Forestry Commission

Thinning Practice
A Silvicultural Guide

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1. Introduction

"A good thinning requires a clear objective, a sharp axe and a cold heart."

Thinning is a silvicultural operation where the main objective is to reduce the density of trees in a stand, improve the quality and growth of the remaining trees and produce a saleable product. Thinning can also achieve other objectives such as altering the species composition of a stand, improving the health of the remaining trees or disturbing an established ground flora to enhance opportunities for natural regeneration.

In this guide we will look at the underlying silvicultural principles which make up good thinning practice and give you guidance on applying thinning in the most common situations of forest management. The guide is designed as a support document to *OGB 9 – Thinning*, and also includes information published recently in *OGB 7 – Managing Continuous Cover Forests* and the Handbook *Managing Native Broadleaved Woodland*. While this guidance reflects our current silvicultural knowledge, it is important to remember that good thinning practice is not a set prescription. The way you thin a stand will mainly depend on your management objectives and may be further influenced by operational or technological constraints. You should therefore interpret carefully the information in this guide, in particular any numerical figures.

1.1 Why thin? – Thinning and management objectives

When a forest is being established decisions on regeneration method, species composition and spacing must be made on the basis of management objectives. Once the stand is established, thinning is the main method of influencing growth and development and it is therefore crucial that thinning practice continues to help achieve management objectives.

> **Key point**
>
> 'the attempt to clarify objectives and decide priorities is the single most helpful step to resolve silvicultural questions.'
>
> Julian Evans, FC Bulletin 62

An example of how management objectives can influence thinning practice can be illustrated by a stand of Sitka spruce, 20 years-old, YC 16. The following management objectives may apply:

1. To maximise economic returns.
2. To produce sawlog quality timber of target diameter 50 to 60 cm dbh.
3. Maintain continuous canopy cover to reduce soil erosion on a steep slope and produce quality timber.

The first objective is typical of the management objective for many conifer forests in the later part of the last century and, on stable sites, led to them being thinned using intermediate thinning and grown on a rotation that was defined by economic criteria. For the second objective the emphasis is clearly on the production of a high value end-product, which would be favoured by crown thinning on a rotation that is determined by the speed of growth of individual trees. The third objective would lead to the transformation of the stand from an even-aged structure to continuous cover management. Terms such as 'intermediate thinning' and 'crown thinning' may be unfamiliar, but are explained later in Section 3. **The main message is that you must have a clear idea of what you are trying to achieve before deciding how to thin the stand.**

An added reason for thinning is that it should be a central part of any mitigation strategy to reduce the impact of future changes in the climate. There are three main reasons for this:

1. wood products from stands that are thinned (and pruned) are more likely to be used in long-term end-uses;
2. thinning helps to maintain healthy, resilient forests that are able to lock up carbon from the atmosphere and store it as woody biomass; and
3. material produced in thinning can be used as woodfuel, a source of renewable energy, to help reduce fossil fuel emissions.

1.2 What type of stand will be thinned?

Any forest in Britain will be composed of a variety of different types of stand that vary in area, species composition, structure and management objectives. Each type of stand will require a different approach to thinning and for this reason the guidance depends on the type of stand you are managing.

Table 1 shows six different types of forest stand depending on the species composition and forest structure:

Table 1 Different types of forest stand for thinning

Structure of forest	Species composition	
	One dominant species	No dominant species
Even-aged stand	A	B
Transformation to CCF	C	D
> 2 canopy strata	E	F

The focus of this guide is even-aged stands, i.e. A and B in Table 1, in Section 3. We consider the other four types of stand in Section 4 . The guide covers mixed species stands in Section 3.10 (types B and D) and Section 4.4 (type F).

1.3 Thinning practice and yield models

A yield model or yield table is a description of how a stand of trees develop over time. The current yield models in use in Britain are published in Forestry Commission Booklet 48. Various models are available for different species, yield classes, initial spacings and types and intensities of thinning. The models represent average growth for a particular combination. The main use of these yield models is to forecast production from large areas of forest. Do not use them as an ideal description of a stand to inform how it should be thinned. For example, a decision to thin a stand of Douglas fir, YC 18, age 30 to produce 523 trees per hectare because this is what the equivalent yield model predicts is misguided. It takes no account of the management objectives, the origins of the stand or its previous management.

Key point

Do not use a yield model as a prescription of how to thin a stand.

Plate 1 There have been many changes in thinning practice over the years, as shown by these photographs taken in 1949 and 2009. However, what has not changed is that when thinning you must be clear about what you are trying to achieve, i.e management objectives. (FC Picture Library 2002837 and 2007422.)

2. Some terms explained

Term	Explanation
Basal area (BA)	Usually expressed in square metres per hectare (m^2/ha), it is the sum of the cross-sectional areas of the stems of a stand measured at 1.3 metres above the ground (known as breast height).
CCF	Continuous cover forestry.
Complex CCF structure	A forest in which there are three or more canopy layers.
Cumulative volume production	This is the total volume in cubic metres per hectare (m^3/ha) produced by a stand over its rotation – the sum of all thinning yields and the final harvest yield.
Current Annual Increment (CAI)	Expressed in cubic metres per hectare per year (m^3/ha/yr), this is the volume production of a stand in one year.
DAMS	Detailed Aspect Method of Scoring – a system for scoring windiness using location and terrain to calculate a score and an essential part of the Ecological Site Classification (ESC) and ForestGALES software.
Genotype	The specific set of genes possessed by an individual.
Final Crop Tree	A tree selected to grow to final harvest or to a selected size. Trees are selected for quality, species, size, timber potential, or conservation value.
Frame tree	A final crop tree in a complex CCF structure.
Heavy thinning	Thinnings that use 110 to 140% of Marginal Thinning Intensity, interrupting canopy closure temporarily or permanently.
Intermediate species	A species that can regenerate under the canopy of a mature stand or in very small gaps (0.05 ha) but require this to be opened up rapidly to ensure good seedling growth.
Light demanding species	A species that produces seedlings that can only make effective growth under a canopy of low density, in large gaps (>0.25 ha) or the open.
Light thinning	Thinnings that use up to 90% of Marginal Thinning Intensity. Canopy closure is only marginally affected, any gaps will be small and close fairly quickly.
Marginal Thinning Intensity (MTI)	The maximum rate at which volume can be removed without causing a loss of cumulative volume production. Current yield models are based on the assumption that Marginal Thinning Intensity equals 70% of the respective Yield Class. The concept of Marginal Thinning Intensity can be applied from the time a stand reaches threshold basal area until the maximum Mean Annual Increment.
Mean Annual Increment (MAI)	Expressed in cubic metres per hectare per year (m^3/ha/yr), this is the cumulative volume production of a stand divided by its age.
Moderate thinnings	Thinnings carried out at 90 to 110% of Marginal Thinning Intensity. They lead to a temporary opening up of the canopy.

Term	Explanation
PAWS	Plantation on an ancient woodland site.
Seed Tree	A final crop tree in a simple CCF structure.
Simple CCF structure	A forest in which there are one or two canopy layers.
Phenotype	The visible characteristics of a tree.
Shade tolerant species	A species that produces seedlings that can make effective growth under a canopy of a mature stand or in very small gaps (0.05 ha).
Thinning intensity	This is the rate at which volume is removed (m^3/ha/yr).
Thinning yield	This is the actual volume in cubic metres per hectare (m^3/ha) removed in a thinning intervention.
Thinning type ratio	The mean size of a tree removed in a thinning divided by the mean size of trees in the stand before thinning; size is usually expressed as dbh (cm) or volume (m^3).
Threshold basal area	Usually expressed in square metres per hectare (m^2/ha) is the minimum basal area a stand must achieve to be fully stocked. Species-specific guidance is given in Table 14 (reproduced from FC Field Book 2).
Transformation	A process that aims to increase within stand structural diversity in even-aged plantations.
Yield Class (YC)	Is the maximum value expressed in cubic metres per hectare per year (m^3/ha/yr) that the Mean Annual Increment of a stand can reach on a given site.
Thinning cycle	This is the interval in years between two successive thinnings.

3. Silviculture of thinning (even-aged stands)

3.1 Understanding thinning

In order to carry out good thinning practice it is important to:

1. understand how a stand of trees would develop over time without any interventions, and
2. be aware of some of the processes that are in action when two trees compete.

The development of a stand of trees, after a major disturbance such as clearfelling or wind damage, without any interventions is illustrated in Figure 1. This shows four different stages that are described in Table 2.

Figure 1 A stand development model showing the changes that may occur in a woodland following a major disturbance

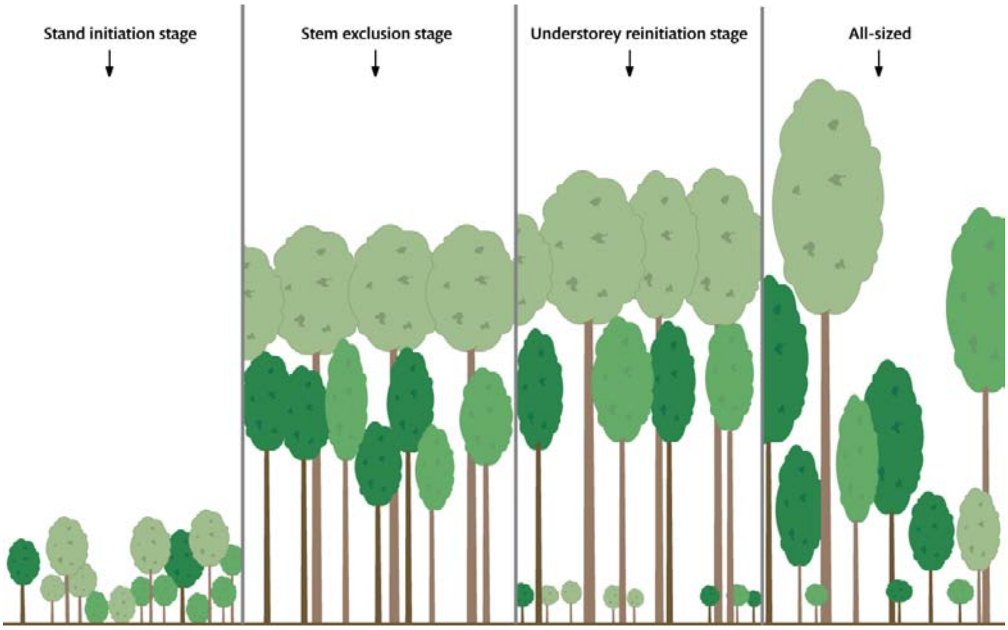
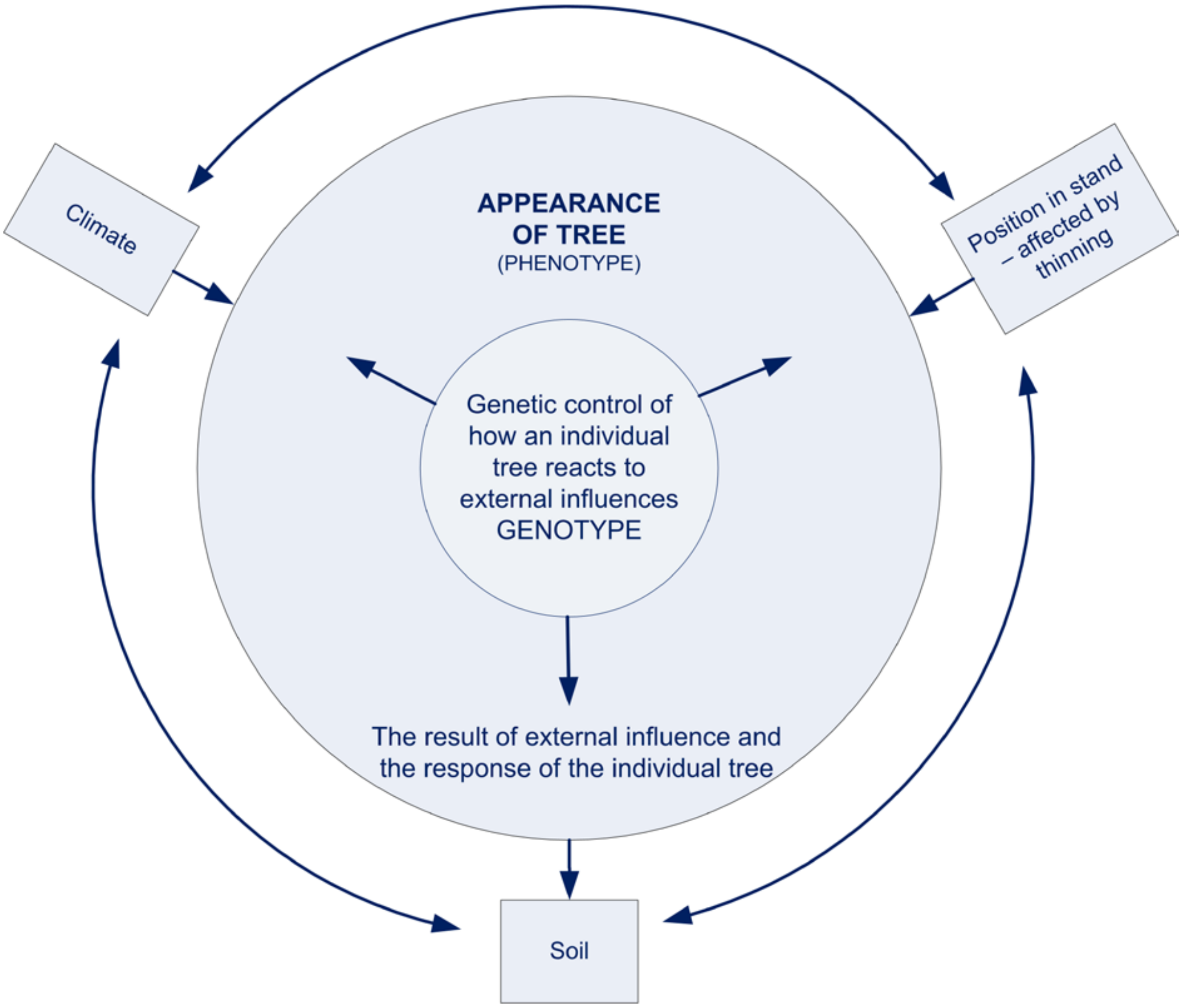


Table 2 Stages of development after a major disturbance

Development stage	Description
Stand initiation	Trees and plants in the ground flora already present will develop and other species present in the surrounding area will start to colonise; trees may be planted or regenerate naturally.
Stem exclusion	Trees and any other woody plants dominate the area and compete with both each other and the ground flora.
Understorey reinitiation	Conditions on the forest floor become much more variable than in the stem exclusion stage, trees and shrubs are sexually mature and produce large quantities of seed; advance regeneration can appear if conditions are conducive.
All-sized	Overstorey trees die and are replaced by others recruited from other parts of the stand. The structure of the stand develops more than two canopy strata.

Once a stand enters the stem exclusion stage, competition between trees for light, water and nutrients is intense. The ability of a tree to compete and survive is the result of a complex set of interacting factors including genetics, position in the stand, size and form of the tree – see Figure 2.

Figure 2 Competition processes acting on individual stands being thinned



For example, a successful genotype may result in large numbers of branches being produced to capture sunlight in the canopy. A certain position may give better access to water and nutrients in the soil enabling a tree to grow quicker than its neighbours. The foliage of species A may be more shade tolerant than species B enabling it to survive longer if it is shaded, however, if species B is shaded by species A its days are numbered! The ultimate result of competition is that some trees will die. Thinning selects trees for an early death and has a powerful effect on the remaining trees.

Plate 2 Most forests in Britain are underthinned as shown by this stand of ash.
(FC Picture Library 39697)

Here are some other important points about thinning.

1. Thinning interventions impact the growth of the stand. Removing a proportion of trees means that more resources become available to the remaining trees, which, after adapting to the new situation, will generally respond by growing faster. Thinning a stand also means that there are fewer trees, so at the stand level growth rate drops after a thinning. This decrease of stand growth will eventually be outweighed by the accelerated growth of the remaining trees, depending on stand age, species characteristics, yield class and thinning intensity.
2. Thinning interventions also create gaps in the canopy, which reduces the support neighbouring trees provide for each other and which may also provide entry points for wind. This leads to a reduction in the stability of the stand. On the other hand, the remaining trees keep deeper crowns and develop better rooting and tapering of the stem, so that their individual stability improves. As the gaps in the canopy close over time, stand stability recovers, and, due to the increased stability of the individual trees, may improve beyond the original level.
3. Finally, by creating gaps in the canopy we change the interior climate of a stand, allowing more sunlight and more rain to reach the soil, which in turn leads to higher soil temperature and moisture, accelerated litter decomposition, and more favourable conditions for the development of ground flora, including natural regeneration. The appearance of young regeneration in many even-aged stands can often be traced back to the last time the stand was disturbed by thinning. However, these effects may only be local and are generally limited and temporary.

3.2 Different types of tree

In order to describe different approaches to thinning, it is necessary to have a classification of different types of tree. The system used in the Forestry Commission for over 50 years is described in Table 3. This identifies seven classes of tree in terms of their shape, size and position of the crown relative to that of neighbouring trees, or stem quality characteristics, or both.

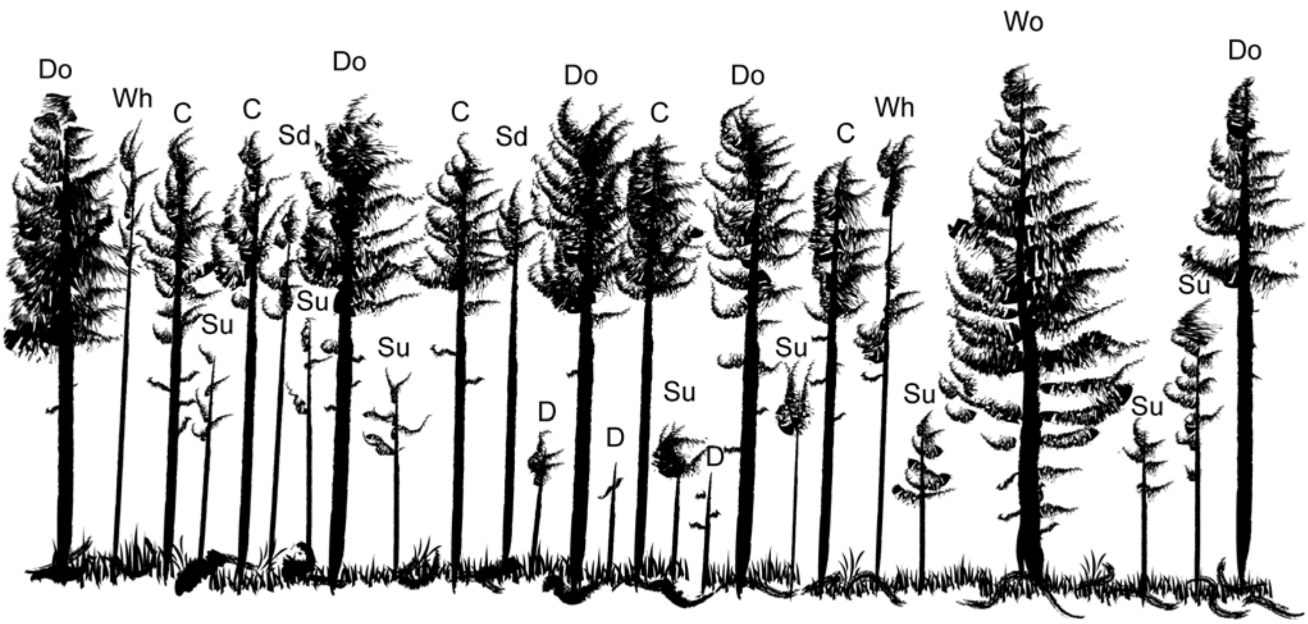
Table 3 A simple way of categorising trees in a stand (see Figure 3)

Tree class	Description
1. Dominant	The crown extends above the general layer for the stand and intercepts direct sunlight across the top and upper branches. Trees have well developed and large crowns, which can be crowded along the lower branches. Tree diameter is usually amongst the largest in the stand.
2. Co-dominant	The crown is within and helping to form the main canopy for the stand and intercepts direct sunlight mainly across the top and upper side branches. Trees have well developed crowns but only of medium size that are crowded at the sides. Tree diameter is among the upper range of those present.
3. Sub-dominant	The crown extends into the lower part of the main canopy and only intercepts direct sunlight on a limited area at the top. The crown is narrow and short. Tree diameter is in the lower range of those present but not necessarily the smallest.

Tree class	Description
4. Suppressed	The crown is entirely below the main canopy and covered by branches of taller trees with little, if any, direct sunlight reaching it. The crown is small, often lopsided, flat-topped and sparse. Tree diameter is amongst the smallest in the stand.
5. Wolf	Dominant trees with exceptionally poor form that can outgrow and damage their neighbours.
6. Whips	Slender stems that occupy the main canopy that can damage neighbouring trees when they sway.
7. Dead and dying	Suppressed or diseased trees that have died or are dying, including leaning and blown trees.

The first four types of tree shown in Table 3 (and Figure 3) will be used throughout this guide to describe different types of thinning. Through the life of a stand there will be changes in the classification of trees; for reasons described in the next section the changes will generally be for the tree to descend into lower classes. The approach in each thinning to the last three types of tree is mainly governed by management objectives. For example, if production of good quality timber is an objective then remove wolves and whips from the stand as soon as possible. However, on a PAWS site an important veteran tree may be classified as a 'wolf' but would be important to retain. The same applies to dead and dying trees, in many native broadleaved woodlands the levels of deadwood are low and retaining dead and dying trees in the stand can be a useful way of increasing the amount of deadwood.

Figure 3 Classification of trees in a stand



Legend: Dominant (DO); Co-dominant (C); Sub-dominant (Sd); Suppressed (Su); Whip (Wh); Wolf (Wo); Dead and Dying (D).

3.3 Response of individual trees to thinning

The response of trees to thinning is an important judgement to make and is generally controlled by the age of the tree, canopy position and shade tolerance of the species as described in Table 4. Repeated observation of a number of young even-aged stands that are thinned using a traditional approach (intermediate thinning at MTI on a five year cycle) will lead to the conclusion that 2 to 3 years after thinning they could be thinned again!

Table 4 Factors affecting the response of a tree to thinning

Age of the tree	The development of any tree passes through three phases: *juvenile*, *full vigour* and *senescence*. In the juvenile phase growth is relatively slow, in *full vigour* growth can be very rapid and then during *senescence* it slows again. These phases can clearly be seen in the top height/age curves in FC Booklet 48 – see Figure 4. They also explain why trees in the *full vigour* phase can respond very quickly to thinning and it can appear that a young stand needs thinning again 2 to 3 years after the last intervention.
Canopy position	Trees with access to direct sunlight (dominants and co-dominants) can generally respond better to thinning. However, to some extent this also depends on species shade tolerance.
Shade tolerance	Species that are shade tolerant or intermediate can respond to thinning if they have been suppressed or over-topped much better than light demanding species – see Table 5.

Table 5 Classification of the main British tree species according to their seedling light requirements

Light demanding	Intermediate	Shade tolerant
European larch	Douglas fir	Western hemlock
Japanese larch	Sitka spruce	Norway spruce
Hybrid larch	Noble fir	Grand fir
Scots pine	Ash	Western red cedar
Corsican pine	Cherry	Yew
Lodgepole pine	Lime	Beech
Birch – silver	Oak – sessile	Hornbeam
Birch – Downy	Oak – pedunculate	Field maple
	Rowan	Sycamore
	Sweet chestnut	
	Whitebeam	

Key point

A useful guide to the history of a tree and its potential to respond to thinning is the relationship between the height of a tree and the length of the crown (or relative crown length as shown in Figure 5).

Key point

A dominant or co-dominant tree from a 'well thinned' stand usually has a relative crown length of at least 30%.

Figure 4 Top height/age curves for Sitka spruce showing juvenile phase, full vigour phase and beginning of senescence

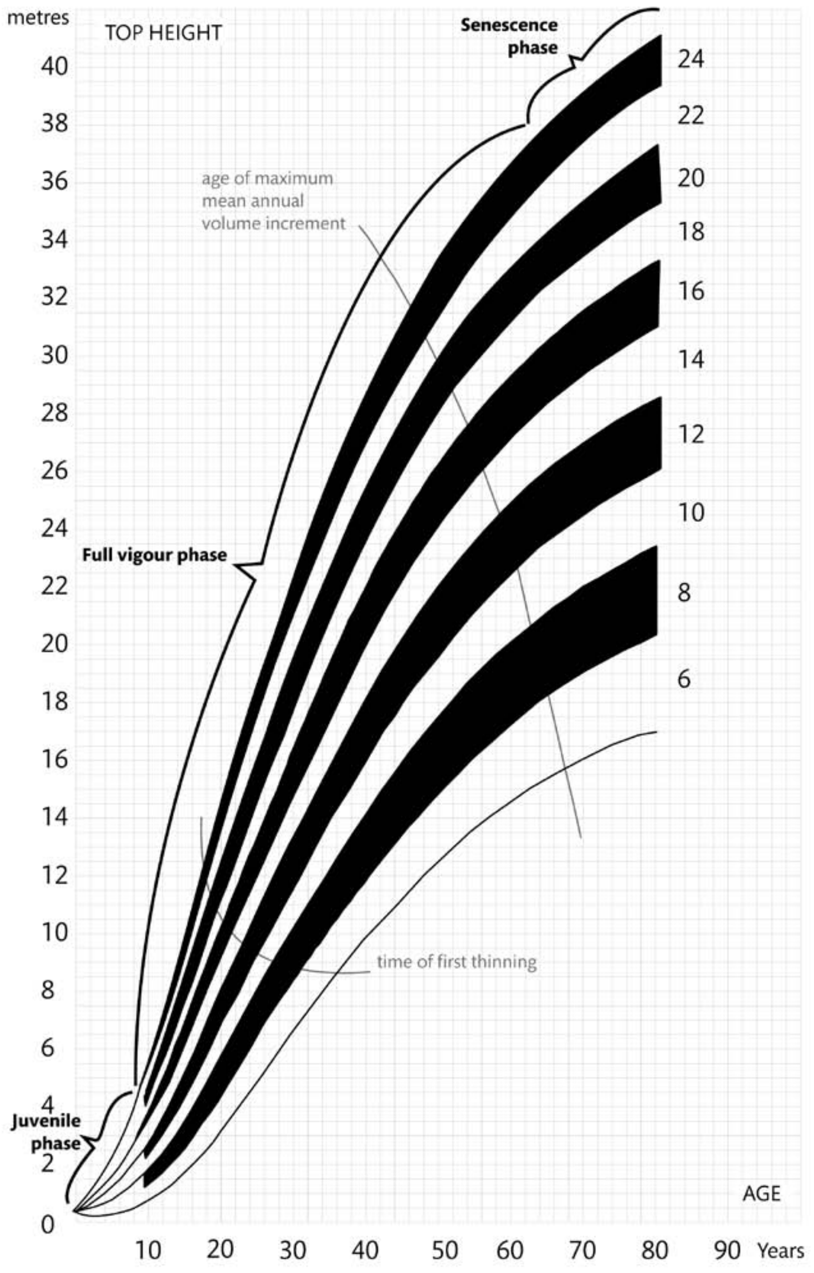
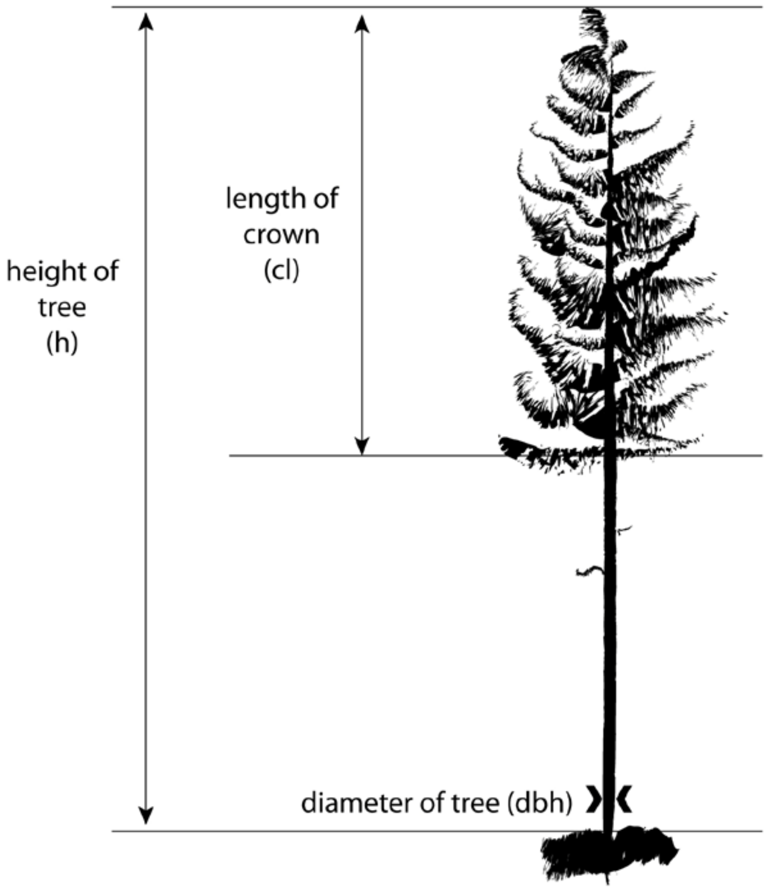


Figure 5 Crown length and height of a tree



3.4 Stocking

When you are thinning stands the concept of 'stocking' is important. Stocking is generally an expression of the basal area[1] per unit area compared with the recommended level. In Britain, fully stocked stands of trees are defined in terms of basal area for different combinations of species, top height and, for broadleaves, yield class – see Table 14. In general, it is recommended that thinning starts when a stand reaches full stocking (a threshold basal area), with any further thinning only taking place once the stand is at or above the threshold basal area again. However, there is an assumption in this that your management objective is to maximize volume production. If it is not, then you do not have to follow the guidance on stocking: **be clear about your management objectives**. For example, if a stand contains valuable ground flora that could be lost under heavy shade, management could aim for less than full stocking to produce conditions suitable for the valuable herbaceous plants. However, if you decide not to keep a stand fully stocked then you must be clear there will be a reduction in the total volume production of the stand.

> **Key point**
>
> Do not assume that you must thin stands to maintain full stocking; the decision **must** include consideration of your management objectives.

[1] Stocking can also be expressed using numbers of trees or volume.

3.5 Systematic and selective thinning

In systematic thinnings, trees are removed according to a predetermined system, without considering the merits of individual trees. Chevron thinning, row thinning and strip thinning are the most common forms. While systematic thinning regulates stand density and, to a certain degree, contributes to the development of individual tree stability, it achieves none of the other objectives of thinning, namely quality improvement, species selection and development of structural diversity. Its use is therefore limited to situations where these requirements are not part of the management objectives. The majority of the guidance described here therefore refers to selective thinning, where trees are removed or retained on their individual merits.

The opening of extraction racks is an essential systematic thinning, their purpose is to establish an access network in the stand for later operations. At present much 'rack only' thinning is done as a first thinning to minimize felling and extraction costs. The operation is not combined with any form of selective thinning of the matrix, or only a limited amount to create space for stacking. However, in terms of silviculture this is an optimal time for selective thinning because the trees are in the *full vigour* phase – see Table 4, and will respond very quickly to thinning. There are also real advantages for improving the crop if wolf trees are removed along with other poorly formed trees at the earliest opportunity. If stability issues prevent a combined first thinning, you could carry out the 'rack only' operation two to three years before the selective thinning. The first thinning window still applies to the selective thinning – see Section 3.6.3.

Key point

Do not carry out first thinnings as rack-only operations without considering the opportunities for crop improvement by combining it with a selective thinning.

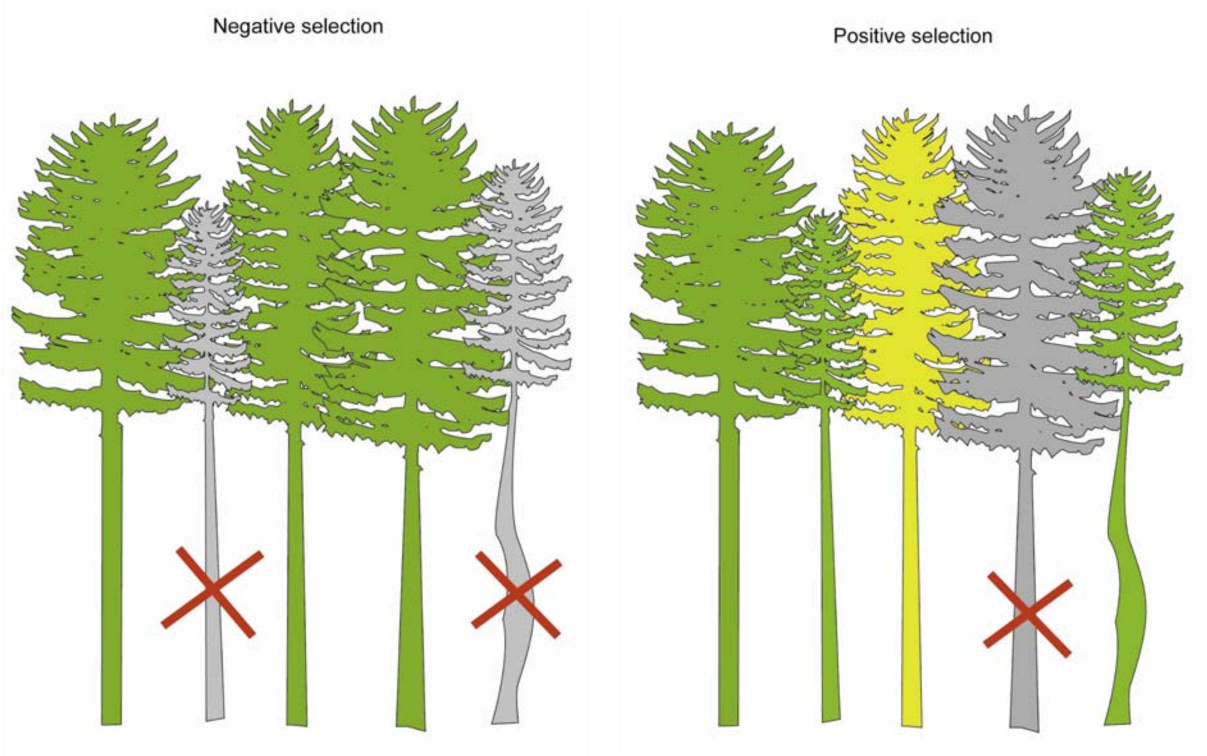
Plate 3 A first thinning in Corsican pine. Initially racks are formed (as shown) and then the matrix will be selectively thinned.

There are two main approaches to selecting the trees to be removed in any thinning, negative selection and positive selection – see Figure 6.

Figure 6 Negative and positive selection

Negative selection – removal of suppressed and poorly formed trees (shown in grey) without considering the growth of remaining trees.

Positive selection – competing trees are removed (shown in grey) to maximise the growth of the 'best' trees (shown in yellow)



Negative selection

Only undesirable trees are removed, thus improving the overall quality of the stand. Undesirable trees include wolf trees, whips and badly shaped trees such as forked, bent and heavily branched individuals, damaged and diseased trees, trees of low increment or low value, and unwanted species.

Positive selection

The best trees of the stand are identified and their growth and development is actively promoted by removing competitors. This approach is usually associated with crown thinning, where management is focussed on a selected number of trees which will eventually form the final crop.

Selective thinning usually makes use of both principles. How much of the tree selection is guided by the negative and the positive principles will mainly depend on the overall quality of the stand, its species composition and your management objectives.

3.6 Thinning interventions

Any thinning can be described in terms of:

- **Thinning type** – which trees to remove and which ones to favour;
- **Thinning intensity** – how many trees, or how much basal area or volume will be removed from the stand in an intervention;
- **Thinning cycle** – the interval in years between successive thinnings; and
- **Distribution of remaining trees** – should this be even or not?

3.6.1 Thinning type

There are two main types of thinning: low and crown thinning. We describe them below along with intermediate thinning, which involves a combination of the ideas in low and crown thinning.

Low thinning

Otherwise known as 'thinning from below' as trees are removed primarily from the lower canopy, i.e. suppressed and sub-dominant trees, and from among the smaller diameter trees – see Figure 7. The aim of low thinning is to concentrate potential for growth on the larger diameter trees by removing competing smaller trees. At higher intensities it becomes necessary to remove some co-dominants, remove those with the poorest form first. Low thinning tends to result in stands of evenly distributed trees, although clumps of dominant trees can develop.

Crown thinning

Otherwise known as 'thinning from above' as trees are removed primarily from the upper canopy, i.e. some dominants and co-dominants – see

Figure 8. The aim of a crown thinning is to give selected dominants freedom to grow rapidly by gradually removing competing trees. A true crown thinning cannot be maintained throughout the rotation of a stand of trees because repeated crown thinnings tend to result in too few dominants remaining to select between. As a result, later thinnings in such stands are often closer to intermediate thinnings. Crown thinning tends to result in more open stands than low thinning and often there is greater vertical structure as small trees tend not to be removed.

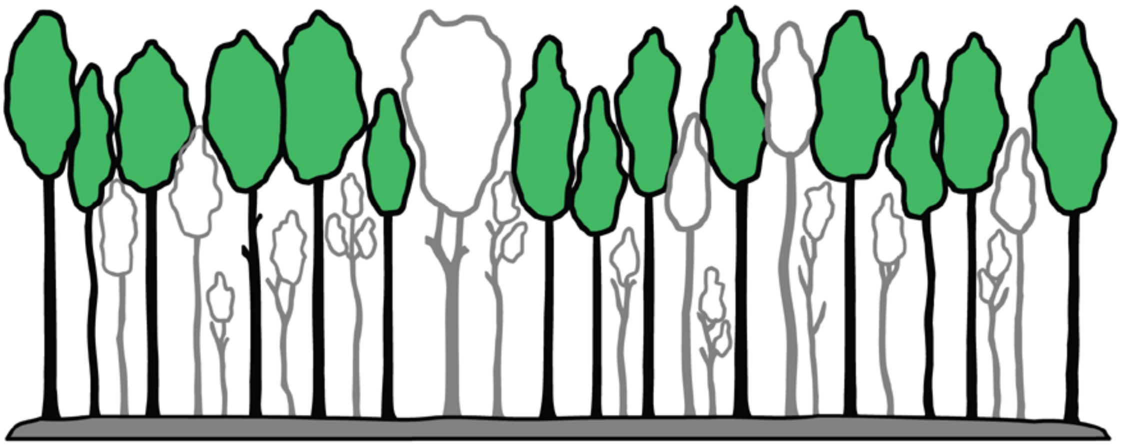
Crown thinning is considered in more detail in Section 4 as it is currently recommended for stands being transformed to CCF. However, this is not the only application of crown thinning in forest management.

Intermediate thinning

This is a common approach to the thinning of conifer stands in Britain. It involves a combination of the ideas behind low and crown thinning, hence the name intermediate – see

Figure 9. As in low thinning, most of the suppressed and sub-dominant trees are removed to favour the growth of the larger trees; at the same time, as in crown thinning, the canopy is opened up and a uniform stand structure is maintained by breaking up groups of competing dominants and co-dominant trees. Intermediate thinning is classed as a low thinning, which is close to being neutral – see Table 6.

Figure 7 Low thinning – an example of trees to remove (shown in outline) and how this would affect the diameter distribution



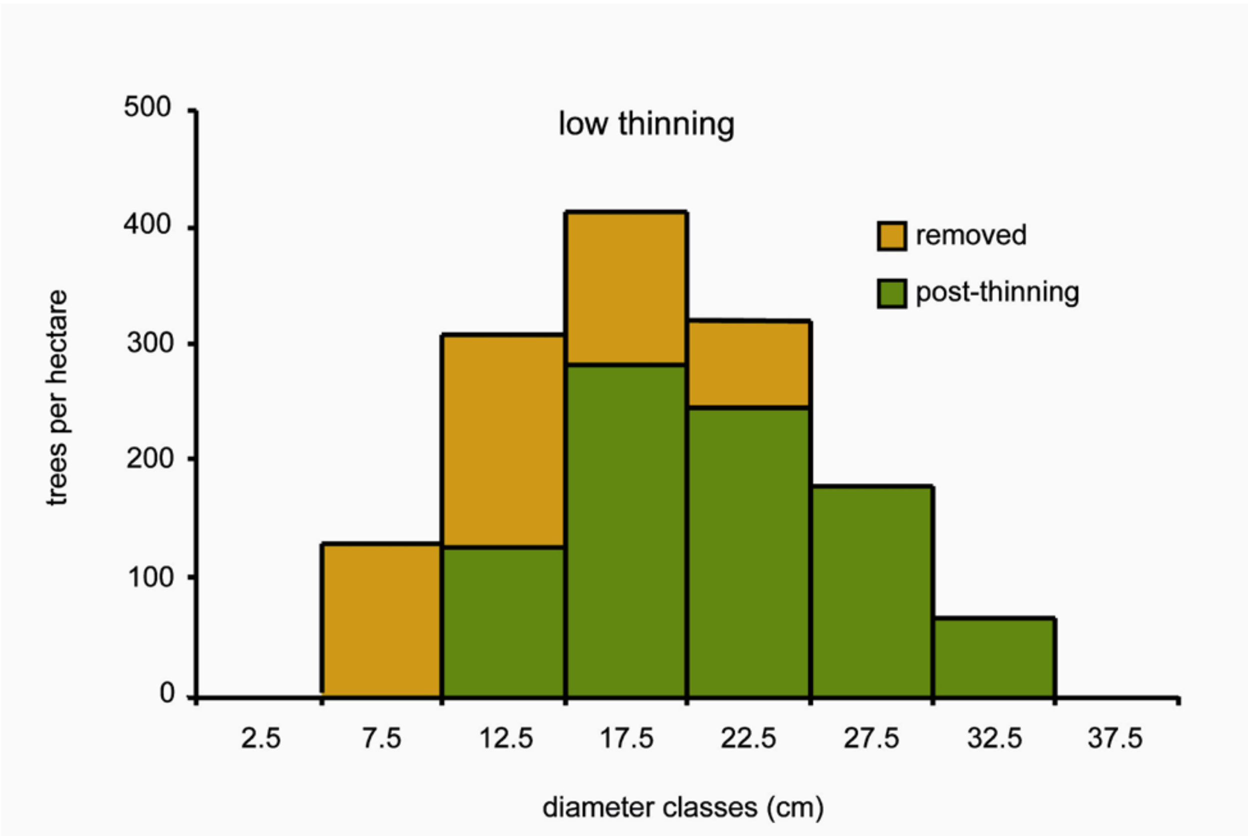
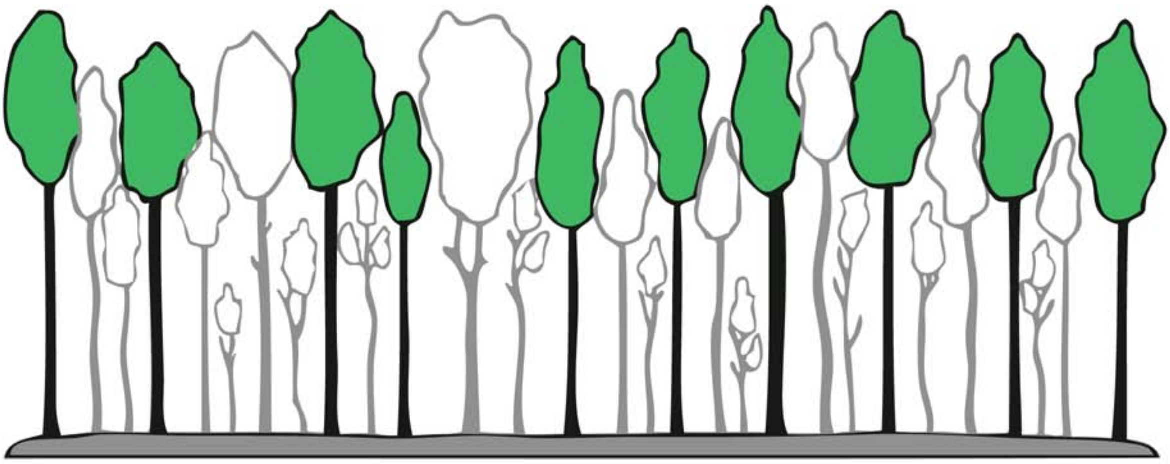
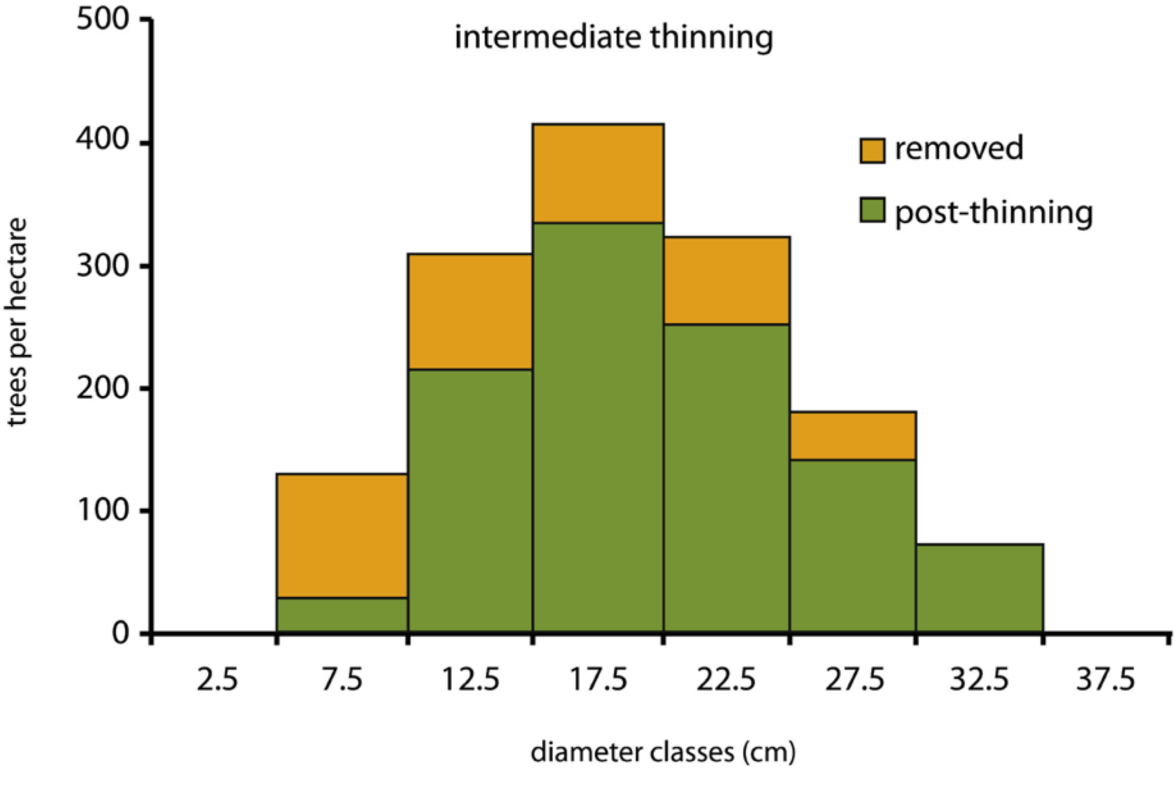


Figure 8 Crown thinning - an example of trees to remove (shown in outline) and how this would affect the diameter distribution.

Figure 9 Intermediate thinning - an example of trees to remove (shown in outline) and how this would affect the diameter distribution.





What type of thinning?

Both types of thinning have their place in forest management. Which one to apply will depend on the tree species, stand age, management objectives, timber markets, stand quality and wind risk.

You are likely to choose low thinnings:

- in late interventions, particularly when the wind hazard is high;
- if you aim to maximise volume production per unit area; and
- if you aim to create a uniform stand structure.

You may choose crown thinnings:

- in early interventions, particularly in stands designated for CCF;
- if you aim to maximise the growth of selected individual trees; and
- if you aim to diversify the stand structure.

Historically in Britain, guidance on thinning practice in conifer and broadleaved stands has been quite different. In conifer stands the emphasis has been on maximising volume production and this has encouraged the use of intermediate thinning at marginal intensity. On the other hand, the thinning of broadleaved stands has focussed on selection for quality and high value markets rather than any yield constraint, and this has tended to favour crown thinning. The approach to thinning we advocate in this guide is for the management objectives to drive the practice of thinning. The result of this will probably be that any artificial distinction between conifers and broadleaves will increasingly become blurred and crown thinning may become more widely used than in the past.

Key point

Management objectives must drive what type of thinning to use in any forest stand. This guide does not advocate a wholesale shift to the use of crown thinning; intermediate thinning will continue to be a good option for many situations.

If you were to select trees for felling at random – regardless of their size or quality – you would achieve a neutral thinning, where all trees had the same chance of being removed. Neutral thinnings are usually the result of non-selective approaches, such as a row or line thinnings, and are also called systematic, schematic or mechanical thinnings.

Thinning Type Ratio

To check what type of thinning you have carried out you can use inventory data of diameter or volume and compare the size of trees removed compared with the stand before thinning, this is the Thinning Type Ratio (TTR):

$$TTR_{dbh} = \frac{DBH_{removed}}{DBH_{pre-thin}}$$

or

$$TTR_{v} = \frac{v_{removed}}{v_{pre-thin}}$$

Where:

$DBH_{removed}$ = mean DBH of trees removed.

$DBH_{pre\text{-}thin}$ = mean DBH of trees before thinning.

$v_{removed}$ = mean volume of trees removed.

$v_{pre\text{-}thin}$ = mean volume of trees before thinning.

An alternative approach is to use a ratio that compares the percentage of basal area removed with the percentage of trees removed (BA/N index):

$$BA/N = \frac{\%BA_{removed}}{\%N_{removed}}$$

Where:

$\%BA_{removed}$ = proportion of basal area (in %) removed.

$\%N_{removed}$ = proportion of number of trees (in %) removed.

From any one stand the Thinning Type Ratio or BA/N index can be used to check what type of thinning has been used by comparing it to the values in Table 6.

Table 6 Thinning types and indices

	Crown	Neutral	Low*
TTR_{dbh}	≥ 1.05	~ 1.0	≤ 0.95
TTR_v	≥ 1.1	~ 1.0	≤ 0.9
N/BA	≥ 1.1	~ 1.0	≤ 0.9

* Intermediate thinnings will have values in the upper part of this range.

From this you should realise that one advantage of crown thinning is that it generally results in the removal of larger trees than low or intermediate thinning and this can have an effect on the economics of the operation.

3.6.2 Thinning intensity

Thinning intensity is a description of how many trees, how much basal area or how much volume will be removed from the stand. The standard approach to this in Britain is to use volume, as described in Field Book 2. The marginal thinning intensity (MTI) is the maximum rate at which volume can be removed without causing a loss of cumulative volume production – see Plate 4. Our current understanding is that this equals 70% of the Yield Class of the stand. This allows the thinning yield to be calculated as a product of thinning intensity, yield class and thinning cycle as shown in Table 7.

Table 7 Example of the effect of changing thinning intensity on yield for a stand of YC 14

Thinning Intensity			MTI (0.7 x YC)		Thinning Cycle (yrs)		Thinning Yield (m^3/ha)
Light	0.8	×	0.7 × 14	×	5	=	39 m^3/ha
Moderate	1.0	×	0.7 × 14	×	5	=	49 m^3/ha
Heavy	1.2	×	0.7 × 14	×	5	=	59 m^3/ha

If your management objective is to maximise volume production per hectare then using a moderate (i.e. MTI) thinning intensity will achieve this if it is used from the time a stand reaches threshold basal area until the age of maximum mean annual increment. However, there will be circumstances when you may want to apply heavier or lighter intensities, depending on the shade tolerance of the tree species, stand age, management objectives, timber markets, stand quality and wind risk.

For example, adopt higher thinning intensities:

- in early interventions, such as first and second thinning;
- in overstocked stands (wind risk and stand age permitting);
- if you have a good market for your thinning products – however, this should not jeopardise the long-term management objective for the stand;
- if you want to remove unwanted species; or
- in early interventions on sites of high wind risk, such as exposed forest margins.

On the other hand, use lower intensities:

- in late interventions, particularly if the wind risk is high and stability is marginal;
- in understocked stands; or
- if your market for thinning products is limited – again, you will need to consider the long-term management goals for the stand; a costly thinning operation may be justified by the benefits to the final product.

Key point

You should note that OGB 9 (Section 6.5.4) states that: *For commercial thinning, do not use an intensity of more than 1.4 × MTI unless you have specific management reasons for doing so, for example, species rationalisation on a PAWS site. This will reduce the overall productivity of the crop and may put the stability of the stand at risk. Record your reasoning in your coupe plan.*

Table 8 Data showing stand development of Norway spruce GYC16 thinned at four different intensities, shown in Plate 4.

Date	Age	No thin				75% MTI			
		No. of trees (per ha)	Stand mean dbh (cm)	Stand volume after thinning (m^3 per ha)	Volume of dead trees (m^3 per ha)	No. of trees	Stand mean dbh (cm)	Stand volume after thinning (m^3 per ha)	Volume of thinnings (m^3 per ha)
1958	25	6471	9.3	144	0	3242	11.8	128	15
1967	33	3987	13.8	349	9	1868	18.0	301	55
1978	44	2408	19.6	616	58	1113	24.9	499	142
1991	57	1592	25.5	747	108	824	32.4	703	103
2001	67	1210	29.9	869	101	591	38.5	768	185
2006	72	1083	32.5	968	35	549	41.5	870	50
Cumulative thinning volume					311				550
Cumulative volume production					1279				1420
Date	**Age**	**100% MTI**				**125% MTI**			
		No. of trees (per ha)	Stand mean dbh (cm)	Stand volume after thinning (m^3 per ha)	Volume of thinnings (m^3 per ha)	No. of trees	Stand mean dbh (cm)	Stand volume after thinning (m^3 per ha)	Volume of thinnings (m^3 per ha)
1958	25	1453	14.9	107	55	979	18.1	101	41
1967	33	804	24.1	245	74	467	28.6	182	106
1978	44	618	35.7	364	202	316	42.3	344	162
1991	57	355	44.8	435*	209	256	53.0	608	0
2001	67	263	51.6	600	0	241	60.7	799	23
2006	72	232	56.5	662	58	211	63.3	776	128
Cumulative thinning volume					598				460
Cumulative volume production					1260				1236

* The plot was affected by windblow in 1984 and the intended thinning intensity could not be sustained throughout the rotation of the crop, in fact only the first three interventions were carried out at 100% MTI. The results show, however, that none of the thinning regimes adversely affected the cumulative volume production; the lowest figure of 1236 m^3/ha being at 87% of the highest performance of 1420 m^3/ha. The main difference lies in the higher stand mean DBH achieved by the higher intensities.

Plate 4 Comparison of no thin, 75% MTI, 100% and 125% on P1935 Norway spruce permanent sample plots at Rheola, south Wales

3.6.3 Thinning cycle

Thinning cycle is the interval in years between successive thinnings. For the purposes of determining thinning yield, the cycle is the number of years before the **next** thinning. The usual length of thinning cycle is from 4 to 6 years in young or fast growing crops and about 10 years for older or slower growing crops. For example, a stand of western red cedar (YC 14) may have a thinning cycle of 5 years during its *full vigour* phase, but when older this could be increased to 7 to 8 years. Similarly a stand of oak (YC 6) could have a thinning cycle of 10 years during its *full vigour* phase but then 12 to 15 years when it is older. Using a longer cycle has the same effect as using a higher intensity: the thinning yield is increased. This may improve the economics of the operation, but could also increase the risk of windblow owing to the more dramatic opening of the canopy.

The question of when to start thinning is important. General guidance on this is to start thinning when stands are fully stocked, that is when they have reached threshold basal area – see Table 14. As a rough guide this is usually reached when stand top height is 10 to 12 m for conifers and 12 to 14 m for broadleaves. However, as with all things in this guide the time of first thinning does depend on management objectives, the stand of trees and the site, as shown in Table 9.

Table 9 Effects of early and late start to thinning

Early start	Late start
For stands subject to high wind risk there are advantages to an early start to thinning to develop more stable trees. This is particularly important for conifers.	A prolonged period of competition will mean that differences between trees, in size and form, will be clearer and the risk of selecting the wrong tree is therefore lower.
As more trees are still around you have more options to select the best trees and the right species.	Keeping stands at high density for longer helps with self-pruning (broadleaves) and to reduce branch size (conifers). In broadleaved stands an option is to start thinning when the desired length of branch free bole has been achieved.
Younger trees react quickly to release from competition.	Larger trees mean lower felling costs per unit volume.

3.6.4 Distribution of trees

In any thinning operation it is generally assumed that a uniform distribution of trees is required (ignoring racks in early thinnings). Uniform stands are clearly the best option when timber production is an important objective as the conditions favour the development of well formed trees. However, if timber production is not an important management objective, the assumption of a uniform distribution of trees may not be valid. An example of this is 'thinning for habitat diversity', which is described in *Managing Native Broadleaved Woodland*. This encourages variable density thinning for specific habitat needs or simply to diversify the structure of a stand in which timber production is not an important objective.

3.7 Final crop tree thinning

Final crop tree thinning is an idea or concept that targets thinning and pruning interventions on selected trees to encourage fast growth of individual trees, usually to achieve a target diameter at breast height. This approach to thinning has been used in a Forest Research experiment at Crumblands in south east Wales; final crop trees were identified in 1953 and are now nearing 60 cm dbh – see Plate 8. However, recently, final crop tree thinning has been applied more generally as a silvicultural tool to focus management on the most valuable trees in a stand in order to achieve maximum value per tree, to develop adequate stability of individual trees and to make sure that the best individuals will have the opportunity to regenerate. Final crop tree thinning has applications in even-aged stands and transformation to CCF, so has relevance to Sections 3 and 4 of this guide. For convenience it is described in detail in Section 4.1.

3.8 Thinning and stability

The decision whether or not to thin a stand must be based on an assessment of wind hazard. You can find guidance on this in OGB 9 (Section 6.2). The factors affecting the wind stability of a forest stand can be divided into three main groups.

1. Species-specific characteristics such as crown form, wood properties and root structure.
2. Site-specific characteristics such as soil type, exposure and altitude.
3. Management-dependent factors such as cultivation, density and structure of the canopy.

These three factors are interconnected and it is the interactions that are important in determining the stability of a forest stand. The focus here is on the third group of factors that relate directly to thinning.

Wind stability is the product of individual tree characteristics as well as the structure of the entire stand. However, individual tree stability and collective stand stability rely on very different principles, and therefore require different silvicultural measures to achieve them.

3.8.1 Stability of individual trees

To clarify what makes a tree stable as an individual it is useful to compare trees that have been grown in the open, in thinned and unthinned stands – see Figure 10.

Figure 10 Crown development and rooting spread of individual trees grown in different competitive environments

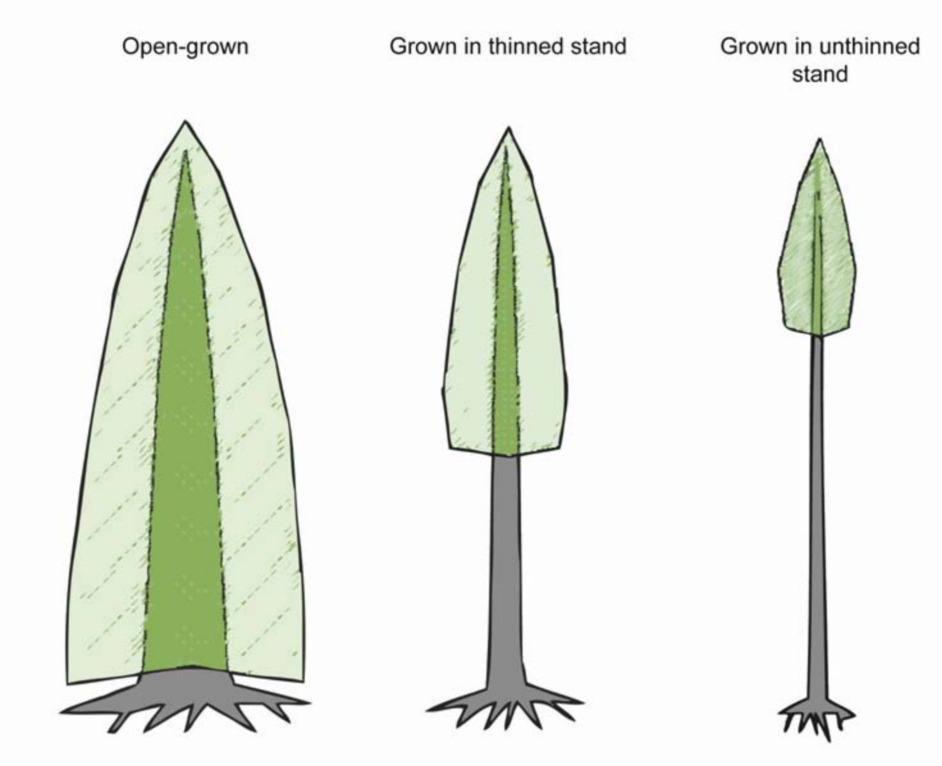


Plate 5 Open grown Norway spruce in an exposed environment at high altitude in the Alps

Open-grown trees adapt to permanent exposure by developing a strong, well anchored root system and a heavily tapered stem – see Figure 10. It is a well established fact that the diameter of the crown of a tree is directly related to the spread of the root system.

Plate 6 Once exposed by heavy thinning or adjacent clearfelling, unthinned stands are very prone to wind damage

Trees grown in unthinned stands have weak root systems, long stems with little taper, and small crowns. The trees rely largely on neighbour support and the structural integrity of the canopy to resist strong wind forces. Once exposed by heavy thinning or adjacent clearfells such stands are very prone to wind damage – see Plate 6.

A useful way to judge the stability of an individual conifer tree is to examine the ratio of tree height to DBH, or the relative crown length – see Figure 5.

The ratio of tree height to dbh can be calculated as: $h/d = \frac{h}{dbh}$

Relative crown length can be calculated as: $cl/h = \frac{cl}{h}$

Where: h = height (m); dbh = diameter at breast height (m); cl = crown length (m), see Figure 5.

Open grown trees and trees from unthinned stands are characterised by values at either end of the range. Trees from thinned stands, which can be considered to be stable, will have values somewhere in between – see Table 10.

Table 10 Guidance on stability of individual conifer trees

	Open-grown tree	Forest stands	
		Stable tree	Unstable tree
Height:diameter*	< 50	< 80	> 100
Relative crown length	~ 1.0	> 0.5	< 0.5

* The stability of trees between 80 and 100 will depend on specific site factors.

3.8.2 Stability of forest stands

The stability of trees in stands depends on the mutual support of neighbouring trees, and the density and evenness of the canopy allowing undisturbed airflow above the tree crowns. The simple rule is: the denser and more uniform the canopy, the higher the stability. You can assess the wind risk of individual stands of trees using a combination of ForestGALES and local knowledge.

Good silvicultural practice uses both individual tree and collective stand stability to ensure low-risk management. Your aim should be to develop the individual stability of trees in early thinnings when stand height and thus wind risk are still relatively low. Also, trees are less able to benefit from thinnings as they age, and you can no longer develop certain characteristics, such as deep crowns, at later stages. Individual tree stability is achieved by thinning early, by thinning more heavily or more frequently, or both, and by applying crown thinning. This is particularly important for stands which you are considering for transformation to CCF – see Section 4.

Once you have good tree stability, you can focus on developing and maintaining stand stability. You achieve this by using moderate thinning intensity and low thinning, or at least by avoiding opening large gaps in the crown canopy.

If you thin stands in areas of medium exposure (DAMS score between 13 and 16) the following general rules should apply.

- Thin more lightly and on a shorter cycle.
- Start with crown thinning, but switch to low thinning later.

- Consider the prevailing wind direction and where the stand is located in the forest block. Adjust thinning intensity if the stand borders on open ground or if the adjacent stand is to be clearfelled soon.

Key point

The higher the wind risk, the earlier thinning must start. Do not delay thinning!

In forests with high exposure (DAMS score >16) opportunities for thinning may be limited.

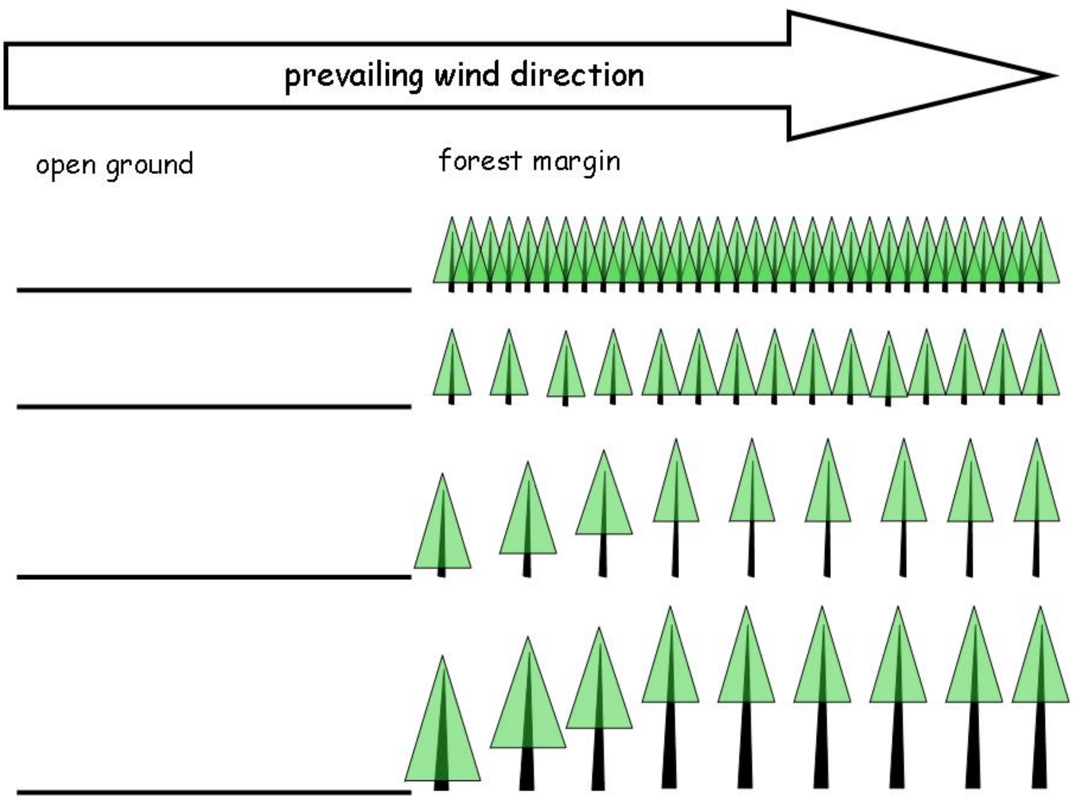
3.8.3 Thinning forest edges

If the edge of a forest stand forms a boundary with open land, or a clearfelled area, it can be subject to the brunt of the windload. Forest edges also fulfil important functions as buffer and exchange zones between woodland and other ecosystems, providing special habitats and shelter for adjacent stands, and greatly affecting the landscape, amenity and biodiversity value of a forest. To protect these important edge habitats it is important to give stability priority over other management objectives, and base it on individual tree stability rather than the integrity of the stand, and the prevailing wind direction.

When applying a first thinning to a forest edge:

- do not delay; and
- thin the outer edge more heavily than the inside as shown in Figure 11.

Figure 11 Thinning a forest edge that borders open ground



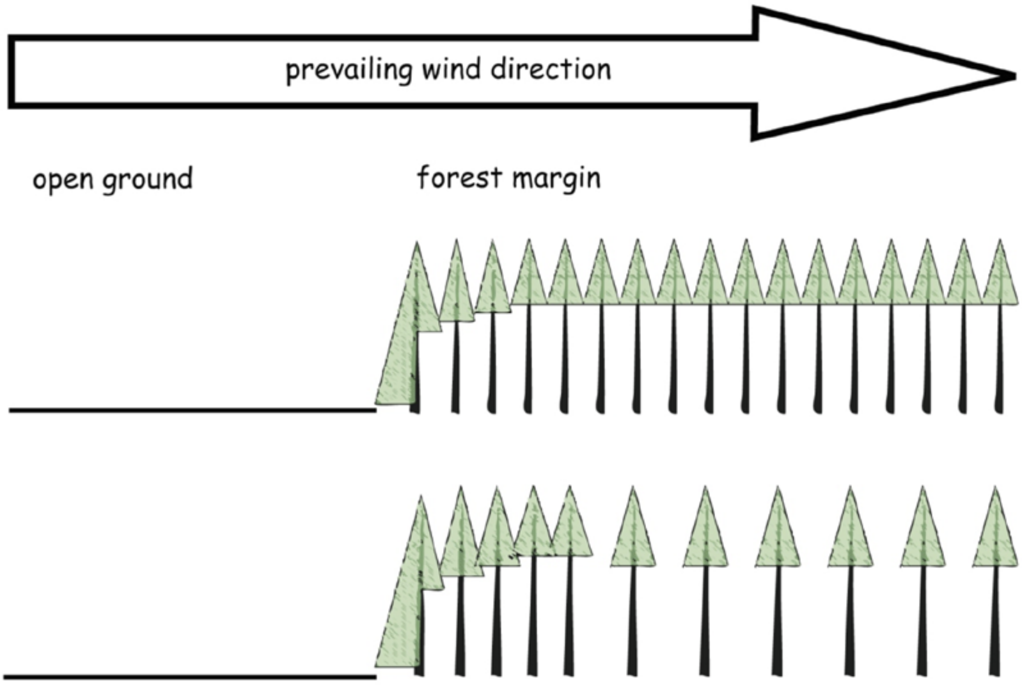
Thinning the outer edge more heavily than the inside will encourage the trees to put on more girth rather than height growth and to retain longer crowns, thus increasing their individual stability. Although this is likely to compromise timber quality and also means a slight loss of productive area, the benefits for improved stability and shelter for the main stand may be worth it.

Key point

Only thin edges as described above if the thinning is early or on time.

If you delay a thinning and you are concerned that the outer edge may be unstable, thin the edge less heavily than the main stand as shown in Figure 12. You need to take great care if the outer edge is already beyond the stage where it can be thinned safely – leave it unthinned. If wind damage occurs after thinning, do not remove it, but leave it as a barrier to protect the main stand.

Figure 12 Leaving unstable edges unthinned

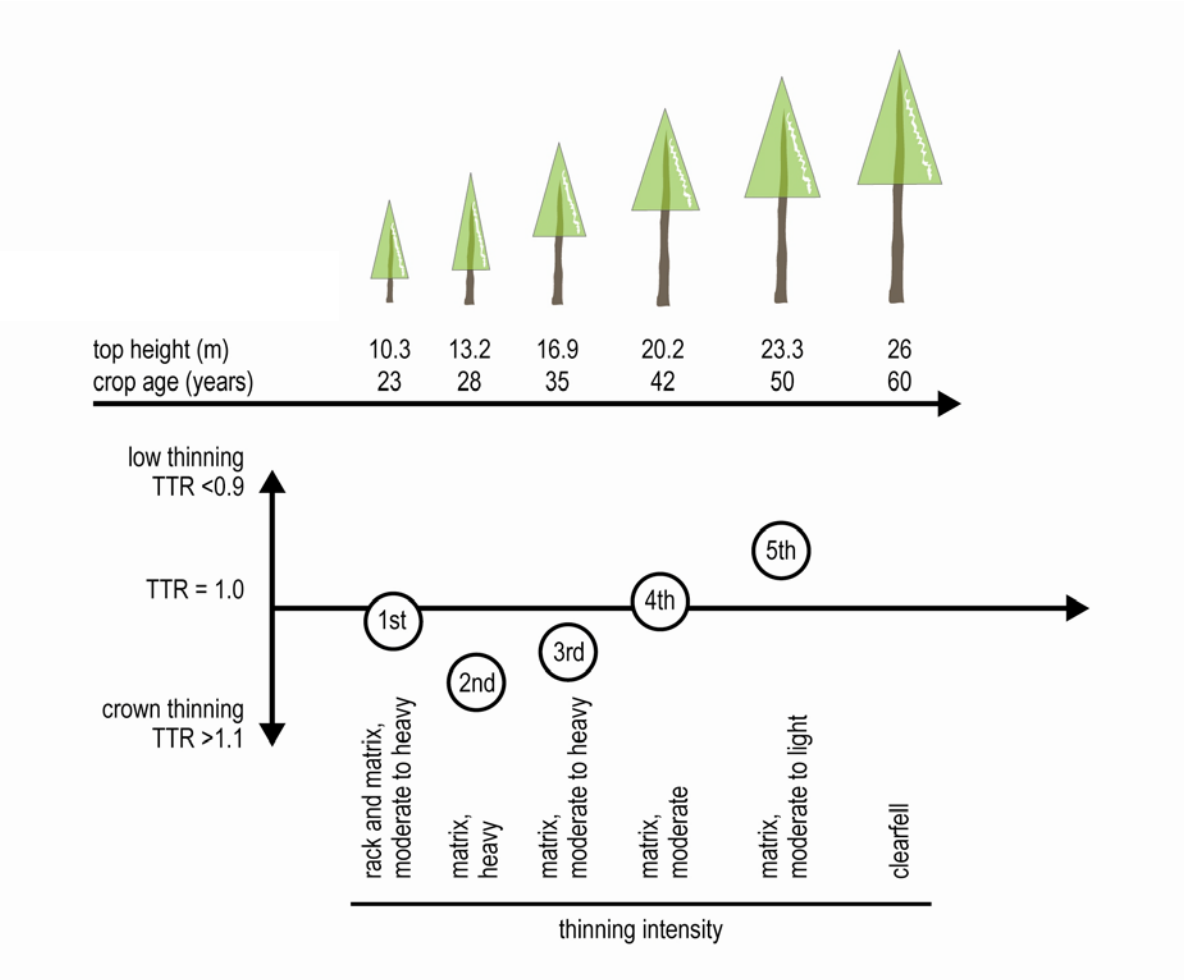


3.9 Thinning regimes

So far this guide has been concerned with individual thinning interventions. However, management objectives are usually only achieved by applying a series of thinnings, i.e. a *thinning regime*. A thinning regime describes when thinning will start and end and the plan for each intervention in terms of type, intensity and cycle. Thinning regimes are a useful idea as they can help encourage forest managers to move away from the conveyer belt of thinning most stands every five years at MTI without considering what they are trying to achieve.

An example of a thinning regime for producing sawlogs in a stand of Sitka spruce is shown in Figure 13.

Figure 13 A thinning regime for a Yield Class 14 Sitka spruce stand managed to produce sawlogs with a target dbh of 50+ cm on a rotation of 60 years. Thinning type, intensity and cycle alter over the production period to address the specific growth pattern of Sitka spruce and the wind risk increasing with stand height.



When designing a thinning regime, consider the following points.

- Each species follows a characteristic growth pattern which will influence the thinning regime. For example, larches and other light demanding species – see Table 5 – require early and heavy thinning to release the crowns and encourage diameter growth. After an early peak, the growth rate slows down so later thinnings have a much reduced effect. Intermediate species such as Sitka spruce will respond to interventions for much longer, and shade tolerant species such as beech and western red cedar can generally be stimulated to increased growth by thinning even at a very late stage.
- Site quality is usually expressed as Yield Class. The higher the yield class the faster the response of the stand to thinning. Wind hazard is also site-specific and will determine whether and how early, how heavily and how often you thin a stand.
- Long-term management objectives also affect your thinning regime. Aiming for high quality sawlogs as your final product will require a much more detailed regime than say pulpwood or chipwood. The higher value of the end product may justify the greater effort involved.

3.10 Thinning mixtures

Plate 7 A second thinning of a mixture of oak and Japanese larch to remove the larch and leave broadleaved woodland

We organised the information in this guide according to six different types of stand as shown in Table 1. Stand types B, D and F are where there is no single dominant species and these are often referred to as 'mixtures'. Guidance on stand types B and D, i.e. those with single canopy strata, is in this section; we look at stand type F in Section 4.4.

When there are two or more species in a stand this is another factor to consider when deciding which trees to remove and leave during a thinning. However, it is a myth that this makes things much more complicated if you have clear management objectives. For example, the management objectives may require concentration on one species, in which case you will prefer to removed any other species. However, a more likely scenario is that the management objectives require the mixture of species to be maintained. In these situations you will need silvicultural skill to take account of the characteristics of each species in terms of the competitive status of each tree, its shade tolerance and potential for future growth. For example, in a mixture of ash and beech, or larch and Norway spruce, one of the species is a light demander and the other is shade tolerant. The light demander, if the stand has been regularly thinned in the past, will respond to the removal of trees that it is in immediate competition with; while this is also true of the other species the fact that it is shade tolerant makes it more resilient and able to respond to an overall reduction in stand basal area. In either situation a delay in thinning will result in a competitive advantage for the shade tolerant species. As a general principle neglect or delay in thinning mixed species stand is more serious than in single species stands.

Key point

Neglect or delay in thinning a mixed species stand is generally more serious than in single species stands.

Mixed species stands can originate from formal planting patterns, the main ones being row and group mixtures, or may have arisen more naturally as a result of natural regeneration or direct sowing. In general, the main principles of thinning in this guide apply equally to these different types of mixture. However, specific problems can occur with mixtures that originate from planting patterns where the growth rate of the species is not as compatible as thought when the mixture was designed. In these cases you will need to shorten thinning intensities or cycles, or both, to maintain the species balance; a different approach would be to review management objectives.

4. Silviculture of thinning (transformation and CCF)

4.1 Final crop tree thinning

The main method of thinning when transforming an even-aged stand to CCF is to target thinnings on selected trees to encourage fast growth of individual trees and enhance their long-term stability. This is an application of final crop tree thinning, which as noted in Section 3.7, applies equally to even-aged stands **not** being transformed to CCF. In an even-aged stand, you use final crop tree thinning where there is a clear management objective to achieve a target diameter at breast height.

The idea of this approach to thinning is that you divide the stand into final crop trees and matrix trees, and focus future silvicultural interventions on the final crop trees. The final crop trees will eventually form the majority of your stand, whereas the matrix trees are considered to be of secondary importance and will largely be removed in thinnings. Final crop tree thinning always uses crown thinning early on and can be combined with pruning – see Section 5 – to enhance the value of the selected trees.

Situations where you are likely to use final crop tree thinning include:

- if you aim to grow quality sawlogs or high value broadleaved timber;
- if your management plan includes pruning of selected trees; and
- if you are considering transformation of the stand to CCF.

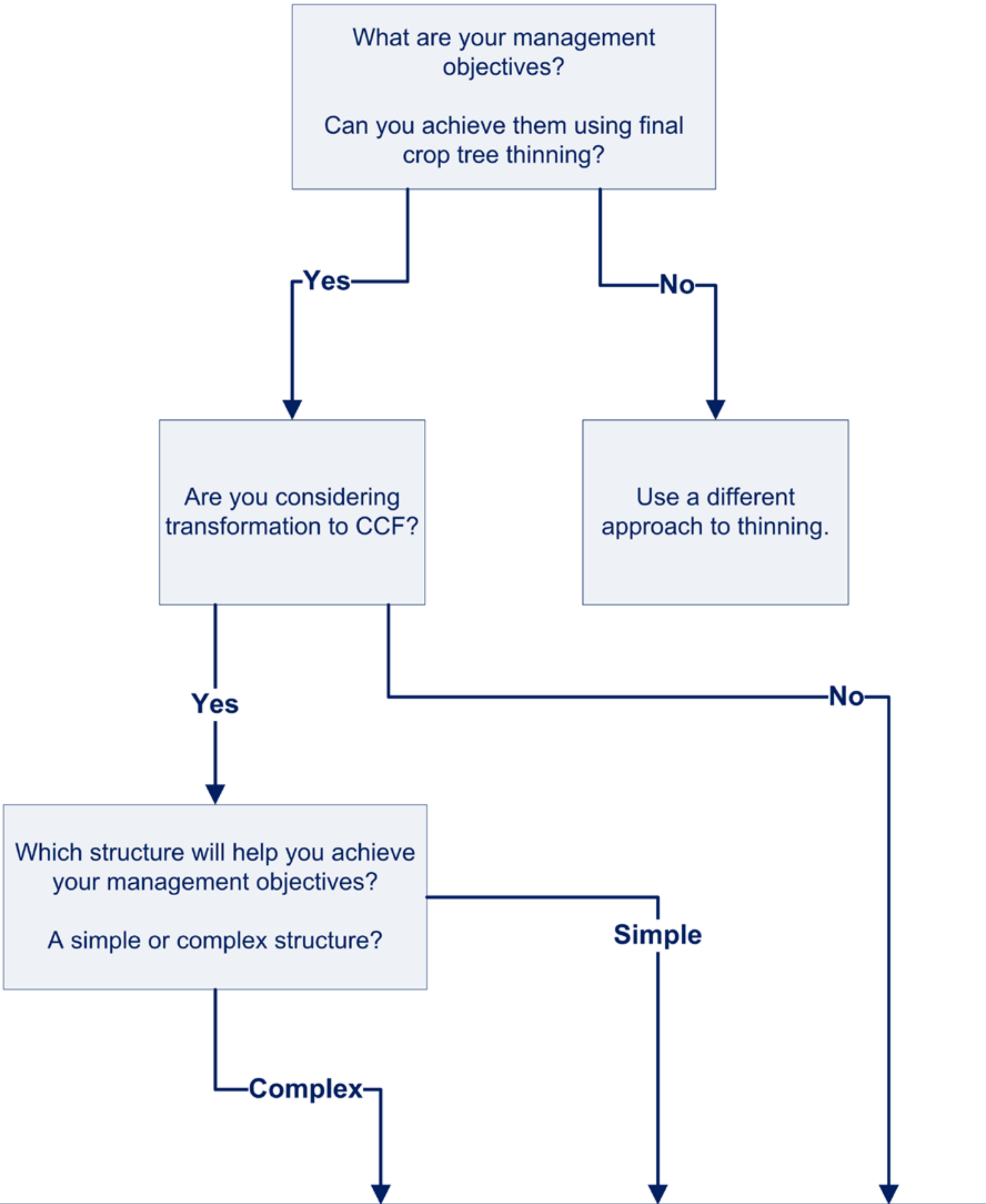
Situations where you are **not** likely to use final crop tree thinning include:

- if you aim to produce mainly chipwood, pulpwood or bio-fuel;
- if you want to maximise volume production per hectare; and
- if you can only apply low thinnings due to stability problems.

The decision tree in Figure 14 clarifies how and when to use final crop tree thinning in relation to management objectives.

Plate 8 Final crop tree thinning in a stand of oak where the objective is to produce a mean dbh of 60 cm on a rotation under 100 years. Measurements when the trees were 78 years-old showed the final crop trees had a mean diameter of 52 cm compared with 42 cm of a more conventional thinning.

Figure 14 Decision tree for using final crop tree thinning



Guidance in Section	**4.2.2**	**4.2.1**	**4.1**
Name of final crop trees	Frame trees	Seed trees	Final crop trees
Density	<50 per ha	100-200 per ha	See Table 11
Distribution	Clumpy	Even	Even

4.1.1 Selecting trees

In a final crop tree thinning there are two types of tree – final crop trees and matrix trees. The priority in any thinning is to remove matrix trees competing with final crop trees (positive selection), being careful not to open up large canopy gaps if there is more than a moderate risk of wind damage. The thinning volume is therefore mainly driven by the number of final crop trees and the level of competition between them and the neighbouring matrix trees. If the number of final crop trees is low you may find that the thinning volume is well below the target for a conventional thinning; in this case you may also selectively thin the matrix trees in order to avoid leaving unthinned patches and to make operations more cost-effective. The other factors to consider when selecting final crop trees are: when to select the trees; the type of tree to select and if and how to mark them.

When to select final crop trees?

In general, the earlier you select the final crop trees that you will keep, the more time there will be to develop desired characteristics. It therefore follows that you can select trees as early as the first thinning. However, this has to be balanced against the fact that early selections will sometimes need to be changed, as early in the life of a stand, the final result of competition may not be apparent. For example, a tree showing good early vigour may develop coarse branching or a selected tree may lose out in competition with a neighbouring unselected tree. For this reason, a less risky option for larger target diameters and when transforming to CCF, is to select trees at or after the second thinning. For broadleaved species the best time of year to select trees is during the dormant season when the features of the stem and crown are more visible.

Type of tree to select as final crop trees

If timber production is an important objective, then you should select trees that are dominants or co-dominants that have a good quality stem and are growing vigorously.

Whether to mark final crop trees?

A key decision is whether or not to mark the final crop trees. A common method is to paint bands or spots on trees. Although there is a cost to doing this, it can be helpful to maintain continuity where staff change or you want to check that selected trees are not being removed in a standing sale.

> **Key point**
>
> If you mark final crop trees it is important that you review your decisions before each thinning to take account of changes that may have occurred since the last intervention.

If you prune trees – see Section 5 – this can also serve as a method of marking final crop trees.

It is not essential to mark final crop trees, particularly where experienced staff have been involved for a long time. Final crop trees should be apparent due to their enhanced growth and better form. An advantage of not marking the trees is that it is much more flexible and you can take into account any changes in tree dominance and form since the last thinning.

4.1.2 Number of trees

If a stand is being transformed to CCF then you will find guidance on the number of final crop trees in Section 4.2 – see Figure 14. However, for even-aged stands where there is a clear management objective to achieve a target diameter, you will find guidance on the density of final crop trees in Table 11. Note that the figures are a suggested **maximum range**: you can use lower numbers than this range if local conditions or the history of the stand mean that the density is unrealistic.

In most situations final crop trees should be evenly spaced throughout the stand and to aid this Table 12 shows the equivalent square spacing of the densities in Table 11. The exception to this is when transforming an even-aged stand to a complex structure, see Section 4.2.2.

Table 11 Number of Final Crop Trees per hectare for different target dbh and species

SPECIES	TARGET DBH (cm)					
	30	40	50	60	70	80
Oak/Ash/Sycamore	240 – 280	140 – 170	90 – 110	60 – 80	50 – 60	40 – 50
Beech/Birch/Sweet Chestnut	270 –310	180 – 220	120 – 160	90 – 120	70 – 100	60 – 80
Larch (EL/HL/JL)		160 – 210	100 – 140	70 – 100		
Norway and Sitka spruce, Douglas fir		260 – 360	190 – 260	130 – 200	120 – 160	100 – 120
Western Red Cedar		420 – 470	310 – 340	240 – 260		
Scots and Corsican pine		300 – 330	200 – 230	150 – 180	110 – 140	80 – 110

Table 12 Equivalent square spacings of tree densities in Table 11

Final crop trees per ha.	50	60	70	80	90	100	110	120	130	140
Distance between trees (m)	14.1	12.9	12.0	11.2	10.5	10.0	9.5	9.1	8.8	8.5
Final crop trees per ha.	150	160	170	180	190	200	225	250	275	300
Distance between trees (m)	8.2	7.9	7.7	7.5	7.3	7.1	6.7	6.3	6.0	5.8

4.2 Transformation to CCF

The following guidance is based on Forestry Commission Information Note 40 and concentrates on how to thin stands being transformed to CCF. An important part of transformation is to decide what type of CCF structure is most appropriate for your management objectives:

1. A simple structure in which there will be one or two canopy layers.
2. A complex structure with three or more canopy layers.

It is likely that simple structures will be more common and can be thinned using similar approaches to even-aged stands. Complex stands will be much less common and require a different approach to thinning.

4.2.1 Simple structure

Plate 9 A marked seed tree in a second thinning of a stand of Sitka spruce in transformation to a simple CCF structure

Thinnings seek to favour the crown development of the seed trees while ensuring that site conditions remain conducive to natural regeneration. Use crown thinning to favour 100 to 200 seed trees per ha that are uniformly distributed over the area. Early thinning should be at a higher intensity (10 to 20%+) than marginal to ensure good crown development on the seed trees.

4.2.2 Complex structure

The basic idea is to create a wider dbh range than in a simple structure by thinning to:

- retain small trees; and
- encouraging fast growth of selected 'Frame' trees.

Select up to 50 Frame trees per hectare that have a 'clumpy' distribution, i.e. they do not have to be particularly evenly distributed. Frame trees must be stable, well-formed dominant trees, as they may need to stay on the site for a long time.

Select a residual basal area for the stand, which on current knowledge should be about 18 to 25 m^2 per ha for larches and pines and 25 to 35 m^2 per ha for spruces and Douglas fir. The choice within this range depends upon the site and the balance between the overstorey and any regeneration. If there is little, or no, regeneration, then choose higher values to provide suitable conditions for seedlings to establish. If there is enough regeneration, which needs to be released, then favour the lower values. The aim at each thinning is to remove enough trees so that you achieve the chosen residual basal area.

Once a new cohort of young trees (i.e. >7 cm dbh, not just seedlings or saplings) has become established during transformation to a complex structure a simple spreadsheet tool is available from Forest Research that can help with the thinning of stands developing into a complex structure. We describe its use in the next section.

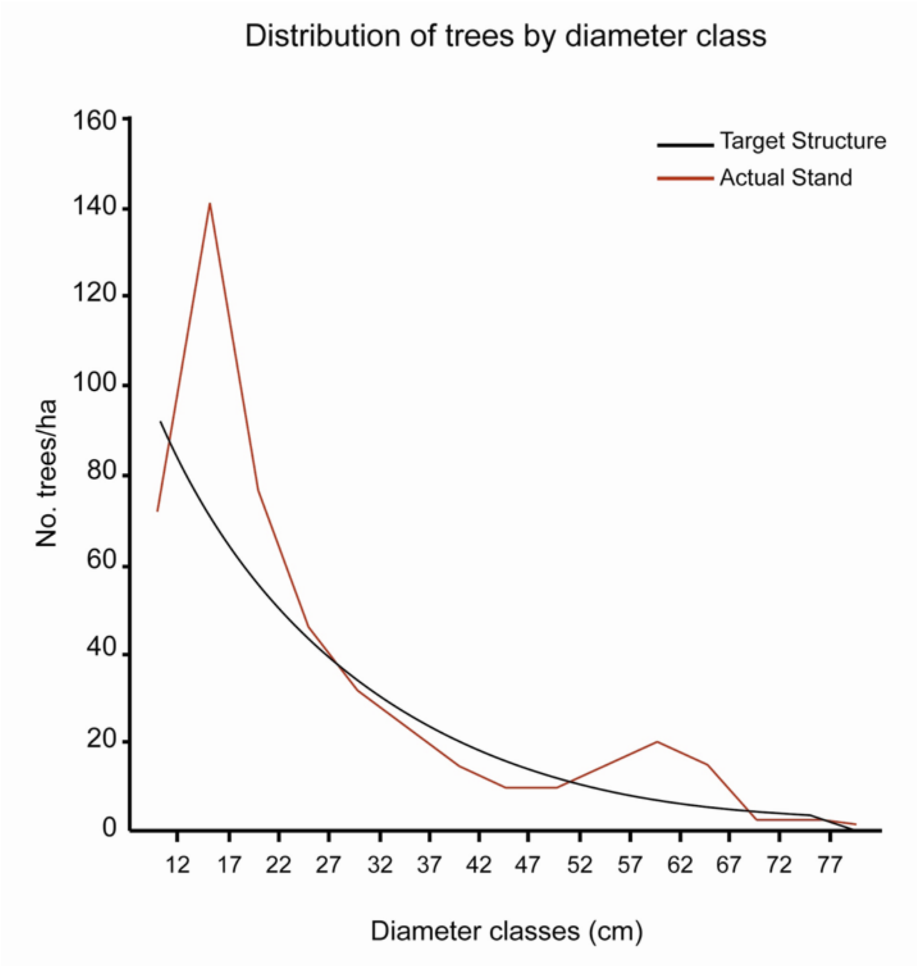
4.3 Thinning complex CCF stands

Very few people involved with forest management in Britain will have any experience of how to thin a complex CCF stand. For this reason Forest Research has developed a spreadsheet that you can use to guide you when marking a thinning in such a stand. The outcome of this is a marking guide, an example of which is shown below which relates to the stand shown in Figure 15.

Table 13 Marking Guide for a complex CCF stand

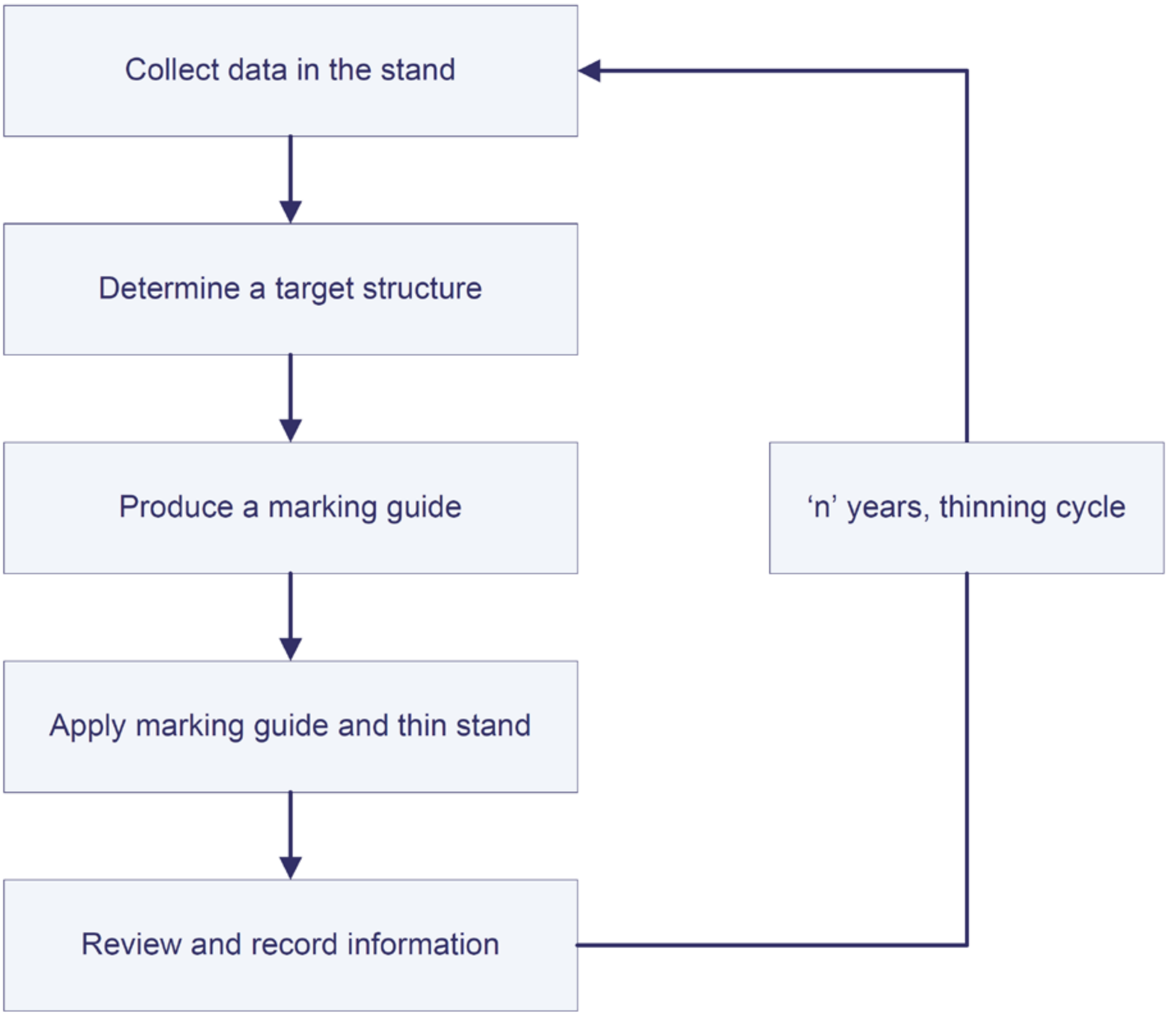
Size class of tree (dbh, cm)	Marking Guide
Small (7-26)	1 in 4
Medium (27-41)	NA
Large (42-56)	NA
Extra large (≥57)	1 in 2

Figure 15 A target and actual structure for a complex CCF stand



Hopefully the simplicity of Table 13 will encourage you to try this method if you have some stands that are developing a complex CCF structure. The guide suggests that half the trees over 57 cm dbh need to be removed as well as a quarter of the small trees. This guidance could then be given to an experienced marking team to implement in the stand. Their job is to decide which small and extra large trees to mark for removal using this guidance along and other management information. For example, the small trees may be uneconomic to remove and a judgement is made not to mark any small trees; in any case some of them would be taken out by the felling of larger trees. In addition, the extra large trees are an important seed source and this must be considered in the decisions about which trees to remove. For example, one species may note be desirable for management objectives and should be targeted for removal.

Figure 16 The process for thinning in a complex CCF stand



4.3.1 Producing a marking guide for complex CCF stands

This process is shown in Figure 16; the main steps are described below.

1.Collect data in the stand

You need to collect data on species and size of the trees in the stand; it is best to use 5 cm dbh classes: 7.0 to 11.9, 12.0 to 16.9, 17.0 to 21.9 etc. You could use data from an abbreviated tariff; another method is to collect data as described in Forestry Commission Information Note 45 (see also Section 10.3 of OGB 7).

2. Determine a target structure

The type of structure you need to determine is shown in Figure 15, it has a large number of small trees, a moderate number of medium sized trees and a small number of large trees. This type of structure is commonly referred to as a negative exponential or reverse-J, which is an attempt to describe its shape. To generate a target structure you need to make management decisions on:

- basal area after thinning, and
- the dbh of the largest tree

The choice of a value for basal area depends on species and site conditions. For light demanding species use a value between 18 and 25 m^2/ha, and shade tolerant species use a value between 25 and 35 m^2/ha (see FCIN40); use higher values on more fertile sites. The dbh of the largest tree is usually set in relation to the timber markets of the local area (use the mid-diameter of the tree from the largest DBH class required, for example 59.5 cm for 57 to 61.9 cm).

You also need information for a value commonly referred to as 'q', which describes the gradient of the line of target structure. The value of 'q' describes the ratio between the number of trees in one size class to the number of trees in the next larger class, for example with a value of 1.5 there would be 1.5 times more trees in a dbh class of 12.0 to 16.9 as in 17.0 to 21.9. Values usually range between 1.0 and 2.0 with higher values producing steeper curves. This parameter will be unfamiliar to many people and little is known about it for forest stands in Britain. Preliminary guidance is to use a value of 1.3.

> **Key point**
>
> Use the target structure to guide your thinning. Achieving the target structure must not become the aim of management.

> **Key point**
>
> Target structures may need to change in response to changes in management (timber markets), the stand (observations of changes in the ground flora) or the local area.

3. Produce a marking guide

Numbers produced from Stages 1 and 2 above are input to the spreadsheet and it will generate a curve for the actual and target structure. In addition, a separate worksheet in the spreadsheet will show a suggested marking guide for the stand. The actual and target structure that relates to the marking guide shown above in Table 13 is the one shown in Figure 15.

Key point

Help and support on thinning complex CCF stands is available from Forest Research.

4.4 Mixed species stands with more than two canopy strata

When thinning a mixed species stand with more than two canopy strata the main things to consider are the desirability of each species in the mixture for management objectives and the shade tolerance of the species – see Table 5.

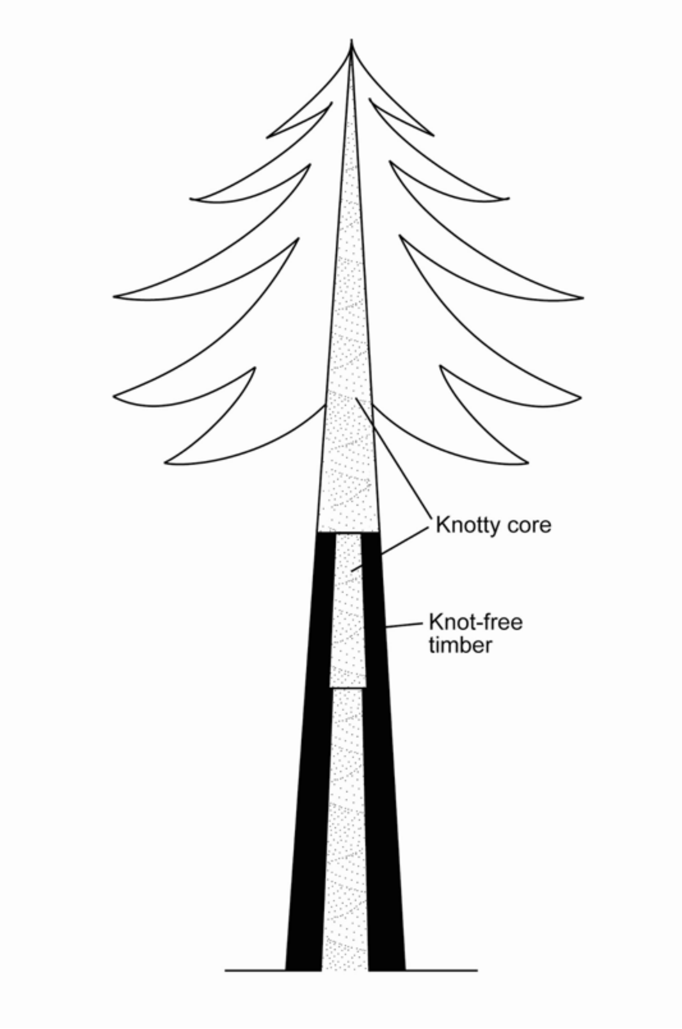
Species that are not desirable for management objectives should be favoured for removal in thinning these sorts of stand. In general a mixture of shade tolerant and light demanding species will 'work' in an even-aged stand – see Section 3.9. However, when there is more than one canopy layer in the forest you need to be aware of the shade tolerance of the species in the mixture.

- If the species are similar in their ability to tolerate shade, then thinning will usually maintain the species balance in the stand.
- If the two components are different in their ability to tolerate shade, thinning will usually favour the more shade tolerant species. During the regeneration phase a group-based system will probably be required to maintain both species groups in the mixture.
- Storeyed mixtures usually have a light demanding species such as oak or larch in the overstorey, and a shade tolerant or intermediate species like beech, fir or spruce in the understorey. These stands are a special case and can be thinned using the same method as complex CCF structure or by treating each species or storey independently, very much like a single species stand.

5. Thinning and pruning

Pruning is an operation that removes branches from the lower part of a tree to produce valuable, knot-free timber on the lower stem of the tree – see Figure 17. Pruning and thinning are intimately linked when the objectives of management include the production of good quality timber. Pruning is a convenient method of marking selected trees in crown thinning and will make sure that the future growth of these trees will produce knot-free timber. However, there is no reason why pruning cannot be combined with other types of thinning.

Figure 17 Longitudinal section of a tree which has been pruned to 6 m and then 9 m in two lifts showing extent of clear (knot-free) timber.



The main type of pruning we consider here aims to improve the quality of timber by reducing the extent of knots on the potentially valuable lower part of the stem. Other types of pruning include brashing, which is the removal of branches up to a height of 2 m to improve access to stands. Formative pruning is the removal of branches from broadleaved trees in the stand initiation phase and you should only use this in stands where the number of trees established is below the recommended level; you can find guidance on this in FC Handbook 9.

Plate 10 Pruning pole-stage oak in which final crop trees have been selected

5.1 Species

In general the timber quality of all species can be improved by pruning. However, in broadleaved species, with the exceptions of cherry, birch and poplar, the ability to self-prune means that you will not have to prune as much if stands are established at an adequate density.

Pruning can remove dead branches (dry pruning) or live branches (green pruning). The latter requires more care as the live cambium is exposed and hence there is a risk that pathogens and pests can use this as an entry point to attack the tree.

Plate 11 Mechanised pruning of larch

5.2 Selecting stands for pruning

Pruning is a significant investment and therefore should only be carried out in stands where there is a good chance that it will help achieve management objectives. To keep risks at a minimum check the following points before you decide to prune.

- Only consider productive stands of high yield classes for pruning.
- The entire stand – not just the selected trees – must be of good overall quality.
- Stability must be high, and must be based on the characteristics of individual trees.
- Do not prune stands exposed to a high general risk of wind damage, butt rot or other pests and diseases.
- Do consider pruning stands that are understocked as a method to improve timber quality to compensate for natural pruning caused by competition.
- There is a reasonable expectation that there will be a premium market for pruned logs of the particular species that will justify the expenditure.

5.3 Selecting trees for pruning

The main challenge in selecting trees for pruning is the same as selecting trees to favour when crown thinning. The trees need to be selected before the final result of the competition processes in a stand of trees becomes apparent – see Figure 2. The best advice is to select well-formed dominant or co-dominant trees. You can use pruning as a method of marking the selected trees in a crown thinning to avoid the use of painted spots or bands. However, when trees are older the immediate effects of the pruning will not be so apparent, although the better growth and form of the pruned, selected trees should hopefully be apparent.

5.4 Pruning practice

The objective of pruning, to produce knot-free timber on the lower part of the stem of a tree, is shown in Figure 17. Pruning is an expensive operation and therefore in practice should normally be planned for one operation up to 6 m. However, if timber is being grown specifically for a market, you may need more operations above 6 m. To judge when the best age to prune is you must balance the following factors:

- prune trees when the dbh is 10 to 20 cm, preferably in the lower part of this range.
- remove no more than 30% of the live crown to minimize the effects on the growth and development of the tree.

The only clear guidance on the best time of year to prune is that cherry must be pruned during the summer (June to August) to minimize the risk of infection by the fungus causing silver-leaf disease. For all other species a pragmatic approach is to prune in the spring before active growth restarts to allow maximum opportunity for pruning wounds to heal over.

Table 14 Threshold basal areas for fully stocked stands (basal area, m^2/ha)

Species		Top height (metres)										
		10	12	14	16	18	20	22	24	26	28	30
Scots pine		26	26	27	30	32	35	38	40	43	46	–
Corsican pine		34	34	33	33	33	34	35	36	37	39	–
Lodgepole pine		33	31	31	30	30	31	31	32	33	34	–
Sitka spruce		33	34	34	35	35	36	37	38	39	40	42
Norway spruce		33	33	34	35	36	38	40	42	44	46	49
European larch		23	22	22	22	23	24	25	27	28	30	–
Japanese and hybrid larch		22	22	23	23	24	24	25	27	28	29	–
Douglas fir		28	28	28	29	30	31	32	34	35	37	40
Western hemlock		32	34	35	36	36	36	37	38	38	39	40
Red cedar		–	49	50	51	53	55	57	60	63	66	70
Grand fir		–	39	39	39	39	39	39	40	41	43	45
Noble fir		–	45	46	46	47	48	49	51	52	54	–
	Yield class											
Oak	4	24	24	23	23	24	24	–	–	–	–	–
	6	–	26	25	24	24	25	25	25	25	–	–
	8	–	27	25	24	24	24	25	26	26	26	–
Beech and	4	–	22	23	25	27	30	–	–	–	–	–
Sweet chestnut	6	–	24	25	25	27	29	31	33	36	–	–
	8	–	–	27	27	27	28	29	31	33	35	37
	10	–	–	28	28	27	27	28	29	31	33	35
Sycamore, ash,	4	–	17	17	18	21	–	–	–	–	–	–
birch and alder	6	–	17	18	19	22	25	–	–	–	–	–
	8	–	17	18	20	22	25	28	–	–	–	–
	10	–	18	19	20	23	26	30	33	–	–	–
	12	–	19	20	21	24	27	31	35	–	–	–