Management of Planted Forests

Basic knowledge

The Management of Planted Forests Module provides information on good practices for the establishment and management of planted forests. It can be seen as dealing principally with the silviculture of planted forests beginning where the module on Forest Reproductive Material stops. It is complemented by the modules on Wood Harvesting, Wood Energy, Forest Pests, Agroforestry, and Forest-based Enterprises. This includes guidance from site selection and choice of planting material through planting and tending.

Acknowledging that planted forests are established for different management objectives and produce a wide variety of products and services, this module provides more detailed information on the requirements for successful establishment and management of planted forests for wood production and environmental protection. It also offers links to other specialised modules in this toolbox, useful tools for forest managers, a range of case studies from different parts of the world, and some important reference materials.

Planted forests are forests predominantly established by planting seedlings or seeds; plantations are a type of planted forest that is characterized by a composition of one or two tree species, regularly spaced, with intensive management (FAO, 2018). In 2020, the global planted forest area was estimated at 294 million hectares (ha), which is seven percent of the world forest area. Of this area, 131 million hectares were plantation, or about 45% of the total planted forest area (FAO, 2020).

Planted forests are managed at scales large and small and for a variety of objectives, including restoration of amenity, environmental protection, biodiversity, carbon sequestration, and wood and non-wood product generation (Bauhus, van der Meer and Kanninen, 2010; Evans, 2009; Lamb, 2011; Stanturf, Palik and Dumroese, 2014). Sustainably managed planted forests have the potential to provide important social and environmental benefits (FAO, 2010). To realize these benefits it is important that plantations are responsibly managed using best practices (FAO, 2006).

Plantations for wood production

Plantations are increasingly seen as representing one end of a gradient of forest management intensification. This is in line with trends towards sustainable intensification in forestry in order to meet the needs for timber and fibre-based products (Silva, Freer-Smith and Madsen, 2019). In most cases, plantations are established with the objective of producing timber, and are capable of producing a wide range of wood-based products including sawlogs, pulplogs and biomass for fuel. In 2014, 45% of industrial round wood was produced from planted forests (Jürgensen, Kollert and Lebedys, 2014). In many cases, large forest plantation estates are planned and managed by professional foresters with a high level of forest education. These are often complemented by plantations established by smaller landowners who also supply timber to the same processing facilities. However, in some countries (including India, Vietnam and Indonesia) small (<100 ha) and very small (<10 ha) plantations are an important component of the total plantation area (Midgley, Stevens and Arnold, 2017). Owners of small plantations may receive or buy improved planting material from government extension agents, large companies, or cooperatives. Sometimes they sell their crop when mature to large companies or cooperatives with enough scale to afford mills and other processing facilities. This model may be particularly useful for these smaller forest owners with limited financial capacity and formal forestry training.

Improving rural livelihoods is another common goal of forest plantations. Forest plantations can be a source of employment to communities living around large scale forest estates, and can provide significant opportunities to address gender inequity by providing a range of different types of employment for families. Plantations also offer opportunities for entrepreneurs and families who establish and manage their own plantations on their farms, or supply goods and services such as the sale of seedlings to plantation owners. On the other hand, forestry can be hazardous and requires good practice to ensure the safety and health of forestry workers (ILO, 1998).

Planted forests for protection and production of ecosystem services

While many planted forests are established for the sole purpose of timber production, well-designed and -managed planted forests can also deliver a suite of ecosystem services (Bauhus, van der Meer and Kanninen, 2010). When properly managed, planted forests can improve the quality of water yielded by a catchment or watershed, protect soil, and buffer against floods and extreme weather events. Planted forests can also complement the biodiversity values of natural forest, for example by acting as a wildlife corridor and as a supplemental habitat and food source.

There are many cases where planted trees are included in the agricultural system for other purposes, including soil enrichment, soil stabilisation and provision of shade. Even where timber is the main crop, there are cases where agricultural crops form a part of the early development phase of the plantation until canopy closure occurs (i.e. taungya systems) or as a field level crop (e.g. turmeric, indigo, pepper, coffee) after canopy closure. In agroforestry situations the trees are usually more widely spaced than in pure stands.

In addition to production of wood and non-wood products, planted forests also have the potential to absorb large quantities of carbon from the atmosphere and to lay it down in their wood. If managed using best practice, reforestation and forest restoration in previously forested areas can be effective for climate change mitigation (see the 2020 IPCC special report on climate change and land, page 27). The long-term effectiveness of planted forests as a carbon sink, however, is strongly dependent on the length of the rotation and the destination of the timber produced, and the land use that preceded the planted forest. Timber used in buildings instead may sequester carbon for decades to centuries and replace carbon-intensive materials like steel and concrete; whereas timber used for biomass energy or pulp products may only sequester carbon for months to years (Oliver *et al.*, 2014). Where plantations are established by replacing forests or other long established natural vegetation, the short-term release of carbon during establishment must be balanced against the longer-term sequestration in the timber; in some cases the carbon balance remains unfavourable for decades.

Enabling conditions for the establishment of planted forests

As a long-term investment (i.e. years to decades) with the potential to provide multiple goods and services to people and the environment, it is important to have a robust governance and management framework in place to foster and sustain investment in planted forests (FAO, 2010). Secure land and tree tenure for those who invest their time and money to establish plantations are therefore prerequisites for plantations, as well as financial planning to fund tending and protection of the investment. There are well-established silvicultural and landscape management approaches to strike a balance between the different goods and services of planted forest (see e.g. Carnus *et al.*, 2006; Stanturf, Palik and Dumroese, 2014). Prerequisites for their implementation are clear and long-term management objectives for the planted forest, and stable management over the plantation lifecycle.

Management of planted forests contributes to SDGs:

Related modules

- Climate change adaptation and mitigation
- Forest and water
- Forest management planning
- Forest pests
- Forest reproductive material
- Land-use planning
- Participatory approaches and tools for SFM
- Protected areas
- Silviculture in natural forests
- Vegetation fire management
- Wildlife management
- Wood harvesting

In more depth

This section provides a brief introduction to the requirements for successful establishment and management of planted forests for timber production and environmental protection. It can be seen as dealing with technical material for planted forests beginning where the module on Forest Reproductive Material stops. It is complemented by the modules on Wood Harvesting, Wood Energy, Forest Pests, Agroforestry, and Forest-based Enterprises. It is complemented by more detailed information recommended in the section on Tools and the examples presented in the Cases. It deals with the technical forestry issues and readers are referred to the non-technical modules in the SFM toolbox for support on forest governance and other conditions necessary to work out before management objectives can be established and management of planted forest can begin.

Site selection and assessment

Selecting sites for the establishment of planted forests requires the careful consideration of social and legal constraints – such as land tenure, the demand for productive agricultural land, and land accessibility. Landowners – public or private – who have made the decision to establish a plantation should have a clear plan for at least the first rotation from planting to harvesting.

Sites should have enough water, warmth, and soil to support a healthy tree crop; care should be taken to avoid planting trees for the production of goods in fragile ecosystems or systems with a high value for conservation, such as wetlands. If a primary management objective or economic consideration is the production of timber, sites should be close enough to a mill or aggregation centre that transportation costs are economic. Planting at scale is not practicable without road access, so all sites considered for planting forests must have road access or the forest manager must be prepared to put in roads. Poorly constructed or maintained roads are perhaps the major source of soil erosion and surface water pollution from planted forest, so roads must be professionally constructed and maintained for sustainable management of planted forest at scale (Dykstra and Heinrich, 1996).

Species choice and site matching

Matching the right planting material to the right site conditions can be the difference between the success and failure of an investment in planted forest. Moreover, each species and provenance of the species has its own tolerances and growth conditions (Webb et al., 1984). As the global climate changes, in some cases managers are evaluating the use of provenances from warmer climate zones or mixtures of provenances to mitigate against climate change risks.

A wide range of factors, such as the purpose of the planted forest, the production goal (if applicable), the prevailing site conditions (e.g. terrain features, climate and soil), the availability of planting stock, and desired silvicultural and growth characteristics, will determine the choice of suitable species in a planted forest. Depending on the purpose, the selected species should yield marketable products such as lumber, fibre, wood fuel, foods, and medicines. Indigenous species may be preferred to introduced species for ecological or social reasons. On the other hand, the planting material from introduced forestry species may have been improved through many generations of artificial selection for fast growth and specific timber properties or stem form. Whether indigenous or introduced, planting material should be evaluated for its risk to the planting environment due to invasiveness, and the risk to it of the planting environment due to pests and disease. The management plan should be able to adequately mitigate those risks if necessary.

Nurseries and planting material

Securing quality planting materials is one of the most important steps in establishing a planted forest. Managers must find a sufficient volume of viable planting material at a bearable costs to meet their management objectives, or else adjust those management objectives.

Whatever the preferred species or provenances for planting material, a vital consideration in planted forest management is the use of high-quality seeds or other propagation material (e.g. seedlings and cuttings) originating from healthy, well-formed parent trees. The use of high-quality propagation material reduces seedling mortality due to transplantation stress and the likelihood of having to replant. For large-scale afforestation/reforestation projects, therefore, it is advisable to produce forest seedlings in specialized forest nurseries, tree seed centres or project-run centralized or decentralized (community) nurseries. Containerized seedlings are preferred over bare-root stock because of the lower risk of dehydration and transplantation shock and increased likelihood of successful establishment (although see Forest pests for an argument for the use of bare-root seedlings). For tree species that fruit rarely or have seeds that are difficult to germinate, clonal planting stock can be produced from individuals that show desirable traits such as high growth rates, pest resistance and wood quality.

Direct seeding of trees

Use of locally appropriate technologies based on local demand is important in the success of planted forest. In some situations, it is preferable to slowly increase forest area tree by tree rather than planting large blocks of trees at a time. In this case, a combination of direct seeding and assisted natural regeneration is a useful approach to the establishment of planted forest.

Direct seeding means directly planting seed (often collected locally from trees with desirable qualities). These are usually collected, planted, and tended by residents based on their own desire to increase trees on their land. Direct seeding has the advantages of lower capital costs, as intensive site preparation, seedling acquisition, and tending are not required.

Enabling conditions for success include residents motivated and trained to collect seed, and to plant them in locations where they can germinate and grow. Management objectives that can accommodate an incremental increase in tree cover with trees scattered across the landscape is necessary for success.

For more information see:

- A practical manual for assisted natural regeneration
- A guide to direct seeding from the USDA
- A practical guide for oak and chestnut in India
- Various materials on the practice in the website of the Action Against Desertification Project

Planting and tending

Ground and site preparation

Preparing a planting site so that it is conducive to the survival and rapid adaptation and growth of the planting stock is paramount to success. To reduce soil erosion and nutrient loss, the complete removal of ground-cover vegetation should be avoided. Mechanical site preparation should not be carried out when the soil water content is at field capacity as this may result in a significant soil compaction, associated with increased density and decreased macro-pore space. If no mechanized low-impact procedures are available, ground preparation should be carried out manually as far as possible to maintain soil texture and reduce nutrient losses. Buffers should be established and used to protect perennial streams and watercourses. Controlled burning may be used to clear larger areas of dense secondary undergrowth but requires expert knowledge to minimize environmental damage. Where the terrain has a 15 percent slope or greater, planting lines should follow the contour. Complete removal of weeds should be avoided during the tending process, to prevent soil erosion.

Tree planting

Successful tree-planting is not simple, and it is by no means the end of an afforestation/reforestation process. Unless weeds are controlled, fertilizer applied (where feasible), and fires prevented, the hard work of tree-planters and the effort expended in the nursery to grow seedlings may amount to little. Thus, afforestation and reforestation must be understood as a long-term process and not just a one-time tree-planting event. For planting to succeed, the following points should be considered a starting point, to be adapted and customized based on local conditions and best practices:

- Several suitable tree species may be planted on a given site. For logistical reasons, in plantations it may be easier to keep the number of species small in a given site and vary species across the landscape.
- Seedlings may be positioned randomly across a site at an average distance between adjacent trees of 2–3 m, or they can be planted in lines or clusters.
- The planting pit for the seedling should be at least 25 cm deep and 25 cm wide (deeper for dry forest areas; see (Chidumayo and Gumbo, 2010, Chapter 9))
- The combined density of planted plus naturally regenerated seedlings is usually in the range of 625 stems per ha (average spacing of 4 m x 4 m) but can go as high as 10 000 (1 m x 1 m) for certain broadleaved species. The planting density should be sufficient to establish a forest stand capable of meeting the objectives while minimizing the cost of seedlings and labour.
- The optimal height of seedlings for planting is generally considered to be in the range of 25–50 cm. When planting into existing vegetation, such as during enrichment planting, seedling height of 50–75 cm may be required because taller plants are more likely to compete successfully with existing vegetation. The higher cost of producing larger plants in the nursery is likely to be offset by lower mortality rates and reduced weeding costs.
- The best time to plant trees is during a period in which the soil is moist and temperatures are moderate (e.g. at the start of the rainy season, and/or in the late spring season). Locally appropriate planting dates can be determined from local meteorological data. Plant early in the morning to reduce heat stress on workers and saplings.

- The logistics of the operation from the nursery to the planting site and into the ground need careful planning to minimize transportation time and exposure of the planting material to desiccating wind and sun.
- In temperate climates, a ground survey should be conducted 3–6 months after the initial planting to assess the establishment rate. Dead seedlings should be replaced at the beginning of the planting season, ideally with seedlings of a similar size to those surviving nearby. In tropical climates or in plantations of fast-growing trees, the survey of establishment and replacement of failed seedlings should be conducted within the same planting season. Using good practice in planting, the forest owner can expect to replace ten to fifteen percent of the seedlings planted.

Protection of seedlings

Tree seedlings, whether natural or planted, need to be protected after establishment against competition from weeds for light, moisture and nutrients; wildfire; and browsing by wild or domestic animals. Planted forests usually fail if seedlings are planted and then abandoned. Dense weed growth will retard the growth of both natural regeneration and planted seedlings – and can cause their death – as a result of competition for moisture, nutrients and light. Weed control helps newly established trees to survive and grow by minimize the damaging effect of other plants on the desired trees. If chemical weeding is deemed necessary for economic reasons, it should only be done by properly trained personnel using the necessary equipment and applying the herbicides according to the manufacturer's instructions and the guidance, regulations and laws of the relevant authorities. Protection of planted tree seedlings against pests and diseases is key for their survival; for more information see (Duryea and Dougherty, 1991; M. Kenis *et al.*, 2019).

Tending, thinning and pruning

Tending and thinning in planted forests are silvicultural operations to improve stand quality by eliminating or suppressing undesirable vegetation, including climbers and vines, and by removing poorly formed, damaged or diseased trees. The objective is to increase the crown development and diameter growth of the trees, to concentrate future increment on the best-formed trees, and to increase the stability of the stand by giving more growing space to the roots of the potential final crop. Canopy closure or the death of the lowest tree branches are indicators for the forest manager that it is time to thin the stand. Tending and thinning operations are significant factors in the achievement of production goals (e.g. high-quality saw logs) in as short a time as possible. Not thinning is usually not appropriate for the production of general utility timber or good-quality saw or veneer logs, but may be suitable for the production of pulpwood or wood fuel.

Pruning is the removal of live or dead side branches, close to or flush with the stem, and of multiple leaders, from a standing tree with the aim of improving the quality of the tree's timber. Pruning is costly and should only be implemented in stands that are expected to yield good-quality saw logs or veneer logs. Many species grown in planted forests self-prune, reducing the need for active pruning of the stand. Where it is necessary, pruning should only be carried out after the first thinning operation, and it should be confined to the potentially good (a.k.a. crop) trees.

Indicative work organization and schedule

Roles, responsibilities and a schedule of work should be developed to implement planted forest projects. It is a common mistake to underestimate the time required for implementation. Reconnaissance surveys of the project site should start two or three years prior to planting. It is usually better to plant relatively small areas annually over several years than to plant a large area in a single season and have large numbers of planted trees die because of a lack of tending. The table presents an example of a work schedule for a medium-to-large-scale planted-forest project aimed at producing saw logs or veneer logs.

Table 1 An Indicative Work Schedule for Planted Forest Investment in a Seasonally dry Environment

Time relative to planting event	**Action**
30 months before	Reconnoitre project site; clarify legal and tenure issues; demarcate boundaries; engage stakeholders and establish consensus; draft a preliminary project plan; start nursery establishment
24 months before	Start controlled seed sourcing and seedling production in nurseries (keeping in mind the best practices for seed and nursery management of the species selected)
12–24 months before	Survey project site; produce topographic land-use map including a designation of forest functions; assess road accessibility and natural regeneration
6 months before	Assess the number, quality and species of seedlings available in nurseries
2 months before (3-4 weeks in tropical climates)	Begin hardening off in the nursery

4–6 weeks before	Demarcate planting plots in the field; mark natural regeneration; prepare planting lines; slash weeds on planting lines down to ground level
1 week before	Brief neighbours and planting teams
1–2 days before	Water seedlings and transport them to the planting site, along with planting equipment and material
Planting campaign (early in rainy season): planting at the specified spacing, plant size 25–50 cm	
1–2 weeks after	Check quality of planting; adjust any poorly planted seedlings
3–6 months after (in the same planting season for tropical climates)	Survey growth and survival of planted trees; undertake weeding and apply fertilizer and repeat as appropriate
Start of dry season	Cut firebreaks; build fire watch towers; organize fire patrols
End of dry season	Survey growth and survival of planted trees; and assess the need for replanting
6–12 months after	Replanting of failed areas (if required)
Tending phase: this period is highly variable, and tending and harvest practices and rotation period vary widely by management objective, ecological zone, and economics	
Subsequent years	Control weeds and climbers along planting lines; regulate shade; and apply fertilizer, as appropriate
Young planted forest	Control climbers along lines and in intervening areas; remove wolf trees (trees that are shading out others), forked trees, multiple leader trees and any other undesirable stems
Medium-aged planted forest	Select 200–300 potential crop trees of superior growth and quality; mark competitors to be removed; conduct thinnings in phases, resulting in the removal of about 60 percent of the trees
Mature planted forest	Thinnings down to final crop trees; about five years before the end of the rotation, conduct the final thinning of the final crop trees to remove about 50 percent of the standing stock to promote natural regeneration (if this is part of the management plan); at the end of the rotation, harvest all remaining crop trees

Economics and costs

Planted forests are long-term investments, with costs associated with, for example, the selection of germplasm, nursery production, site preparation, establishment, tending, weeding and other silvicultural operations, protection and harvesting. Some indicative costs, which will vary greatly depending on local conditions, are given below. For more information, see the SFM Toolbox Module on Forest Finance. The total costs of a successful planted-forest project in the tropics, including seedling production and all materials and labour for planting, maintenance and monitoring over three years, is likely to be in the range of US$1000–3,000 per ha (Evans and Turnbull, 2004, table 6.1; FAO and UNCCD, 2015, table 2; Hitimana, 2019, personal communication). Planted forests are considerable investments, therefore, and their long-term protection is essential.

After a plantation is established, tending will depend not only on the skill of the forest manager and their luck with unplanned natural disturbances (fire, windstorms, pests and diseases) but also on economics. Plantations are often managed for the goods they can produce and revenues that can be generated from their products; costs are incurred throughout a rotation but only recuperated with the harvest of timber or ingresses from payment for ecosystem services, hunting permits, or similar. In the period between incurring costs and selling trees to pay those costs (the investments maturation), the owner's accounting reflects the cost of his capital, comprising (Zhang and Pearse, 2012):

- the prevailing interest rate (the opportunity cost of his investment)
- inflation, as if it is positive a unit of currency is less valuable tomorrow than today
- risk, usually based on known and quantifiable risk to the standing timber or price
- uncertainty, things that the owner cannot predict or know but reflect a personal or cultural perception of a likely future

Thus species that grow quickly, shorter rotations, and forgoing precommercial thinning and pruning may be more attractive as a business proposition if the cost of capital is high. In economically, politically, or socially unstable situations a landowner may rationally invest less and harvest earlier in his planted forest, regardless of the silvicultural merits of tending. For the landowner running a plantation business, his investment should at least make the same return as the long-alternative risk-adjusted rate of return from other viable investments.

Local benefits

Financial benefits, such as those created by employment, the harvesting of forest products, ecotourism, and environmental services, are the most obvious and measurable sources of motivation for stakeholders to participate in tree-planting projects. Additionally, neighbours of planted forests often regard less tangible benefits, such as improving the environment (e.g. soil and water resources) and village infrastructure (e.g. the renovation of school buildings), maintaining cultural traditions, and political gain (e.g. the strengthening of land-tenure rights), as equally – or more – important reasons to plant trees and reforest landscapes.

Topical issues

Climate change adaptation

The higher intensity, quantity and frequency of biotic and abiotic hazards (e.g. extreme weather events) projected as a consequence of climate change could increase the vulnerability of planted forests and have serious impacts on forest productivity and the provision of environmental services. FAO's Climate change guidelines for forest managers set out specific interventions to reduce the risk to planted forests posed by climate change.

Biotechnology

The application of biotechnologies in planted forests is seen by many as an opportunity to provide new tree varieties and reproductive materials adapted to changing environmental, social and economic conditions. Genetic engineering, for example, has the potential to increase the productivity of planted forests and to generate planting material that is more resilient to pests, water scarcity and the impacts of climate change (FAO, 2014, Chapter 8). However, there are also serious concerns about the potential environmental risks posed by genetically modified organisms. They include the possibility of developing aggressive, invasive species, and the loss of biodiversity due to the displacement of traditional cultivars by a small number of genetically modified organisms.

Forest Certification

Forest Certification is a tool for promoting social, environmental and economic sustainability of forest management. It is an important market mechanism for promoting sustainable forest management that provides a proof-point that forests are being managed in a responsible manner. A certification label on a forest product informs potential buyers that the product was produced in a well-managed forest in accordance with a given set of standards. For more information, see the SFM Toolbox Module on Forest Certification.

Natural and planted forests

Globally, demand for forest products such as lumber, wood fibre, woodfuel and non-wood forest products is increasing, driven by demographic changes, economic growth, policies that favour the use of renewable energy, and worldwide campaigns advancing the value of wood as an environmentally friendly material. At the same time, the area and quality of natural forests is declining, and remaining natural forests are increasingly being designated for the protection of soil and water, biodiversity conservation and other purposes that preclude or limit wood production (FAO, 2020). Thus, the role of planted forests in meeting the growing demand for forest products is increasing (Carle and Holmgren, 2008; Jürgensen, Kollert and Lebedys, 2014; Payn *et al.*, 2015). To achieve positive outcomes it is important that planted forest not supplant remaining healthy natural forest and that best practices are implemented and monitored by the global community (FAO, 2006).

Planted forests and biodiversity

Biodiversity underpins the functions that forests provide to people and the environment. Biodiversity in forests is primarily conserved through wild populations of trees and the organisms that occur with them; this biodiversity can be seen both as having inherent value (e.g. for cultural or spiritual reasons) as well as having value for utilitarian purposes, as a toolbox and template of options that helps improve resilience. Natural forest ecosystems conserve the majority of terrestrial biodiversity; the importance of the maintenance of biodiversity in forest ecosystems has therefore been emphasized in various international conventions and agreements.

While planted forests can complement natural forests in biodiversity conservation, they do not substitute for the functions of natural forests as a reservoir of biodiversity. Planted forests can be seen as a specialized use of a narrow portion of the biodiversity conserved in natural forest. When managers wish to increase the diversity of goods and services from planted forest, or increase resilience of the forest to disturbance or change, it then becomes desirable to increase biodiversity in the planted forest as well. This may be done at the genetic, species, compartment, or landscape level; and may also be done through the rotation of the crop over time in the same place (Carnus et al., 2006).

Further learning

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