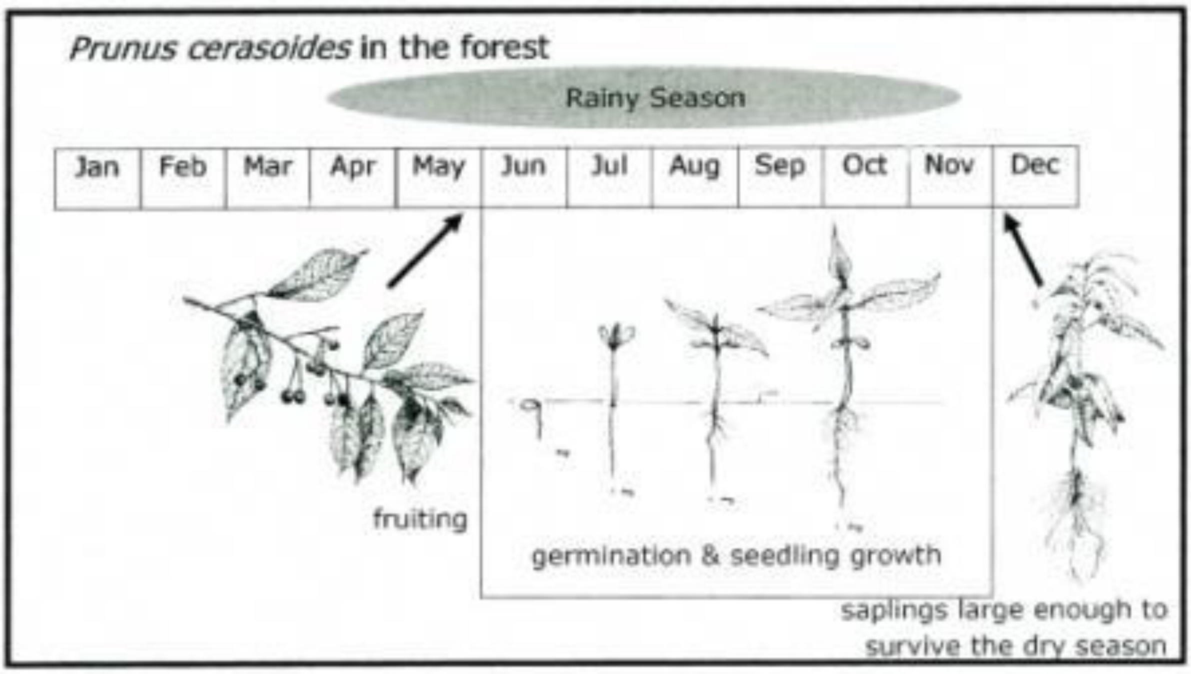
How tall should the saplings be at planting time?

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.

6.6

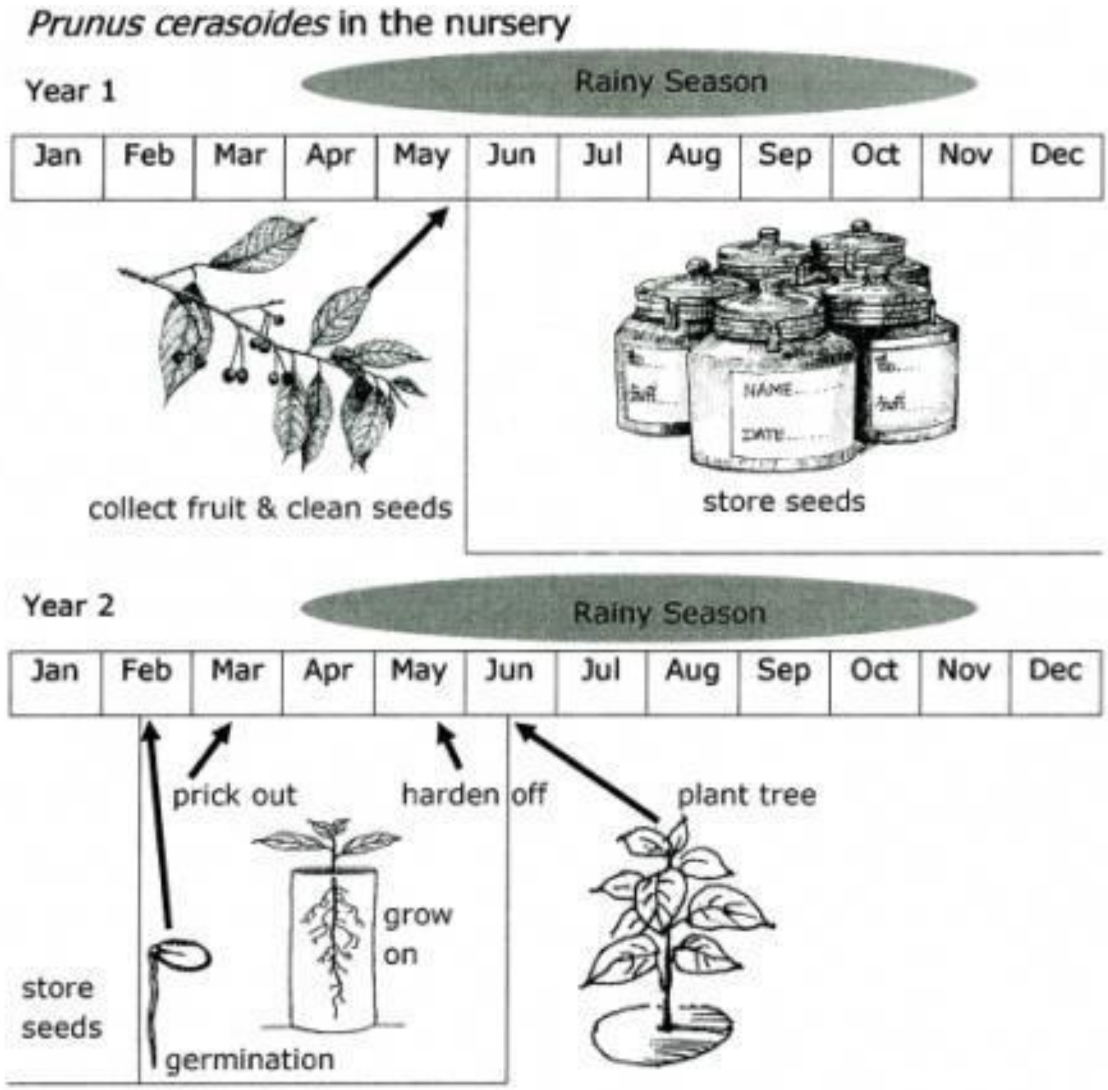


6.7



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

6.8



Prunus cerasoides in the nursery
Year 1
Rainy Season
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
NAME
DATE
collect fruit & clean seeds
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 6.7 *—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 6.8 *— 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

7. - Tree Planting, Maintenance and Monitoring

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.

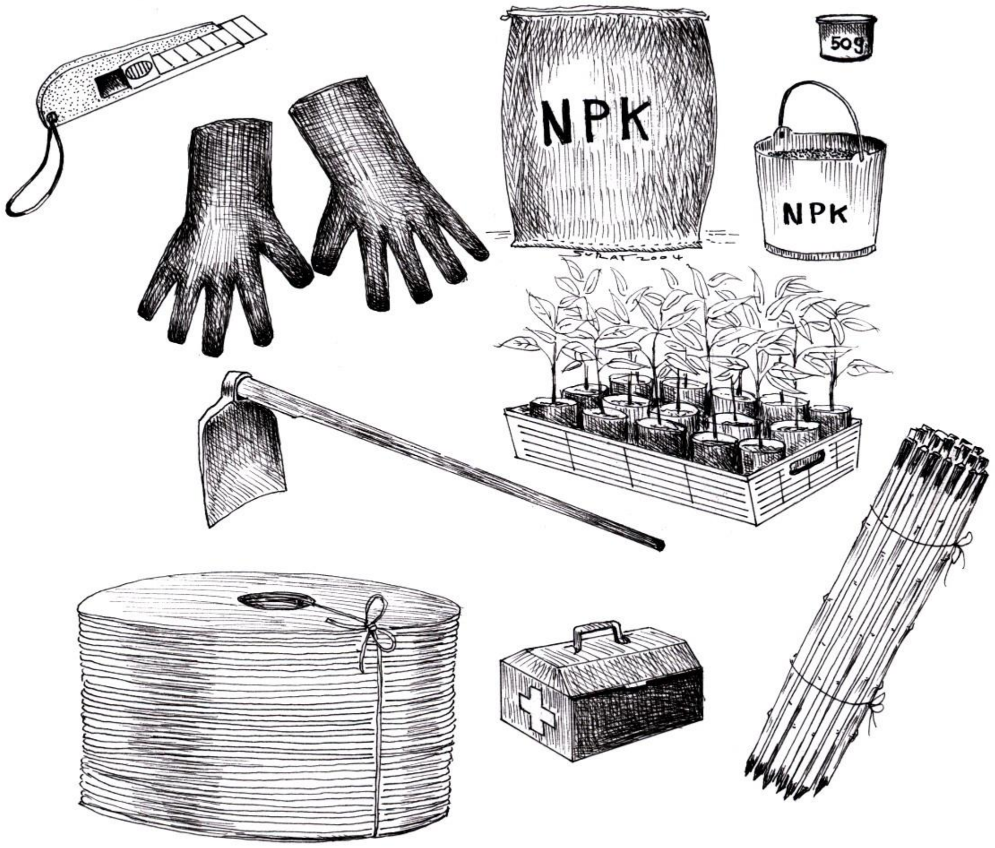
Planting

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.

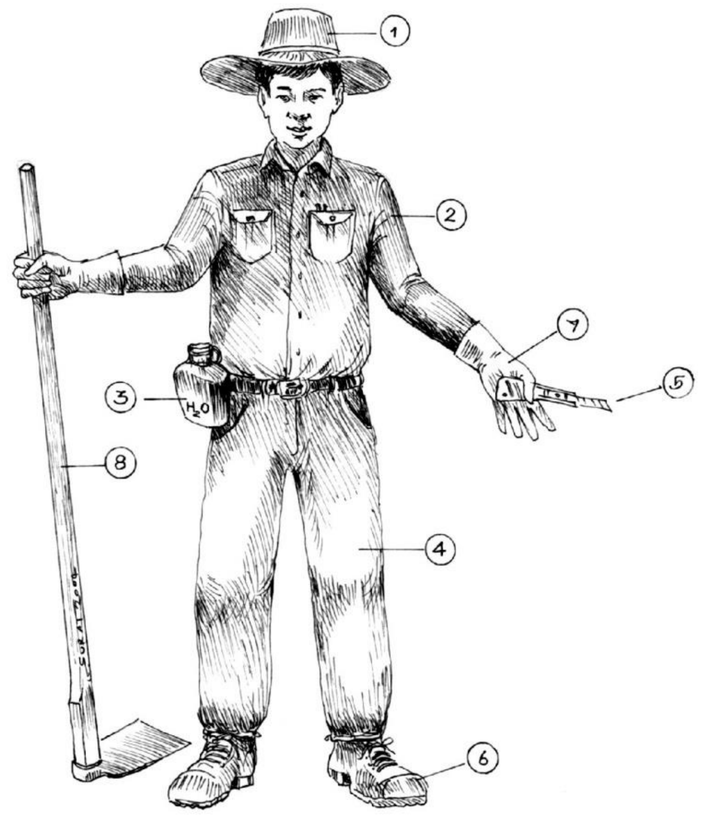
Figure 7.1 – *materials for planting day: box cutters to slice open plastic bags; gloves, fertilizer with buckets for distribution and small cups to measure out the dose required for each tree; saplings in baskets for distribution to planting spots; bamboo poles to mark planting spots, hoe for digging 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 7.2 - *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.*

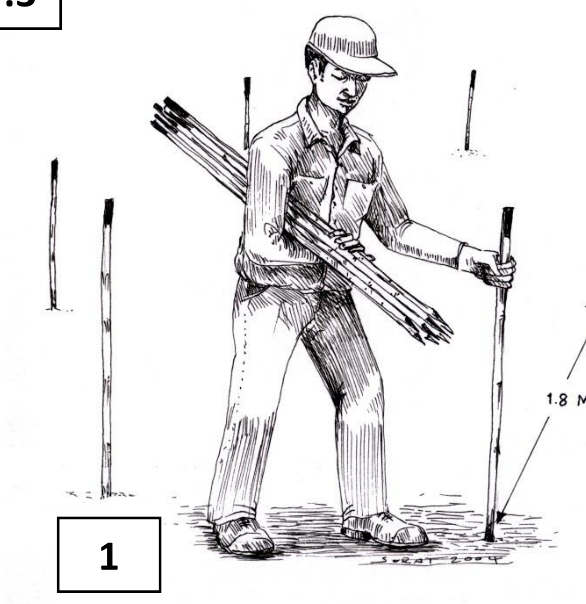
7.1



7.2



7.3



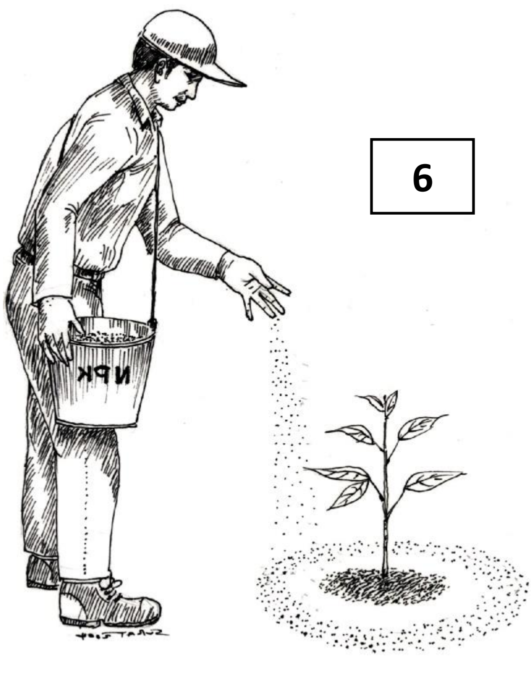
1

2

3

4

5



6

Figure 7.3 – *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.

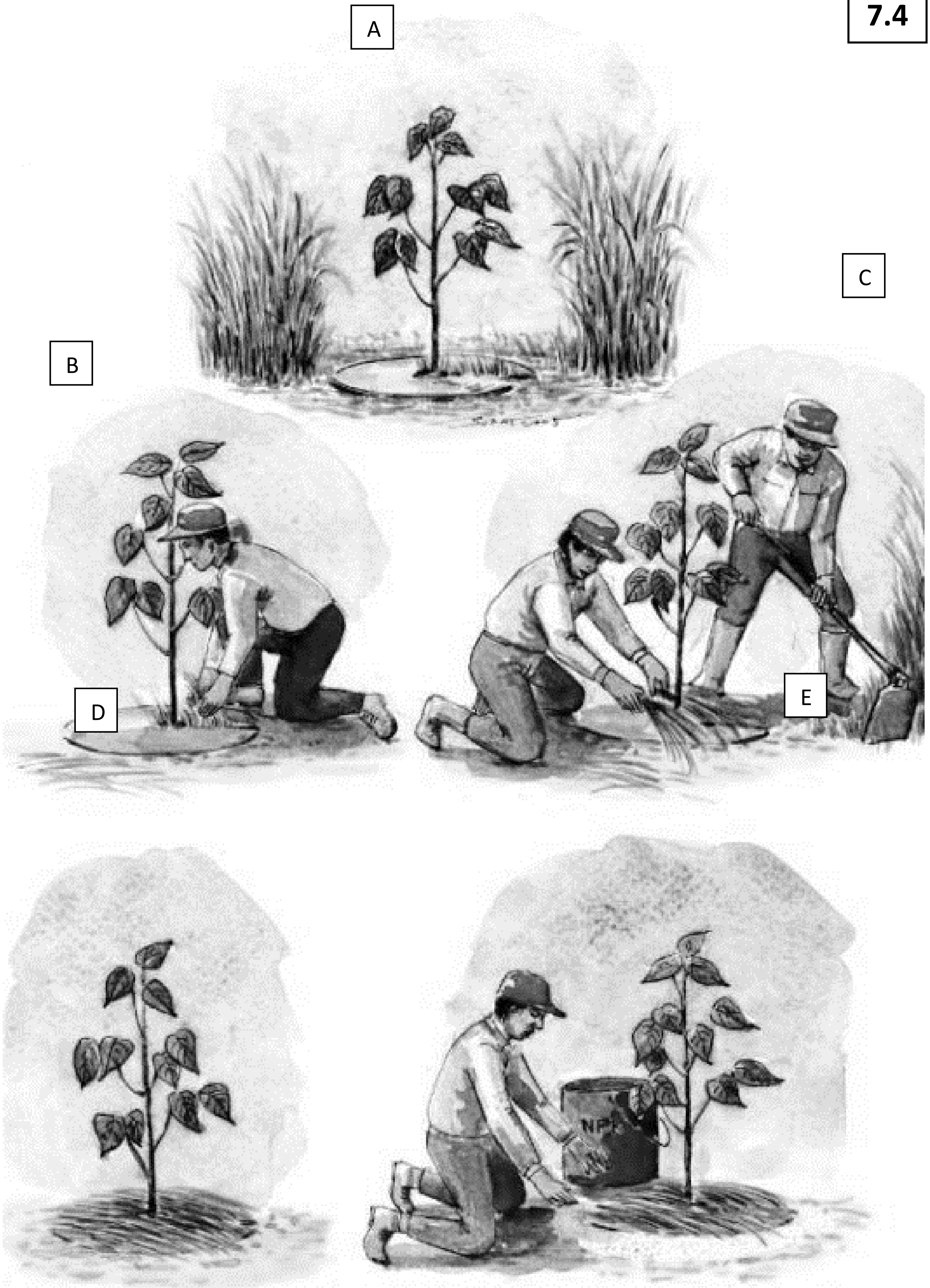
Weeding

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 7.4 - *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).*

7.4



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

Monitoring Forest Restoration

Control and treatment sites

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 1.

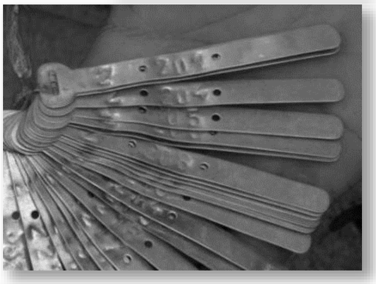
Circular sample units (SU's) have become the international standard for monitoring vegetation recovery as a result of restoration activities. Position SU's evenly across both the control and restoration sites. A minimum of 10 SU's should be positioned across the restoration site and 10 more across the 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 and take four photographs. Record SU details on Data Sheet 2.

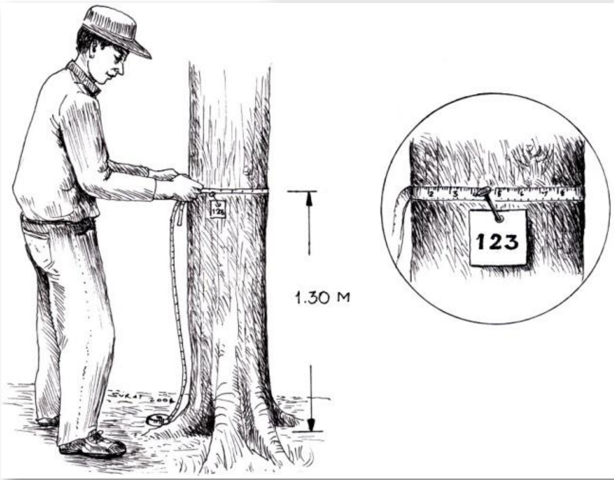
Box 7.1 - Photo monitoring procedure

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 7.2 - 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.





Data Sheet 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 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		

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.

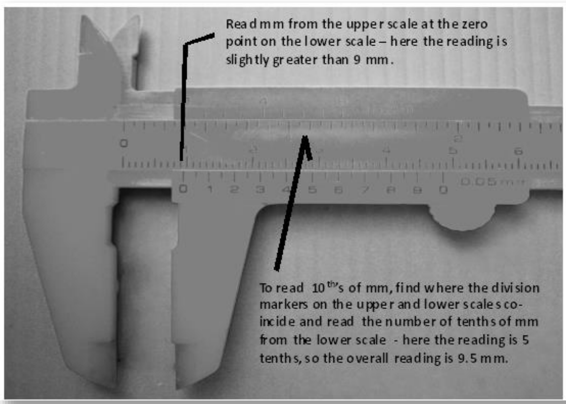
Within each SU, label every tree sapling taller than 50 cm and every live tree stump and then use Data Sheet 3 to record i) the label number, ii) the species name (both local name and scientific name), iii) height, iv) for small saplings, root collar diameter (RCD mm) or for larger trees (if girth at 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.

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.

Box 7.3 - 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.



Data Sheet 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.							

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. Furthermore, the mortality of small regenerants should be lower in the restoration site.

On the restoration site, more tree seedlings smaller than 50 cm tall (uncounted in the ground flora) should grow into the >50 cm size class (counted on Data Sheet 3) compared with the control site. From the data collected during the second monitoring, count the number of new regenerants, recorded in each SU, which are taller than 50 cm, but which were **not** labelled in the first survey (i.e. they were shorter than 50 cm in the first survey). Calculate the means (and SD's) for the restoration and control sites and perform a t-test, to determine if the difference between the means is significant.

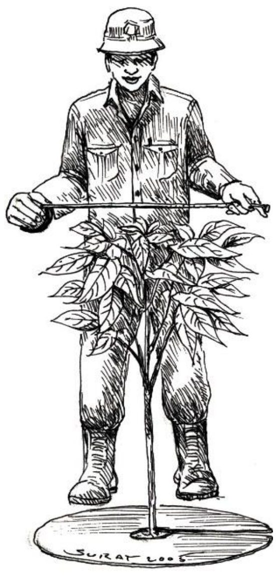
For each labelled regenerant, surviving in **both** surveys, calculate the relative growth rate (RGR) as follows:

$$\frac{\ln H\ (2^{nd}\text{ survey}) - \ln H\ (1^{st}\text{ survey}) \times 36{,}500}{\text{No. days between measurements}}$$

...where ln H = natural logarithm of regenerant height (cm). RGR is an estimated annual percentage increase in size. It takes account of differences in the original sizes of the regenerants, so it can be used to compare regenerants that were larger at planting time with those that were smaller. The same formula can be used to calculate relative growth rates of root collar diameters and crown widths. To determine if RGR differs between the restoration and control sites, perform a t-test to compare the mean RGR values of each species with more than 5 surviving individuals on each site (over combined SU's)

In each SU, count the number of regenerants recorded as dead in the second survey and express as a per cent of the number of live regenerants counted in the first survey. Exclude tree stumps and trees > 5 cm GBH from the count. Calculate the mean value and SD for the restoration and control sites and perform a t-test, to determine a significant difference in mortality between the means.

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



8. - Biodiversity Monitoring – Bird Community Field Exercise

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 to 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

9.1 - DATA ANALYSIS - GERMINATION TESTS, TREE SURVIVAL AND GROWTH

Definitions

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 embryonic development (after-ripening); ii) chemical inhibition of metabolism; iv) blocked mobilization of food reserves or v) lack of plant-growth hormones. Dormancy, due to seed coverings, can be caused by i) lack of water or oxygen reaching the embryo; ii) physical restriction of embryo expansion or iii) chemical inhibitors.

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.

Germination trials

Collect fruits when they are fully ripe but just before they are dispersed or consumed by animals. Label each seed tree with a unique number and fill in a seed collection data sheet (Figure 5.5). Germination trials can answer two basic questions: i) how many seeds germinate (per cent germination) and ii) how quickly or slowly they germinate. Both of these variables can be manipulated to grow tree saplings for a specific planting time.

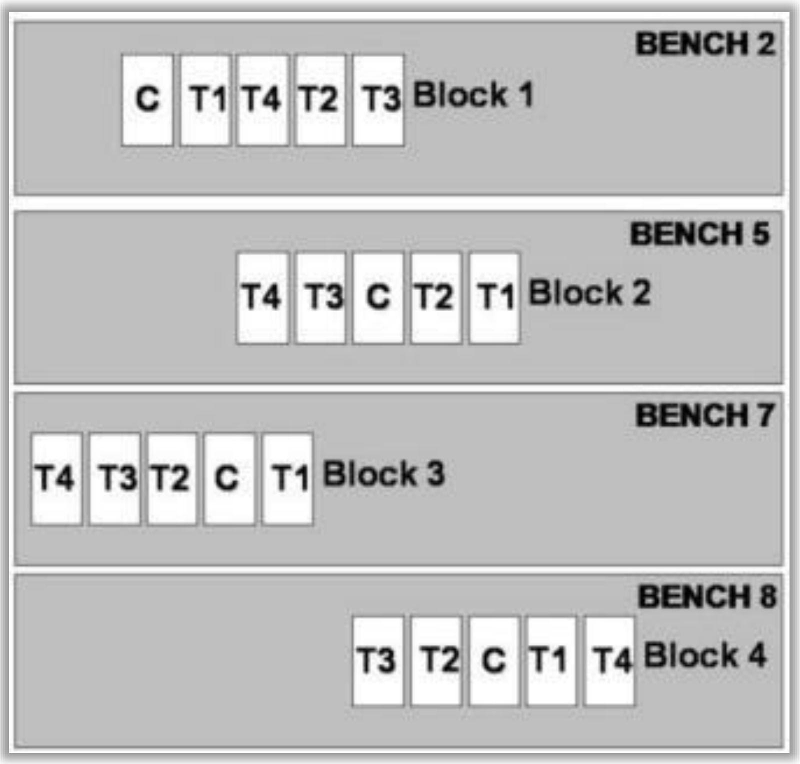
What treatments should be tested?

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.

Figure 9.1.1 – *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.*

Figure 9.1.2 – *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.*

9.1.1



9.1.2

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

Experimental Design

Use a **randomized complete block design** (RCBD) (Figure 9.1.1) 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.

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.

Germination curves

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.

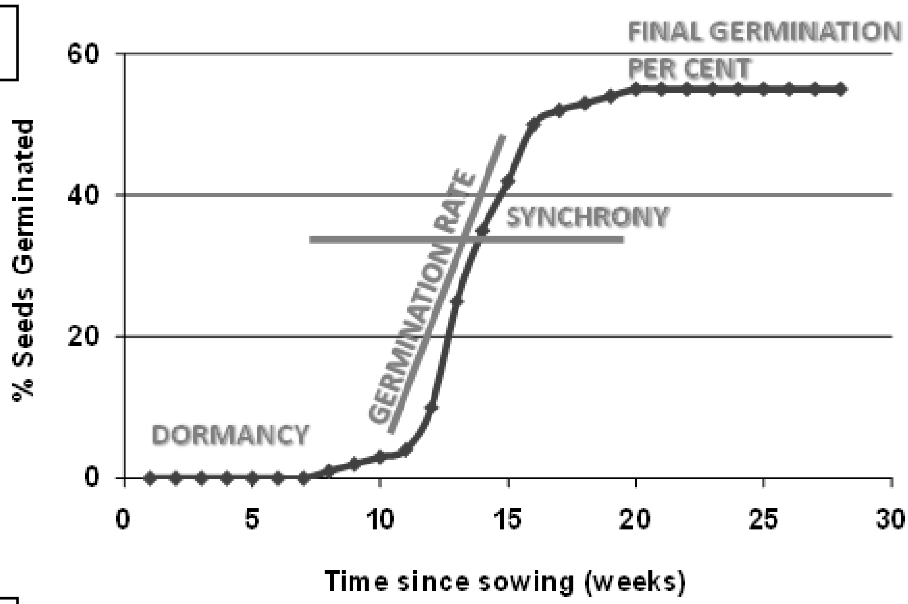
Decisions can be made even without the need for complex statistical tests. In the example here, a pre-sowing seed treatment accelerates germination but reduces the germination per cent, compared with the control. Faster germination may mean the difference between achieving a crop of saplings ready to 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.

Figure 9.1.3 – *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 horzontal axis. Germination curves show dormancy, germination rate, synchronicity and final germination per cent.*

Figure 9.1.4 – *Median length of dormancy is time taken for germination of half the seeds that finally germinate.*

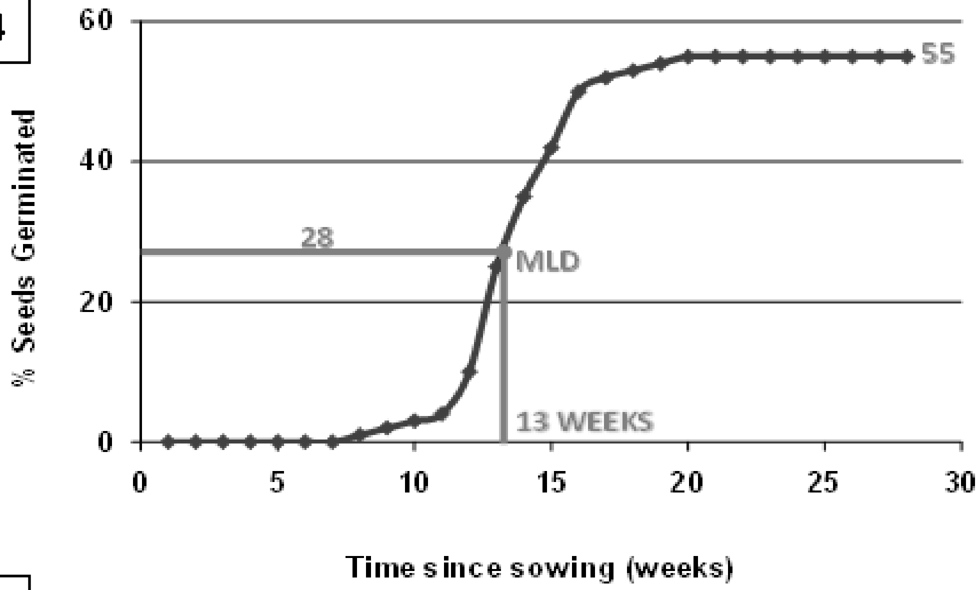
Figure 9.1.4 – *Germination curves allow rapid evaluation of the effectiveness of treatments.*

9.1.3



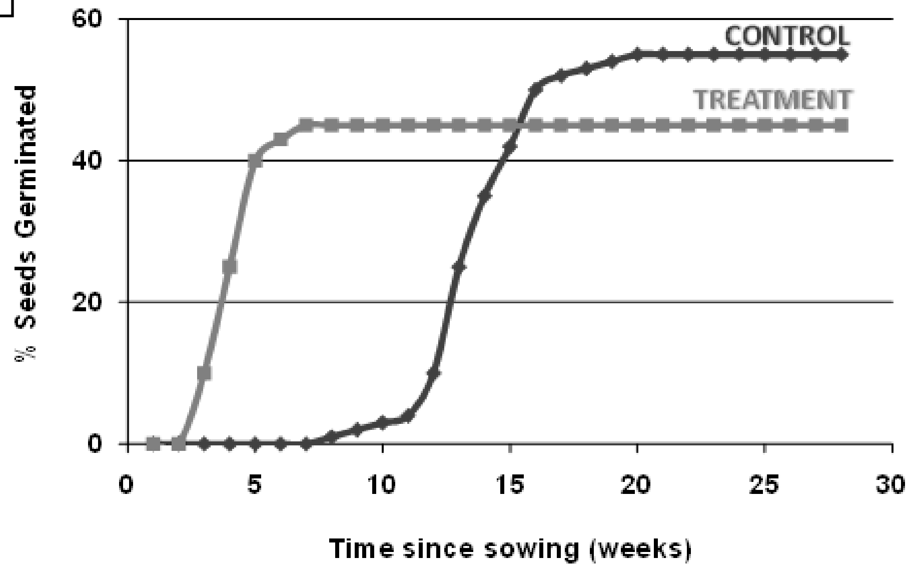
FINAL GERMINATION PER CENT
GERMINATION RATE
SYNCHRONY
DORMANCY
% Seeds Germinated
Time since sowing (weeks)

9.1.4



55
28
MLD
13 WEEKS
% Seeds Germinated
Time since sowing (weeks)

9.1.5



CONTROL
TREATMENT
% Seeds Germinated
Time since sowing (weeks)

How is dormancy measured?

Dormancy is time between sowing a seed and emergence of its radicle (embryonic root). It varies among the seeds. Median length of dormancy (MLD) for a seed batch is the length of time between sowing and germination of half the seeds which eventually germinate. In Figure 9.1.4, MLD would be the time between sowing and germination of the 28th seed, i.e. 13 weeks.

More advances analysis ANOVA and t-tests

For a more detailed analysis of germination test results, 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. Both these tests can be done using the Data Analysis Tool Pak of MS Excel. Full details are in the appendices of "[Research for Restoring Tropical Forest Ecosystems: A Practical Guide](https://www.forru.org/library/0000156)". https://www.forru.org/library/0000156.

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. 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 and Analysis

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.

For each replicate, count the number of saplings that survive until planting-out time. Then calculate the mean value for each treatment (or species) and the standard deviation; repeat for the control. Apply ANOVA to determine if differences among treatments or species are significant. If so, then use paired comparisons between each treatment mean and the control mean, to identify which treatments significantly increase survival. Use the Data Analysis tool in MS Excel, as for germination trials

Represent sapling growth graphically by constructing a growth curve. Plot time elapsed since pricking out (horizontal axis) vs. mean sapling height (or mean RCD), 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.

Also calculate relative growth rates (RGR), which removes the effects of differences in the original sizes of seedlings/saplings, immediately after potting, on subsequent growth, i.e. 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…

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

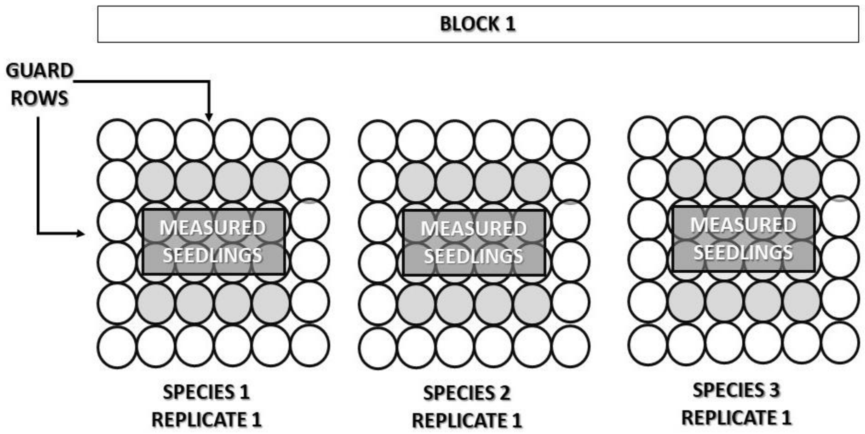
…where ln FS = natural logarithm of final size (height or RCD) and ln IS – natural logarithm of initial size.

Figure 9.1.6 – *RCBD experiment for comparing growth among species - Block 1.*

Figure 9.1.7 – *Typical data-collection sheet for seedling growth trial in a nursery.*

Figure 9.1.8 – *Growth curves allow rapid evaluation of the effectiveness of treatments. Trees of this species reach a size suitable for planting in January, 6 months ahead of planting time. Therefore, seed stroage, to delay germination is recommended.*

9.1.6



9.1.7

Species: Prunus cerasoides S.no.: S71B1

Pricked out: June 6th 1997 BLOCK:1 TREATMENT: NONE (CONTROL)

HEIGHT DATA (CM)

		SEEDLING NUMBER															
DATE	DAYS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	AVG
7/6/97	1	5.0	4.0	3.5	2.0	4.0	3.0	4.0	3.0	3.5	3.0	5.0	4.0	3.0	4.0	4.5	3.7
25/7/97	49	11.0	12.0	8.0	3.0	8.0	5.5	7.5	5.5	6.5	8.5	12.0	9.0	8.5	9.0	9.5	8.2
8/9/97	94	29.0	38.0	23.0	33.0	x	16.0	19.0	17.0	13.0	14.0	35.0	20.0	25.0	16.0	16.0	22.4
23/10/97	139	67.0	67.0	44.0	34.0	x	32.0	35.0	25.0	32.0	29.0	66.0	27.0	50.0	28.0	31.0	40.5
7/12/97	184	70.0	70.0	55.0	34.0	x	52.0	61.0	36.0	48.0	47.0	71.0	38.0	58.0	40.0	52.0	52.3
23/1/98	231	73.0	70.0	57.0	34.0	x	64.0	67.0	41.0	52.5	53.0	80.0	46.0	72.0	43.0	66.0	58.5
9/3/98	276	73.0	70.0	60.0	34.0	x	64.0	67.0	49.0	58.0	54.0	81.0	55.0	73.0	53.0	75.0	61.9

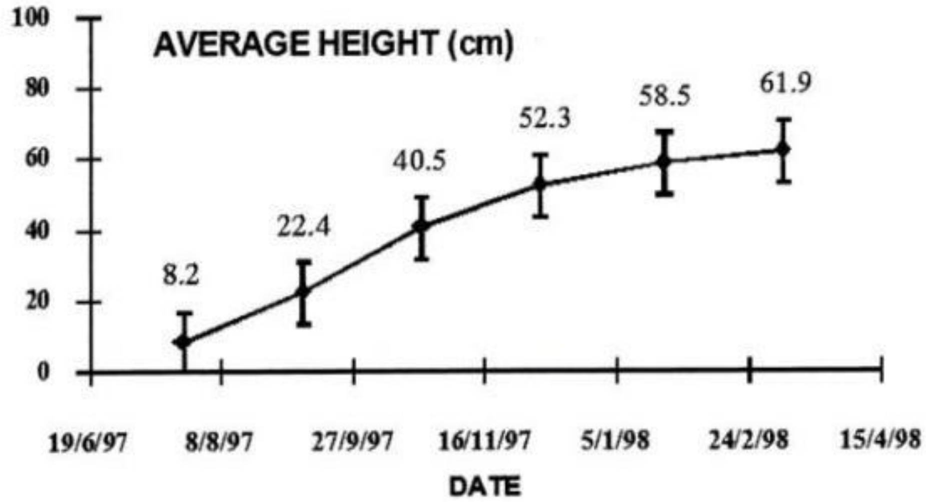
ROOT COLLAR DIAMETER DATA (MM)

		SEEDLING NUMBER															
DATE	DAYS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	AVG
7/6/97	1	0.5	0.7	0.4	0.8	0.4	0.5	0.6	0.7	0.6	0.7	0.7	0.6	1.0	0.6	0.7	0.6
25/7/97	49	1.4	2.2	1.3	1.1	1.3	1.0	1.5	1.6	1.3	1.2	1.4	1.1	2.1	1.3	1.4	1.4
8/9/97	94	2.8	3.2	2.7	1.4	x	1.5	1.6	3.3	2.7	2.5	2.4	2.5	2.2	2.3	1.4	2.3
23/10/97	139	4.2	4.0	3.0	1.7	x	1.8	2.1	3.3	2.7	2.7	3.6	2.5	3.0	2.3	1.6	2.8
7/12/97	184	4.4	4.0	3.0	2.5	x	2.9	2.9	3.3	2.7	3.0	3.7	3.0	3.0	2.3	3.0	3.1
23/1/98	231	4.4	4.0	4.2	2.5	x	4.5	4.5	3.3	3.2	3.5	4.2	3.0	4.0	2.6	4.5	3.7
9/3/98	276	5.2	6.0	4.2	2.6	x	5.0	5.5	3.6	4.0	4.3	4.6	3.5	4.5	3.0	5.0	4.4

HEALTH DATA (0-3)

		SEEDLING NUMBER															
DATE	DAYS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	AVG
7/6/97	1	2.5	2.5	2.5	1.5	2.0	1.5	3.0	3.0	2.5	3.0	3.0	2.5	2.0	3.0	3.0	2.5
25/7/97	49	3.0	3.0	3.0	2.0	3.0	2.5	3.0	2.5	3.0	3.0	3.0	3.0	3.0	3.0	3.0	2.9
8/9/97	94	3.0	3.0	3.0	2.0	x	2.5	3.0	3.0	2.5	2.5	3.0	3.0	3.0	3.0	2.5	2.8
23/10/97	139	3.0	2.5	3.0	2.5	x	3.0	3.0	3.0	3.0	3.0	3.0	3.0	1.5	3.0	3.0	2.8
7/12/97	184	3.0	3.0	3.0	3.0	x	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
23/1/98	231	3.0	3.0	3.0	3.0	x	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
9/3/98	276	3.0	3.0	3.0	3.0	x	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0

9.1.8



9.2 - Data Analysis - Bird Species Richness

After finishing the bird watching field work (Chapter 8) arrange the data sheets in order of time and then make a list of the first 10 **DIFFERENT** bird species that you saw 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										No. of lists on which the species occurs
		1	2	3	4	5	6	7	8	9	10	
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

10.1 - Planning Logistics – Scheduling, Labour And Budgeting (Guided Discussion)

Scheduling restoration tasks

Forest restoration takes time. Plan early for project success. If trees are to be grown in a nursery near the planting site, nursery construction and seed collection should begin 18 months to 2 years before the planned first planting date. An example schedule for a forest restoration project, from planning to canopy closure, is illustrated below.

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.

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.

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 rai up to about 50 rai). 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 reduces the labour required from each household. The example detailed below shows how the labour required to replant each rai of forest declines with increasing community size and 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 truly appreciate the benefits of forest restoration and have strong motivation, they are usually willing to work on a voluntary basis.

		Person-days labour per ha (2 years)						
Area Dependent work		**Year 1**	**Year 2**	**Total labour required for**				
				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
**Assuming zero natural regeneration i.e. planting 3,000 trees per ha*				1,686	2,626	3,790	7,270	13,052

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), and then download the budget-calculation spreadsheet, to perform “collaborative costing”, involving all stakeholders, particularly the funder. Project the spreadsheet on a screen, enter the number of trees that should be planted (derived from the RSA) – adjust the other cost parameters to local rates (according to feedback from stakeholders) and enter the area to be planted. Discuss other unit costs with the whole group and enter accordingly. Look at the bottom line and if necessary, negotiate with the funder where cost savings can be made.

This is the link for the spreadsheet: shorturl.at/aEQ07

10.2 - Working with Stakeholders (Guided Discussion)

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