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PLANTATION SILVICULTURE

Contents

Forest Plantations

J Evans, Imperial College London, Ascot, UK

Definition

Forest plantations embrace a range of forest types, with the common feature that the majority of the trees present were established by planting (or deliberate seeding). However, this simple statement belies the fact that when mature, many planted forests can appear similar to natural forest formations. While a geometrically shaped forest monoculture of a nonnative species is plainly artificial, many old and famous forests in Europe appear natural and reveal little of their mainly planted origin. Examples include the New Forest (UK), parts of the Black Forest (Germany), parts of the Forêt de Compiègne (France), and almost all the forests of Denmark.

There is no internationally agreed definition of a forest plantation, or 'planted forest,' the expression now widely used to embrace the continuum of forest types where forest origin is known to be by planting or direct seeding. Successive international experts meeting on The Role of Planted Forests in Sustainable Forest Management in Chile (1999) and New Zealand (2003) have recommended that the question of definition be considered. This is because the boundary between planted and natural forests is often indistinct and, among countries, there are different degrees of management, and different objectives for planted forests and a complementarity between natural and planted forests.

International agreement on a definition is not finalized, but harmonization of definitions is led by the United Nations Food and Agriculture Organization (FAO) in collaboration with several other bodies. Here discussion is confined to the more obvious types of forest plantations over which few will argue, where use of formerly nonforest land, or regularity of shape, or choice of species, or intensity of management, readily points to their artificial origin. This will include afforestation, which is the act or process of creating forest land by planting trees where forest historically did not exist such as grasslands, or to stabilize sand dunes, and reforestation, where the act or process of changing previously deforested lands back to forest land is mainly by planting trees. This commonly occurs where forest is logged or clear-felled and the next crop, of the same or a different species, is established by planting.

History

Planting trees has a long history and is recorded from ancient civilizations, e.g., the Old Testament portion of the Bible. But planting trees as a way of regenerating forests used, for example, for timber production and as a means of afforestation, is more recent. In the UK significant planting dates from the sixteenth century, and the practice only became commonplace across Europe by the eighteenth century. The nineteenth century saw plantation establishment as one means of 'modern' organized forestry and in Germany it became fashionable as an efficient way of growing a uniform crop of trees. The twentieth century saw major plantation establishment, initially in temperate and Mediterranean climatic regions and, since the 1950s, to an increasing extent in the tropics and subtropics.

Tree introductions have facilitated plantation development. Many successful plantations were built on experience gained from arboreta and trials of exotic (introduced) species. Both in temperate and tropical environments, this approach yielded species that have proved amongst the most successful of all plantation species, outstanding examples of which are conifers from the Pacific Northwest of America into western Europe, *Pinus radiata* from California into southern-hemisphere countries such as Australia, Chile, New Zealand, and South Africa, teak (*Tectona grandis*) from India, Myanmar (Burma), and Thailand into many tropical countries, and several Australian eucalypts in the tropics and subtropics. Together these trees form many millions of hectares of productive forest plantations far from their native habitats.

Today forest plantations of all types probably amount to some 187 million ha or about 6% of all closed forest in the world. Exact figures are uncertain owing to variable standards between countries of recording forest plantation statistics, including the vexed issue of definition.

Future Developments

There is already a substantial resource of planted forest, and current establishment of new plantations at an annual rate of several million hectares will soon result in such forest becoming the main source of wood products. This is predicted to occur in about 30 years' time if current rates of planting continue, and possibly a little sooner if massive afforestation arises from carbon sequestration initiatives. A total forest plantation resource of 300 million ha would satisfy the great bulk of world wood requirements for the foreseeable future.

An increasing area of planted forest is only one anticipated development. The nature of planted forests is also likely to shift in balance from: (1) domination by exotic species to greater emphasis on native ones, though exotics will always play an important role; (2) a largely industrial focus to industrial, rural development, rehabilitation, and environmental roles; and (3) a single-use to multiple-use forest.

Types of Plantation

Industrial Plantations

Industrial plantations are the arable crops of forestry; their principal objective is to grow a product, usually timber, efficiently. The main purposes include fuel production – firewood and charcoal, pulpwood for paper and cardboard, panel products, sawtimber (lumber), and sometimes veneers. Commonly one plantation supplies several of these products in the course of a rotation. Other products may also arise, whether as other round timber products, or in nontimber benefits such as amenity or even biodiversity enhancement where a plantation is growing on an impoverished site. But the dominant objective is to grow a commercial product.

While most industrial plantations are successful they have largely failed in one area: the growing of high-grade cabinet timbers for furniture and similar quality uses. In temperate countries this arises from the very long rotations required and in the tropics from silvicultural difficulties with growing mahoganies and related species of Meliaceae, because of shoot borers, and the complexity of domesticating dipterocarps, merantis, and rosewoods.

Some industrial plantations of trees are grown for nontimber forest products (NTFPs) used in naval stores, gums, and resins. Although extensive, rubber plantations (*Hevea brasiliensis*) have not generally been considered as plantation forestry since their main product is rubber latex. Today such plantations are now also exploited for their wood, which is finding a ready market in the manufacture of less bulky furniture.

Industrial purpose dominates management in terms of species choice (usually only one), stocking density, thinning prescriptions, rotation length to maximize financial returns or grow crops to a particular market specification, and clearcutting silvicultural systems for efficiency of harvest.

Social and Community Plantations and Woodlots

Planting trees is one way of compensating for loss of natural forests as a means of providing domestic products such as building poles, fencing materials, firewood, and even fodder for livestock. It was widely promoted in the 1970s and 1980s in countries of the African Sahel, in India and elsewhere usually in the drier tropics, but was not always successful. Sometimes choice of species was poor, sometimes tenure and ownership of land or even of the planted trees were unclear, but commonly the problems lay in a failure to involve the local community or villagers adequately in the decision-making process.

Today tree planting for social and community needs is embraced as part of rural development forestry and is subject to participatory processes to place it firmly in local people's control. In India these are sometimes termed 'communities of protection' or community-based forest management (CBFM) in the Philippines, while in Ethiopia many planting projects begun as food-for-work initiatives during the 1980s' famine have become a village resource. Collectively these kinds of plantation projects now often form part of joint forest management (JFM) initiatives.

Social and community plantations possess many of the same features as industrial crops: they are often, but not exclusively, single species and they tend to be block plantings, though size may be as little as 0.01 ha. As well as supplying one or more products they may confer benefits of shade and shelter, amenity, and even soil erosion control.

Environmental Planting and Buffer Zones

Some plantations have been established to harness their protective functions. While it is almost always better to conserve natural woodland cover for purposes of erosion control and catchment management, where little or no forest exists tree planting can be a useful complement to the other activities, such as terracing and check dams. This can generate conflict over water use – trees generally consume more water than other land uses, and exceptionally plantations have even been used to dry swampy areas as a way of reducing stagnant water in which malaria-carrying mosquitoes breed so prodigiously.

Not all plantation species are suitable for environmental planting. For example, plantations of teak and some eucalypts develop a thin or no litter layer, are prone to ground fires, and suppress understory vegetation, all of which makes them ill-suited for soil erosion control.

Buffer zone planting is where trees are deliberately planted to take pressure away from natural forest. Trees are established in the zone around natural forest to provide an alternative source of forest products, both woody and NTFPs. In this way pressure on natural forest is eased. Also this zone assists wildlife conservation by enlarging the area of woody cover and generally discouraging people from encroaching into natural forest. It is important that such buffer zone plantings are properly managed and, for example, include fruit trees to benefit local people.

Substantial development of plantations has also taken place to combat desertification, to stabilize dunes, to act as shelterbelts and windbreaks, and related benefits.

Rehabilitating Degraded Land and Restoring Natural Forest

Since about 1990 a number of cases have demonstrated that, under certain conditions, the recreation of a woodland environment by planting trees can act as a precursor for recovery, restoration, or regeneration of natural forest formations. Plantations suppress vigorous weeds, especially grasses; internally they bring a more equable microclimate; and generally they provide conditions often more conducive to regeneration of trees. In this sense plantations are an intermediate stage between (say) farmland and natural forest and help the process of forest restoration. The importance of such restoration often makes it eligible for funding from the Global Environment Facility (GEF).

A prominent example are the thousands of hectares of *Cordia alliodora* plantations in Ecuador which have led to successful natural regeneration in the understory of native rainforest hardwoods of *Virola* and *Brosimum* spp. In Ethiopia plantings of exotic pepper trees (*Schinus molle*) eucalypts (mainly *E. camaldulensis*) and silky oak (*Grevillea robusta*) on a woodland scale have led to rapid recolonization and recovery of native acacia (*Acacia abyssinica* and *A. tortilis*) and *Erythrina variegata* within the plantation area.

Enrichment Planting

Degraded natural forest is sometimes enriched by planting desirable tree species. Where the proportion of planted trees constitutes less than 50% of the forest, it is not considered to be a plantation. As a silvicultural system it is less common today than 30 years ago owing to expense in maintaining planted trees and, generally, indifferent success.

Carbon Sequestration

To date few plantations have been deliberately established to store carbon as one means of mitigating the rise in atmospheric carbon dioxide, which is partly responsible for global climate change. It is likely that carbon trading and financing under clean development mechanism (CDM) schemes will emerge and lead to increased investment in afforestation and reforestation. Should such plantations be established, and predictions are as high as 100 million ha worldwide in the next 50 years, the object of management will be to maximize carbon sequestration. Such plantations could potentially supply wood products, and possibly other benefits as well, but will inevitably have substantial land-use and people-related impacts.

Amenity Planting

Some tree planting has the principal objective of providing esthetic and recreational values to the urban and periurban environment. Such plantations may also provide some timber products and, where the previous land was impoverished, will enrich wildlife values too.

Plantation Silviculture

Characteristics

A feature of almost all forest plantations is that, at least for the first rotation, they are established in even-aged blocks usually of one species (monoculture). While there are many exceptions, these features of even age and single species simplify management but may increase the risks of damage from biotic and abiotic sources.

Plantations also tend to be regular in shape, with boundaries commonly following the artificial and often straight legal boundary to a property or area of land.

Species Choice

The first consideration is the objective of the plantation and what the main purpose of tree planting is. This, along with issues such as intensity of management, will largely determine what species are selected.

Much care is taken to match tree species with plantation site conditions. Commonly introduced (exotic) species are used when they offer greater productivity than the native alternatives. Many examples were cited earlier. It is clear that choice of species alone is insufficient to achieve optimum productivity, and seed origins and provenances from across the range of a potentially suitable species, as well as the fruits of selection and breeding programs, require investigation.

Understanding site is equally important and sophisticated analytical tools now exist, such as climatic mapping and environmental analysis, to characterize site and its potential for tree growth.

Establishment, Management, and Protection

Forest nurseries Almost all planted forests, as the name implies, are established by planting trees. These are young trees, usually grown in a forest nursery for 6 months to 3 years, depending on species and locality, to produce a plant typically 15–50 cm tall which is hardened off and taken to the planting site, which is often many kilometers from the nursery (**Figure 1**). This contrasts with most arable farming where seeds are sown where the plant is to grow.

Forest nurseries raise plants using one of two main methods: (1) either beds are prepared in the ground in which seed is sown into finely cultivated soil, and the seedlings are cared for, conditioned, and lifted to produce bare-root plants, sometimes called 'transplants'; or (2) seeds are sown individually into containers filled with a special soil-mix in which

Figure 1 Extensive plantations of spruce, mainly *Picea sitchensis* in Northern England 50 years after afforestation began. © J. Evans, 2004.

the young plants grow and are subsequently taken to the planting site still with a small root ball attached. Plants grown in containers have many names, usually depending on the kind of container system used: 'containerized plants' is sometimes used as the generic term. Typically bare-root methods are cheaper per plant, but containerized plants are more robust, surviving better in adverse conditions such as drought experienced at the time of planting.

A few plantations, such as poplar and quite often teak, are planted by inserting hardwood cuttings called 'sets' or 'stump plants.' Woody material of these species readily roots, thus allowing this form of vegetation propagation to be used.

Site preparation Sites for planting are usually degraded land or poor-quality pasture unfit for agriculture and of little conservation or other importance. Clearing existing natural forest simply to provide a site for tree planting is today strongly deprecated and is contrary to certification schemes, e.g., Forest Stewardship Council (FSC) principles governing plantation development. Of course, reforestation is a different case.

The planting site itself may need one or more of the following operations – vegetation clearance, cultivation, tillage, bedding, drainage, fertilizing, and fencing – before planting can begin. Assessment of such needs depends on local experience and evidence from research trials and is frequently one of the largest expenses in establishing a plantation. Prescriptions cannot be laid down, but the aim of such work is to undertake the minimum preparation and protection necessary to secure high tree survival and vigorous growth over a whole rotation.

Tree planting Planting is not a difficult operation, but must be done with care to insert roots into mineral soil. In most situations containerized seedlings or transplants should be inserted to root collar depth, but occasionally where water stress is a problem, deeper planting may be done to ensure root contact with moist soil. It is important that all trees are planted vertically and not left leaning at an angle. Planting takes place at the start of the wet season in the tropics and subtropics or in the fall or spring in temperate latitudes prior to leaf flush. Typically, 1000–4000 trees are planted per hectare depending on the object of the plantation.

Newly planted trees must be protected from browsing damage and from vigorous weed competition to allow trees to become well established. Weed control may be required from 1 to 5 years. Some plantations may need a single application of fertilizer to aid growth or correct a nutrient deficiency but the practice is not required on many sites. Phosphorus is the most commonly limiting nutrient for satisfactory tree growth and on many tropical sites a small quantity of the micronutrient boron is required. Application of pesticides at the time of planting is, unlike farming, the exception rather than the rule when tree plantations are planted on formerly nonforested sites. Pesticide use is sometimes required when replanting a former forest site, such as a second rotation crop, to control insects such as weevils, and in the tropics, termites and leaf-cutting ants.

If more than 20% of newly planted trees die, additional trees may be planted, a process with many names, including 'infilling,' 'blanking' and 'beating-up.' It is not worth doing more than once since delayed plantings invariably fail to catch up with the original trees and are destined to become suppressed.

Once plantations are established and are no longer suffering weed competition or damage from browsing animals, the next operation is frequently cleaning, i.e., the removal of unwanted woody growth.

Thinning and pruning Once the canopy has closed, plantations may be subject to regular thinning until the trees have reached desired final crop size. Thinning aims to remove poor trees to favor the best remaining ones and normally begins once a stand has reached 8–10 m height. Each thinning removes one-quarter to one-third of trees present at intervals of 3–10 years, depending on age and vigor of the stand, until rotation age is reached.

Pruning of side-branches may be done on the lower bole, up to 6–8 m, to produce high-grade knot-free timber. It is carried out in stages at around the time of first and second thinning.

Rotations and Regeneration

Plantations are grown for a purpose, and it is this purpose that determines rotation length. Some plantations may be managed to maximize their economic return, but more commonly trees are grown until they reach a size that is optimum for the intended market. Clearly, firewood plantations will be grown on a shorter rotation than trees grown for sawtimber (lumber) or veneer when large trees are required. Also, in plantation management, a few trees may be left much longer than the usual rotation for reasons of amenity or wildlife benefit.

In the tropics rotations can be as short as 2–3 years for small-sized products, 5–20 years for industrial products such as woodpulp, and 10–40 years for lumber-sized material. In temperate conditions rotation lengths are commonly two to five times as long.

Most plantations are clear-felled and sites replanted, the latter operation taking advantage of any genetically improved stock or even a change of species since the previous crop was established. Some plantations are regenerated naturally using seed from the preceding final crop trees or, where the species is suitable and small-sized products sought, from coppicing, i.e., forming the new crop from stump shoots (sprouts) of the felled trees. Coppicing is common for firewood and pole crops such as many eucalypt plantations in the tropics.

Plantation Yields and Productivity

Growth Rates and Yields

Because a suitable species is carefully matched with the planting site and because trees are spaced evenly to occupy the site and all are harvested, plantation productivities are usually considerably greater than that of natural forest (**Figure 2**). The typical range of yields is: 3–20 $m^3 ha^{-1} year^{-1}$ in temperate plantations, 5–35 $m^3 ha^{-1} year^{-1}$ in Mediterranean climates, and 5–50 + $m^3 ha^{-1} year^{-1}$ in the tropics and subtropics.

The main factors causing the above wide variation in plantation growth rates are tree species, fertility and exposure of site, and length of growing season, namely adequate summer warmth in high latitudes or sufficient moisture in Mediterranean and tropical regions where severity (length) of dry season is critical. Within these general climatic parameters moisture (rainfall amounts) often determines good and poor years for tree growth.

Maximum productivity from a site is also affected by stocking and for how long trees are grown. Long rotations to achieve large tree sizes for specified markets may diminish site productivity potential since older trees, while not overmature biologically, slowly decline in growth rate.

Figure 2 Plantation of native *Cordia alliodora* on abandoned ranch land in Lcuador which has led to good regeneration of other native hardwoods. © J. Evans, 2004.

In the future yields can be expected to increase owing to genetic improvement ranging from simply choosing a better provenance to possible use of genetic modification technology.

Problems with Plantations

Monoculture and Risk of Pests, Diseases and Other Threats

The uniform conditions of growing one tree species in large even-aged blocks may expose plantations to greater risk of damage from pests and diseases. Ecologically the potentially large food resource, the close proximity of trees to pass on infection, and even direct root contact beneath ground all suggest greater risk and potentially rapid build-up of a threatening pathogen or pest. Where an exotic (introduced) species is used, some freedom from damage is often observed in the first rotation, but this is often transitory. For example, extensive plantations of lodgepole pines (*Pinus contorta*) in Scotland (UK) grew well on very inhospitable sites throughout the 1950s and 1960s but in 1977 began to be devastated by a hitherto benign insect species associated with native Scots pine (*Pinus sylvestris*), *Panolis flammea*. The severity of damage was so great that lodgepole pine is no longer planted.

Other well-known examples include defoliation by the psyllid *Heteropsylla cubana* of the once widely planted multipurpose tree species *Leucanea leucocephala*, and *Sirex* wood wasp infestation of *Pinus radiata* plantations in Australia and recently in South America. Fungal pathogens causing serious damage such as defoliation, wood decay, or root mortality are the blights on poplar, fomes (*Heterobasidion* spp.) damage to many conifers, and *Phytophthora* spp.

All these and many other threats place plantations at considerable risk. However, experience teaches that most are containable provided that good silviculture limits risk of stress to trees through careful matching of species with site and related operations, and provided that adequate research can inform integrated pest/pathogen management programs and strategies. Only occasionally has a species been precluded owing to the threat of a devastating pest or disease, e.g., *Dothistroma* damage to *Pinus radiata* planted in the tropical highlands, and psyllid damage to *L. leucocephala*.

Abiotic Damage

The uniformity of plantation conditions can render them particularly vulnerable to fires, storms, frosts, droughts, and related events. In the late 1990s one-sixth of the entire Usutu Forest in Swaziland in southern Africa, a plantation of some 72 000 ha, was destroyed by either fires or hail damage, necessitating massive replanting programs. In the UK the threat of windthrow in forest plantations determines rotation length on many more exposed sites, with the aim of cutting trees just prior to the time they are predicted to blow down.

Sustainability of Yields Over Time

With significantly greater productivity than most natural forest, the question of sustainability of plantation yields becomes important. Could the more intensive silviculture lead to declining yields in the long term? It is difficult to answer this question categorically, and the situation will vary with site, because few plantations have been grown successively for more than two rotations and almost none for more than three rotations. However, what evidence does exist suggests that productivity is unlikely to decline; indeed, it may increase with improvements in genetic stock of plants. In one of the most intensively studied examples in Swaziland there is no evidence of yield decline after three whole rotations of pines grown for pulpwood, and even some signs of improving productivity.

There are some well-publicized exceptions to the above, namely plantations of *P. radiata* in South Australia, *Cunninghamia* in subtropical China, and *Picea abies* in Germany. In each case research has either demonstrated or at least pointed to causal factors that explain the yield decline. Such factors include excessive compaction of soil when harvesting trees, failure to conserve organic matter, and inadequate attention to invasive weeds, especially grasses. On no site does the growing of a single tree species in monoculture itself appear to be a primary cause of the problem. Indeed, in the case of South Australia, current growth rates of pine plantations now greatly exceed that of the previous rotations.

Outlook

As noted, there is already a substantial resource of planted forest which continues to expand and is destined to become the main source of wood products. What must be hoped is that this will include not only industrial grades of lumber but also high-quality timbers to replace diminishing supplies from natural forest. What must also be hoped is that much of future planting in developing countries will be fully integrated into rural development and local people's aspirations to contribute in the many ways plantations can to sustainable livelihoods.

Other emerging trends include increased planting of trees outside the forest, such as in agroforestry, partnerships between corporate enterprises and smallholders, rehabilitation of degraded land, and environmental protection roles.

Plantations as a way of growing trees efficiently appear sustainable. They will fully come to play the enormous role they can only if environmental, political, and social imperatives are addressed alongside those of sound silviculture.

Acknowledgement

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See also: **Afforestation**: Ground Preparation; Species Choice; Stand Establishment, Treatment and Promotion - European Experience. **Operations**: Nursery Operations. **Plantation Silviculture**: Rotations; Short Rotation Forestry for Biomass Production; Stand Density and Stocking in Plantations; Sustainability of Forest Plantations; Tending. **Silviculture**: Managing for Tropical Non-timber Forest Products. **Social and Collaborative Forestry**: Joint and Collaborative Forest Management.

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