Coppice Silviculture Practiced in Temperate Regions

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Introduction

Coppice is a word that is used by foresters to cover many things including: a type of woodland consisting of trees that are periodically cut; the multistemmed trees that occur in such woodlands; the process of felling the trees; and the production of new shoots by recently cut stools. The management of woodlands as coppice has a long history and archeological evidence indicates that the process was used in prehistoric times. The basic method is simple and relies on the ability of many trees to regrow from the stumps remaining after felling. At its simplest, woodland comprising single-stemmed trees which have grown from seed are clear-felled and allowed to regrow. Repeated felling produces the multistemmed stools typical of coppice woodland. In the developed world elaborate forms of coppice management to control yield, and provide a sustainable supply of small wood and large timber, reached their zenith prior to industrialization when alternative fuels, building materials, and chemicals became more readily available. However, in these regions the art of coppice management has been in decline for 100–200 years and many woodlands have been transformed to high forest. There are still about 50 million ha of coppice within the industrialized nations but only 60% of this is classified as utilizable (**Table 1**). However, during the last two to three decades there has been a resurgence of interest in coppice grown on short rotations, primarily for use as a biofuel although longer rotations are used for the production of pulp woods. In contrast coppice has remained an important system of management in tropical areas where demand for fuel and small-diameter wood, for building purposes is still high. In addition to the use of naturally occurring species and woodland, several million hectares of plantation, often comprising species of eucalyptus, have been established.

Table 1 Estimated areas (ha $\times$ 10^3) of coppice woodland[a] in industrialized temperate/boreal countries

Region	*Utilizable*	*Non-utilizable*[b]
Nordic and Baltic	16	0
Central Europe	7687	64
Southern Europe	13 506	4411
Commonwealth of Independent States	12 643	16 071
USA and Canada	0	0
Australasia and Japan	56	0
Total	33 908	20 546

Data adapted from UN-ECE/FAO report ECE/TIM/SP/17, Geneva Timber and Forest Study Paper no. 17 (2000).
[a] Figures are for both simple coppice and coppice with standards.
[b] Non-utilizable, not available for wood supply for a variety of conservation, protection, or economic reasons.

Silvicultural Systems

Three systems of coppice woodland management are generally recognized: simple coppice, coppice with standards, and the coppice selection system. In many areas these idealized systems are probably impracticable at the present time and *ad hoc* systems of irregular cutting are likely to be more typical. Pollarding, which is similar to coppicing and also relies on the ability of the trunk to sprout new shoots, can be used to manage individual trees.

Simple Coppice

In this method the woodland is managed as an even-aged single-story crop grown for fuelwood and small/medium-sized material. The coppice is cut on a regular rotation, the length of which depends not only on the product required but also on species, location, and rate of growth. Theoretically the coppice is managed by sequential cutting of coupes throughout the woodland, with the woodland divided into a number of coupes equal to the number of years in the rotation; one coupe is then cut each year. Coppice woodlands managed in this way, with coupes cut at the appropriate time are said to be 'in-cycle' or 'in-rotation' (**Figure 1**).

Short rotation coppice woodlands are a special example of simple coppice in which the lifespans of any shoots or stools are short in comparison to those of traditional coppice woodlands. For example, typical rotations for clonal stands of *Populus* and *Salix* short rotation coppice are 2–4 years, with the expected lifespan of stools being 10–20 years before they are replaced when yield declines – perhaps four to five rotations in total. In contrast, mixed broadleaved coppice woodlands managed to produce fuel and small-diameter wood, may be cut on 20-year rotations with some stools capable of surviving for centuries.

Coppice with Standards

These woodlands are multistoried with an even-aged lower story of coppice underwood cut regularly to produce small material, and a partial overstory of uneven-aged standard trees which are usually grown

Figure 1 A recently felled coupe of in-cycle, simple sweet chestnut (*Castanea sativa*) coppice approximately 15 years old (Kent, UK). Reproduced with permission from Harmer R and Howe J (2003) *Silviculture and Management of Coppice Woodlands*. Forestry Commission, UK.

from seed and allowed to grow to a sufficient size to produce large timber. This system is more difficult to manage than simple coppice as it is necessary to manage the number, age class distribution, and location of large overstory trees which affect the growth of the understory crop. The underwood is managed as simple coppice, and after cutting each coupe the number and age class distribution of the standards present is adjusted: it is necessary to remove the oldest, reduce numbers of those of intermediate ages, and recruit new standards. This system is rarely used in the tropics.

Coppice Selection System

This method is similar to that for the selection system in high forests. Within the woods managed using this method the stools have populations of stems that are both of different sizes and ages. A target diameter for the product is set, and the age at which the crop achieves this fixes the length of the rotation: this period is divided into a suitable number of felling cycles and the woodland area is divided into a number of annual coupes which equals the number of years in the felling cycle. Harvesting of stems that have reached the target diameter occurs annually within one of the coupes; all smaller stems remain uncut. This is a special system which is rarely applied and is only likely to work well with shade-bearing species; for example, it has been used with *Fagus sylvatica* on poor ground in mountainous areas where the remaining canopy can have advantageous effects protecting both the new shoots and soil from damaging environmental factors such as frost, drought, and erosion.

Pollards

A pollard is a tree that is cut like coppice, but the new shoots grow from a trunk that is several meters long and they are not subjected to browsing damage from animals which can be allowed to graze beneath the trees. The branches are harvested periodically, after one or more year's growth, when the crown is partially or totally removed. Although ancient pollards persist and others managed for ornamental purposes are often seen in urban areas, this method of management is generally unimportant in the developed world. However, in arid regions of the tropics pollarding remains an important method of management to provide products such as fuelwood and animal fodder.

Biology of Coppice Shoots

The ability of trees to resprout is an adaptation that promotes survival after damage to the aboveground parts of the tree by a variety of factors such as fire, storm damage, and pathogens. Not all species of tree will produce coppice shoots and the phenomenon is more common in angiosperms than gymnosperms (**Table 2**). Some species regenerate more readily from

Table 2 Illustrative list[a] of angiosperms and gymnosperms that have been reported to regenerate by coppice shoots

Angiosperms	*Gymnosperms*
Acacia spp.[b]	*Araucaria araucana*
Acer pseudoplatanus[c]	*Cryptomeria japonica*
Aesculus hippocastanum[c]	*Cunninghamia lanceolata*
Albizzia spp.[b]	*Pinus echinata*
Alnus glutinosa	*Pinus rigida*
Betula pendula	*Pinus serotina*
Carpinus betulus[c]	*Sequoia sempervirens*
Castanea sativa	*Taxodium distichum*
Cornus florida	
Corylus avellana	
Eucalyptus spp.[b,c]	
Fagus sylvatica[c]	
Fraxinus excelsior	
Gmelina spp.[b]	
Liquidambar styraciflua	
Nothofagus obliqua	
Platanus occidentalis	
Populus spp.[b,c]	
Prunus serotina	
Quercus spp.[b]	
Salix spp.[b,c]	
Sorbus aria	
Tectonia grandis	
Tilia spp[b,c]	
Ulmus spp[b,c]	

[a] This list is not exhaustive.
[b] Many species or clones in this genus are known to produce coppice shoots.
[c] One or more species in this genus is reported to produce coppice shoots from adventitious buds (i.e., stool sprouts).

stumps than others, for example regrowth of *F. sylvatica* is poor relative to that of *Alnus glutinosa* and *Castanea sativa*. The capability of individuals within a species to regenerate from cut stumps varies with a variety of factors such as the age, size, and vigor of the tree prior to felling.

Origins of Coppice Shoots

Two types of coppice shoot are recognized, these develop from either suppressed or adventitious buds on the stump remaining. In the North American literature these are termed stump and stool sprouts respectively. In addition some species produce root suckers which are new shoots that grow from adventitious buds formed on the tree's roots.

Stump sprouts These are the most common type of coppice shoots found on broadleaved trees. As shoots of broadleaved trees grow they produce lateral buds that are associated with both leaves and bud scales. Most of these newly formed buds are suppressed by the apical meristem and do not grow during the season in which they are formed: they become dormant and will not grow into shoots until their dormancy has been broken by exposure to winter conditions or by other causes. The fates of lateral buds vary: on a typical temperate broadleaved tree some near the shoot tip form branches; many will die; and others, often the smallest, remain suppressed and return to the dormant state growing slowly outwards as the stem increases in diameter. Throughout subsequent annual cycles of growth the suppressed buds remain poorly developed, but they may divide to form large clusters of small buds embedded in the bark. Such suppressed buds are the primary source of most coppice shoots.

Stool sprouts Coppice shoots can also grow from adventitious buds that develop from tissues not closely associated with suppressed buds. Although many woody plants have the potential to form adventitious buds few are formed on stems. When a tree stem is cut adventitious buds and coppice shoots often arise in the ring of callus that develops between the wood and the bark of the stump. Unlike suppressed buds most adventitious buds do not undergo a period of dormancy and they develop into shoots in the season in which they are formed. Whereas suppressed buds are connected to the vascular system via a vascular trace, adventitious buds and shoots must develop a new connection with the plant's vascular system. Adventitious coppice shoots are uncommon, short-lived and generally unimportant in the regeneration of most broadleaved trees (**Figures 2** and **3**).

Silvicultural Factors

The silviculture of traditionally managed coppice woodlands evolved through centuries of practical experience, and there has been relatively little detailed research to investigate and understand the general biology of established coppice stools and shoots. In contrast, considerable effort has been expended during the last 10–20 years studying the growth, physiology, yield, establishment, harvesting, etc., of short rotation coppice crops. Most detailed knowledge on the biology of coppice comes from observations made on regrowth from stumps of single-stemmed trees that have not previously been coppiced, rather than complex multistemmed coppice stools. Many studies have shown that regrowth from such stumps following felling is influenced by age and diameter, but as these are related, their individual effects are difficult to disentangle.

Number and growth of coppice shoots For most species it is not possible to give precise advice about the effect of either stump size, or age, on the probable number of shoots that will be produced

Figure 2 Stump sprouts growing from suppressed buds on an established stool of hazel (*Corylus avellana*). Courtesy of the Forestry Commission.

Figure 3 Stool sprouts growing from adventitious buds formed in the cambium of a recently felled 60-year-old beech tree (*Fagus sylvatica*). Courtesy of the Forestry Commission.

and how they will grow. In general there are relationships between either stump diameter or age, and number of shoots produced and their initial growth. The relationships vary with species and site but overall the number and growth of shoots tend to decline with the size and age of stumps.

Mortality of stumps In general, the mortality of stumps tends to increase with both age and size, but the relationships vary with species. Site quality may influence the success of coppicing by its effect on vigor with slow-growing stools on poor sites re-growing less well than those on good sites. Although several suggestions have been made to explain the decline in shoot numbers and survival of stumps as they become older or larger, there has been little detailed study. The changes may be related to the loss of viable dormant buds from the stem either due to age or reduced vigor; the presence of a thick bark which restricts the growth of deeply embedded buds; and changes that occur when the trees reach the age at which they flower. In productive, managed woodlands dead stools can be replaced by planting or layering (a form of vegetative reproduction using shoots of live stools).

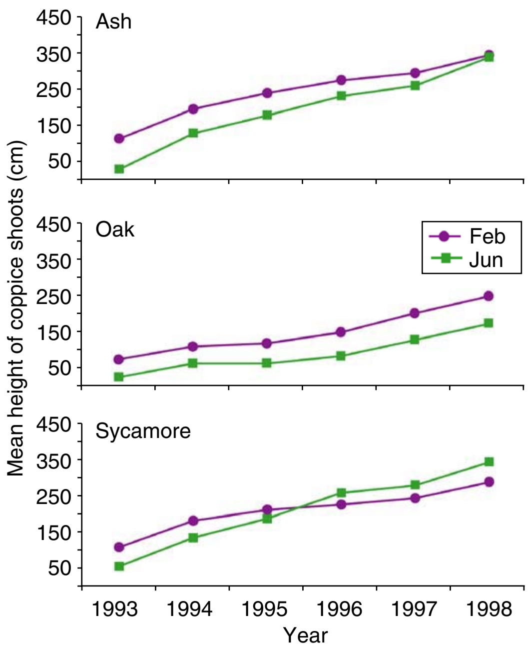

Figure 4 Mean length of the three longest shoots that regrew from stumps of 6-year-old saplings of ash (*Fraxinus excelsior*), oak (*Quercus robur*), and sycamore (*Acer pseudoplatanus*) felled in February or June 1993. The height differences gradually disappeared for *F. excelsior* and *A. pseudoplatanus,* but after six growing seasons the shoots on stumps of *Q. robur* felled in June remained shorter than those cut in February. Reproduced with permisssion from Harmer R and Howe J (2003) *The Silviculture and Management of Coppice Woodlands*. Edinburgh, UK: Forestry Commission.

Seasonal effects Season of felling can influence regrowth and whilst there is some variation between species, it has generally been found that stem survival, and initial numbers and growth of new shoots (**Figure 4**), is usually better when trees are cut during the dormant season. However, this is not necessarily true of all species and in subsequent years the initial differences in numbers and growth of shoots may disappear (**Table 3**). Due to insufficient growth and hardening-off, shoots produced late in the season after summer cutting can suffer more severe winter damage than those that grow early in the season.

Height of the stump The position of the cut and size of the stem remaining can influence subsequent growth. The initial number of shoots produced by some species increases with stump height but differences decline with time. When stumps are cut high the probability of butt rot occurring in the stems that develop is increased. This can have consequences for both the quality of stems in stored coppice, and the longevity of the stool. On some species, the shoots that arise on high-cut stumps develop from buds in areas of thick bark which constricts development of the vascular connection and can affect the stability of the coppice shoot. Shoots that arise at or below ground level can develop their own root systems.

Longevity of Stools

The lifespan of a stool will depend on a variety of factors including species, environment, and management: good growing conditions where soils are fertile, the climate is favorable, and overstory canopy cover is low, will enhance longevity of the stools. Those that are cut on a regular rotation when stems are young and of small diameter will survive longer than those that are cut on less regular, long rotations. Neglected stools can survive for many years with stems attaining large dimensions, but their ability to regrow after cutting will decline with age.

Table 3 Mean number of coppice shoots after 1 and 6 years of regrowth on stumps of three species that were 6-year-old saplings when they were felled in February, April, or June in 1993[a]

	February		*April*		*June*	
	1 year	*6 years*	*1 year*	*6 years*	*1 year*	*6 years*
Fraxinus excelsior	7.8	3.1	10.4	4.2	7.3	3.8
Quercus robur	8.1	4.5	6.7	4.6	7.8	4.2
Acer pseudoplatanus	6.4	3.2	9.0	3.9	11.6	3.6

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[a] Over the period of observation there were, for all species, a reduction in the number of branches present on the stump, and a decline in the relative differences between months of felling.

Browsing Animals

Although coppice shoots can be used as a source of fodder, the browsing of shoots during the early years of regeneration can have an adverse effect on the re-establishment of canopy cover. Prolonged severe browsing can ruin crops, kill stools, and seriously degrade woodland. Provision of adequate protection to the stools from browsing animals is probably the most important operation necessary to ensure successful regrowth of new shoots. Whether the method used is physical exclusion of animals, or control of population size, it must be of sufficient duration to allow re-establishment of robust shoots on stools throughout the woodland. The length of time for which protection is required will vary with a variety of factors including tree species, growing conditions, and type of animals present. Alternatively browsing damage can be avoided by managing trees as pollards.

Management of Stools and Standards

Woodland management by coppicing can play an important role in maintaining biodiversity by providing a wide range of habitats created by variation in both time and space across a range of factors such as structure, light environment, and age of trees. Relative to high forest, traditionally managed coppice woodlands have a large amount of open space and edge habitats, and a range of tree size and age classes, varying from newly regenerating shoots to mature standards. Consequently, the apparent biological interest in a small area of coppice may be greater than for a similar area of high forest. Although coppice woodlands are traditional and provide a sustainable resource, they are managed and have characteristics that differ significantly from natural woodlands including: the size and rate of gap formation; the age structure of trees and compartments; species mixture; amount of dead wood; size; and the flora and fauna present. Many former coppice woodlands have been transformed to high forest and although this trend is likely to continue there are good reasons, both cultural and biological, for the retention of some woodland under traditional systems of coppice management. However, such woodlands must be managed using best available practice otherwise their value may diminish.

Stool Management

Failure to manage stools within a woodland correctly may lead to their death and changes in a number of woodland characteristics; for example, a reduction in stool density and canopy cover, and a change in the structure and species mixture.

Method of cutting The quality of the cut is more important than the tool used. It is important that cuts are clean with no separation of the bark from the remaining stump. Traditionally coppice was cut manually using hand-tools, and whilst these may still be appropriate for young stems with small diameters (e.g., 7–8-year-old *Corylus avellana* stems for hurdle making, or 2-year-old *Betula pendula* for brooms and horse jumps) a chainsaw is probably the only realistic option for cutting most stools (**Figure 5**). The systematic spacing of stools, uniformity of growth, and the easy terrain of sites with young short rotation coppice allows mechanized harvesting. However, efficient use of harvesters within traditional coppices is difficult due to the variable distribution, growth, size, and structure of stools; the terrain; and the need to avoid damage to stools that will regenerate to produce the next crop.

Angle of cut Tradition suggests that stems should be cut to ensure that water drains from the center of the stool; the cut surface of the stump should have a sloping face to shed water, and be south-facing to dry more quickly. Although there is generally little quantitative evidence to support these logical suggestions, young red alder stumps with a flat surface showed greater mortality than those with cut surfaces having southerly or westerly aspects (**Figure 6**). The structure of many coppice stools will make it difficult to fell stems leaving a cut surface with a generally southerly aspect, but all cuts should be clean and wherever possible slope towards the outside of the stool.

Position of cut Maintain the stool at a level close to the ground. When establishing new coppice stools from single-stemmed trees cut as close to the ground as possible, on existing stools fell just above the height of the last cut leaving short stumps from the most recent stems. It is generally inadvisable to cut into old wood below the level of the last cut as successful resprouting is less likely to occur.

Time of felling The best time to cut coppice is during the dormant period: the bark is less likely to tear from the wood; stump mortality will probably be reduced; and new shoots are likely to grow better and suffer less frost/winter damage than shoots formed after a summer cut.

Conversion to High Forest

Many woods that were traditionally managed as coppice have developed a high forest structure following growth after the cessation of regular

Figure 5 Coppice worker using a billhook for felling and trimming 3-year-old *Castanea sativa* stems that will be made into walking sticks. Courtesy of the Forestry Commission.

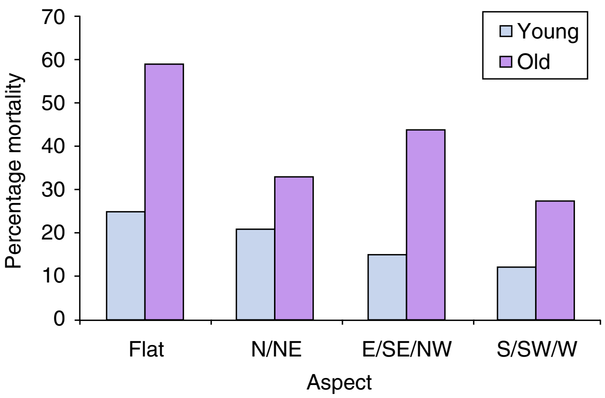

Figure 6 Percentage mortality of young (1–5-year-old) and old (6–16-year-old) red alder stumps in relation to aspect of cut surface. Data adapted from Harrington C (1984) Factors influencing initial sprouting of red alder. *Canadian Journal of Forest Research* 14, 357–361.

cutting. These crops, which comprise trees known as 'stored coppice,' are simple to create but may not be appropriate for all sites or species. This is the situation that currently affects many neglected woodlands with overmature coppice stems, on old coppice stools which, if cut, may neither survive nor produce a suitable crop for the future.

Stored coppice Although storing coppice is a simple procedure it has a number of drawbacks which may influence the decision on whether it should be used. In comparison to single-stemmed trees of the same species, growth may be inferior, the stems be of worse form with more butt sweep, and the inclusion of wood from the old stool may cause stem defects. The trees produced are often less stable than single-stemmed trees grown from seed which may cause problems of windthrow after subsequent felling operations. The quality of stored coppice can be improved by thinning to remove from the stool all stems except those which are judged to be the straightest and most vigorous: the stools may be 'singled,' leaving only the best stem. Storing coppice is likely to be most successful where stools are young, vigorous, have been cut close to the ground, and are free from decay.

Managing Standards

Well-defined, systematic procedures to control yield from standards have been developed but these have generally fallen into disuse as most large timber is now grown as high forest. The fundamental principle of the method is that number of standard trees in each age-class should be approximately half of that in the next younger class, with about 50–100 standards per hectare of all age-classes, most of which are young: a possible age-class structure is shown in **Table 4**. When the underwood is felled at the end of each rotation the mature trees (age-class IV) are felled, new standards (age-class I) are

Table 4 Possible age-class structure for standards in coppice cut on a rotation of 20 years. Adapted with permission from Harmer R and Howe J (2003) *Silviculture and Management of Coppice Woodlands*. Forestry Commission, UK

Age class of standard	*Rotation number*[a]	*Number of stems to remain*[b] *(ha^{-1})*
I (young)	1	50
II	2–3	30
III	3–4	13
IV (old)	4–6	7
Total		100

[a]The age of the standards defined by the number of coppice rotations for which they have been retained.
[b]Number of standards retained in each age-class.

recruited and intermediate ages thinned. The number of coppice cycles for which a standard is retained depends on species, length of coppice cycle, growth rate, and size of timber required.

The adverse effect of standards on the growth of coppice is well known, and is related to the canopy cover and crown density which influence light, water, and nutrient availability. Silvicultural systems of coppice with standards describe the management of standards in terms of stem numbers, rather than size of individual tree canopies and the amount of shade cast. Under well-managed coppice with standard woodlands, most standards should be young and small, and cast little shade compared with those that are old, large, and cast a lot of shade. Species differ in the amount of shade that they cast, varying in both size of crown produced and the density of leaf cover within the crown. This affects the density of standards of each species that can be maintained with a woodland, and trees such as *F. sylvatica*, *Tilia cordata*, and to a lesser extent *Quercus* spp., which have very dense crowns that can cast heavy shade, should be avoided.

The Future for Coppice Woodlands

In many areas of the world existing coppice woodlands are relics of a bygone age when there was a much greater demand for the crops produced by this simple method of management. Many woodlands have already been converted from coppice to high forest and this trend is likely to continue as the crops produced are more marketable. In contrast, the amount of short rotation coppice may increase if the promises of cost-effectively producing a long-term sustained yield can be turned into reality, and suitable methods of utilization firmly established.

Well-managed coppice woodlands regenerate quickly and the period of time without canopy cover is short relative to that of some high-forest systems where large gaps are made in the canopy. This will have obvious benefits for protection of the physical environment. Similar benefits may be obtained by use of continuous cover forestry, but the temporal and spatial variation in characteristics such as distribution and age-class of crop, and the light environment within the woodland, will differ to that for coppice. Conversion to such high-forest systems is likely to lead to the loss of species that flourish under the routine system of gap creation produced by regular coppicing. The establishment of short rotation coppice plantations may have positive benefits for a variety of characteristics including biodiversity, nutrient capture, and erosion, especially when established on agricultural land.

As traditional coppice woodlands provide a cultural link with the past and can be of important biological interest they are unlikely to disappear completely, but it seems likely that the area of woodland actively managed as coppice will continue to decline.

See also: **Operations**: Small-scale Forestry. **Plantation Silviculture**: Short Rotation Forestry for Biomass Production; Sustainability of Forest Plantations. **Silviculture**: Silvicultural Systems. **Temperate and Mediterranean Forests**: Temperate Broadleaved Deciduous Forest. **Tree Physiology**: Physiology of Vegetative Reproduction; Shoot Growth and Canopy Development.

Further Reading

Buckley GP (1992) *Ecology and Management of Coppice Woodlands*. London: Chapman & Hall.

Evans J (1992) *Plantation Forestry in the Tropics*, 2nd edn. Oxford, UK: Oxford University Press.

Harmer R and Howe J (2003) *The Silviculture and Management of Coppice Woodlands*. Edinburgh, UK: Forestry Commission.

Harrington C (1984) Factors influencing initial sprouting of red alder. *Canadian Journal of Forest Research* 14: 357–361.

Kozlowski TT (1971) *Growth and Development of Trees*, vol. 1, *Seed Germination, Ontogeny, and Shoot Growth*. New York: Academic Press.

Kramer PJ and Kozlowski TT (1979) *Physiology of Woody Plants*. New York: Academic Press.

Macpherson G (1995) *Home-Grown Energy from Short-Rotation Coppice*. Ipswich, UK: Farming Press.

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

Peterken GF (1996) *Natural Woodland*. Cambridge, UK: Cambridge University Press.

Rackham O (1980) *Ancient Woodland*. London, UK: Edward Arnold.