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Sawn Timber *see* **Solid Wood Products**: Glued Structural Members; Lumber Production, Properties and Uses; Structural Use of Wood.

SILVICULTURE

Contents

Silvicultural Systems

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Introduction

A silvicultural system is a planned series of treatments for tending, harvesting, and reestablishing a stand. The main systems, their variations, and applications are described in this article. There is no fundamental difference between the systems practiced in tropical and temperate parts of the world. Variations often have to be introduced in both, for example in the wet tropics to accommodate the species-rich nature of the forests, and the relatively small number of species with timber that is commercial by current standards.

Classification of Systems

The classification of silvicultural systems, which are by their nature often flexible and imprecisely defined, is not easy. They differ, and can therefore be classified in three major ways. First, the method of regeneration used can be from coppice or root suckers, or by planting, direct seeding, or natural regeneration. Although coppice systems are clearly distinguished, most others can use any of the other three techniques. Secondly, the even-agedness of a stand puts selection systems at one extreme, and clear-cutting and coppice systems at the other. Other systems have two or more age classes for at least part of the rotation. Finally, systems can also differ in the size of the silvicultural unit. This ranges from the compartment in shelterwood and clear-cutting systems to progressively smaller areas in strip and group systems. The place of the selection system in this hierarchy is debatable, depending on whether one considers that each felling is applied to the stand as a whole, or whether each tree is treated individually.

A consideration of these three axes of variation suggests the following classification:

1. (a) Stands originating from stool shoots or suckers of vegetative origin: coppice systems.
   (b) Stands predominantly of seedling origin: high forest systems—**2.**

2. (a) Felling and regeneration are distributed continuously over the whole area, giving rise to an uneven-aged (irregular) stand: selection or polycyclic systems.
   (b) Felling and regeneration are concentrated on one part of the forest area only at any one time—**3**.
3. (a) Systems of successive regeneration fellings such that the old stand is removed by several fellings over a period of years. This gives rise to an approximately two-aged stand for a period in the regeneration cycle: shelterwood systems.
   (b) Old stand is cleared by a single felling, giving rise to an even-aged stand: clear-cutting (or clear-felling) system.

There are also various group, strip, wedge, and edge systems that are considered here (but not by all authors) as variants of the three basic high forest systems, as determined by the age structure within each. These are discussed later.

Coppice System

Coppice shoots arise primarily from concealed dormant buds that grow from the stump of a tree following cutting (**Figure 1**). They can also develop from buds on roots in some species, to give rise to root suckers, and a few reproduce by both methods.

The coppice system relies upon these methods of vegetative production after each stand of trees has been felled to provide the next generation. Coppice regeneration has an advantage over seedlings in that ample supplies of carbohydrates are available from the parent stool and its root system, so new shoots grow very vigorously from the start. However, coppice shoots of most species seldom grow to the dimensions of trees grown from seed, so the system is used to produce small-sized material. The ability to coppice is far more common in broad-leaved trees than in conifers. Species also vary greatly in their vigor of coppicing: poplars, willows, and eucalypts are generally very good. The longevity of a stool varies with its health, species, and site. Some are relatively short-lived, lasting only two or three rotations, while others, such as *Tilia cordata*, are almost indestructible. Among suitable species, no method of regeneration has a greater certainty of such rapid and complete success, and in the rather rare circumstances today where coppicing is profitable, no other method of regeneration is cheaper. The system can be attractive financially because coppice rotations are much shorter than those in high forest where trees are grown from seed.

Variants of coppicing include coppice-with-standards, pollarding, and shredding, the latter two being mostly associated with wood pasture and isolated trees rather than woodland.

- Woodlands managed as coppice-with-standards usually consist of simple even-aged coppice as the underwood, and an overwood of standards which are normally trees of seedling rather than coppice origin (**Figure 2**). The latter are uneven-aged and the two components have quite different rotation lengths. The system provides both large and small stems from the same piece of land, and is the oldest of all deliberately adopted systems of forest treatment. Cuttings are made in both the overwood and underwood at the same time. When the coppice underwood has reached the end of its rotation and is cleared, standards which have reached the end of theirs are also removed and new ones introduced.

Figure 1 Coppice shoots growing from a sweet chestnut (*Castanea sativa*) stump in Sussex, UK.

Figure 2 Oak coppice with standards in Germany. In this picture, the coppice has recently been cut for fuel wood, after growing for about 25 years, and has been stacked ready for removal. Most of the standards, which are trees of seedling origin, are left and a good indication of the range of ages (sizes) can be obtained.

Figure 3 *Eucalyptus globulus* grown on a 7–10-year coppice cycle for paper pulp production in Portugal.

- In pollarding the trees are cut 1.5–3.5 m above the ground, rather than at ground level, and allowed to grow again. This puts the regrowth out of reach of cattle and other browsing animals. Any tree that can be coppiced will respond to pollarding, except those where suckers are depended upon. Today, pollarding is mostly done for ornament.
- Shredding involves the repeated removal of side branches on a short cycle, leaving just a tuft at the top of the tree. It was practiced in Europe to feed cattle on the leafy shoots removed from trees, especially elm on land where there was little grass. Today it is sometimes carried out in countries with Mediterranean or monsoon climates, such as parts of Nepal, where there is a long, dry, grassless season, while deeper-rooting trees can provide ample fodder from their leaves.

Coppicing is one of the oldest forms of forest management, but it has been in decline in many temperate regions since at least the mid-1800s as a result of industrialization. Plastic, metal, and other alternatives are now available to replace the many objects and implements formerly made of wood of small dimensions. Improvements in infrastructure for distributing gas, electricity, and coal also means that wood is seldom required as a fuel outside the tropics.

In its modern form, coppice is extensively used for the production of pulpwood (e.g., from *Eucalyptus*; **Figure 3**), and for short-rotation energy crops (from

Salix and *Populus*), as well as for fuelwood, mostly in the tropics (e.g., *Leucaena leucocephala*). It is normally worked on a clear cutting system.

High Forest Systems

Selection System

Selection systems involve the manipulation of a forest to maintain a continuous cover, to provide for the regeneration of the desired species and controlled growth and development of trees through a range of diameter classes which are mixed singly (in single-tree selection systems) or in groups (group selection systems). Successful management can be very complex. It depends on a sound ecological knowledge, experience, in which considerable intuition may be involved, and silvicultural judgment. It aims for the maintenance of a stable and relatively unchanging forest environment.

Stands managed on a selection system are, at all times, an intimate mixture of trees of all age classes (**Figure 4**). There is no concept of a rotation length, or of a regeneration period, as both harvesting and reestablishment take place regularly and simultaneously throughout the stand. The only silvicultural interventions are selection fellings, which are typically carried out every 5–10 years throughout the stand. These fellings are a combination of regeneration tending, cleaning, thinning, final felling, and regeneration felling. This can be difficult as the needs of each of the age classes must be taken into account and trees of all sizes are removed. An important feature of selection felling is that it concentrates on improving the quality of the stand rather than felling to remove the largest and best stems, which may result in impoverishment.

Without careful intervention there is usually a tendency for a more even-aged structure to evolve, and also for the different age classes to become spatially separated, so that a group structure develops. In an extreme case, this would result in even-aged, single-storied groups. This occurs with light-demanding species, and such a group selection system is the only form of the selection system which is appropriate to them.

The length of the period between successive selection fellings varies. Short periods (less than 5 years) allow better stand management, particularly of young trees. Long periods result in larger volumes of timber being removed at each visit, making them more economical. They also improve the success of regeneration of light-demanders because the canopy is opened up more.

Selection or polycyclic systems are appropriate for the management of tropical high forests in, for example, West Africa. The best European examples are in the silver fir (with beech and Norway spruce) forests of central Europe. In temperate regions, selection systems are largely confined to mountainous areas where a continuous protection of the soil against erosion and often against avalanches is of great importance. They also protect the soil against leaching and are suitable for regeneration of frost-sensitive species. Selection forests are probably the ideal for conserving landscapes, and appropriate for forests around towns where an apparently unchanging view is important, but contrary to popular belief they do not necessarily even approximate to natural forests in many places where they are applied.

The term 'group selection' is widely used and loosely applied to any irregular or group system. It should strictly refer only to systems in which a stand

Figure 4 A selection forest of predominantly Norway spruce (*Picea abies*) and European silver fir (*Abies alba*), with some beech (*Fagus sylvatica* L.) in the Jura mountains, France.

is subdivided into groups, each of which is, for a large part of its life, uneven-aged, and has more than one storey. They are also referred as 'irregular shelterwood' systems. In practice, group selection closely resembles the selection system, as there is usually no fixed rotation length or regeneration period. It differs in that a time eventually comes when all remaining old trees must be removed, whereas in true selection working no such time ever arrives. There is, therefore, a shelterwood notion: an older stand providing protection for a younger one which is replacing it, but the period of shelter is often over 50 years. It also differs from a selection system in that more emphasis is placed on obtaining and developing regeneration in groups rather than uniformly through the stand.

Shelterwood System

The essential feature of the system is that even-aged stands are established, normally by natural regeneration, under a thinned overstory that produces sufficient shade and a moderated environment for young trees to establish. It is removed as soon as establishment is complete. Treatments usually include the following (**Figure 5**):

1. Preparatory felling: essentially a late thinning to encourage the development of the crowns of future seed bearers.
2. Seeding felling: once it is clear that there is going to be a good seed crop, a third to a half of the stems are removed. The understory and any regeneration already present are also removed. Cultivation may be carried out to assist seedling establishment (**Figure 6**).
3. Secondary fellings: usually two to four fellings, at 3–5-year intervals, with timing and intensity carefully regulated to allow seedlings to grow, but also to prevent rank weed growth (**Figure 7**).
4. Final felling: the last secondary felling in which the remaining overstory is removed. The damage done to regeneration in later fellings is not usually serious, especially if the regeneration is young and supple, dense and even-aged.

The whole series of operations normally takes 5–20 years. Infrequent mast years and frost-sensitive seedlings both necessitate long regeneration periods. The secondary fellings for a light-demanding species must be few and rapid and the whole process may be completed in 5 years.

If seed production is infrequent, then it may take 20 years to obtain adequate regeneration. The stand will then be somewhat uneven-aged and patchily distributed, in which case the system grades into the group shelterwood. Some authors state that one of the main advantages of this system is its simplicity, but in areas where mast years are infrequent,

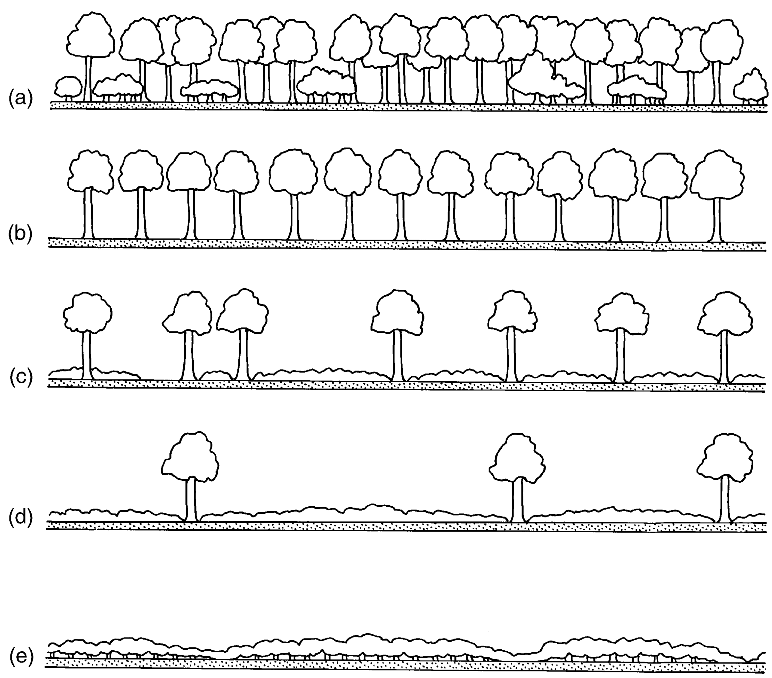

Figure 5 Uniform shelterwood system, showing successive stages of regeneration in oak forest. It typically takes 5–8 years from a successful seed fall to removing the last of the adult trees. (a) The forest before regeneration begins, with understory trees and shrubs; (b) after the seeding felling; (c) a secondary stage where adult trees have been removed around successfully established regeneration; (d) a late secondary stage where very few adult trees remain; (e) the young regenerated stand with all the previous generation of trees removed.

Figure 6 Shelterwood system with oak (*Quercus petraea*). A seeding felling has just been carried out, removing a third to a half of the trees. The understory and any regeneration already present have also been removed and the ground has been cultivated to assist seedling establishment. Bellême forest, Normandy, France.

Figure 7 Shelterwood system with oak (*Quercus petraea*). A late secondary felling, at an intensity and time to allow the prolifically produced seedlings to grow, but also to prevent excessive weed growth. Bellême forest, Normandy, France.

obtaining a fully stocked, even-aged regeneration is a major managerial problem. The shelterwood system can also be used with planted stock where natural seeding is insufficient or irregular, where a change of species is required, and where seed-bearers are insufficient in number or quality.

Variants to the system include both group and strip systems that consist of shelterwood regeneration fellings carried out in a strip ahead of the advancing edge of the final felling. They are sometimes considered more suitable than the shelterwood systems for light-demanding species.

Group shelterwood systems involve retaining an overstory for a short period to provide shelter for the new stand, which is approximately even-aged. The main difference from the shelterwood system, apart from the small size of the areas worked, is the fact that if advance or existing regeneration is present, it is used as the focus of a regeneration felling. (In a strict shelterwood system, existing regeneration would be removed with the understory.) Groups are gradually enlarged by carrying out regeneration fellings (seeding, secondary, and final fellings successively) around the edges until eventually they meet and merge. The regeneration period is generally longer (15–40 years) than with the shelterwood system, and the resulting stand is therefore somewhat more uneven-aged.

Stands managed under a shelterwood system have many features in common with those established by planting under a clear-cutting system. They can be pure, even-aged, and uniform in structure and density over large areas.

Clear-cutting System

This system is universally applied and is likely to remain the predominant silvicultural system in forests managed primarily for profitable wood production. Its main advantages include simplicity, uniformity, and, in particular, the ease of felling and extraction. The use of clear-cutting does not necessarily preclude the use of natural regeneration (as is done in a variant, the 'seed tree' system, where a small number of widely spaced adult trees are retained for seed production), but the system almost always operates with establishment by planting (**Figure 8**). The main advantages of planting arise from its artificiality and minimum reliance on unpredictable natural events. Enough plants can be ordered for the desired year and can then be evenly distributed across the whole area, in rows, to facilitate subsequent tending. This makes reliance on natural regeneration seem like a technique inherited from a primitive 'hunter–gatherer' technology, whereby the time of arrival and dissemination of seed, the genetic quality, and even the species of the regeneration are largely outside the control of the manager.

However, planting is expensive, losses may be high, especially through drought, and since stocking is usually orders of magnitude lower than with good natural regeneration, the resulting stand may be of lower quality. Disadvantages of clear-cutting, rather than of planting, largely arise from the lack of protection, leading to a rise in the water table, extremes of temperature including frost, leaching and soil acidification, and rank weed growth. Clear-cutting is widely regarded as the least desirable system for both landscape and conservation but these disadvantages can be reduced by the use of small coupe-fellings (0.2–2 ha).

Clear-cutting is based strongly upon principles of economics and finance. It provides good opportunities for using labor-saving equipment and machinery efficiently; management is simple and work can be carried out with little skilled supervision. Management can, in fact, be intensive, and hence cost-effective. For production systems where profit is a major motive, clear-cutting is invariably the choice, unless some biological or environmental factor of the locality rules it out.

Group clear-cutting involves felling all the trees in a group prior to restocking. The stand within each group will always be even-aged, but the stand as a whole will contain groups of a wide range of ages, and possibly of all ages. The individual groups may be pure or mixed in species composition, and may be established by natural regeneration, or planting, or a combination. Group clear-cutting is particularly appropriate to strong light-demanders as the only protection given to the young trees is from side shelter. Group sizes commonly range from coupes of about 50 m in diameter (0.2 ha) to areas of a hectare in extent.

Group, Strip, Wedge, and Edge Systems

The various group systems are considered here to be variants of the three main high forest systems, giving group clear-cutting, group shelterwood, and group selection systems. A whole compartment of a group clear-cutting system may therefore be uneven-aged, but each individual group will be even-aged and managed on a clear-cutting system. Similarly, strip,

Figure 8 Extensive even-aged plantations of Sitka spruce (*Picea sitchensis*) in Scotland.

wedge, and edge systems can be considered as variants of each of the three basic high forest systems, depending on the type of stand treatment that is carried out ahead of the advancing felling edge. This gives strip-felling, and strip-shelterwood systems, and also strip variants of the group systems, such as strip-group shelterwood.

In all group systems, the size of the group is a critical characteristic. Large groups are easier to manage, and are essential for light-demanders. The most useful range is probably 0.1–0.5 ha; larger groups are needed in taller and more uneven-aged stands. The shape and orientation of the groups can have a major influence on the variation of microclimate within them, and considerable emphasis is laid on this in central Europe. General observations are that a north–south orientation of an elliptical or rectangular group provides a good compromise between wind and sun, and that light-demanders should be near the north edge, and frost-tender species near the south.

The layout of groups is vital in facilitating management of the stands. Wherever possible, the first groups to be regenerated are those located furthest from the road, thereby minimizing the amount of timber that has to be extracted through a young stand. Fencing costs for small groups are inordinately high and this has always been considered a major disadvantage of any group system.

Group systems come closest to imitating the structure of a natural stand, at least in many temperate regions, and are therefore increasingly recommended for use.

Choice of Silvicultural System

Foresters continually have to choose between different silvicultural and management systems to achieve different mixes of products and benefits from specific forest areas. No single system is ideal for all situations. The choice is most often between even-aged monocultures that are usually, but not always, based on planting and clear-cutting and various uneven-aged systems based on natural regeneration.

The factors that govern the choice of a silvicultural system are silvicultural, economic, and socioeconomic, and include:

- the reproductive requirements and habits of the desired tree species
- the site itself may indicate, or at least rule out certain systems. Where conditions are particularly suitable for seeding and germination, systems for regenerating large coupes can be used, but where they are less certain, much smaller coupes are preferable
- constraints and requirements imposed by wildlife
- likelihood of problems arising from insect pests, fungal diseases, fire or climatic hazards, such as frequent high winds. The latter usually necessitate use of the clear-cutting system, and put the shelterwood system at extreme risk
- the size, age, and vigour of the existing trees may dictate the system
- the introduction of a new species to a site, or genetically improved strains, usually requires planting and even-aged systems
- the nature of the topography and soil may dictate the system
- constraints on manpower, money, equipment, and markets all have considerable influence on the choice of system.

Woodland management can be thought of as grading from intensive through to extensive. The former implies careful and expensive tending to produce valuable high-quality timber and the latter a lower-input approach, accepting mixed and uneven-aged stands, and producing, cheaply, rather lower-quality timber. Intensive management is normally associated with clear-cutting and shelterwood systems. The less intensive approach is more appropriate to selection and group systems, which need careful, but not capital-intensive, management to run well.

The same distinctions apply to the strategy adopted for obtaining and using natural regeneration: one could either invest time and money in trying to get a full stocking from any one seed year (i.e., a shelterwood system with careful preparatory thinnings, cultivation, and weed control) or one could operate a group, or selection, system with minimum preparation for seed, but accepting and using the steady trickle that establishes itself, largely unaided. Both approaches have their merits and the high-input one is not always the most profitable. The low-input approach is particularly appropriate to owners of small woodlands who do not have large sums to invest or where the forest is composed of many species, few of which are merchantable, as in many tropical forests.

Stands of irregular structure and tolerant (shade-bearing) species are best suited to uneven-aged silviculture, and it is also best practiced on fragile sites, steep slopes, sites with high water tables, and very dry sites that would be adversely affected by complete removal of the forest cover, even for short periods. Even-aged systems are most appropriate in stands of intolerant (light-demanding) species and should be used to return over mature, decadent, diseased, or insect-infested stands to productivity.

See also: **Afforestation**: Species Choice. **Plantation Silviculture**: Multiple-use Silviculture in Temperate Plantation Forestry; Rotations; Sustainability of Forest Plantations. **Silviculture**: Coppice Silviculture Practiced in Temperate Regions; Natural Stand Regeneration; Unevenaged Silviculture. **Windbreaks and Shelterbelts**.

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Bamboos and their Role in Ecosystem Rehabilitation

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Introduction

Bamboos are a treelike, 'woody' plant of the grass family and botanically, one of the closest relatives to rice. It thus combines the best of both worlds – it grows speedily like a grass and in much the same way, while at the same time, it produces a considerable amount of high-strength and easily processed woody material with similar properties. It can grow in very poor soils, but also responds admirably to fertilization and irrigation, much like the modern rices, resulting in a doubling or more of size and annual biomass production.

Within the area of their natural distribution, bamboos are the plant equivalent of the domesticated animal like the cow, sheep, and goat. The high strength-to-weight ratio of the poles, and the absence of cross-fibers that lends bamboo to easy linear splitting, are characteristics that have made rural communities choose bamboo over other trees when it comes to structural as well as diverse subsistence uses. Over 1 billion people on earth live in houses that are reinforced with bamboo, even where wood is available nearby.

There are hundreds of traditional uses of bamboo, from food, construction material, housing, and bridges to household articles, and use in agriculture, fisheries, transportation, and in village industry. Bamboo also finds use today as a structural material, as a wood substitute, food, fuel, and a filtration medium.

Diversity

Bamboos are the most diverse group in the grass family, and the most primitive subfamily. The taxonomy of bamboos remains poorly understood, though the general consensus seems to be that the subfamily Bambusoideae has between 60 and 90 genera with 1100 to 1500 species, with the vast majority being tropical. The main reason for this large variation in diversity estimates is that flowering bamboos are few and far between. Most bamboos flower once in several years (and die thereafter), with the vegetative period extending up to several decades, but commonly 30–60 years for the more useful species. Hence taxonomists have to contend with having to do species determination mainly on the basis of vegetative material, which results in open-ended results that need a flowering specimen for confirmation.

Propagation

Bamboos are commonly propagated using vegetative (clonal) means and, when available, by seeds. The latter method is more common in tropical areas where the bamboos flower and set seed more frequently. Most bamboos produce copious quantities of seed (botanically termed caryopses that are technically fruits); these are called 'bamboo rice' and are even used as such. The rare exceptions are species such as *Melocanna baccifera* that produce large fruits, often the size of small mangoes. In some bamboos, infertility is rampant, with few viable seeds being produced.