Trials have been successful and local communities and farmers' groups are now successfully cultivating the plant and obtaining a good income from sales locally and export to Nigeria. Silviculture in these cases is synonymous with horticulture.

The Market Takes Over

When market demand is for consistent quality, reliable large volumes, and a product which is a profitable export, it is often only a matter of time before production becomes industrialized (**Figure 4**). At this point market forces take over and capital is invested in large-scale or at least farm-scale production which almost inevitably takes the production process away from small-scale farmers, gatherers, and the poor. This is the end of the road to domestication; from this point onwards agriculture and horticulture take over. However, through long association, the tag NTFP may still remain as evidenced by articles in the *Journal of Non-Timber Forest Products* covering *in vitro* propagation of trees and provenance trials for common farm trees (e.g., neem).

Although often advocated, and in many instances necessary, captive production or cultivation (*ex situ*) is not without its conservation risks. Domestication can lead to environmental degradation, pollution, and reduction in genetic diversity as well as loss of incentives to conserve wild populations.

See also: **Biodiversity**: Plant Diversity in Forests. **Ecology**: Human Influences on Tropical Forest Wildlife. **Medicinal, Food and Aromatic Plants**: Edible Products from the Forest; Forest Biodiversity Prospecting; Medicinal and Aromatic Plants: Ethnobotany and Conservation Status; Medicinal Plants and Human Health; Tribal Medicine and Medicinal Plants. **Non-wood Products**: Resins, Latex and Palm Oil; Rubber Trees. **Sustainable Forest Management**: Definitions, Good Practices and Certification.

Further Reading

Boffa J-M (1999) *Agroforestry Parklands in Sub-Saharan Africa*. Rome: FAO.

Booth FEM and Wickens GE (1988) *Non-Timber Uses of Selected Arid Zone Trees and Shrubs in Africa*. Rome: FAO.

Cunningham A (2000) *Applied Ethnobotany*. London: Earthscan.

Falconer J (1990) *The Major Significance of 'Minor' Forest Products*. Rome: FAO.

Murrieta JR and Rueda RP (1995) *Extractive Reserves*. Gland, Switzerland: IUCN.

Oyen LPA and Lemmens RHMJ (2002) *Plant Resources of Tropical Africa: Precursor*. Wageningen, The Netherlands: Plant Resources of Tropical Africa.

Robinson JG and Bennett EL (1999) *Hunting for Sustainability in Tropical Forests*. New York: Columbia University Press.

Russo L, Vantomme P, Ndeckere-Ziangba F, and Walter S (2001) Non-wood forest products. *FAO Forestry Paper* 140: 81–98.

Sequeira V and Bezkorowajnyj PG (1998) Improved management of *Butea monosperma* (Lam.) Taub. for lac production. *Forest Ecology and Management* 102: 225–234.

Verheij EWM and Coronel RE (1991) *Plant Resources of Southeast Asia: Edible Fruits and Nuts*. Wageningen, The Netherlands: Pudoc.

Wong JLG, Thornber K, and Baker N (2001) *Resource Assessment of Non-Wood Forest Products*. Rome: FAO.

Unevenaged Silviculture

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Introduction

Uneven-aged silviculture may be defined as the tending and regeneration of woodlands or forests which contain trees of several age classes in intimate mixture. In terms of silvicultural systems (*see* **Silviculture**: Silvicultural Systems) this would, strictly speaking, include only selection and group selection systems. A looser interpretation might include stands of trees with only two or three age classes, such as coppice-with-standards or even-aged crops which have been underplanted with younger trees. However, these will either be managed as overlapping even-aged crops, which will be maintained as such, or as the first stage towards a truly multiaged stand.

Stands of trees which are basically even-aged may also go through a period when some of the older trees are retained while younger trees become established, as in shelterwood systems, so that the stand will be temporarily uneven-aged to some degree, but the silviculture which is involved will remain essentially even-aged. Similarly, areas of forest may, for various reasons, be divided into smaller units, but the silviculture of these units would still be described as even-aged if each is managed with reference to its age and area, even if each unit is very small. The essential difference, in silvicultural terms, between even- and uneven-aged silviculture is that the latter does not take any direct account of the age of the trees or the area which is occupied by each age class. Age and area, as such, are ignored. This involves a fundamentally different approach, both in theory and in practice.

History of Uneven-Aged Silviculture

In many parts of the world there have been periods when forests have been managed on an uneven-aged basis. Often, this was carried out without sufficient understanding, consistency, or care, and led to the removal of the best timber trees and/or inadequate regeneration of young trees, leaving the forest inadequately stocked or containing few trees of value. This led to a desire to adopt more organized forms of silviculture, and even-aged silvicultural systems with clearfelling came to be regarded as the best way to manage forests. This was most notably so in Germany in the latter part of the eighteenth century, and forests managed in that way were certainly easier to organize and control.

Towards the end of the nineteenth century a few foresters, most notably in Switzerland, became unhappy with the even-aged approach and developed systems of selection, whereby individual trees or small groups of trees were selected for removal and the forest was never subjected to clearfelling. Recording and management of the growing stock were by periodic measurement of all trees above a minimum size, enabling productivity and changes in growing stock to be assessed over time. These forests typically included spruce (*Picea abies*), silver fir (*Abies alba*), and beech (*Fagus sylvatica*) growing in their natural habitat, and management in this way was seen as being fairly natural or 'close to nature.' Other advantages were perceived, including reduced risk of soil erosion and avalanches of snow, greater emphasis on the production of large stems, and reduced costs of planting. This approach became more widespread in some areas and, from early in the twentieth century, Swiss law has forbidden felling of any areas greater than 2 ha without special consent. Slovenia followed suit in 1950, and state-owned forests in a number of German provinces have been managed without clearfelling since the 1980s.

Elsewhere, experience was less satisfactory. Methods which may have been successful in spruce/silver fir/beech forests in Switzerland did not always transfer readily to conditions in Scandinavia, North America, or other parts of the world, and uneven-aged silviculture fell out of favor in such countries during most of the second half of the twentieth century.

In Germany, an organization called Arbeitsgemeinschaft Naturgemässe Waldwirtschaft (Working Group on Woodland Management Using Natural Methods) was formed around 1950 to promote forestry which utilized natural processes as far as possible, and this eventually provided a catalyst for the creation of Pro Silva (a pan-European organization with similar objectives) in 1989. This now has national groups in most European countries, and there has been a considerable resurgence of interest in uneven-aged silviculture or 'continuous cover' forestry in many parts of Europe and North America. Elsewhere in the world, in places such as New Zealand and many tropical countries, there has in recent years been a dichotomy of silviculture, with even-aged plantations of timber species on the one hand and conservation of what remains of the natural forest, in the form of nature reserves, on the other. Harvesting of timber on a sustainable basis from natural tropical forests has been attempted in a number of places, but has not had a generally good track record. This has often been due to a combination of political, social, and economic problems rather than to any intrinsic silvicultural difficulties.

Felling and Regeneration

For management purposes, forests are usually divided into compartments (typically between 5 and 50 ha in temperate forests, but often much larger in tropical regions) which are relatively uniform in terms of physical attributes such as soil type and slope, and which are of a convenient size to be dealt with as part of an annual program of thinning or felling. In uneven-aged forest, each compartment will be visited every few years (usually between 5 and 12 years, depending mainly on the rate of growth) and selected trees removed.

The selection of trees for removal needs to be undertaken with several objectives in mind, and demands a degree of skill and experience. Where timber production is a main object of management there will be an emphasis on favoring trees of good form and growth potential by the removal of trees which are coarsely branched or which have already reached their maximum potential value. The removal of any one tree should, in theory, maximize the value of the forest, in terms of current and future income combined. The forester will be constantly striving to improve the quality of the trees and the overall value of the forest at minimum cost.

At the same time, the removal of trees should not be carried out in such a way as to cause instability of the forest. In particular, in places where there is a high risk of damage from wind, only a limited proportion of the timber volume should be removed at any one time and it may be necessary to leave some big trees to provide stability, if their removal would leave other trees vulnerable to being uprooted or broken by the wind. However, uneven-aged forests are, in general, less likely to suffer catastrophic damage from wind than vulnerable stages of

even-aged forests. In vulnerable areas, removal of more than about one-sixth (15–17%) of the standing volume of timber at any one time might be inadvisable. If, on a highly productive site in a vulnerable area, annual increment were equal to 5% of the standing volume, that would imply a felling cycle of only 3 years in such areas, whereas if increment is equal to only 2% of the growing stock a felling cycle of 8 years would be appropriate.

There is a viewpoint which considers that the best way to manage forests in areas where gale-force winds are frequent and soils are wet and anaerobic is to grow trees with an even-aged unthinned canopy and then to clearfell them before they start to be blown down. If conditions are not so severe, then it is likely that an irregular structure will be less subject to catastrophic windthrow than an even-aged structure and will, in the long term, be more sustainable and more economic.

If a greater proportion of the standing volume can be removed without causing instability or other problems, a longer felling cycle may be appropriate. This will improve the economics of the harvesting operation, and may favor the regeneration of light-demanding species, but shorter felling cycles will allow better stand management and will tend to favor shade-tolerant species. In some instances removal of more than 50% of the standing volume may be possible. However, such heavy felling is likely to reduce the range of size classes and the productivity of the stand for several years and removal of more than 30% at any one time would be unusual.

Trees of unwanted species will be preferentially removed, while maintaining a reasonable diversity of species, and mature trees of desired tree species may be retained for longer than normal in order to ensure an adequate supply of seed.

In uneven-aged stands, a mixture of tree species is nearly always easier to manage than a single species, and also tends to have greater biodiversity and fewer problems with pest species.

Wherever possible, regeneration will be by natural seeding rather than planting, as this will be cheaper and easier to manage on an extensive basis. The selection of trees for felling will take into account the need to allow space for some seedlings and saplings of desired tree species to survive and grow, although these will not normally occupy more than 15% of the forest area at any one time. Too many saplings can be a problem, as they may require costly thinning or respacing to prevent them becoming overcrowded and spindly. With shade-tolerant species, in particular, there will often be seedlings present which are growing very slowly in shaded conditions and are 'waiting' for an opportunity to grow. If some of the mature trees are removed in that area, these established seedlings are then likely to make more rapid growth, due to the additional light and a reduction in competition for soil moisture and nutrients, even if there is some increase in the growth of herbs and shrubs, or other tree species. Ideally, individuals or small groups of saplings should then be able to grow rapidly into the upper canopy; and, ideally, these should require little or no tending until they reach a useful size and thinning can be done at no net cost.

The balance between the various factors can be critical, and obtaining natural regeneration is not always easy. However, it should be only one of several considerations in the mind of the person who is deciding which trees to remove, and should not be allowed to dominate the system.

Other factors (**Figure 1**) also influence the success or failure of natural regeneration, including the numbers of grazing or browsing animals such as deer, sheep, goats, cattle, rabbits, and hares. If these are too numerous there may be no successful regeneration, either planted or natural, unless fencing or other methods of control or protection are implemented.

Structure of the Growing Stock

The growing stock of uneven-aged forests often tends to follow a negative exponential curve, when numbers of trees are plotted against their stem diameters (**Figure 2**). This curve is frequently referred to as a reverse-J or simply a J-curve. It can be expressed mathematically, and an 'ideal' curve can be produced for any particular area of forest, but the mathematical formula requires the input of data on the required ratio between the numbers of trees in one diameter class and the next, and the 'ideal' basal

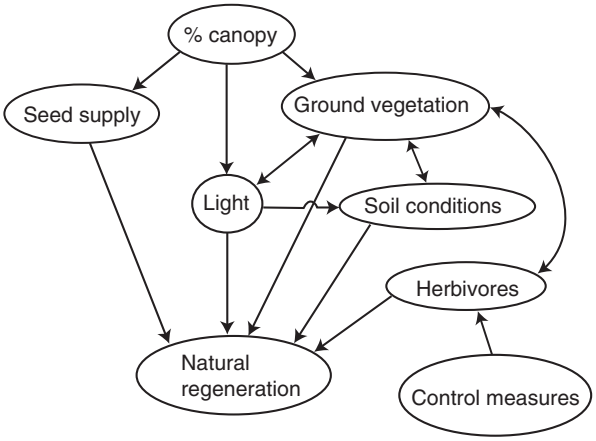

Figure 1 Factors affecting natural regeneration. © R Helliwell.

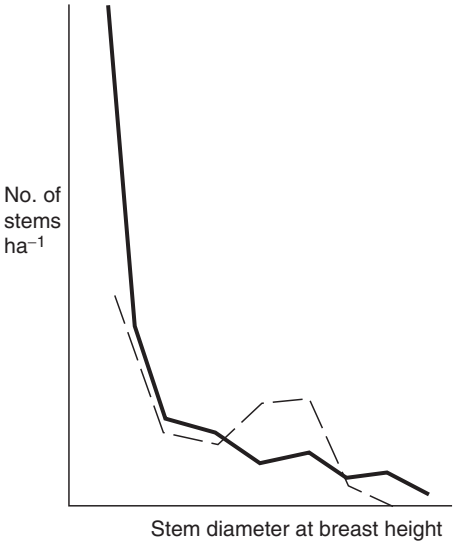

Figure 2 Typical distribution of stem sizes and numbers. (The dashed line indicates an abnormal distribution.)

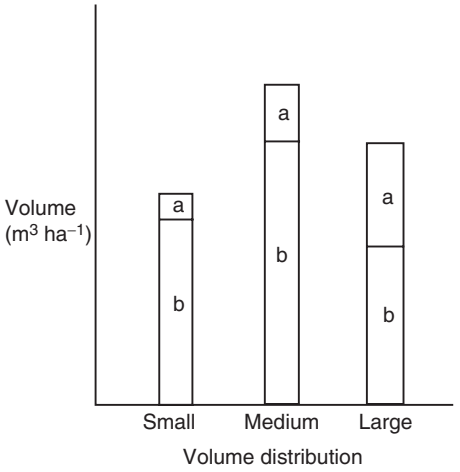

Figure 3 Typical distribution of size classes, by volume. a = species a; b = other species.

area of the stand. Neither of these can be known until a period of management experience has been obtained and data collected from several periodic measurements. It tends, therefore, to be something of a circular process, and it is probably better to regard the J-curve simply as an expression of what is happening, rather than as a prescriptive tool. Its exact form is probably not important, although any major difference from the general negative exponential form (such as a large hump in the middle: **Figure 2**) may indicate that all is not as it should be. Slavish attempts to make the forest conform to such a curve are not likely to be necessary, and may result in unnecessary expense.

One alternative to plotting stem numbers against diameters is to plot the volume of different size classes of tree, usually in three classes: small, medium, and large. The relative volumes in each class will depend to some extent on the size categories which are selected, but this method can provide a better visual impression, as significant changes in the volume of large trees may scarcely be visible on a J-curve, but will be quite clear if presented as volumes (**Figure 3**). As with J-curves, however, there is no easy way to determine the 'ideal' distribution of size classes.

Yield Prediction

Under even-aged systems there will usually be published yield tables available, which tabulate the rate of growth of trees of a given species against volume production, based on data from sample plots. If the age of the trees is known and the height of the dominant trees is measured, such yield tables can then be applied to predict future timber production by establishing a site index or yield class.

There are no such yield tables for uneven-aged stands, as the age of the trees is not known (and younger trees can sometimes spend several decades 'waiting' to grow, so their actual age is not of any particular relevance). The volume of timber which is likely to be produced from an uneven-aged stand can only be assessed by reference to the site type (i.e., the soil and climate) and tree species, or to previous records of production from the site or similar sites in the locality.

Control of the Growing Stock

If periodic measurements are taken of the growing trees (usually by the use of sample plots) and of any trees that are blown down or harvested, a picture will be built up of the growth of the forest and any changes in the growing stock. It is usual for managers to adopt tentative targets for the appropriate volume or basal area of the standing crop, which they think will give optimum timber production and regeneration. If the volume of the growing stock becomes too large, there is likely to be inadequate recruitment of smaller trees and it is possible that the larger trees will be so overcrowded that useful timber increment will stagnate and the individual trees lack stability and vigor, and they may even suffer outbreaks of diseases or pests as a result of the stresses which result from this. On the other hand, if the growing stock is too small, there may be an excess growth of troublesome herbs, shrubs, or climbers, and timber volume production will be reduced, as there will be fewer trees on which volume can accrue.

Control of regeneration by measuring the size of gaps or the amount of daylight at ground level is not a part of normal practice in uneven-aged silviculture. Reliance is placed on adjusting the intensity of felling according to the perceived response to previous fellings. This is more a matter of judgment than following a set formula.

Shade-Intolerant Species

Uneven-aged silviculture is particularly well suited to shade-tolerant tree species, such as beech and silver fir, which can regenerate in the relatively shaded conditions which are created by the removal of a small percentage of the standing volume. Other species, such as pines and oak in north temperate countries, or the various species of mahogany (e.g., *Swietenia* and *Khaya*) in the tropics, which require more light for regeneration and growth, are sometimes perceived as being less well suited. It is, however, possible to manage such species on an uneven-aged basis if they are well matched to the site and if there are no other more shade-tolerant species that would tend to replace them. In marginal cases, a shift from single stem selection to a group selection system may allow sufficient regeneration of the less shade-tolerant species to maintain an adequate percentage of those species in the stand.

Nature Conservation

There appear to have been few direct studies of the relative merits of different forms of silviculture for nature conservation. Uneven-aged silviculture may not provide suitable conditions for mobile or ephemeral species that utilize clear-felled areas, and if all the forest in a region is managed in this way it may be necessary to have some clear-felled areas (which would include any coppiced areas) or permanent open space, in order to allow such species to survive. However, uneven-aged forest provides a much greater degree of stability and continuity for the many species which require this. It is also easier to leave some trees to grow to senescence, and to provide a continuity of deadwood for species of fungi, insects, and birds which make use of this. The greater structural complexity of uneven-aged forest provides a greater variety of ecological niches at a local scale than do even-aged stands (and should be more ecologically stable as a result).

See also: **Biodiversity**: Biodiversity in Forests. **Plantation Silviculture**: Sustainability of Forest Plantations. **Silviculture**: Coppice Silviculture Practiced in Temperate Regions; Silvicultural Systems.

Further Reading

Dawkins HC and Philip MS (1998) *Tropical Moist Forest Silviculture and Management*. Wallingford, UK: CAB International.

Hagner M (ed.) (1992) *Silvicultural Alternatives. Proceedings from an Internordic Workshop*, June 22–25, 1992. Report 35. Umeå, Sweden: Sveriges Lantbruksuniversitet, Institutionen för Skogsskötsel.

Hart C (1995) *Alternative Silvicultural Systems to Clear-Cutting in Britain: A Review*. Forestry Commission bulletin no. 115. London, UK: HMSO.

Kelty MJ, Lawson BC, and Oliver CD (eds) (1992) *The ecology of mixed-species forests. dordrecht*. The Netherlands: Kluwer Academic Publishers.

Kuper JH and Maessen PPThM (eds) (1998) *Proceedings of the Second International Congress of Pro Silva (1997) Apeldoorn, The Netherlands* (in English, French, or German). Apeldoorn, The Netherlands: Dutch Pro Silva Congress Foundation.

Matthews JD (1989) *Silvicultural Systems*. Oxford, UK: Clarendon Press.

O'Hara KL (1998) Silviculture for structural diversity. A new look at multiaged systems. *Journal of Forestry* 96(7): 4–10.

O'Hara KL (2001) The silviculture of transformation – a commentary. *Forest Ecology and Management* 151: 81–86.

O'Hara KL (2002) The historical development of uneven-aged silviculture in North America. *Forestry* 75: 339–346.

Otto H-J (ed.) (2000) *Third International Congress of Pro Silva, Fallingbostel, Germany* (in English, French, or German). Langenhagen, (Hanover), Germany: Poppdruck.

Peterken GF (1996) *Natural Woodland. Ecology and Conservation in Northern Temperate Regions*. Cambridge, UK: Cambridge University Press.

Pro Silva (1993) *Proceedings of First European Congress, Besançon, France* (in English, French, or German). Besançon, France: Centre Régional de la Propriété Forestière de Franche Comté.