Chapter 7

Tree planting, maintenance and monitoring

Taking a tree from its container and planting it firmly into the soil is probably the archetypal image of forest restoration. It represents the culmination of months of planning, seed collection and nursery work. However, it is by no means the end of the forest restoration process. Deforested sites are harsh places: exposed, sunny and hot and often alternating between being parched and waterlogged. If trees are not provided with adequate care and protection over the first two years after planting, many will die and the effort expended in producing them will be wasted. The labour and materials required to ensure that the planted trees perform well are often under-estimated. Often, budgets run low or labour becomes unavailable, sometimes resulting in project failure and the need to start all over again. It is therefore a false economy to cut back on post-planting maintenance. Monitoring is another often-neglected task that is essential not only to provide data on tree survival and growth but also to provide an opportunity to learn from past successes and failures. Monitoring is now a required feature of all restoration projects that are funded through carbon trading.

7.1 Preparing to plant

Optimising the timing of tree planting

The optimal time for planting trees depends on soil water availability. In areas that have a seasonal climate, trees should be planted early in the rainy season, once rainfall has become regular and reliable. This gives the trees the maximum time to grow a root system that penetrates deep into the soil, allowing them to obtain sufficient water to survive the first dry season after planting. Where rainfall is more evenly spread throughout the year (i.e. no month has less than 100 mm), trees can probably be planted at any time.

Preparing the restoration site

First, take steps to protect any existing, naturally established trees, seedlings, saplings or live tree stumps. Inspect the plots thoroughly, taking care not to miss smaller tree seedlings that might be obscured by weeds. Place a brightly coloured bamboo pole next to each plant and use a hoe to dig out weeds from a circle of 1.5 m in diameter around each plant. This makes the natural sources of forest regeneration more visible to workers, so that they avoid damaging them during weeding or tree planting. Impress upon everyone working in the plots the importance of preserving these natural sources of forest regeneration.

About 1–2 weeks before the planting date, clear the entire site of herbaceous weeds so as to improve access and to reduce competition between weeds and trees (both planted and natural). The weed-pressing technique, often used for ANR, detailed in **Section 5.2**, might be adequate for sites that are dominated by soft (non-woody) grasses and herbs. Where weed pressing is ineffective, however, weeds must be dug out by the roots. First, slash the weeds down to 30 cm or so, then dig them out by their roots with a hoe and leave them to dry out on the soil surface. Make sure a first-aid kit is on hand to deal with any accidents.

Removing weed roots

Mere slashing encourages many weed species 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 actually intensifies root-competition with the planted trees, rather than reducing it. So, digging out the roots of weeds is essential, although the labour required to do so is considerable. Unfortunately, digging out roots also disturbs the soil, increasing the risk of soil erosion. Furthermore, there is a significant risk of accidentally slashing naturally established tree seedlings or saplings. For these reasons, and to reduce labour costs, we recommend use of glyphosate to clear plots for planting (but NOT for weeding after planting).

Herbicide use

Using a slow-acting, broad-spectrum, systemic herbicide, such as glyphosate (which is available in various formulations) can greatly increase the efficiency of weeding, reduce costs and avoid the need to disturb the soil. Such herbicides kill the entire plant, and thus prevent weeds from regenerating rapidly by vegetative growth.

Wait for the slashed weeds to begin to re-sprout before spraying them with a non-residual herbicide, such as glyphosate. Wear appropriate protective clothing as directed by the information sheet accompanying the product – usually gloves, safety glasses, rubber boots and water-proof clothing.

Slash weeds down to below knee height at least 6 weeks before the planting date. Leave the cut vegetation on site, as it will help to protect the soil from erosion and can subsequently be used as mulch around the planted trees. Wait at least 2–3 weeks for the weeds to start to sprout afresh; then spray the new shoots with glyphosate.

How does glyphosate work?

Glyphosate kills most plants, only a few species are resistant. It rapidly breaks down in the soil (i.e. it is non-residual) and so, unlike some other pesticides (e.g. DDT), it does not accumulate in the environment. The chemical is absorbed through leaves and is translocated to all other parts of the plant, including the roots. The weeds die slowly, gradually turning brown over 1–2 weeks, and the only way they can re-colonise the site is by growing from seeds. This takes much more time than re-sprouting from slashed shoots or root stocks. So, newly planted trees have about 6–8 weeks of relative freedom from weed competition. During this time, their roots can colonise soil formerly occupied fully by weed roots.

How should glyphosate be applied?

Apply herbicides on a dry windless day to prevent drift onto any naturally regenerating tree seedlings. Do not spray if rain is forecast within 24 hours after application. Within a few hours after spraying, rain and even dew render the chemical ineffective.

Large pumps mounted on pick-up trucks and long hoses that are used to spray crops might be available in agricultural communities, but they are not very accurate and their use makes it difficult to avoid spraying natural regenerants. Therefore, we recommend the use of 15 litre backpack tanks with directional spray nozzles, mounted on long wands.

Pour 150 ml of the glyphosate concentrate into a 15-litre-tank backpack sprayer and top up with clean water to the 15 litre mark. You will need to repeat this 37–50 times (using 5.6–7.5 litres of concentrate) per hectare. You should also include a wetting agent to facilitate the uptake of the chemical by the weeds.

Check the wind direction and work with the wind behind you, so that the spray is blown forwards rather than back into your face. Pump up the pressure in the backpack tank with the left hand and operate the spray wand with the right hand. Use low pressure to produce large droplets, which sink rapidly, before they can drift very far. Walk slowly across the site, spraying strips about 3 m wide by making gentle sweeps from side to side in front of you. If you accidentally spray a tree seedling or sapling, immediately tear off any leaves on which drops of the herbicide have fallen so that the chemical is not absorbed into the plant and transported to the roots. To avoid spraying the same area twice, add a dye to the glyphosate, so that you can see where you have already sprayed. If you accidentally spray the chemical onto your skin or in your eyes, wash with large amounts of water and see a doctor.

As soon as possible after spraying, take a shower and wash all clothes worn during spraying. Clean all of the equipment used (backpacks, boots and gloves) with large quantities of clean water. Make sure that the waste water does not flow into a drinking water supply; let it seep slowly into a sump pit or into the ground where there is no vegetation, far away from any water course.

Is glyphosate dangerous?

The United States Environmental Protection Agency (EPA) considers glyphosate to be relatively low in toxicity and without carcinogenic effects. It breaks down rapidly in the environment and does not accumulate in the soil. It is rated least dangerous when compared with other herbicides and pesticides. Nevertheless, if basic safety instructions are ignored, glyphosate can damage people's health and the environment, so read the instructions provided by the supplier before using it and follow them carefully. Ingestion of the concentrated solution can be lethal.

When diluted for use, glyphosate has low toxicity to mammals (including humans) but it is toxic to aquatic animals, so don't clean any contaminated equipment in streams or lakes. Research is also beginning to show that glyphosate might affect soil organisms. These minor potentially damaging effects of the chemical on the environment must, however, be weighed against the damaging long-term consequences of failing to restore forest ecosystems. Glyphosate is used only once, at the beginning of the forest restoration process. Use of the herbicides after trees have been planted is not recommended (en.wikipedia.org/wiki/Glyphosate).

Fire should not be used to clear plots

Fire kills any naturally established young trees while stimulating the re-growth of some perennial grasses and other weeds. It also kills beneficial micro-organisms such as mycorrhizal fungi and removes the possibility of using slashed weeds as mulch. If fire is used, organic matter is burnt off and soil nutrients are lost in smoke. Furthermore, fires that are intended to clear a planting plot can spread out of control and have the potential to damage nearby forest or crops.

How many saplings should be brought in?

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 this figure minus the number of naturally established trees or live tree stumps estimated during the site survey (see **Section 3.2**). 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 that will shade out weeds and eliminate weeding costs. Shade is the most cost-effective and environmentally friendly herbicide. Planting fewer trees results in a continued need for weeding over many years and, consequently, increases the total labour costs required to achieve canopy closure.

The tree spacing used in forest restoration is also closer than that between trees in most natural forest, so some competitive thinning will take place. This provides the restored ecosystem with an early source of dead wood, a vital resource for many forest fungi and insects. Planting at even higher densities is counter-productive as it leaves too little room for the establishment of incoming recruit tree species and therefore delays biodiversity recovery (Sinhaseni, 2008).

How many tree species should be planted?

For a plot with stage-3 degradation, count how many tree species are well represented by the sources of natural regeneration recorded in the site survey (see **Section 3.2**) and deliver enough species to top up that number to at least 30 or around 10% of the estimated species richness (if known) of the target forest type (see **Section 4.2**). For a plot with stage-4 degradation, plant as many species of the target forest type as possible. Nurse plantations can be monocultures of single species or mixtures of a few species (e.g. *Ficus* spp. + legumes; see **Section 5.5**).

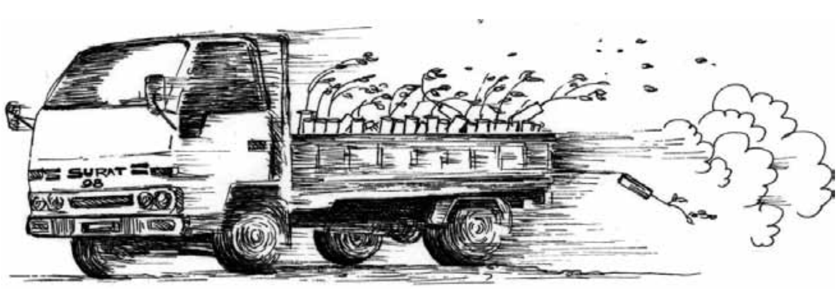
Transporting saplings

Saplings are very vulnerable, particularly to wind and sun exposure, once they leave the nursery, so take care when transporting them to the site. Select the most vigorous saplings in the nursery after grading and hardening-off (see **Section 6.5**). Label the saplings that you intend to include in your monitoring program, then place all of the saplings upright (so as to prevent spillage of potting mix) in sturdy baskets. Water the saplings just before loading them into the vehicle, and transport them to the planting plot the day before planting.

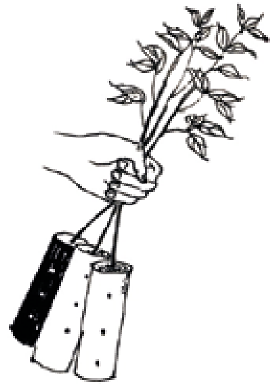
If plastic bags are in use as growth containers, do not pack them so tightly that they lose their shape. Also, do not stack containers on top of each other as this will crush shoots and break stems. If an open truck is used, cover the saplings with a layer of shade netting to protect them from wind damage and dehydration. Drive slowly. Once the plots have been reached, place the saplings upright beneath any available shade and, if possible, lightly water them again. If you have enough baskets, keep the saplings in the baskets as this makes it easier to carry them around the plot on planting day.

Protect the young trees on the way to the restoration site.

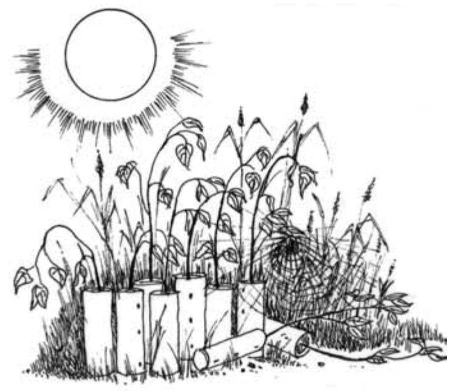
SLOW DOWN! Don't throw away a year's work in the nursery on the journey to the planting site. When transporting saplings, drive with care.



Carry saplings onto the restoration site like this …



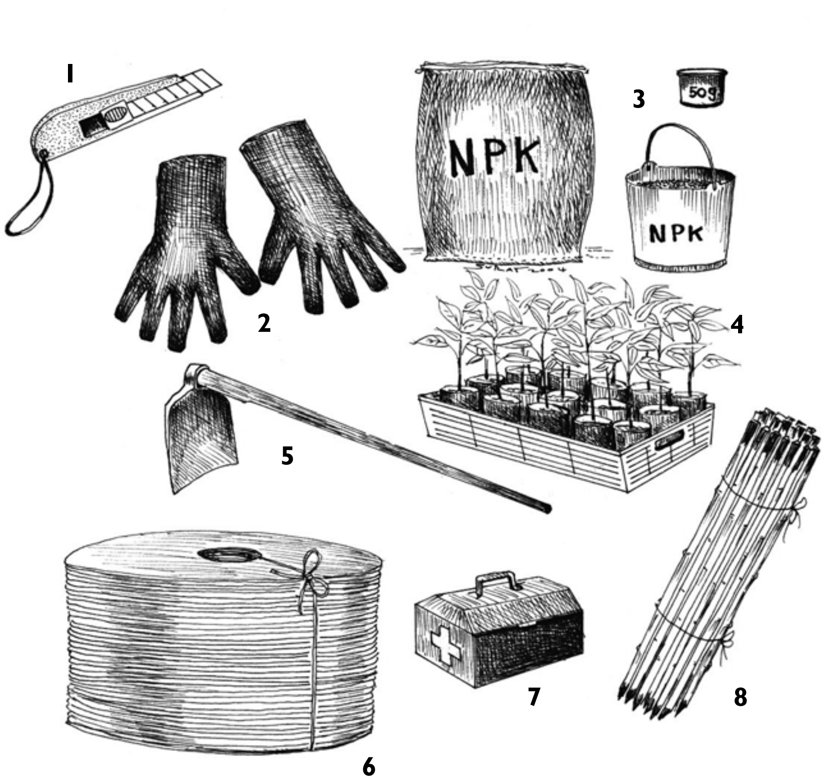
… not like this (it damages the stems) …



… and don't leave them exposed.

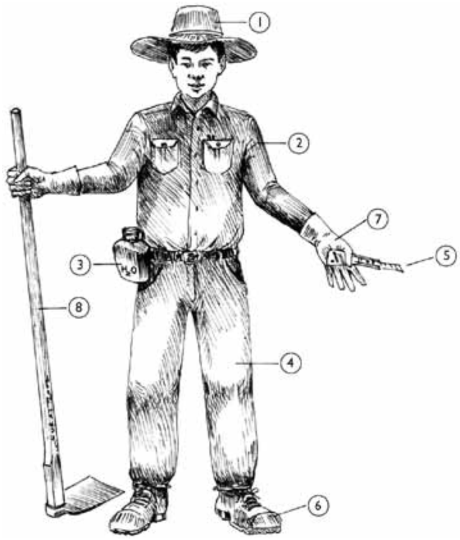
Planting materials and equipment

The day before planting, transport planting materials to the plots along with the saplings. These include a bamboo stake and mulching material (if required) for each sapling as well as fertiliser. Protect these materials from rain by covering them with a tarpaulin.



1. Knife
2. Gloves
3. Fertiliser, bucket and pre-measured cups to deliver the correct dose
4. Baskets for saplings distribution
5. Hoes for hole digging
6. Mulch mats
7. First-aid kit
8. Bamboo poles

Other preparations for the big day?



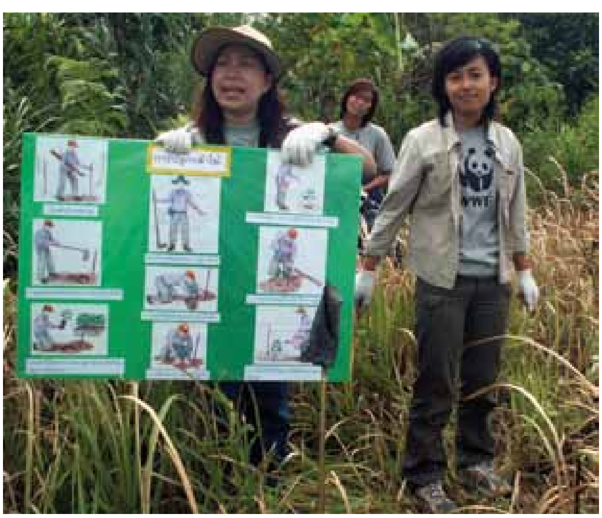
The perfectly prepared planter, with (1) a hat for sun protection; (2) a long-sleeved shirt; (3) plenty of water to drink; (4) long trousers; (5) a box cutter for slashing open plastic bags; (6) strong boots; (7) gloves and (8) a hoe for digging the planting holes.

A few days before the planting event, hold a meeting of all project organisers. 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 each will be responsible for planting and how many trees they must plant. Use a planting rate of 10 trees per hour to calculate the number of people required to complete the planting within the desired time limit.

Ask the team leaders to tell their team members to bring gloves, box-cutters (to slash open plastic bags), buckets, hoes or small shovels (to fill in the planting holes) and (if fertiliser is to be applied) cups. In addition, team leaders should advise the planters to carry a bottle of water and to 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. Organise 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. Finally, consider whether the project and the local community might benefit from media coverage of the event and, if so, contact journalists and broadcasters.

7.2 Planting



Enthusiasm alone is not enough. A little bit of training at the start of a planting event can help to prevent costly mistakes.

Tree planting events do much more than just put trees in the ground. They provide an opportunity for ordinary people to become directly involved in improving their environment. They are also social events, helping to build community spirit. Furthermore, media coverage of a planting event can portray a positive image of the community as responsible stewards of their natural environment. Tree planting can also have an educational function. Participants can learn not only how to plant trees but also why. Take time at the beginning of the event to demonstrate the planting techniques to be used and to make sure that 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, fertiliser application and fire prevention.

Spacing distances

First, mark where each tree will be planted with a 50-cm split-bamboo pole. Space the poles at 1.8 m apart or the same distance away from naturally established trees or tree stumps. Try not to position the stakes in straight rows. A random arrangement will give a more natural structure to the restored forest. Staking out the plots can be done either on planting day or a few days in advance.

Use split bamboo to space out the trees.

Planting method

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. This 'random' planting is known as an 'intimate mix'.

Baskets and hand carts can be used to haul the saplings to their planting positions.

Beside each bamboo pole, use a hoe to dig a hole that is at least twice the volume of the sapling's container, preferably with slanting sides (breaking up the soil around the root system will also help the roots to establish). At the same time, use the hoe to drag away dead weeds in a circle of 50–100 cm in diameter around the hole.

If the saplings are in plastic bags, slash each bag up one side with a sharp blade, taking care not to damage the root ball inside, and gently peel away the plastic bag. Try to keep the medium around the root ball intact, and expose roots to the air for no more than a few seconds if possible.

Dig holes twice the size of the container.

Carefully slice open bags and peel back the plastic.

Planting day can be enjoyed by the whole family.

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 labelled 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. It is not usually necessary to tie the sapling to the pole for support. The poles are used merely to indicate the location where each tree should be planted.

Next, apply 50–100 g of fertiliser in a ring on the soil surface about 10–20 cm away from the sapling stem. Chemical burning can occur if fertiliser contacts the stem itself. Use pre-measured plastic cups to apply the correct fertiliser dose. Note that chemical fertilisers are usually expensive and might not be necessary for all sites.

Press soil around the stem to make it firm.

Use measuring cups to deliver the correct fertiliser dose.

Cardboard mulch mats are particularly effective on dry degraded soils. On wetter, fertile soils, they disappear too quickly.

Then (optionally) place a cardboard mulch mat of 40–50 cm in diameter around each planted sapling. Anchor the mulch mat in position by piercing it with the bamboo stake and pile dead weeds onto the cardboard mulch mat.

If there is a water supply nearby, water each planted sapling with at least 2–3 litres at the end of the planting event. 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.

For inaccessible dry sites, plant trees when rain is forecast, but if it is possible to water the trees after planting, then do so. Pump water from a stream or truck it in by tanker.

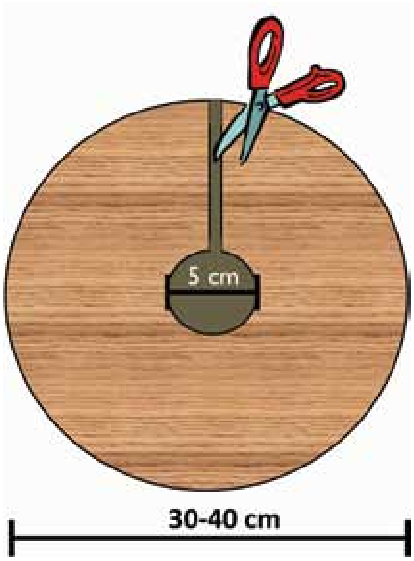
Remove plastic bags to clean the site.

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.

Choosing a chemical or inorganic fertiliser

Determining that a site's soil has nutrient deficiencies requires costly chemical analyses and access to a laboratory (see **Section 5.5**). It is rarely worth the cost because, regardless of soil fertility, most tropical trees respond well to the application of a general-purpose chemical fertiliser (N:P:K 15:15:15) 3–4 times a year for 2 years after planting. Use doses of 50–100 g per tree per application. The effect is to boost growth in the first few years after planting, accelerate canopy closure, shade out herbaceous weeds and 'recapture' the site. Spreading the fertiliser in a ring around the base of the tree is more effective than placing fertiliser in the planting hole because the nutrients percolate down through the soil as the roots begin to grow into the surrounding soil.

On lowland sites with poor lateritic soils, organic fertiliser seems to be more effective than chemical fertiliser (FORRU-CMU, unpublished data), possibly because it breaks down and is leached from the soil more slowly. Thus, it delivers nutrients to the tree roots more evenly over a longer period.



The cost of chemical fertiliser fluctuates with the price of oil, and so costs have risen steeply in recent years and are likely to continue to do so. Organic fertilisers vary greatly in composition, but they are much cheaper than chemical fertilisers. Find a reliable supply of an effective local brand and stick with it, or work with local communities to start producing fertiliser from animal waste. The purchase of fertiliser from local villagers provides another way in which the community can benefit economically from a restoration project.

Mulching to reduce desiccation and weed growth

Mulch is a material placed on the ground around a sapling that can increase its survival and growth, particularly by reducing the risk of drying out immediately after planting. Mulching is particularly recommended when planting on highly degraded soils in drier areas. It has less effect when used in plots that have fertile upland soils or in the ever-wet tropics. Mulching materials vary widely from rocks and pebbles to wood chips, straw, sawdust, coconut fibre, oil palm fibre and cardboard.

Corrugated cardboard makes excellent mulch mats. It is widely available and relatively cheap. Ask your local supermarket to donate their waste cardboard or other packaging materials for making mulch mats. Cut the cardboard into 40–50 cm diameter circles. Cut a hole in the middle of the circle of about 5 cm across and make a narrow slit from the circle's perimeter to its centre. Open the circle along the slit and place the hole centrally around the tree stem. Make sure that the cardboard does not touch the stem as it could abrade them, creating wounds that 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 benefits (FORRU-CMU data).

Most weed seeds are stimulated to germinate by light. Mulching around planted saplings blocks out light and thus prevents weeds from re-colonising the ground in the immediate vicinity of planted trees. Furthermore, mulching cools the soil, thereby reducing the 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.

Mulch mats, cut from recycled corrugated cardboard, are cheap and effective in reducing the immediate post-planting mortality of planted trees, particularly on drought-prone sites with poor soils. They suppress weed growth and thus reduce the labour costs of weeding. Fertiliser is applied in a ring around the base of the tree. Cardboard mats last about a year if care is taken not to disturb them during weeding operations.

Polymer gel can be used to improve hydration

Water-absorbent polymer gel can help keep the roots of planted trees hydrated and reduce transplantation stress. On well-watered highland sites, it is usually unnecessary, but when used in combination with cardboard mulch mats, it can significantly reduce the immediate post-planting mortality of trees planted in dry areas on poor soils (see **Section 5.5**).

Quality control

Even when planting techniques are demonstrated at the beginning of the event, it is inevitable that some trees will not be planted properly. Once the planters have left the site, team leaders should inspect the planted trees and correct errors. Make sure that all the trees are upright, that the soil around them has been properly firmed down, and that monitoring labels have not become buried. Look for any saplings that have not been planted and either plant them or return them to the nursery. Refill any holes that have no trees in them. Clear the site of spare bamboo poles, fertiliser sacks, plastic bags and any other garbage.

Direct seeding

Direct seeding can dramatically reduce the costs of planting a forest. It is also much easier to carry out than the laborious process of planting containerised trees, but few tree species can currently be established efficiently by this technique (**Table 5.2**). At present, the method remains complementary to conventional tree planting. The pros and cons were discussed in **Section 5.3**, but the practical techniques are presented below.

Optimal timing for direct seeding

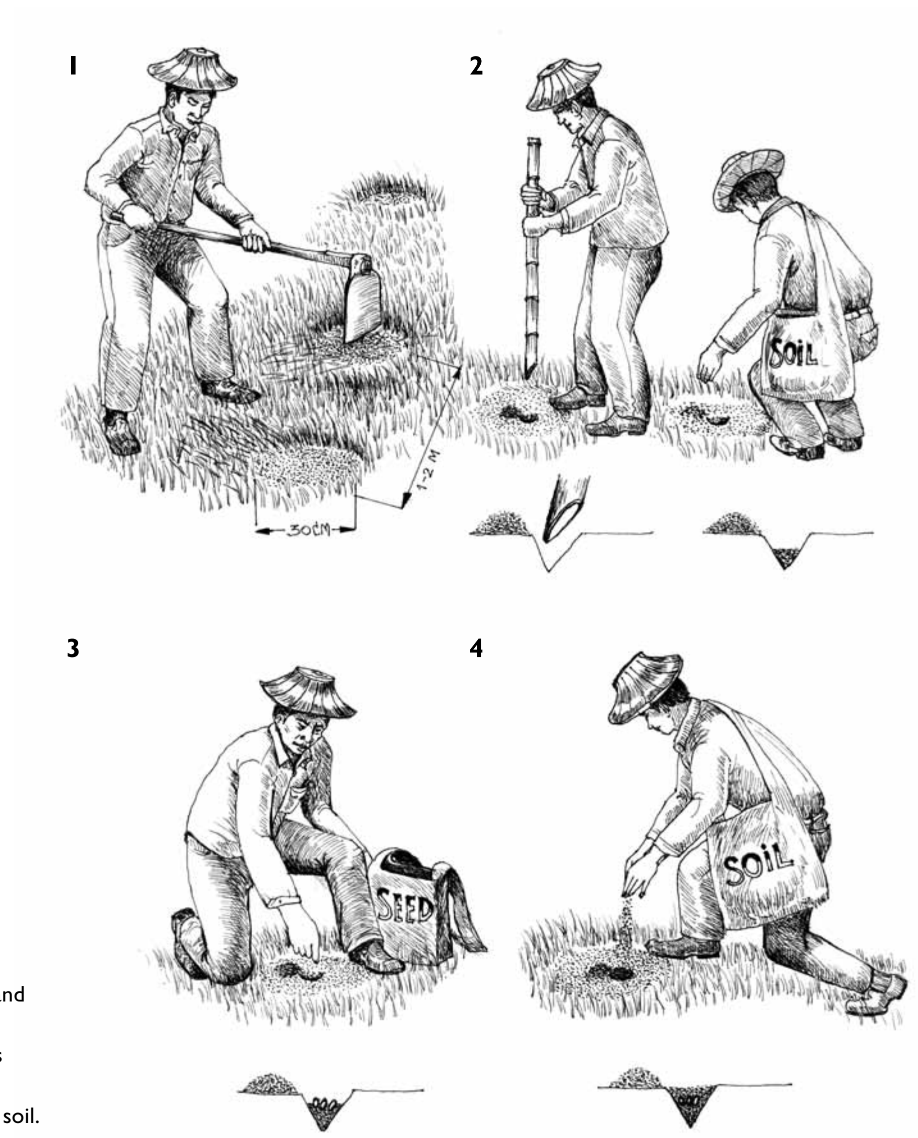
In ever-wet tropical regions, direct seeding can be implemented at any time (except during drought conditions). In seasonally dry areas, direct seeding should be carried out at the start of the rainy season (alongside conventional tree planting). This allows sufficient time for germinating seedlings to grow root systems that are capable of accessing enough soil moisture to enable the young plants to survive the first dry season after sowing. Unfortunately, the rainy season is also the peak time of year for both weed growth and the breeding of rodent seed predators, so control of these two factors is particularly important. It has been suggested that these problems would be avoided by direct seeding late in the rainy season, but recent results have confirmed that early sowing, to achieve extensive root growth before the dry season, is the overriding consideration (Tunjai, 2011).

Ensuring seed availability

Seeds must be stored from the time of fruiting until the start of the rainy season. Many tropical tree species produce recalcitrant seeds that lose viability rapidly during storage, but the storage period required for direct seeding is less than 9 months and so storage might be possible. See **Sections 6.2** and **6.6** for more information on seed storage.

Direct seeding techniques

At the beginning of a rainy season, collect seeds of the desired tree species (or remove them from storage). Apply any pre-sowing treatments that are known to accelerate the germination of the relevant species. Dig out weeds from 'seeding spots' of approximately 30 cm across, spaced about 1.5–2 m apart (or the same distance from natural regenerants if present). Dig a small hole in the soil and loosely fill it with forest soil. This ensures that beneficial symbiotic micro-organisms (e.g. mycorrhizal fungi) are present when the seed germinates. Press several seeds into each hole to a depth of about twice the diameter of the seed and cover with more forest soil. Lay mulching material, such as the pulled weeds, around the seeding spots to suppress further weed growth. During the first two rainy seasons after seeding, pull weeds by hand from the seeding spots as required. If multiple seedlings grow up at any seeding point, remove the smaller, weaker ones, so that they do not compete with the largest seedling. Carry out experiments to determine the most successful species and techniques for direct seeding at any particular site.



1. First, clear weeds from seeding spots.
2. Next, make small holes and add forest soil.
3. Then, press several seeds into the loose soil.
4. Finally, cover with forest soil.

7.3 Caring for planted trees

In deforested sites, planted trees are subjected to hot, dry, sunny conditions as well as to competition from fast-growing weeds. Protective measures (as described in **Section 5.1**) must be implemented to prevent fire and cattle from killing both planted trees and any natural regenerants that are present. Weeding and fertiliser application (see **Section 5.2**) are also essential for at least 18–24 months after planting in order to maximise tree growth and accelerate canopy closure. No further maintenance is necessary after canopy closure.

Fire prevention and excluding livestock

The cutting of fire breaks, organisation of fire suppression teams and exclusion of livestock from restoration sites are discussed in **Section 5.1**.

Weeding

Weeding reduces competition between planted or naturally established trees and herbaceous plants. On nearly all tropical sites, weeding is essential to prevent high tree mortality in the first two years after planting. The ring-weeding and weed-pressing methods described in **Section 5.2** can be applied equally well to planted trees as to natural regenerants.

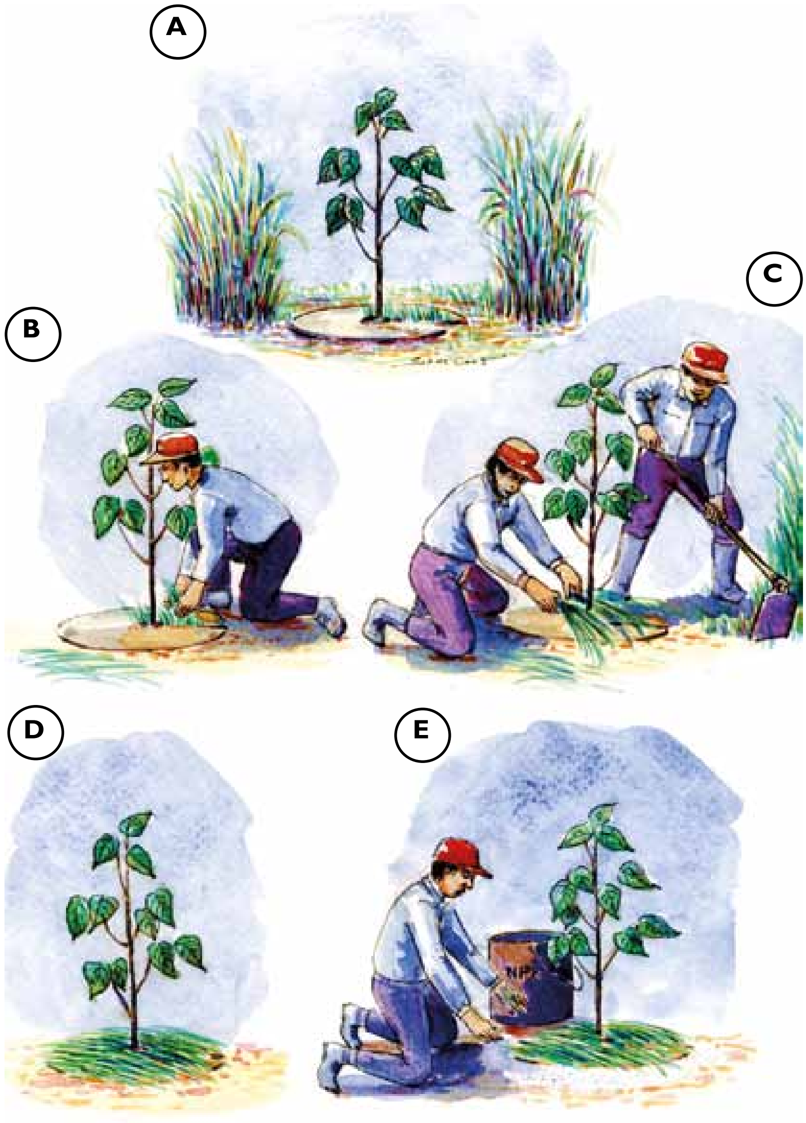
Weeding frequency

The frequency of weeding depends on how fast the weeds grow. Visit the site frequently to observe weed growth and carry out weeding well before the weeds grow above the crowns of the planted trees. Weed growth is most rapid during rainy seasons. After planting, weed around planted trees at 4–6-week intervals for as long as the rains continue. If weed growth is slow, it may be possible to reduce the weeding frequency. It should not be necessary to weed during dry seasons.

In seasonal forests, allow some weed growth to occur before the end of the rainy season to help to shade the planted trees and thereby to prevent desiccation when the weather is hot and dry. Remember, however, that this also increases the fire risk, so only do this where fire prevention measures are effective. Where fire is particularly likely, try to keep the planted plots free of weeds at all times. The labour force required for weeding varies with weed density but, as a guide, budget for 18–24 days labour per hectare.

How long must weeding be continued?

Weeding is usually necessary for two rainy seasons after planting. In the third year after planting, the frequency of weeding can be reduced if the crowns of the planted trees begin to meet and form a forest canopy. By the fourth year, the shade of the forest canopy should be sufficient to prevent further weed growth.



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

Weeding techniques

The weed-pressing method described in **Section 5.2** may be used to flatten weeds growing between the trees. If the weeds are not susceptible to pressing, then use machetes or a ‘weed whacker’ (a mechanical hand-held weed cutter), keeping well away from both planted and natural trees to avoid accidentally slashing them.

A more delicate approach is required around the trees themselves. Wear a pair of gloves and gently pull out any weeds growing close to tree stems, including any growing through mulch. Try not to disturb the mulch too much. Use a hoe to dig out weeds close to the mulched area by their roots. Lay uprooted weeds around the trees on top of the existing mulch. This shades the soil surface and inhibits the germination of weed seeds, even as the organic mulch rots away. Try to ensure that uprooted weeds do not touch the tree stems as such contact can encourage fungal infection. Apply fertiliser around each tree immediately after weeding.

Frequency of fertiliser application

Even on fertile soils, most tree species benefit from the application of additional fertiliser during the first two years after planting. It enables the trees to grow above the weeds rapidly and to shade them out, thus reducing weeding costs. Apply 50–100 g fertiliser, at 4–6-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 fertiliser around the edge of the mulch mat. Chemical fertiliser (N:P:K 15:15:15) is recommended for upland sites, whereas organic pellets produce significantly better results on lateritic lowland soils (but see **Section 7.2**). Weeding before fertiliser application ensures that the planted trees benefit from the nutrients and not the weeds.

7.4 Monitoring progress

All tree-planting projects should be monitored, but there are many different approaches to monitoring, ranging from basic photo-monitoring and assessment of tree survival rates (described here) to complex field trial systems designed to investigate species performance, the effects of silvicultural treatments and biodiversity recovery (described in **Section 7.5**).

Why is monitoring necessary?

Funders want to know if the tree planting they pay for is successful, so monitoring results are usually an essential component of project reports. Initially, this means finding out whether or not the planted trees have survived and grown well in the first few years after planting, but the ultimate measure of success is how fast the restored forest becomes similar to the target forest ecosystem in terms of structure and function (see **Section 1.2**) and species composition (see **Section 7.5**). Interest in monitoring techniques is growing rapidly and the monitoring systems being proposed are becoming ever more complex and stringent. This is because of the value now being put on forests as carbon stores. Small errors in monitoring can result in the gain or loss of large sums of money in carbon trade. Therefore, if your project is funded by a carbon-offset scheme (e.g. REDD+), make sure that you follow the monitoring protocols stipulated by the funder and be prepared to have every aspect of your monitoring program closely scrutinised.

Simple monitoring using photography

The most simple way to assess the effects of tree planting is to take photographs before planting and at regular intervals (once per season or annually) thereafter. A neighbouring site, where no forest restoration has been implemented, can be similarly photographed so that restoration can be compared with unassisted natural regeneration. Locate points with a clear view of both the planted sites and notable landmarks. Mark the position of the points with a metal or concrete pole or paint an arrow on a large rock. Set the camera to the highest resolution and widest zoom and try to use to same camera for all shots. Frame each shot so that a landmark is positioned on the left-hand or right-hand edge of the picture and so that the horizon is aligned close to the top edge (i.e. minimise the amount of sky in the picture). Record the date, point number, location (co-ordinates if you have a GPS), and age of plot and use a compass to measure the direction in which the camera is pointed. The photos in **Section 1.3** (p. 14) are good examples. In these pictures, the large black tree stump serves as a reference point.

As soon as possible, download the photos onto a computer and back them up to a storage device or the internet. Use a logical file-naming system so that the photos can easily be arranged in chronological order and by point location (e.g. 2013_Point1_Plot141231). When you return to take more photos, take the previous ones with you, so that you can use the landmarks to position the new shots to be as similar as possible to the previous shots.

Photos are easy to take and share, and they provide an easily understood representation of the progress of restoration projects. However, funders usually require some kind of monitoring of tree survival and growth. In that case, label a subset of the trees planted and measure them at regular intervals.

Sampling trees for monitoring

The minimum requirement for adequate monitoring is a sample of 50 or more individuals of each species planted. The larger the sample is, the better. Randomly select trees to include in the sample; label them in the nursery before transporting them to the planting site. Plant them out randomly across the site, but make sure that you can find them again. Place a coloured bamboo pole by each tree to be monitored; copy the identification number from the tree label onto the bamboo pole with a weather-proof marker pen and draw a sketch map to help you find the sample trees in the future.

Labelling planted saplings

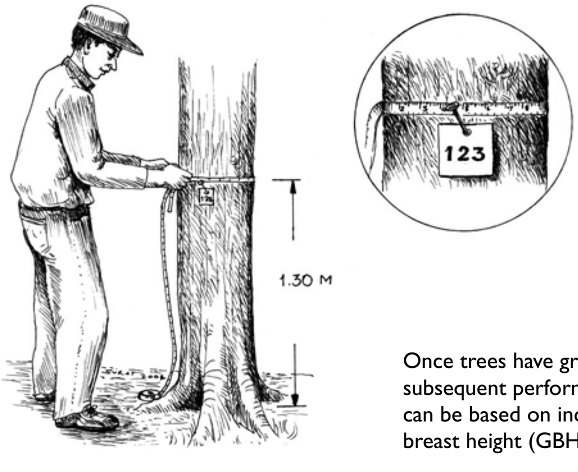
The soft metal strips used to bind electrical cables, which are available from builders' supply stores, make excellent labels for small trees. They can easily be formed into rings around tree stems. Use metal number punchers or a sharp nail to engrave an identification number on each label and bend them into a ring around the stem above

Before planting, place metal strip labels around the tree stems. Make sure they do not get buried during planting. Label numbers could include information on species, year of planting, plot number and tree number. For example, 22-48 12-3 could mean the 48th individual of species number 22, planted in plot 3 in the year 2012. Keep accurate records of your numbering system.

the lowest branch (if present). This will prevent the label from being buried when the tree is planted. Alternatively, drink cans may be cut up to make excellent tree labels. Cut off the top and bottom of the cans and slice the cans' walls into strips. Use a tough ball-point pen or nail to press identification numbers into these soft metal foil strips (on the inside surface). The strips can be formed into loose rings around saplings' stems.

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

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



Once trees have grown large, subsequent performance monitoring can be based on increase in girth at breast height (GBH).

Monitoring tree performance

To monitor tree performance, work in pairs with one partner taking measurements and the other recording data on pre-prepared record sheets. One pair can collect data on up to 400 trees per day. Prepare record sheets that include a list of the identification numbers of all labelled trees in advance (see **Section 7.5**). Take along the sketch maps made when the labelled trees were planted to help you find them. In addition, take a copy of the data collected during the previous monitoring session. This can help you sort out tree identification problems, especially for trees that might have lost their labels.

When to monitor

Measure the trees 1–2 weeks after planting to provide baseline data for growth calculations and to assess immediate mortality, which might result from transplantation shock or rough handling during the planting process. After that, monitor the trees annually; in seasonal forests, this task should be undertaken at the end of each rainy season. The most important monitoring event, however, is at the end of the second rainy season after planting (or after about 18 months), when field performance data can be used to quantify the suitability of each tree species to the prevailing site conditions (see **Section 8.5**).

What measurements should be made?

Rapid monitoring of tree performance can involve simple counts of surviving and dead trees, but recording the condition of planted trees each time they are inspected can give an early indication of whether something is going wrong. Assign a simple health score to each tree and record descriptive notes about any particular health problems observed. A simple scale of 0 to 3 is usually sufficient to record overall health. Score zero if the tree appears to be dead. For deciduous tree species, don't confuse a tree with no leaves in the dry season with a dead one. Do not stop monitoring trees just because they score zero on one occasion. Trees that appear dead above ground could still have living roots from which they might 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 height of planted trees from the root collar to the highest meristem (growing point).

More detailed monitoring of tree performance involves measuring tree height and/ or girth (for calculation of growth rate) and crown width. In the first year or two after planting, tree heights can be measured with 1.5 m tape measures mounted on poles. Measure the tree height from the root collar to the highest meristem (shoot tip). For taller trees up to 10 m, telescopic measuring poles can be used. These poles are commercially available but can be home-made. Measurements of girth at breast height (GBH), rather than of height, are easier to make for taller trees and can be used to calculate growth rates.

Calculations of tree growth rates that are based on height can sometimes be unreliable as shoots can occasionally be damaged or die back, resulting in negative growth rates for small saplings even though the tree could be growing vigorously. Consequently, measurements of root collar diameter (RCD) or GBH often provide a more stable assessment of tree growth. For small trees, use callipers with a Vernier scale to measure RCD at the widest point (for use of callipers, see **Section 6.6**). Once a tree has grown tall enough to develop a GBH of 10 cm, measure both the RCD and the GBH the first time and only GBH thereafter.

Suppression of weed growth (an important framework characteristic) can also be quantified. Measuring crown width and using a scoring system for weed cover can help to determine the extent to which each tree species contributes to site 'recapture'. Use tape measures to measure the width of tree crowns at their widest point. Imagine a circle of about 1 m in diameter around the base of each tree. Score 3 if weed cover is dense over the whole circle; 2 if weed cover and leaf litter cover are both moderate; 1 if only a few weeds grow in the circle and 0 for no (or almost no) weeds. Do this before weeding is due to be carried out.

Measure crown width at the widest point to assess canopy closure and site 'recapture'.

Data analysis

For each species, calculate per cent survival at the end of the second rainy season after planting (or after 24 months) as follows:

$$\% \text{ Survival estimate} = \frac{\text{No. of labelled trees surviving}}{\text{No. of labelled trees planted}} \times 100$$

Use per cent survival of the labelled sample trees to estimate how many trees of each species survived across the whole site. Then determine the survival percentage of the total number of trees planted as shown in **Table 7.1**.

Table 7.1. Example calculation of species' survival rates.

Species	No. of labelled trees in sample	No. of labelled trees surviving	Estimated % survival (%S)	Total no. of trees planted (TP)	Estimated no. surviving (TP × %S/100)
S004	50	46	92	1,089	1,002
S017	50	34	68	678	461
S056	50	45	90	345	311
S123	50	48	96	567	544
S178	50	23	46	358	165
Totals				**3,037**	**2,482**
Estimated overall % survival		**81.7**			

To determine significant differences in survival between species, use a Chi-square (χ^2) test. Fill in a table with the number of dead and alive trees of the two species you want to compare as follows:

Species	Alive	Dead	Total
S123	48	2	50
S178	23	27	50
Total	71	29	100

a	b	a+b
c	d	c+d
a+c	b+d	a+b+c+d

Calculate the Chi-square (χ^2) statistic, using the formula:

$$(\chi^2) = \frac{(ad-bc)^2 \times (a+b+c+d)}{(a+b) \times (c+d) \times (b+d) \times (a+c)}$$

A significant difference in survival is indicated by a calculated Chi-square value exceeding 3.841 (with a <5% probability of error). This critical value is independent of the number of trees in the samples. In the example above, 30.35 greatly exceeds the critical value, so we can be very confident that S123 survives significantly better than S178 (for more information, go to www.math.hws.edu/javamath/ryan/ChiSquare.html). Remove species with low survival rates from future plantings and retain those with higher survival rates (see **Section 8.5**).

Calculate mean tree height and RCD for each species and calculate relative growth rates (RGR; see **Section 7.5**). To show significant differences among species, use the statistical test, ANOVA (see **Appendix A2.2**).

Monitoring other aspects of forest restoration

Detailed survey methods that are used to determine forest recovery are described in **Section 7.5**, but if you do not have the capacity or resources to implement them, then simple informal monitoring can at least provide stakeholders with the sense of achievement needed to sustain interest in the project. Make regular visits to the planted plots and record when the first flowers, fruits or birds' nests are seen on or in each of the planted tree species. Record any sighting of an animal (or their signs), especially of seed-dispersers. Once canopy closure occurs, survey the plots for naturally establishing tree seedlings or saplings and record the return of notable species. This helps to provide an impression of how quickly the restored forest begins to resemble the target forest and how fast biodiversity recovery occurs.

Monitoring for carbon accumulation

Many funders want to know how much carbon is being stored by the trees in a restoration project so that they can offset their carbon footprints or cash in on the carbon trade. Consequently, funders often require project implementers to follow international accreditation and monitoring standards, which include independent audits to verify carbon accumulation. There are many different forest carbon standards that differ in the way that they are used to survey forestry projects for carbon offset. The four that are most relevant to forest restoration projects are listed in **Table 7.2**. If your project is registered with one of these organisations, make sure you follow the monitoring protocols that they stipulate. The development of the Project Design Document (PDD), 'validation' and 'verification' of carbon storage, well as carbon credit registration can cost anywhere between US$ 2,000 to US$ 40,000. Such high charges effectively exclude small organisations from participating in these schemes, except in the case when numerous organizations bundle their projects together to obtain certification. Furthermore, community organisations often lack the expertise needed to complete the complex application and verification procedures. Our advice to small organisations is to seek sponsorship through corporate social responsibility mechanisms that are independent of carbon funding.

Table 7.2. Carbon standards organisations.

Organisation	Notes	Website
CarbonFix	Simplified, user-friendly standard that guarantees high-quality carbon credits. Adaptable to the needs of project developers and funders. Recommended for restoration projects.	www.carbonfix.info
Verified Carbon Standard (VCS)	A high-quality standard that guarantees that the carbon credits are real, verified, permanent, additional and unique. Provides detailed methodologies to quantify reduced carbon emissions.	www.v-c-s.org
Plan Vivo	Projects are allowed to develop their own methodologies in association with research institutes or universities. Objectives include a positive impact on rural communities. Quantification of carbon accumulation lacks the general rigour of other standards.	www.planvivo.org
Climate, Community & Biodiversity (CCB) standard	Quantifies the co-benefits of socio-economic and biodiversity factors, but advises use of VCS to certify carbon credits.	www.climate-standards.org

To estimate carbon accumulation in a forest that is undergoing restoration, you need to know the mass of trees per unit area. Tree trunks and roots contain most of the above-ground carbon in a forest; the amount of carbon in tree leaves and ground flora is almost negligible compared with that in the trunks and roots.

Simple measurements of the girths of the tree trunks over a known area can provide a rough approximation of most of the above-ground carbon (AGC), which is calculated using published equations (termed 'allometric' equations) that describe the relationship between a tree's diameter at breast height (and/or tree height) and its above-ground dry mass in kilograms. These equations are prepared by researchers who fell trees of widely differing girths and then dry and weigh them piece by piece. Different equations are used for different forest types and even for different tree species, so project developers need to search the literature for an equation that most closely matches the forest type that is being restored (see Brown, 1997; Chambers *et al*., 2001; Chave *et al*., 2005; Ketterings *et al*., 2001; Henry *et al*., 2011). The use of these equations involves some tricky maths, so ask a mathematician if you don't understand them.

The alternative, if allometric equations do not exist for the required forest type, is to use default values of forest type based on international, domestic or local sources. The default international values are listed in **Table 7.3**.

To sample carbon accumulation in the field, use metal poles to mark at least 10 permanent sample points across the restoration site. Use a 5-m-long piece of string to determine which trees are within 5 m of the poles and then measure their girths at breast height (1.3 m from the ground). Divide tree girth by pi (3.142) to convert to tree diameter. Then use the allometric equations to estimate the above-ground dry mass of each tree in kg from its diameter. Convert to a per-hectare value as follows:

$$\frac{\text{Sum of above-ground dry mass (kg) of all trees in all circles} \times 10{,}000}{\text{No. circles} \times 78.6}$$

Divide the result by 1,000 to convert to metric tonnes (i.e. Megagrams (Mg) in SI units) per hectare and compare your results with values typical for tropical forests (**Table 7.3**) to see how close your restored forest is to typical forest target values.

Table 7.3. Typical above-ground biomass figures for different types of tropical forests. Drier tropical forests typically contain less biomass than wetter ones (IPCC, 2006; Table 4.7).

Forest type	Continent	Above-ground biomass (tonnes dry mass per hectare)
Tropical rain forest	Africa, N. & S. America, Asia (continental), Asia (insular)	310 (130–510) 300 (120–400) 280 (120–680) 350 (280–520)
Tropical moist deciduous forest [= Seasonal tropical forest]	Africa, N. & S. America, Asia (continental), Asia (insular)	260 (160–430) 220 (210–280) 180 (10–560) 290
Tropical dry forest	Africa, N. & S. America, Asia (continental), Asia (insular)	120 (120–130) 210 (200–410) 130 (100–160) 160

To calculate the mass of tree roots multiply the above-ground biomass by 0.37 for tropical evergreen forest or by 0.56 for drier tropical forest (Table 4.4 in IPCC, 2006) or consult Cairns *et al*. (1997) for ratios for other forest types. When these results are added to above-ground biomass, you have an estimate for tonnes dry-mass of trees per hectare.

The carbon content of dry tropical wood varies considerably among species, but the average value is around 47% (Table 4.3 in IPCC, 2006; Martin & Thomas, 2011). Therefore, multiply the result by 0.47 to arrive at an estimate of the mass of carbon in trees per hectare.

To find out how much the carbon is worth, convert tonnes of carbon into an equivalent value of tonnes of carbon dioxide by multiplying by 3.67, then look up the value of a tonne of carbon dioxide equivalent on the carbon credit markets at: www.tgo.ot.th/english/index.php?option=com_content&view=category&id=35&Itemid=38. See also World Agroforestry Centre manual, available free from: www.worldagroforestry.org/sea/Publications/files/manual/MN0050-11/MN0050-11-1.PDF.

7.5 Research for improving tree performance

If you have sufficient resources, you may wish to consider turning your forest restoration project into a research program in which you collect more information than usually comes from the basic monitoring procedures outlined above. This requires collecting data in a systematic way, over several 'replicated' plots — a so-called 'field trial plot system' or FTPS for short. An FTPS can be used to compare the performance of planted tree species, to evaluate the effects of silvicultural treatments, to assess biodiversity recovery and carbon accumulation and to determine the optimum design and management of restoration plots. It can also become a valuable demonstration tool that can be used to teach others effective restoration techniques and how to avoid repeating expensive mistakes.

What is an FTPS?

An FTPS is a set of small plots (typically 50 × 50 m = 0.25 ha), each one planted with a different mixture of tree species and/or silvicultural treatments using the randomised complete block design described in **Chapter 6** (p. 198) and in **Appendix A2.1**. Each planting season, new plots are added to the system. In the new plots, the tree species and treatments that worked best in previous years are retained, using the selection procedure described in **Section 8.5**, while poorly performing species and unsuccessful treatments are dropped to make room for new species and treatments to be tested. If the work goes well, the younger plots out-perform the older ones because an FTPS is gradually improved in response to incoming data. Therefore, select an area for an FTPS that has plenty of unused land available for future expansion. An ideal area for planting over a 10-year period should be at least 20 ha.

Using the recommended spacing of 1.8 m between trees and a standard plot size of 50 × 50 m requires about 780 trees per plot. With a minimum acceptable sample size of 20 individuals per species, this allows for a maximum of 39 species to be tested each year.

Objectives for an FTPS

An FTPS has three main objectives: i) to generate scientific data that are used to develop 'best field practices' for effective forest restoration; ii) to test the practicability of those best practices; and iii) to provide a demonstration site for education and training in forest restoration methods.

The scientific questions addressed by the FTPS can include:-

- Which of the tree species tested meet required criteria?
- What is the optimum planting density?
- What silvicultural treatments (e.g. weeding, fertiliser application, mulching etc.) maximise the performance of the planted trees? How frequently and for how long should such treatments be applied?
- How can plantation design be optimised (e.g. how many species per plot)?
- Which species can or cannot be grown next to each other?
- How fast does biodiversity recover? How does distance to nearest forest affect biodiversity recovery?

An FTPS is also a valuable education and training facility.

Research in an FTPS should address the simpler questions (relating to species performance and silvicultural treatments) first and explore more complex issues (such as species mixes, distance to natural forest and so on) later. As all of the trees in the plots are of known age and species and most are labelled, the FTPS inevitably becomes a research resource that is much sought after by other scientists and research students.

Where should the FTPS be established?

In reality, the position of an FTPS can be determined by basic questions of land ownership and proximity to the FORRU host organisation, but where possible, try to take into account of the scientific and practical considerations below.

Scientific considerations

Uniformity — plot experiments are notoriously vulnerable to variability in site conditions. It might be difficult to separate the effects of treatments applied in different plots from the effects of differences in environmental conditions among the plots. To some extent, this problem can be compensated for by using a randomised complete block experimental design, but it helps if the FTPS is established over fairly uniform terrain in terms of elevation, slope, aspect, bedrock, soil type and so on.

Vegetation — match the restoration techniques tested in an FTPS with the initial degradation stage of the site (see **Section 3.1**).

Conservation value — FTPSs are particularly valuable when located within a protected area or its buffer zone, or wherever biodiversity conservation is the top management priority. Using an FTPS to create corridors to link forest remnants gives it extra conservation value.

Practical considerations

Accessibility and topography — reasonably convenient access, at least by 4WD vehicles, is essential, not only for planting, maintenance and monitoring the planted trees but also to facilitate visits to the plots for education purposes. Select an area within 1 or 2 hours drive of the FORRU nursery or headquarters. Obviously flatter sites are easier to work with than steep ones.

Proximity to a local community that supports the idea of forest restoration — this enables the exchange of scientific and indigenous local knowledge and access to experience of the social aspects of framework forestry. A local community can provide a source of labour and security for trial framework species plots (see **Section 8.2**). The importance of including all stakeholders in discussions about FTPS establishment was covered in **Chapter 4**. Abandoned, former agricultural land where cultivation has become too difficult or uneconomic because of deteriorating environmental conditions is ideal.

Land tenure — if the FORRU host organisation does not own the land, it must enter into agreement with the authority that controls land use in the area. This will most probably be the government department in charge of forestry or conservation or possibly a local community.

Establishing the plots

An FTPS consists of several treatment plots (T) and two kinds of control plot: 'treatment control' (TC) plots and 'non-planted control' (NPC) plots. First, decide on a standard set of procedures to follow to establish the TC plots. The standard protocol should be based on current best-known practices for growing trees in the area, which can be derived from experience and indigenous knowledge and by considering local conditions. The standard protocol can be improved year-by-year by incorporating the treatments that were most successful in the analyses of each year's field experiments. Each year the effects of new treatments, applied in the T plots, are measured by comparison with the TC plots.

Start with the following protocol and modify it to suit local conditions:

- Six to eight weeks before planting, measure out the plots; demarcate the corners with concrete posts or similar and make a map of the plots, clearly indicating plot identification numbers and which plots will receive which treatments.
- Then, slash weeds down to ground level (except in non-planted control plots), but avoid cutting any naturally established tree seedlings and saplings and coppicing shoots (mark them beforehand with coloured poles or flags).
- One month before planting, apply a non-residual herbicide (e.g. glyphosate) to kill sprouting weeds.
- Label the trees and plant at the appropriate time.
- Plant the appropriate number of candidate tree species (if possible equal numbers of all species, at least 20 trees of each species per plot) spaced, on average, 1.8 m apart. Randomly mix the species across each plot.
- If necessary, apply 50–100 g of NPK 15:15:15 fertiliser in a ring about 20 cm away from the stems of planted trees at planting time.
- During the first rainy season (or the first 6 months after planting in a wet forest) repeat the fertiliser treatment and weed around the trees (using hand tools) at least three times, at 6–8 week intervals (adjust frequency according to the rainfall and rate of weed growth).

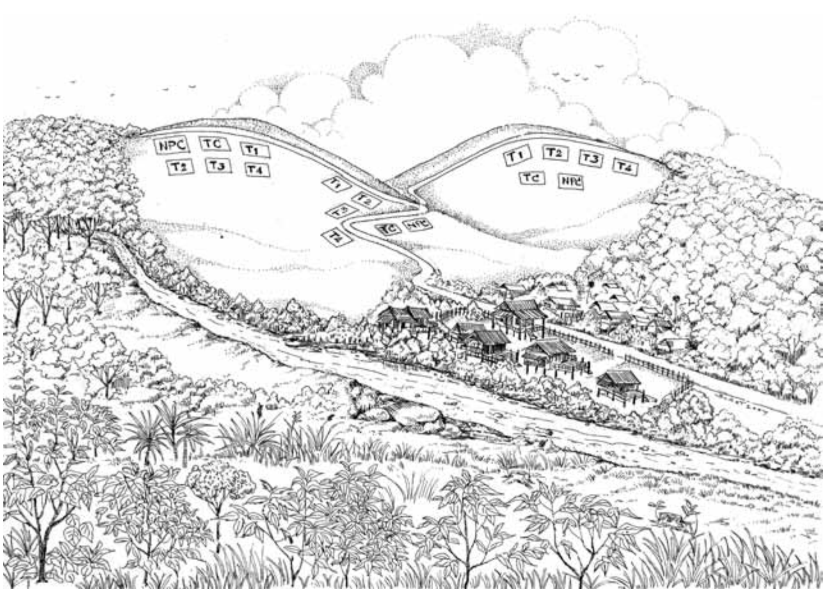
- At the start of the first dry season after planting (in seasonal tropical forests), cut fire breaks around the plots and implement a fire prevention and suppression program.
- Repeat weeding and fertiliser application during the second rainy season after planting.
- At the beginning of the third rainy season, assess the need for further maintenance operations.

Immediately adjacent to the TC plots, establish 'treatment' (T1, T2, T3, etc.) plots, simultaneously in exactly the same way, but vary only one component of the standard protocol (e.g. fertiliser or weeding technique etc.). Tree performance in the T plots is then compared with that in the TC plots.

Experimental design

A randomised complete block design (RCBD) is recommended. Block together single replicates of each type of T plot with one TC plot and replicate the blocks in at least three locations across the study site (4–6 locations would be better). Position the blocks at least a few hundred metres apart, if possible, to take into account variability in conditions (slope, aspect and so on) across the study area. Randomly allocate treatments to each T plot within each block. Plant 'guard rows' of trees around each plot and block to prevent one treatment from influencing another and to reduce edge effects.

Next add 'non-planted control' (NPC) plots, in which no trees are planted, no treatments are applied and the vegetation is left undisturbed to undergo natural succession. The function of NPC plots is to generate baseline data on the natural rate of biodiversity recovery in the absence of forest restoration plantings and treatments. Biodiversity recovery in the restoration plots is then compared with what would have happened naturally if forest restoration had never been implemented. Associate one NPC plot with each block of TC and T plots. If the NPC plots are adjacent to the planted plots, birds that are attracted by the planted trees will 'spill over' into the NPC plots. So NPC plots should be placed at least 100 m away from planted plots.



A randomised block design, with three blocks spread across the study area. Blocks are positioned at least a few hundred metres apart and not far from remnant forest. T = treatment plot; TC = control plot and NPC = non-planted control plot.

Choice of treatments

Consider the main factors that limit tree survival and growth at the study site, and design treatments to overcome them. For example, if soil nutrients are limiting, try varying the type of fertiliser, the amount applied each time and/or the frequency of application. Alternatively, experiment with adding compost to the planting hole. If competition with weeds is the most obvious limiting factor, try varying weeding techniques (e.g. hand tools or herbicide) or the frequency of weeding, or try using dense mulch (e.g. cut weeds or corrugated cardboard) to suppress the germination of weed seeds in the immediate vicinity of planted trees. Other treatments to try include placing polymer gel or mycorrhizal inoculae in planting holes or subjecting trees to various pruning treatments before planting.

Write a field experiment plan

Prepare a working document, containing the following information:

- a sketch map of the plot system, indicating plot identification numbers and which plots receive which treatments;
- a list of species planted in the plots and the label numbers of each tree planted in each plot;
- a description of the standard planting protocol;
- a description of the treatments to be applied in each plot and a schedule for their application;
- a schedule for data collection.

Consistent application of silvicultural treatments is one of the most important and costly components of field experiments.

Make sure all FORRU staff receive a copy of the document, understand their roles in establishing, maintaining and monitoring the plots, and have been adequately trained in how to apply the specified treatments. One of the main causes of experiment failure is inadequate or inconsistent treatment application.

Monitoring field experiments

Labelling saplings

Label trees in the nursery before planting them, as described in **Section 7.4**. The minimum information on the label should be the species number and tree number. Additional information could include the plot number and year of planting, but whatever system is used, no two trees in the entire plot system should carry the same label numbers, no matter when or where they are planted.

When to monitor

As with basic monitoring (see **Section 7.4**), collect data about two weeks after planting and at the end of each growing season (i.e. rainy season), with the most important monitoring event being at the end of the second rainy season after planting. Additional monitoring at the end of each dry season can provide more detailed information about when and why trees die.

What measurements should be made?

Record survival, health, height, root collar diameter, crown width and weed score for both planted trees and natural regenerants, as for basic monitoring (see **Section 7.4**).

Maintains original order when sorting the spreadsheet

From previous monitoring event

See 'Survival and Health' for scores

See 'Suppression of weed competition' for scores

Planted Tree Monitoring

File Name: Monitoring Data at MSM (Uni project)

Plot Name: 2006 | Plot Location: Ban Mae Sa Mai watershed

Monitoring Date: 5th November 2006 | Recorder/s: CK, PT, TS, SK

ORDER NUMBER	SPECIES NUMBER	LABEL NUMBER	PREVIOUS NOTE	ROOT COLLAR DIAMETER (mm)	HEIGHT (cm)	CROWN WIDTH (cm)	HEALTH SCORE (0–3)	WEED SCORE (0–3)	NOTE
401	344	10		15.0	49.5	56.0	3	3	
402	344	11		22.4	82.0	69.0	2	3	
403	344	12		29.4	185.0	95.0	2	3	
404	344	13		24.4	125.5	74.0	2	3	
405	344	14	DEAD						
406	344	15		13.6	46.0	71.0	2	3	
407	344	16		20.6	66.5	63.0	3	2	
408	344	17		12.4	76.0	83.0	2	3	
409	344	18		16.0	59.0	60.0	3	2	
410	344	19		12.8	47.5	51.0	2	3	
411	344	20		28.4	177.5	89.0	3	2	
412	364	1		10.2	52.0	50.0	2	3	
413	364	2		21.4	49.0	7.0	2	3	
414	364	3		19.3	111.0	96.0	3	2	
415	364	4		14.2	55.0	44.0	2	3	
416	364	5		15.4	54.0	68.0	3	3	
417	364	6		10.5	53.5	54.0	2	3	
418	364	7		13.7	86.0	77.0	2	3	
419	364	8		15.7	100.0	62.0	2	3	
420	364	9		19.4	98.0	57.0	2	3	
421	364	10		14.8	61.0	49.5	2	2	
422	364	11		[illegible]	[illegible]	94.5	[illegible]	[illegible]	

Same as for phenology and germination trials

Additional observations that might assist data interpretation and future monitoring

			15/7/98	19/11/98	9/11/99	5/10/00	15/7/98	19/11/98	9/11/99	5/10/00
Plot No.	Species No.	Tree No.	Health Score (0–3)	Health Score (0–3)	Health Score (0–3)	Health Score (0–3)	Height (cm)	Height (cm)	Height (cm)	Height (cm)
1	7	1	3	3	2	3	39	93	147	231
1	7	2	3	2	3	3	39	109	173	287
1	7	3	2	3	3	3	53	144	229	347
1	7	4	2	NF	0	0	56	NF	-	-
1	7	5	3	3	3	3	59	164	265	354
1	7	6	2.5	0	0	0	32	-	-	-
1	7	7	3	3	3	3	43	81	128	252
1	7	8	3	3	3	3	41	68	108	171
1	7	9	0.5	0	1	2	30	-	21	40
1	7	10	3	2.5	3	3	64	63	237	300
1	7	11	3	0.5	3	3	49	48	160	300
1	7	12	0.5	0	NF	0	34	-	NF	-
1	7	13	2.5	0	0	0	44	-	-	-
1	7	14	2	1.5	3	2.5	30	29	106	297
1	7	15	2	2	0	0	27	26	-	-
1	7	16	3	2.5	3	3	23	43	90	125
1	7	17	3	3	2.5	3	37	51	140	166
1	7	18	3	2.5	3	0	39	60.5	20	-
1	7	19	3	3		3	28	99	NF	341
1	7	20	2.5	2.5	1.5	3	35	46.5	53	110

Sort the data first by species number and then by tree number.

Data analysis and interpretation

Organise the spreadsheet

First, enter the field data into a computer spreadsheet. Insert new data to the right of previously collected data, so that one row represents the progress of an individual tree running chronologically from left to right. Next, sort the data by rows, first by species number and then by tree number. This groups all trees of the same species together. Insert the date on which the data were collected in the cell immediately above every column heading. Then sort the spreadsheet by column (left to right), first by column heading (row 2) and then by date (row 1). This groups the same parameters together in chronological order from left to right. The data can now be easily scanned for interesting features or anomalies and manipulated to extract the values required below for more detailed statistical analysis.

Comparing species

As in the nursery experiments, you could start by comparing survival and growth among species. To compare differences in survival, start with trees in the TC plots only: scan the spreadsheet and count the number of surviving trees in the TC plot in each block. If the same number of trees of each species was planted in every plot, simply enter the number of surviving trees into a new spreadsheet, with species as column headings and one row per block (or replicate), as shown below. If different numbers of trees of each species were planted, then calculate the percentage survival in each plot and enter those data into the new spreadsheet. Then follow the instructions in **Appendix 2** to arcsine transform the data and carry out an ANOVA. In this case, each species is the equivalent of a 'treatment' (there is no control when comparing species).

15/7/98	19/11/98	9/11/99	5/10/00	19/11/98	9/11/99	5/10/00	9/11/99	5/10/00
RCD (mm)	RCD (mm)	RCD (mm)	RCD (mm)	Weed Score (0–3)	Weed Score (0–3)	Weed Score (0–3)	Width of Canopy (cm)	Width of Canopy (cm)
6.2	14.8	23.3	36.7	3	2.5	1	73	115
7.1	17.3	27.5	45.6	2.5	2	2	86	143
9.4	22.9	36.4	55.1	3	2	1	114	173
9.2	NF	-	-	NF	-	-	-	-
10.1	26.2	42.2	56.3	1.5	1	0.5	148	200
6.7	-	-	-	-	-	-	-	-
5.5	12.9	20.3	40.1	1	1	0.5	64	126
4.5	10.8	17.1	27.2	1.5	1	1	95	150
6.1	-	2.1	5.4	-	-	-	-	-
6.7	18.2	29.6	59	1.5	1	1	150	200
5.1	13.4	21.6	47	1.5	1	2	103	200
4.3	-	NF	-	-	NF	-	NF	-
6.5	-	-	-	1.5	-	-	-	-
5.6	9.3	13	37	1.5	2	2	93	150
5.6	6.1	-	-	1.5	-	-	-	-
3.2	10.6	18	21	1.5	1.5	1	80	75
5.4	15.2	25	22	1.5	2	1	90	125
4.3	3.9	3.4	-	1.5	1.5	-	23	-
5.9	24	NF	54	1.5	NF	0	NF	200
5.6	9.2	12.8	14	1.5	0.5	2	65	108

Then sort columns by heading and then by date to group parameters together in chronological order from left to right.

The same procedure can be followed to compare the species-means of height, root collar diameter (RCD), crown width, and relative growth rates in each TC plot, although these data do not need to be arcsine transformed. In addition to the absolute size of the trees (height or RCD), it is useful to know how fast the trees are growing. This is

SPECIES

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20
Block 1	24	4	10	2	25	20	15	10	2	14	25	24	18	5	7	8	12	17	1	5
Block 2	22	2	11	3	25	21	16	13	3	15	24	24	13	6	8	9	13	16	2	6
Block 3	26	3	12	2	25	23	14	14	5	16	25	25	18	7	9	8	14	15	1	7
Block 4	25	4	13	3	24	22	15	13	6	13	24	23	18	8	7	7	13	17	2	6

Number of surviving trees of each species in the treatment control plot (TC) of each block at the end of the second rainy season after planting. Twenty-six trees of each species were planted in each TC plot.

especially important in forest restoration projects for carbon storage. The bigger the tree to begin with, the faster it grows, so relative growth rate (RGR) is used to compare the growth of different trees. RGR expresses the increase in the size of the plant as a percentage of the average size of the plant throughout the measurement period, and thus it can be used to compare the growth of trees that were relatively large at planting time with those that were relatively smaller. RGR can be calculated in terms of tree height as follows:

$$\frac{\ln H \text{ (18 months)} - \ln H \text{ (at planting)} \times 36{,}500}{\text{No. days between measurements}}$$

...where ln H is the natural logarithm of tree height (cm). RGR is an estimated annual percentage increase in size. It takes account of differences in the original sizes of the trees planted, so it can be used to compare trees that were larger at planting time with those that were smaller. Compare the mean values of RGR among species by ANOVA. The same formula can be used to calculate the relative growth rates of root collar diameters and crown width.

Species comparisons, based solely on field performance, are not enough to inform a definitive decision on which species to plant. See **Section 8.5** to see how field performance data can be combined with other important parameters when making the final decision on which species work best.

Comparing treatments

The effects of treatments on individual species can be determined using exactly the same analytical procedure. From the main spreadsheet, count the number of surviving trees (or calculate % survival) of a single species for each of the treatment and control plots in all blocks. Construct a new spreadsheet with treatments as the column headings (TC, T1, T2, etc.) and blocks (or replicates) as rows. Then follow the instructions in **Appendix 2** to arcsine transform the data and carry out an ANOVA.

Substitute the survival data with mean plot values for height, RCD, RGR, crown width and reduction in weed score to determine the effects of treatments on other aspects of field performance (there is no need to transform these data). Then repeat the same procedure for all other species.

Different treatments will affect different species in different ways. It is impractical to provide treatments that are optimal for each species in plots with 20 or more species, so the objective of the analysis is to determine the optimum combination of treatments that have a positive effect on most of the species planted.

Experiments with direct seeding

Direct seeding was described as a potential low-cost alternative to tree planting in **Sections 5.3** and **7.2**, but scant information is available about which tree species are suitable for this technique (**Table 5.2**). The success or failure of the direct seeding of each tree species depends on a combination of many factors, including seed structure and dormancy, attractiveness of the seeds to seed predators, susceptibility of the seeds to desiccation, soil conditions and surrounding vegetation. Therefore, experiments are necessary to determine whether a tree species establishes better by direct seeding than by planting nursery-raised saplings and to determine the cost savings achieved (if any).

Information needed for direct seeding experiments

Before a direct seeding experiment can be started, it is first necessary to know: i) what is the optimum pre-sowing treatment to accelerate seed germination; and ii) if fruiting does not occur at the optimum time for direct seeding (i.e. the start of the rainy season in seasonal tropical forests), what is the best seed-storage protocol for retaining seed viability during the period between the seed collection and the direct seeding. The nursery experiments required to answer these questions are described in **Section 6.6**. They will take at least a year to complete before direct seeding experiments can begin.

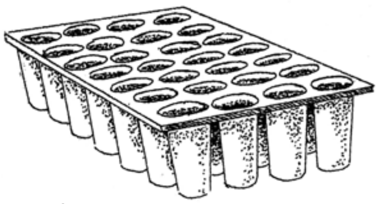
One of the main causes of failure of direct seeding is seed predation. If seeds are treated to accelerate germination before they are sown into deforested sites, the time available for seed predators to find and consume the seeds is reduced, and consequently the chances that the seed will survive long enough to germinate are increased. Treatments that accelerate germination in the nursery can, however, sometimes increase the risk of seed desiccation in the field or make seeds more attractive to ants by exposing their cotyledons. For tree species with recalcitrant seeds that are difficult to store, direct seeding is only an option for those species that fruit at the optimum direct seeding time.

Steps of direct seeding experimental design

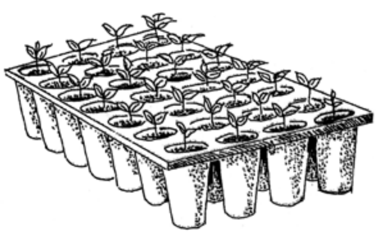
Collect seeds, clean and prepare them and store until 4–6 weeks after the onset of the rainy season.

In the nursery

Techniques are detailed in **Section 6.6**.



Sow seeds and carry out a standard germination test.

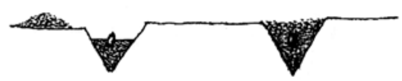


Transfer germinated seedlings into pots.

In the field

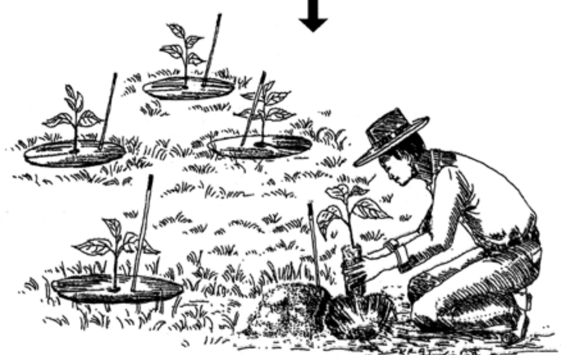
Techniques are detailed in **Section 7.4**.

Clear points at 3.6 m spacings and dig small holes with bamboo rods, half filling them with forest soil.



Sow one seed at each point and cover with more forest soil.

Monitor germination weekly.



Transplant nursery-grown saplings into the field. Plant one nursery-grown sapling next to each direct seeded sapling (about 1.8 m apart) to create pairs of trees and monitor subsequent performance of both.

Methods for direct seeding experiments

Collect seeds from several trees, combine and mix them, clean and prepare the seeds in the standard way and, if necessary, store them until planting time using the most efficient storage protocol developed from previous experiments.

In the nursery, sow seeds into modular trays and carry out a standard germination test, comparing control (non-treated) seeds with those subjected to the most efficient treatment to accelerate germination developed from previous experiments.

In the field, use the same experimental design as that used in the nursery, with the same number of treatment and control replicates and the same of seeds in each replicate, but instead of using modular germination trays, sow the seeds at direct seeding points marked with bamboo poles and spaced about 3.6 m apart across the study site. Sow one seed at each point.

Monitor seed germination weekly, both in the field and in the nursery and analyse the results using the method already described in **Section 6.6**. In the field, after germination is finished, try to dig up and inspect any non-germinated seeds. This might help to determine how many seeds were removed or damaged by seed predators and how many appear intact but simply failed to germinate.

In the nursery, once germination has ended, transfer the germinated seedlings into pots in the usual way. Use the standard protocol, developed from previous experiments, to grow the plants in the nursery. Monitor and analyse growth as described above. Monitor the plants in the same way in the field.

Once the saplings in the nursery have grown tall enough to be planted out, transplant them into the field as usual. This may be 1 or 2 years after direct seeding took place. Plant one nursery-raised sapling next to each sapling established by direct seeding (about 1.8 m apart) to create pairs of trees. Monitor the field performance of the paired trees for at least two years after planting out of the nursery-raised saplings. Use paired t-tests to compare the growth of the nursery-raised and direct-seeded trees.

Other experiments with direct seeding

There are many other treatments that can be incorporated into this basic experimental design. If burying fails to deter seed predation in the field, try experimenting with treating the seeds with chemical repellents to make the seeds unattractive to seed predators; but do not forget to test the effects of the chemical repellents on seeds germinated in the nursery in case the repellent also has an effect on germination.

Experiments that vary the maintenance procedures used around direct seeding points might also suggest how results could be improved. Try altering the weeding or mulching regime around the direct seeding points to prevent the germination of weeds in the immediate vicinity of the young seedlings, especially in the first few months after germination or sow more than one seed at each direct seeding point to overcome the effects of low germination rates.

Direct seeding certainly works for some species. Compare the direct-seeded *Sarcosperma arboreum* tree on the left with the nursery-raised one germinated from the same seed batch on the right.

Can direct seeding save money?

Since direct seeding does not require a tree nursery, it should reduce the costs of forest restoration. Direct seeding does, however, require weeding around the seeding points as the young, recently germinated seedlings are highly vulnerable to competition from weeds. The application of fertiliser and mulch around the direct seeding points in the first year also has added costs. A detailed account of all expenses must therefore be kept throughout a direct seeding experiment to determine whether this technique does actually reduce the overall costs of forest restoration.

7.6 Research on biodiversity recovery

The ultimate measure of the success of forest restoration is the extent to which biodiversity returns to the levels associated with the target forest ecosystem. The purpose of biodiversity monitoring is therefore to determine to how fast this occurs and ultimately to improve restoration methods so as to hasten biodiversity recovery.

Monitoring *all* biodiversity is not practical, so for forest restoration, biodiversity monitoring focuses on those components that relate directly to the re-establishment of natural forest regeneration mechanisms, particularly seed dispersal and the seedling establishment of recruit tree species (i.e. in-coming tree species not including those planted). Some species or groups might serve as indicators of the overall health of the forest.

Four crucial questions are:

- Do planted trees (and/or ANR techniques) produce resources (e.g. flowers, fruits and so on) at an early age that are likely to attract seed-dispersing animals?
- Are seed-dispersing animals present in the area, and if so, are they actually attracted by these resources?
- Do seeds that are brought in by those animals actually germinate, increasing the species richness of the tree seedlings or saplings naturally establishing beneath the planted trees?
- Do wind-dispersed seeds also establish naturally?

Here, we present a few techniques that can be used to answer these questions. Monitoring the performance of planted trees can show clear improvements within 2–3 years, but the recovery of biodiversity takes much longer; monitoring may continue over periods of 5–10 years, but at less frequent intervals.

The requirement for biodiversity monitoring must be considered from the beginning of field experiments during the design of a FTPS. Non-planted control plots must be included in a FTPS, and a biodiversity survey of the control plots and the plots to be subjected to restoration treatments must be carried out before the site preparation. This provides the essential baseline data against which subsequent changes in biodiversity can be compared. Biodiversity is then surveyed in both control and restoration plots and compared with that in nearby intact forest (i.e. the target forest community).

After each data collection session, two types of comparisons are performed: i) before vs. after comparisons between current data and baseline (pre-planting) data; and ii) control vs. restoration plot comparisons. In this way, the enhanced biodiversity recovery brought about by restoration actions can be distinguished from that due to natural ecological succession. Relative biodiversity recovery can then be calculated as a percentage of that recorded by the same methods in target forest.

Phenology studies

Frequent walks through the restoration plots while noting which trees are flowering and fruiting can yield most of the data needed to determine whether the trees within the restoration plots are producing resources that are likely to attract seed-dispersing animals. Establish a trail system through the centre of all plots. Walk the trails monthly, recording the following information for trees within 10 m of the trail:

- date of observation;
- block/plot identification number;
- tree number (including species number);
- presence of flowers or fruits: use the 0–4 scoring system (see **Section 6.6**);
- wildlife signs: nests, tracks, faeces and so on either on or near the trees;
- direct observations of animals using the tree for feeding, bird perching and so on.

Enter each observation, as a single row, into a spreadsheet to allow easy compilation of the data by species or date. Determine the youngest age (time since planting) at which the first individuals of a species commence flowering and fruit set. The frequency of observations (within a species) can be used as a general indication of the prevalence of flowering or fruiting at the species level. For additional detail, measure the girth at breast height (GBH) (or RCD) and the height of the flowering or fruiting trees to establish correlations between tree size and age at maturity. The flowering of some species can be inhibited if the trees are heavily shaded by adjacent tree crowns. If there is some variation in the incidence of flowering within a species, a shade score for each flowering tree can also be recorded. In addition to assessing the production of wildlife resources by planted tree species, monthly surveys can yield much additional information about the planted trees species, such as the outbreak of pests and diseases, and can provide early warning of disturbances to the plots by human activities. This kind of simple qualitative monitoring is an excellent way to involve local people in monitoring forest restoration sites as it is easily learned and requires no special skills.

Nursery stock of *Bauhinia purpurea* starts flowering and fruit set within 6 months after planting, providing food for birds and insects.

Wildlife monitoring

All re-colonising wildlife species (both plants and animals) contribute to biodiversity, but seed-dispersing animals can accelerate biodiversity recovery more than other species. Birds, fruit bats and medium-sized mammals are the major groups of interest, but of these, the bird community is the most easily studied.

Birds are an important indicator group

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

- they can be relatively easy to see and many are easy to identify;
- good identification guides now cover most of the tropics;
- most species are active by day;
- birds occupy most trophic levels in forest ecosystems — herbivores, insectivores, carnivores and so on — and hence a high diversity of birds usually indicates a high diversity of plants and prey species, especially insects.

What questions should be addressed?

- What bird species occurred in the area before restoration?
- What bird species are characteristic of the target forest ecosystem and do those species return to restored forest plots? If so, how soon after restoration actions?
- Which of the bird species that visit the plots are most likely to disperse the seeds of forest trees into restoration plots?
- Which bird species disappeared as a result of forest restoration activities and when?

When and where should bird surveys be carried out?

Survey the entire FTPS once it has been demarcated but before implementing any activities that are likely to alter bird habitats (i.e. before preparing the site for planting). This survey provides the baseline data against which changes are compared. Thereafter, carry out bird surveys of the same intensity in both restoration plots and control plots and also in the nearest area of target forest (see **Section 4.2**). Annual bird surveys

Bird Survey Record Sheet
Date: 17/12/05
Block number: G1
Start time: 06.30
File name: Restoration plot, 10 years old
Weather: sunny, very warm
Plot number: EG01
Finish time: 09.30
Recorders: DK, OM

Time	Species	No. of birds (sex)	Sight or song/call	Distance from point (m)	Activity	Tree species (if appropriate)
06.30	Black-crested bulbul	2	Sight	10	Feeding on fruit	*Ficus altissima*
06.30	Bar-winged flycatcher-shrike	1	"	10	Foraging for insects	*Ficus altissima*
06.30	Hill blue flycatcher	1	"	10	Fly catching	*Choerospondias axillaris*
06.40	Sooty-headed bulbul	3	"	15	Flushed from crown	*Betula alnoides*
06.45	Yellow-browed warbler	2	"	5	Moving through canopy, foraging	Many species
06.45	Pallas's warbler	1	"	5	Moving through canopy, foraging	Many species
06.45	Eurasian jay	2	Heard calls	30	Calling from nearby trees	Unknown
06.50	Magpie robin	1 male	Sight/ song	8	Foraging on forest floor, also short burst of song	
06.55	Lesser coucal	1	Sight	10	Flying through trees	
07.05	Striated yuhina	10+	"	5	Moving through canopy, feeding	Many species
07.10	Mountain bulbul	2	"	12	Feeding on fruit	*Ficus hispida*
07.22	Asian house martin	25+	"	50	Hawking insects overhead	
07.30	Scarlet-backed flowerpecker	1 male	"	5	Feeding on nectar	*Erythrina subumbrans*

are usually sufficient to detect changes in bird communities. Carry the surveys out at the same time each year as bird species richness will fluctuate according to seasonal migration patterns. Observe birds during the first 3 hours after dawn and the last 3 hours before sunset. Timetable 1-hour observation periods in each plot, alternating around the plots at hourly intervals, but ensure that, over the entire survey period, all plots are studied for the same number of hours, spread evenly among morning and evening observational periods.

Data collection

Use the 'point count' method to count birds from the centre of each plot. This method can be used to both count species and estimate bird population density (Gilbert *et al*., 1997; Bibby *et al*., 1998). Stand in the centre of each plot and record all bird contacts for 1 hour by both sight and song. Record the species and numbers of birds and estimated distance from the observer when birds first appear in the plot. To reduce the risk of recording the same individual birds several times, do not record the same bird species entering the plot for five minutes after first recording that species. Record the tree species (and tree number if labelled), in which birds have any activity (particularly feeding) and their position (trunk, lower canopy, upper canopy etc.).

Use binoculars, telescopes and your ears to detect birds within 20 m of a single point in the centre of a forest restoration trial plot.

Data analysis

Answer most of the questions listed earlier by simply scanning the species lists and counting the number of bird species that re-colonise the restoration plots and those that disappear as a result of forest restoration activities.

To calculate the extent of recovery in the bird community, compare the species list for pristine target forest with that for the restoration plots. Calculate the percentage of the species found in the forest that are also found in the restored plots and look at how this percentage changes over successive survey times. Next, determine which of those species are frugivorous. These are the crucial species that are most likely to disperse seeds from forest into restoration plots.

For a quantitative analysis of the species richness of bird communities, we recommend the MacKinnon list method (Mackinnon & Phillips, 1993; Bibby *et al*., 1998), which provides a means of calculating a species recovery curve and a relative abundance index. For full step-by-step instructions and a worked example see Part 5 of FORRU, 2008 (www.forru.org/FORRUEng_Website/Pages/engpublications.htm).

Bulbuls are the 'work horses' of forest restoration in Africa and Asia. They feed on fruit in remnant forest and drop seeds of many tree species in forest restoration plots.

Mammals

Mammals can be divided into two groups of interest: i) fruit-eating species that are capable of dispersing seeds from intact forest into restored sites (e.g. large ungulates, civets, fruit bats and so on); and ii) seed predators, which could limit the seedling establishment of recruit tree species in restored sites (particularly small rodents).

Mammals are much more difficult to survey than birds as most species are nocturnal and very shy, so direct observations of mammals are usually few and far between. Opportunistic, anecdotal data (rather than systematic, quantitative data) are more commonly used to determine the recovery of mammal communities after forest restoration.

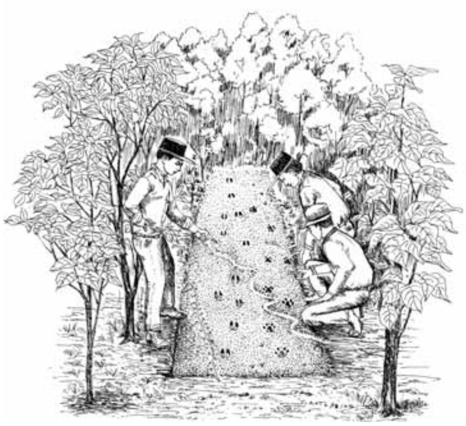
For medium-sized or larger mammals, camera trapping is a very effective way of determining the return of species to restoration sites. Digital cameras housed in camouflaged, weatherproof cases that are triggered by movement in the field of view have never been cheaper (starting at US$ 100–200). Password protected electronics means that the cameras are of no value to potential thieves. The batteries last several months and thousands of pictures can be accumulated on a single memory card (e.g. www.trailcampro.com/cameratrapsforresearchers.aspx).

Camera traps capture black and white images at night (without flash) and colour images during the day of any moving thing. The hog badger (top left) and the large Indian civet (top right) bring seeds into restoration plots. Leopard cats (lower left) help to control seed predators. Cameras can also help to detect illegal hunting (lower right).

Live trapping, using locally available rat traps, is another useful technique, particularly for small mammals such as rodents, but it is labour intensive and therefore expensive. Lay out baited traps 10–15 m apart using a 7 × 7 grid pattern. Expect capture rates of below 5%, so a great deal of effort is required for relatively few data. Expect to record a sharp decline in the populations of rodent seed predators in restoration plots by 3–4 years after planting, by which time the dense, herbaceous vegetation that provides cover for such small mammals will have been shaded out by the developing forest canopy. When handling wild animals, make sure your vaccinations against animal-borne diseases, particularly rabies, are up to date.

Most records of mammals in forest restoration plots must come from indirect observations of their tracks, feeding remains and other signs. These can be recorded during the regular phenology monitoring of planted plots and control (non-planted) plots. The frequency of observations can be used as an index of abundance and to determine whether individual mammal species are increasing or declining in numbers. Carry out a similar survey, with the same degree of sampling effort, in the nearest remnant of intact forest to determine what percentage of the original mammalian fauna re-colonises restored plots.

Sand traps make footprints clearer and easier to identify.



For a more quantitative assessment, use sand traps to record the density and frequency of mammal tracks. Clear away leaf litter from sample plots and sprinkle the soil surface with flour or sand. Mammals that walk over the sample plots will leave clear foot prints that can be measured and identified.

Last, anecdotal information can be collected from local people by interviewing. Use pictures in mammal identification hand books (rather than local names) to ask local people which mammal species they see frequently in the FTPS and remnant forest nearby and whether such species appear to be increasing or declining in abundance.

Monitoring 'recruit' tree species

In tropical forest ecosystems, most seeds are dispersed by animals. One of the main objectives of bird and mammal surveys is to determine whether restoration sites attract seed dispersers, but do the seeds that are brought in by animals actually germinate and grow into trees that contribute to overall forest structure? This question can be answered by periodic surveys to identify 'recruit' tree species (i.e. non-planted tree species that naturally re-colonise the site).

In forest ecosystems, the tree community is a good indicator of overall community biodiversity. Trees are the dominant ecosystem component, providing various habitats or niches for other organisms, such as birds and epiphytes. They are the base of the food web and account for most of the nutrients and energy in the ecosystem. The more diverse the tree community, the more likely it is that other elements of biodiversity will recover. Trees are easy to study. They are immobile, easy to find and relatively easy to identify.

What questions should be addressed?

- What tree species are present before forest restoration activities commence?
- What percentage of the tree species that comprise the target forest ecosystem re-colonise the restoration plots?
- Which forest herb species re-colonise the forest restoration plots and how soon after tree planting?

When and where should vegetation surveys be carried out?

Survey the area of the FTPS once it has been demarcated but before implementing activities that alter the vegetation (i.e. before preparing the site for planting). This provides the baseline data against which changes are compared. Thereafter, carry out vegetation surveys with the same sampling effort in both restoration plots and control plots and also in the nearest area of target forest to determine how many species from the target forest ecosystem re-colonise the restoration plots.

In seasonally dry climates, the character of the vegetation, particularly the presence or absence of annual herbs, varies dramatically with the seasons. To capture this variability, carry out vegetation surveys 2–3 times each year in the first few years after planting and subsequently at longer intervals. If you only have resources to carry out annual vegetation surveys, make sure they are always carried out at the same time of the year. Weeding in the first few years will of course disturb the vegetation. Therefore, carry out vegetation surveys just before weeding is scheduled.

Vegetation sampling methods

Establish permanent circular sampling units (SUs), across the entire study site, with equal numbers of SUs in restoration plots, controls (NPCs) and remnant target forest. Mark the centre of each sample unit with a metal or concrete (non-burnable) pole and use a 5 m piece of string to determine the perimeter of each SU. Position at least four SUs randomly in each 50 × 50 m plot. Species that are present outside SUs can also be recorded as being 'present in the environs'. Although not contributing to the diversity indices for the SUs described below, they will provide added qualitative evidence of biodiversity recovery.

Data collection

Within each SU, label every tree sapling that is taller than 50 cm. For each labelled tree, record: i) the label number; ii) whether the tree has been planted or naturally established; iii) the species name; iv) height; v) RCD (or GBH if large enough); vi) health score (see **Section 7.5**); vii) crown width; and viii) number of coppicing stems. Any tree seedlings or saplings that are shorter than 50 cm can be considered to be part of the ground flora.

When starting vegetation surveys, work with a professional botanist in the field if at all possible.

A ground flora survey can be carried out at the same time, but for this survey, the radius of the SU can be reduced to 1 m. Record the names of all recognised species, including all herbs and vines and all woody trees, shrubs and climbers (shorter than 50 cm). Assign an abundance score to each species (e.g. use the Braun-Blanquet scale or the Domin scale).

For species identifications, it is easier to work directly with an expert taxonomic botanist in the field rather than to collect voucher specimens for all of the species encountered and have them identified later at an herbarium.

Data analysis

Analyse the data for trees taller than 50 cm and the rest of the ground flora separately. Prepare a spreadsheet with the species listed in the first column (all species encountered during the entire survey in all SUs) and SU numbers in the top row. In each cell, enter the number of trees of each species in each SU (or the abundance score). The species list for the entire survey will be long and the number of species in each SU will be relatively low, so most of the values entered into the data matrix will be zero. However, the zero values must still be entered to allow calculation of indices of similarity and/or difference. Add data from each subsequent survey to the right of the current data, so that the data can be sorted into chronological order easily by column.

Begin by simply scanning the data and comparing species lists for restoration plots, non-planted controls and target forest. Which sun-tolerant pioneer species are the first to be shaded out by planted or naturally regenerating trees? Which species that are typical of the target forest type are the first to become naturally established in restoration plots? Are they wind dispersed or animal-dispersed? If the latter, which animal species are most likely to have brought their seeds into the restoration plots? Which of the planted tree species are most likely to have attracted these important seed-dispersing animals? Answers to these questions can be found without complex statistical analysis, and they will help you to decide how to improve the species mixtures and plantation design of future field trials in order to maximise biodiversity recovery rates.

One of the simplest ways to address the question of how similar the restoration plots are becoming to the target forest is to calculate a 'similarity index'. The simplest one to calculate is Sorensen's Index:

$$\frac{2C}{(RP + TF)}$$

... where RP = total number of species recorded in restoration plots, TF = total number of species recorded in target forest and C = number of species common to both habitats. When all species are found in both habitats, the value of Sorensen's index becomes 1, so biodiversity recovery can be represented by how closely the value of the index approaches 1 over time. Similarly, restoration plots can be compared with NPC plots, with the expectation that the index would decline over time as the restored forest becomes less similar to open degraded areas. In recently restored tropical forest plots, the index would be most suitable for comparing plant, bird or mammal communities.

Table 7.4. Example of how to calculate a similarity index.

	Restoration plots	**Target forest**
Species A	Present	Absent
Species B	Absent	Present
Species C	Present	Present
Species D	Present	Present
Species E	Absent	Present
	C	2
	RP	3
	TF	4
	Sorensen's index	**0.57**

Sorensen's index uses presence/absence data only and is easy to calculate, but it ignores the relative abundance of the species being recorded. More sophisticated 'resemblance functions', which take abundance into account, are described by Ludwig and Reynolds (1988, **Chapter 14**). These more complex calculations can be used (e.g. in cluster analysis and ordination) to classify the SUs according to how similar or different they are to each other.

CASE STUDY 5 Kaliro District

Country: Uganda

Forest type: *Albizia–Combretum* woodlands

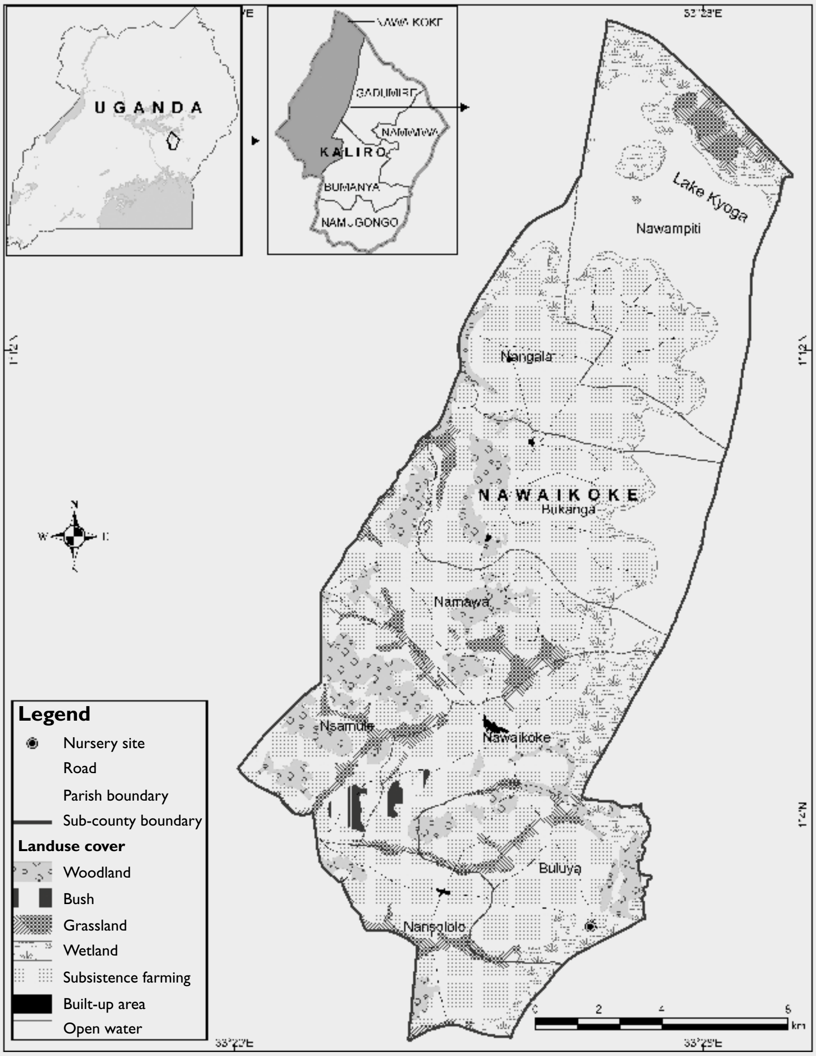
Nature of ownership: Mainly privately owned small-scale farms.

Management and community use: Mixed farming, trees cut for charcoal production and timber, land cleared for cultivation.

Level of degradation: A substantial number of mature trees are cut down for harvesting or cleared for agriculture.

Background

This study was a part of my PhD research '*Ecology, conservation and bioactivity in food and medicinal plants in East Africa*', which investigated the seed germination and seedling growth of medicinal tree species and tested the applicability of the framework



species method for conserving medicinal trees and the environment in Kaliro district, Uganda. It followed previous ethnobotanical studies to determine useful plant species, including medicinal ones (Tabuti *et al*., 2003, Tabuti 2007).

Local traditional healers identified five woody medicinal plants as among the most important, but difficult to find: *Capparis tomentosa*, *Securidaca longipedunculata*, *Gymnosporia senegalensis*, *Sarcocephalus latifolius* and *Psorospermum febrifugum*. In a field survey, we found seeds of *C. tomentosa*, *S. longipedunculata* and *S. latifolius* and set up a direct seeding trial plot, but this method was not successful.

We therefore decided to experiment in Norway and achieved high seed germination in light and rapid early seedling growth of *Fleroya rubrostipulata* and *Sarcocephalus latifolius* (Stangeland *et al*., 2007). We also wanted to establish new plot trials back in Uganda, but needed to find more effective field methods. Two of my colleagues, working in Thailand, told me about the framework species method used there (FORRU, 2008; www.forru.org). I adapted the technique and established a nursery according to FORRU's guidelines in March 2007. Some seeds were collected from the surrounding landscape, whereas others were procured from the National Tree Seed Centre, which also provided advisors to help with establishing the nursery.

Establishment of experimental plots

Although this study aimed to secure a supply of local medicinal plants, other useful tree species, some of them exotic, were also planted to encourage positive attitudes to tree planting: altogether 18 indigenous and 9 exotic tree species were studied (Stangeland *et al*., 2011).

The criteria for the selection of species were as follows: i) medicinal woody species in high demand and/or becoming rare locally; ii) other useful tree species whose production might encourage a positive attitude among users (e.g. fruit trees, timber and fuel-wood trees); and iii) nitrogen-fixing tree species to improve the soil and reduce fertiliser requirements. Species selection was facilitated by previous local studies (Stangeland *et al*., 2007; Tabuti, 2007; Tabuti *et al*., 2009). Our objective was to test the applicability of the framework species approach in establishing multipurpose tree gardens growing products that would otherwise be harvested from woodlands.

Three groups of traditional healers provided land and took care of the seedlings after planting. One healer in each group established a multipurpose tree garden on his own land. The trees were not harvested during the first year when we monitored growth, but

Rose Akelo shows the seedlings to visitors at the inauguration of the nursery 04.08.2007 (Photo: T. Stangeland).

Nursery staff and traditional healers planting seedlings in March 2008 (Photo: T. Stangeland).

subsequently, the healers were free to cut the trees as needed. We provided seedlings and money for ploughing and fence material, while the groups of healers prepared land in March 2008, put up the fence, planted the seedlings and weeded the plots three times during the first rainy season. During the first rainy season, after tree planting in April 2008, beans were planted between the tree lines to provide some short-term benefit, increase motivation for weeding and increase soil fertility through nitrogen fixation.

How well did the FORRU methods work in Uganda?

Germination exceeded 60% for about half the species tested (48%). This contrasted with results from Thailand, where 80% of species had high germination rates (Elliott *et al*., 2003). African tree species may thus have lower germination success or a greater

Monitoring survival and growth 13 months after planting. From the left Patrick Nzalambi, Joseph Kalule, Alexander Mbiro, Torunn Stangeland and Lucy Wanone (Photo: T. Stangeland).

need for pre-treatment than Asian species. Thirteen months after planting, seedling survival was satisfactory and comparable with the results from Thailand (Elliott *et al*., 2003). Almost two thirds (63%) of the planted tree species achieved survival rates in excess of 70%, despite a severe drought in 2009. Height growth was also good, with one-third of species achieving excellent growth (>160 cm tall) and 30% achieving acceptable growth (>100 cm tall) 13 months after planting.

Eleven of the 27 tree species tested qualified as 'excellent' framework species (Stangeland *et al*., 2011). Eight more species qualified as 'acceptable'. All of these species can be recommended for restoration and multipurpose tree garden planting. Eight were ranked as 'marginally acceptable'.

Potential of the framework species method in Africa

Our experience suggests that there is considerable potential for applying the framework species approach in Africa. The human populations of East African countries have more than trebled during the past 40 years, resulting in immense pressure on land for cultivation. More than 80% of people still use firewood or charcoal to cook their food, a demand met largely by plantations of exotic tree species, whilst indigenous trees have declined and become vulnerable to extinction. We found the framework species method to be practical and cost-effective. The groups of healers involved in our work have become much more interested in raising seedlings and planting trees. In fact, when we visited the site in March 2011, we found that the two groups in Nawaikoke had merged and bought land for their own nursery, building on the experience from the project.

By Torunn Stangeland