Forestry Commission

Silvicultural Guide

Successful underplanting
by
Gary Kerr and Jens Haufe

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1. Introduction

The aim of this Guide is to provide you, the forest manager, with guidance on how to carry out underplanting. Underplanting is the planting of young trees under an existing canopy, either as part of a process of regenerating the existing stand or to introduce an understorey to enrich and diversify the forest structure. Planting trees into the sheltered environment of an existing forest can confer silvicultural advantages, particularly against unseasonal frosts and heavy rainfall; however, there are also risks, such as failure to prepare the stand and consider future operations. Underplanting is very different to restocking, which is familiar to most forest managers in Britain, and the aim of this Guide is to give you clear information on how to achieve successful underplanting.

The policy background for the increased use of underplanting in Britain's forests is the emphasis given to building a more resilient, diverse forest estate to help reduce the risks of pests and pathogens and the impact of future changes in the climate. The increased use of continuous cover management and mixed-species stands can develop a more resilient forest estate and in some circumstances will require the use of underplanting (Kerr, 2008). Underplanting, if well designed and implemented, can be a reliable method of regenerating stands being managed using continuous cover or a way of increasing the number of species in an even-aged stand.

Case study – Bärenfels Forest District, Saxony, Germany

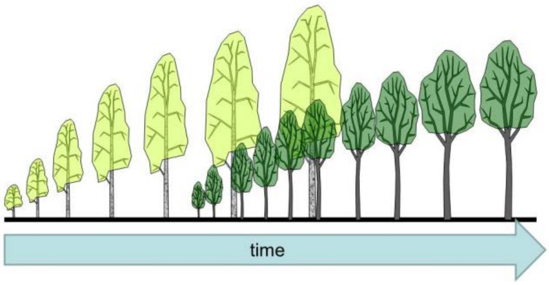
Beech has been underplanted in order to supplement natural regeneration of Norway spruce. This approach has been widely adopted in mountainous regions of Central Europe, where spruce monocultures are converted into mixtures, including beech and European silver fir, which constitute the natural woodland type on many sites.

The term 'underplanting' is a general term that describes the establishment of a young stand (understorey) under the canopy of an old one (overstorey). In countries with a longer silvicultural tradition than the UK, more specific terms are used; for example, in Germany there are separate terms for four different types of underplanting.

For practical purposes this Guide defines two types of underplanting according to the objectives and the timescale of retaining and managing both storeys:

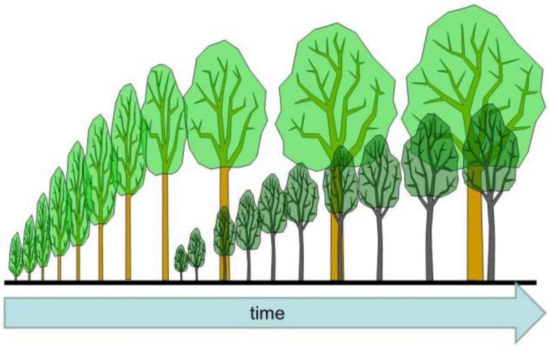
Regeneration underplanting

The young stand or understorey is intended to eventually replace the overstorey and is usually an element of management using continuous cover. The overstorey and understorey coexist for some time, until the overstorey is removed.



Stand improvement underplanting

The young stand or understorey is intended as a supplement to the existing stand. The overstorey and understorey are managed together for the remainder of the rotation period, which will usually result either in a clearfell/restock scenario or, occasionally, continuous cover management.



Although the practical implications for establishing the understorey are similar in both cases, the purpose of underplanting and the ecological context differ and therefore you need to consider them. In this Guide when the term 'underplanting' is used the information applies to both regeneration and stand improvement underplanting; where we give more specific guidance, we use the terms 'regeneration underplanting' and 'stand improvement underplanting'.

Because underplanting is commonly associated with continuous cover management the silviculture of planting in canopy gaps is included in this Guide. Fortunately the ecological principles of planting canopy gaps are similar to those of underplanting, despite the fact that the young stand is, strictly speaking, not being established directly under a canopy. The creation of canopy gaps followed by planting can be used to create continuous cover stands with a simple (1 or 2 canopy layers) or complex structure (3 or more canopy layers). You will find information on the use of regeneration underplanting and different silvicultural systems in Table 1.

This Guide applies to high forest stands in Britain that are conifer, broadleaved or mixed species. It does not cover the use of direct sowing of tree seed. There are examples of the successful use of direct sowing elsewhere in Europe but research and practical experience in the UK indicates that predation by small mammals is a significant constraint and direct sowing is not recommended until we have a better understanding of how to achieve success.

This Guide is structured into five stages that describe the process of successful underplanting:

1. Objectives
2. Ecological context

3. Design and planning
4. Implementation
5. Monitoring and review.

Within the context of this Guide most of the advice given is general rather than specific to particular combinations of species and site conditions. Successful underplanting requires you to understand the underlying principles and then apply them based on a good knowledge of the silvicultural characteristics of tree species and the sites where they are growing. A good way of learning is to examine previous examples of underplanting of the specific species/site combination you are considering. You can do this by looking for past examples in the forests in your region and by discussion with other forest managers.

The checklist in Section 1.1 will help you plan successful underplanting.

Table 1 Use of underplanting in silvicultural systems

Silvicultural system	Notes on use of and design of underplanting
Uniform shelterwood	The canopy is opened evenly with the intention of achieving a new stand that is even-aged. Underplanting will generally occur in a single operation with young trees planted in a reasonably even pattern with planting positions selected so that they cause minimal interference with the root systems of existing trees (i.e. good planting positions assessed by looking down).
Group shelterwood	The canopy is opened in scattered gaps, not necessarily all of the same size, and the intention is to achieve a new stand with a less regular structure than in the uniform shelterwood. Underplanting will generally occur in gaps with young trees planted where they have the best chance to survive and grow rapidly (i.e. good planting positions assessed by looking up).
Irregular shelterwood	This system is best used in areas where natural regeneration is reliable. The canopy is opened in an irregular pattern over a much longer time period (20 to 40 years) than the uniform or group systems and the intention is to achieve a complex stand structure (3 or more canopy strata). If you use underplanting its main function will most likely be to enrich areas that do not regenerate or alter species composition in the later stages of the regeneration period.
Selection systems	This system is best used in areas where natural regeneration is reliable. Any use of underplanting would be to enrich areas that do not regenerate or change species composition in group selection systems. Hence any underplanting would be similar to that used for group shelterwood.
Strip systems	This is the best option in areas of high wind risk and limited stand stability (provided there is consideration of the prevailing wind direction) and where natural regeneration is reliable. Use of underplanting would be either in the strip before or after final removal of the canopy. The aim would be to enrich areas that do not regenerate or change species composition. The pattern of underplanting could be similar to a uniform, group or a mixture of both.

1.1 Underplanting checklist

Ten key questions need to be answered for successful underplanting:

1. What is your long-term vision for the stand?
2. Are you planning a **regeneration underplanting** or a **stand improvement underplanting**?
3. What are the benefits you expect from the underplanting? How will they help achieve your management objectives for the stand?
4. What species or mixture of species will be planted? What species or mixture of species constitutes the overstorey?
    a. How have you assessed if the underplanted trees are adapted to site conditions?
    b. How have you taken into account that the underplanted trees will be in a shaded and more sheltered environment than when restocking?
5. How has the stand been prepared to ensure the underplanted trees can thrive after they have been planted?
    a. What is the canopy cover (best measure) or basal area of the stand?
    b. What is the shade tolerance of the underplanted trees?
    c. How will the preparation of the overstorey (e.g. thinning, creation of gaps) alter the risks of wind damage?
6. What is your plan for planting the trees?
    a. What plant type and size of tree will be used?
    b. How will the trees be planted?
    c. What spacing will be used?
    d. What ground preparation are you planning (if any) and how will it affect the roots of canopy trees?
    e. Does your design include plans for future operational access to thin the stand?
7. How will the trees be maintained after they are planted?
8. What measures are you taking to protect the trees from mammals, pests and diseases?
9. If using group planting: are the canopy gaps large enough to ensure that all the trees planted can thrive for at least five years?
10. How will you monitor the success of your underplanting so you can learn from what you have done to improve silvicultural practice in your area?

2. Objectives

There is no doubt that establishing a young stand underneath the canopy of an overstorey creates some operational challenges and these continue when the overstorey requires thinning or felling. There can be increased costs associated with changes in operational working needed for underplanting, but these must be balanced against the benefits; for example, avoiding the requirement to restock, greater flexibility with tree species choice, reduced risk of weevil damage, potential for improved timber quality, higher species and structural diversity, better conditions for regeneration and the potential for soil improvement. In order to decide when underplanting is appropriate, it is essential to consider the general management objectives for the site. The main reasons for underplanting include:

Regeneration underplanting

- Changing species: the existing stand may not be growing well because of poor species choice, forest health problems or it may be a management objective to increase the number of species in the stand.
- Improving genotype: the existing stand may be of an inferior provenance, improved genotypes may be available or it may be sensible to diversify the genetics of the stand.
- Natural regeneration of the desired species has failed: attempts to regenerate the stand have not been successful or resulted in regeneration by undesirable species.
- Establishing sensitive species: frost-sensitive species are often easier to establish under the shelter of a canopy.
- Establishing species under difficult site conditions: this may be the case where you are establishing more demanding species on exposed sites under the shelter of an overstorey, but the principles of good species choice must still apply.

In essence, regeneration underplanting is appropriate when replacement of an existing stand via natural regeneration is not possible or not desirable as part of continuous cover management. The management objectives for the site must consider the species or mixture being underplanted, as these will eventually become the future forest stand. You should set a time frame for the overlap period when over- and understorey co-exist and you must plan and carry out forest operations in the existing overstorey with great care in order not to endanger the growth and development of the developing understorey.

Stand improvement underplanting

- Improving yield: an overstorey of light demanding species with large crowns and/or long rotations provides the opportunity to create an understorey and this can increase the productivity of the site.
- Improving timber quality of the main crop: in particular oak, which is prone to epicormic growth and will benefit from the shading effect of an understorey.
- Providing ecological benefits: this includes control of aggressive ground vegetation, development of a suitable seedbed for natural regeneration of the main species, improvement of the humus layer and nutrient recycling processes, better stand stability and resilience.

Case study – DNB affected stands in Thetford

Dothistroma needle blight (DNB) caused by the fungal pathogen *Dothistroma septosporum* was first recognised in Thetford forest in 1997 and has led to significant changes to silvicultural practice. The stands of Corsican pine most heavily affected and with little chance of recovery are underplanted to ensure future timber production. Underplanting takes place in such stands at first thinning (below 20 years) with a range of shade tolerant species, including Douglas-fir, grand fir, European silver fir, Serbian spruce, western red cedar, Atlas cedar, Japanese red cedar, Macedonian pine, Weymouth pine and coast redwood.

Case Study – DNB affected stands in Sherwood

A different approach has been used in Sherwood Forest to underplant these mid-rotation stands of DNB affected Corsican pine compared with Thetford. Initially the extraction racks are being planted with shade tolerant conifers following a mechanical screefing to prepare planting positions. The basal area of the stand is **above** the range shown in Table 3 of this Guide (shade tolerant trees planted under a light demanding canopy) but this is not a concern because: (1) the stand is affected with DNB and (2) the plan is to carry out further line thinnings between the planted racks and then underplant these in a similar way as shown in the picture.

Photos by Tim Medlock and Nigel Connor

- Diversifying the stand structure: adding species and/or structural diversity to the stand may be a forest management objective.

Stand improvement underplanting is similar to regeneration underplanting in that it aims to establish an understorey at some point during the life of the overstorey. Where stand improvement underplanting differs is that the two canopy layers are usually managed and harvested together, regardless of whether the final harvest is carried out as a clearfelling or as part of continuous cover management. The permanent nature of a two- or multi-storey canopy with stand improvement underplanting dictates that in almost all cases more than one species will be involved. The roles of both canopy layers are clearly defined. The overstorey includes the main species, usually light demanding or intermediate, whereas the understorey has a secondary role and contains a more shade tolerant secondary species. Management objectives need to encompass the role of both storeys. The main advantages of stand improvement underplanting are the ecological benefits it provides; its main challenge can be the more complex forest operations which require higher levels of skills and expertise.

Case studies - New Forest and Cuckoo Wood, Monmouthshire

This oak stand in the New Forest was established in 1853 and underplanted with beech in 1930. The beech understorey serves several purposes: it keeps the oak stem clean from epicormics, provides a suitable seedbed for oak regeneration, and adds to the overall productivity of the site.

An 85-year-old oak stand at Cuckoo Wood, Monmouthshire. The understorey of sycamore originates from coppicing but provides the classic benefits otherwise achieved by stand improvement underplanting: preventing epicormic growth in the main crop, additional produce and suppressing undesirable ground vegetation.

Photos by Mark Malins

Stand improvement underplanting is likely to be most appropriate on sites where the additional costs can be justified by a higher expected outcome, either in biomass or timber quality.

In regeneration or stand improvement underplanting, the management objectives for the stand must include:

- the tree species involved, their proportions and role;
- the envisaged stand structure (even-aged, simple CCF or complex CCF);
- the specific benefits the stand will provide, i.e.:
    - economic (major and minor produce expected, sporting);
    - environmental (conservation, mitigation of climate change, water quality etc.);
    - social (amenity, recreation, landscape and cultural value);
- the envisaged method of regeneration once the stand, or individual trees have delivered the management objectives. (Options range from clearfell/restock via simple CCF scenarios to complex CCF structures, such as single tree selection.)

It is usually helpful to develop a long-term vision of what the stand should look like together with management objectives. You should record management objectives and visualised stand structure in the Forest Design Plan to facilitate the work of future forest managers. Examples of how this could be done are shown in Section 9.

Case study - Stand improvement underplanting in Craigvinean

Japanese larch stand in Craigvinean Forest, Tay Forest District, with a stand improvement underplanting of Norway spruce. The light demanding nature of larch demands heavy and early thinning, and a fairly open canopy throughout the rotation. This in turn allows for a secondary crop to be grown underneath, on a slightly shorter rotation. In this case the spruce was planted 25 years after the larch, presumably after the first two thinning interventions had been carried out.

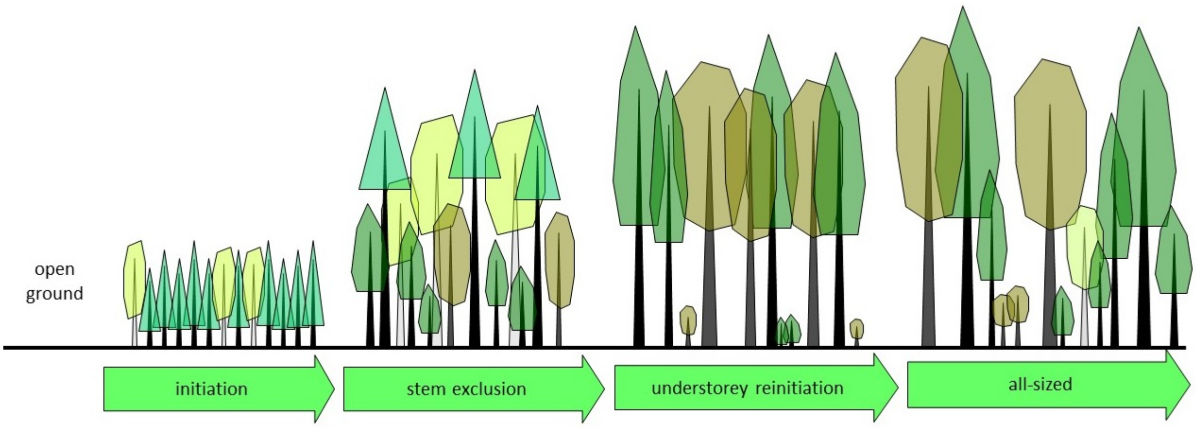
3. Ecological context

Many of you forest managers in Britain will be familiar with the silviculture of restocking following clearfelling, which has been widely and successfully applied. The main difference between restocking and underplanting is that canopy trees remain on site while regeneration progresses. This requires a fundamental change in approach because the canopy trees:

1. influence the growth and development of the young trees;
2. influence the species composition and growth of the ground flora;
3. have live root systems that are present near where trees will be planted;
4. will influence operational working.

The next section 4 'Design and planning' considers how you can take account of many of the differences between underplanting and restocking. Before you consider these factors it is important to appreciate the ecological context of any underplanting operation as this is important for success. A useful model to help understanding has been described by Oliver and Larson (1996) and describes how a stand develops following a disturbance. The model suggests that the development of a regular stand of a single species can be divided into a number of different stages as described in Figure 1. The model describes how a stand develops following the loss of trees on an area and identifies four stages of development. The first stage is 'stand initiation', during which trees and plants from the surrounding area colonise. The second stage is 'stem exclusion' during which trees dominate and there is intense competition and as a result many die. The third stage is 'understorey reinitiation' when small gaps in the canopy appear; conditions on the forest floor become much more variable; trees and shrubs are sexually mature and produce large quantities of seed and advanced regeneration can appear if conditions are suitable. The last stage is 'all-sized' when the structure of the stand becomes diverse and trees have an uneven-aged structure.

Figure 1 Stand development after a disturbance



When this model is applied to underplanting there are two main points.

1. In the stand initiation phase or during the stem exclusion stage the dominant trees will be growing very quickly. If underplanting is carried out during this

period (roughly 10 to 40 years in a conifer stand) any canopy opening will quickly close, so the design of the underplanting will have to be robust to ensure the survival and growth of trees. This can be a particular problem with stand improvement underplanting, which generally occurs earlier than regeneration underplanting, and methods to ensure success are outlined in section 4 ‘Design and planning’.

2. In general, underplanting is best carried out in conditions similar to the ‘understorey reinitiation’ phase because conditions are most likely to ensure the survival and growth of planted trees. This is a good approach for regeneration underplanting because it generally will be carried out near the time when overstorey trees reach a marketable size.

Another situation in which it is helpful to have an understanding of ecological processes is regarding the changes that can occur after young trees have been planted. A common observation is that after planting natural regeneration will appear. In many cases this is because the disturbance and changes while trees are being planted improve conditions for natural regeneration: vegetation is often controlled; the ground flora and soil are disturbed; favourable sites for seed germination and seedling growth are created. Such unplanned regeneration can present opportunities for further species diversification and increased stocking, and should only be controlled if it is not a desirable species or the density needs to be adjusted.

Pests and diseases are currently a major issue in British forestry and you will need to consider the implications of this if underplanting is justified. The survival rate amongst understorey trees is affected in various ways. In extreme cases natural mortality may occur due to the lack of light. However, more often low light levels may facilitate the development of fungal diseases (e.g. mildew) because of the moister and calmer microclimate. Because of their sparser foliage underplanted trees may also be more vulnerable to insect damage (e.g. aphids). However, there is no general trend, the risk of pests and diseases is very specific to tree species and site conditions.

The last and possibly most important aspect considered in this section is the impact of mammals on newly underplanted trees. A common observation is that newly planted trees are preferentially browsed compared with any existing natural regeneration on the site. Scientifically this is very difficult to determine; however, the weight of anecdotal evidence suggests it is a real effect. Protection of newly planted trees from mammal damage is essential and methods to achieve this are outlined in the following sections on ‘Design and planning’ and ‘Implementation’.

4. Design and planning

The most helpful thing you can do to start the process of designing a successful underplanting scheme is to develop a long-term vision of the stand that relates management objectives to the future structure of the stand and species composition; examples of how this could be done are shown in Section 9. If these require the application of continuous cover management then you will usually favour regeneration underplanting; however, if they are to include improvement of broadleaved timber quality or diversification of even-aged stands then you will use a stand improvement underplanting. Note that these two methods are not mutually incompatible; for example, stand improvement underplanting can eventually lead to stands being managed using continuous cover.

The design and planning of a successful underplanting involves the following main factors:

1. Species choice
2. Stand environment
3. Protection from mammals
4. Group planting
5. Operational planning
6. Timing of the underplanting
7. Stability of the stand.

4.1 Species choice

These are the main criteria for good species choice.

1. Each species planted must be adapted to the site conditions.
2. The species or species mixture must be compatible with the overstorey for shade tolerance and, for stand improvement underplanting, growth rate.
3. The species or mixture must help achieve management objectives.

Selecting the correct species is key to the success of underplanting and the above criteria are considered in more detail below.

4.1.1 Site adapted tree species

Using tree species which are adapted to site conditions is a fundamental principle of sustainable forest management. Site conditions can be split into **climatic factors**, such as warmth, wetness, exposure and **soil factors**, such as fertility, moisture, texture, stoniness and rooting depth. The species planted must be matched to site conditions both now and, importantly, under predicted climate change. If you are changing the current species or increasing the number of species you must have good evidence that the species you choose can thrive on the site now and in the future. The best way to do this is to visit the site, make observations, dig soil pits, examine the ground vegetation and local topography, and use local experience. The Forestry Commission's Ecological Site Classification Decision Support System (ESC-DSS) (freely available on the internet at https://www.eforestry.gov.uk/forestdss/) is a useful support tool in this process, in particular for the climatic conditions and climate change predictions. ESC offers a suitability estimate for 60 different tree species (mainly those in Table 2). The accuracy of this estimate largely depends on the quality of the input information and there are weaknesses in the quality of information for some species on soils in some areas of the country. We recommend that all ESC suitability assessments are **based on information specific to the site**: do not plan on the basis of the ESC default options.

For underplanting use the ESC-DSS with particular care as most of the expert judgements that form the basis of the system use experience of restocking open ground. Experience has shown that the generally more sheltered environment in which underplanting takes place can lead to better species performance than would be expected from the DSS. If the limiting factor of a species under ESC is a climatic one or soil wetness, then it is possible that the species suitability may be better than forecast, e.g. 'suitable' rather than 'marginal'. This may affect the overall rating of a species because the DSS bases this on the lowest suitability rating of any of the climatic and soil factors considered. An example of how ESC has been used to consider species choice for underplanting in Clocaenog Forest in northeast Wales can be found on Page 17.

Case study – Stourhead (Western) Estate

This stand is predominantly conifer with a broadleaved element that is being transformed to a group selection system. The broadleaved element is valued but is not regenerating due to browsing pressure. Underplanting of small groups of broadleaves in treeshelters situated in canopy gaps is being used as a method to retain the broadleaved element of the stand.

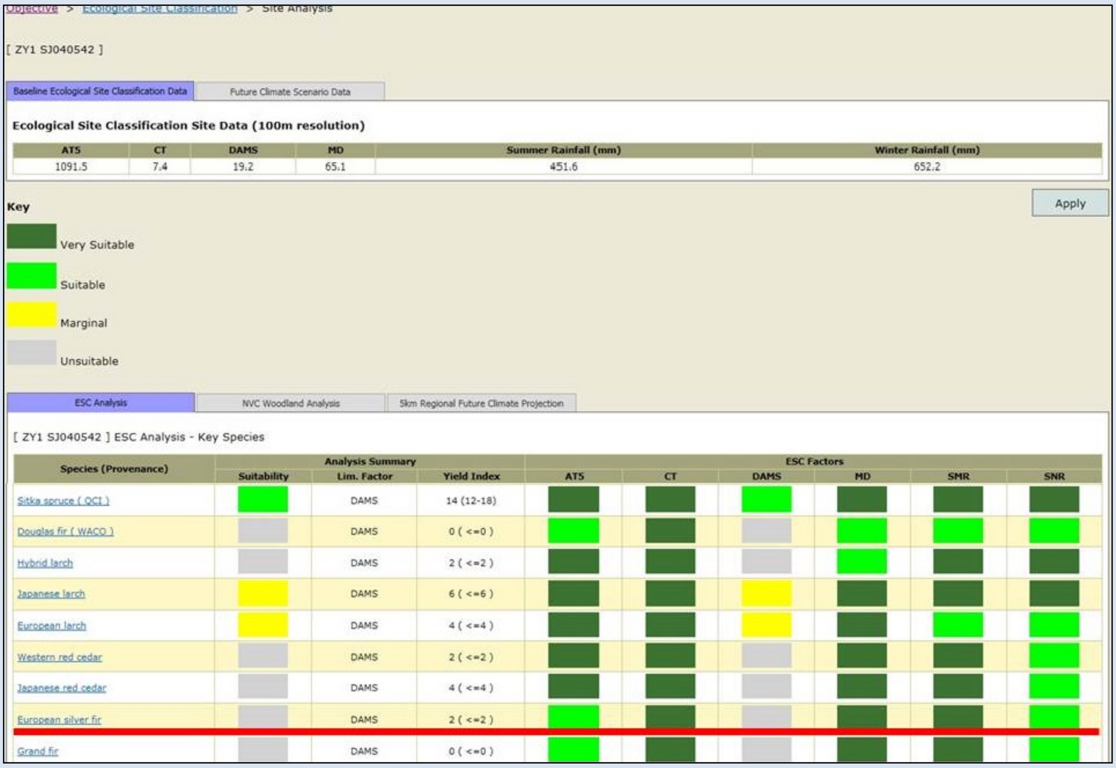
Table 2 Shade tolerance of main and emerging species in Britain

Light demanding	Intermediate	Shade tolerant
Main species		
European larch	Douglas-fir	Grand fir
Japanese larch	Noble fir	Norway spruce
Hybrid larch	Sitka spruce	Western hemlock
Corsican pine		Western red cedar
Scots pine		Yew
Lodgepole pine		
Silver birch	Ash	Beech
Downy birch	Cherry	Field maple
	Sessile oak	Hornbeam
	Pedunculate oak	Sycamore
	Rowan	Small-leaved lime
	Sweet chestnut	Wych elm
	Whitebeam	
Emerging species*		
Cedar of Lebanon	Atlas cedar	Coast redwood
Maritime pine	Leyland cypress	European silver fir
Radiata pine	Macedonian pine	Japanese red cedar
Wellingtonia	Oriental spruce	Lawson's cypress
	Serbian spruce	Caucasian silver fir
	Weymouth pine	Pacific silver fir
Common alder	Big leaf maple	
Grey alder	Norway maple	
Italian alder	Silver maple	
Red alder	Red oak	
Aspen		
London plane		
Common walnut		
Black walnut		

* A group of species that have been identified as possible candidates for more extensive planting but where knowledge and understanding is incomplete; for more information see http://www.forestry.gov.uk/fr/treespecies.

Case study – ESC species choice check for Clocaenog Forest

We used the ESC (version 3) to check the suitability of a site in Clocaenog Forest, Wales for underplanting with European silver fir (ESF) under a canopy of Sitka spruce. The site is an intergrade iron pan soil at about 400 m above sea level with a slight westerly aspect (NGR SJ 040 542). The ESC analysis indicated (see ESC screen display below, ESF underlined in red) that European silver fir was unsuitable, the main constraining factor being windiness (DAMS score of 19.2) despite all other factors being ‘very suitable’ or ‘suitable’. Because underplanting creates a more sheltered environment we made the judgement, based on site observations, that European silver fir would establish well before the Sitka spruce overstorey was removed and this has proved to be correct (see lower picture).



Objective > Ecological Site Classification > Site Analysis

[ZY1 SJ040542]

Baseline Ecological Site Classification Data | Future Climate Scenario Data

Ecological Site Classification Site Data (100m resolution)

AT5	CT	DAMS	MD	Summer Rainfall (mm)	Winter Rainfall (mm)
1091.5	7.4	19.2	65.1	451.6	652.2

Apply

Key

Very Suitable

Suitable

Marginal

Unsuitable

ESC Analysis | NVC Woodland Analysis | 5km Regional Future Climate Projection

[ZY1 SJ040542] ESC Analysis - Key Species

Species (Provenance)	Analysis Summary			ESC Factors					
	Suitability	Lim. Factor	Yield Index	AT5	CT	DAMS	MD	SMR	SNR
Sitka spruce (QCI)		DAMS	14 (12-18)						
Douglas fir (WACO)		DAMS	0 (<=0)						
Hybrid larch		DAMS	2 (<=2)						
Japanese larch		DAMS	6 (<=6)						
European larch		DAMS	4 (<=4)						
Western red cedar		DAMS	2 (<=2)						
Japanese red cedar		DAMS	4 (<=4)						
European silver fir		DAMS	2 (<=2)						
Grand fir		DAMS	0 (<=0)						

4.1.2 Compatibility of overstorey and understorey species

To ensure that the overstorey and understorey species are compatible, you have to consider two main factors: shade tolerance and the stocking density of the overstorey. We consider shade tolerance here and the density of the overstorey in the next section; Table 3 links these two factors together and rates likely success.

Shade tolerance is best viewed as a relative ranking of a species' ability to survive beneath a full canopy of another species. For example, western red cedar can survive under a Scots pine canopy, but if the positions of the two species were swapped, Scots pine would probably not survive for long under western red cedar; hence western red cedar is more shade tolerant than Scots pine. Similarly sycamore can generally survive under an oak canopy, but the reverse is less likely although not impossible. The shade tolerances of tree species used in British forestry are shown in Table 2 but note that shade tolerance is not 'fixed' and can vary with factors such as age and the availability of water and nutrients.

Table 3 Shade tolerance and basal area options for underplanting

		Likely success of option and maximum basal area of canopy trees* ($m^2 ha^{-1}$)		
		Canopy trees		
		Shade tolerant	**Intermediate**	**Light demanding**
Understorey species	**Shade tolerant**	30	30-35	35-40
	Intermediate	20	25	30-35
	Light demanding	10	15	20

Key	
	Well matched and may work at basal areas above those indicated.
	Should only be applied at or below basal area shown. If this is not possible group planting should be considered.
	In most circumstances group planting will be a better option.

* These **indicative figures** are based on Hale (2004); note that two stands of the same basal area, one with 150 big trees and the other with 1000 small trees, will transmit different amounts of light.

Shade tolerant and intermediate tree species are much better suited to underplanting and therefore offer more flexibility with regard to planting pattern and choice of silvicultural system. Underplanting with light demanding species is mainly associated with regeneration underplanting and group planting, i.e. where the next generation of trees is established before the final harvest of the existing crop. In such cases the high light requirement of the understorey needs to be accounted for by heavier interventions in the overstorey, a shorter overlap period (i.e. the time between establishment of the understorey and final removal of the overstorey), and the choice of a suitable silvicultural system, i.e. the strip or group system.

For stand improvement underplanting, you will need to consider the expected growth rate of both over- and understorey trees. Species choice should ensure that the understorey trees do not grow into the main canopy where they might compete with the main crop which is intended to provide the main product at the end of the production cycle. For example, hornbeam may be preferable to beech when underplanting oak because of its reduced height growth potential (see also Section 4.6 on 'Timing').

4.1.3 Management objectives

For regeneration underplanting the young trees will develop into the future overstorey and therefore there must be a direct link between species choice and management objectives for the site. However, for stand improvement underplanting the link is not quite as clear because in most cases the understorey only has a secondary role. For example, if the purpose of the understorey is solely to provide additional produce, then species choice should focus on yield class and possibly timber quality. Where the understorey is designed to suppress epicormics in the main crop and/or control ground vegetation, you will need to pay more attention to the ability of the species to cast shade. Stand improvement underplanting for diversification needs a choice of tree species primarily for their ecological benefits.

4.2 Stand environment

A preliminary guide to the likely success of different underplanting scenarios in terms of the shade tolerances of the overstorey and the young trees being planted is shown in Table 3. In general, species that are shade tolerant are much less constrained than those that are light demanding. If you are using a mixture of species to underplant it is advisable to design the planting to ensure the least shade tolerant species will survive and grow.

In addition to shade tolerance, the shading effect of the canopy trees is an important factor to consider for successful underplanting (for more detail see Hale (2004)). There are many different ways to assess the shading effect of the canopy trees but a convenient way is for you to use basal area. For example, an overstorey of 5 $m^2 ha^{-1}$ will have limited effects on planted trees irrespective of whether they are a shade tolerant or light demanding species. However, this is not the case if the basal area of the overstorey is 30 $m^2 ha^{-1}$. For each of the shade tolerance scenarios in Table 3 a maximum basal area range for the canopy species is also given. The aim is to ensure that you consider both shade tolerance and stand density when designing successful underplanting schemes using a uniform pattern. The basal area guidance is provisional and based on our experience of underplanting in Britain and so you should interpret it with care.

Many even-aged stands in Britain are at basal areas well above the values in Table 3 and a pre-requisite for successful underplanting is to thin the stand to achieve lower basal areas ensuring this does not compromise stand stability; you can find more information on this in *Thinning Practice: A Silvicultural Guide* (Kerr and Haufe, 2011).

Ideally you should identify all emerging problems related to growth of the underplanted trees and competition with the canopy and other vegetation by monitoring and using interventions designed to alleviate the problem (see section 6 'Monitoring and review').

4.3 Protection from mammals

Protecting trees from mammal damage is an **essential part of any underplanting** and you should achieve this by exclusion (fencing or individual tree protection), control of the population or a combination of both approaches. More detailed guidance on this can be found in Chapter 7 of *Managing Native Broadleaved Woodland* (Harmer *et al*., 2010) and is readily transferable to underplanting.

Case Study – Fencing of DNB affected stands in Sherwood

On these sites (see Page 9) deer protection is by use of black Netlon attached to overstorey trees with cable ties. Experience has shown this to be quick and cheap to erect, is easily repaired and can be dismantled and re-used readily. Despite the fact that deer can, if they wish, destroy it, results show that through careful planning of scale and location it provides sufficient deterrent effect.

Photo by Andy Powers

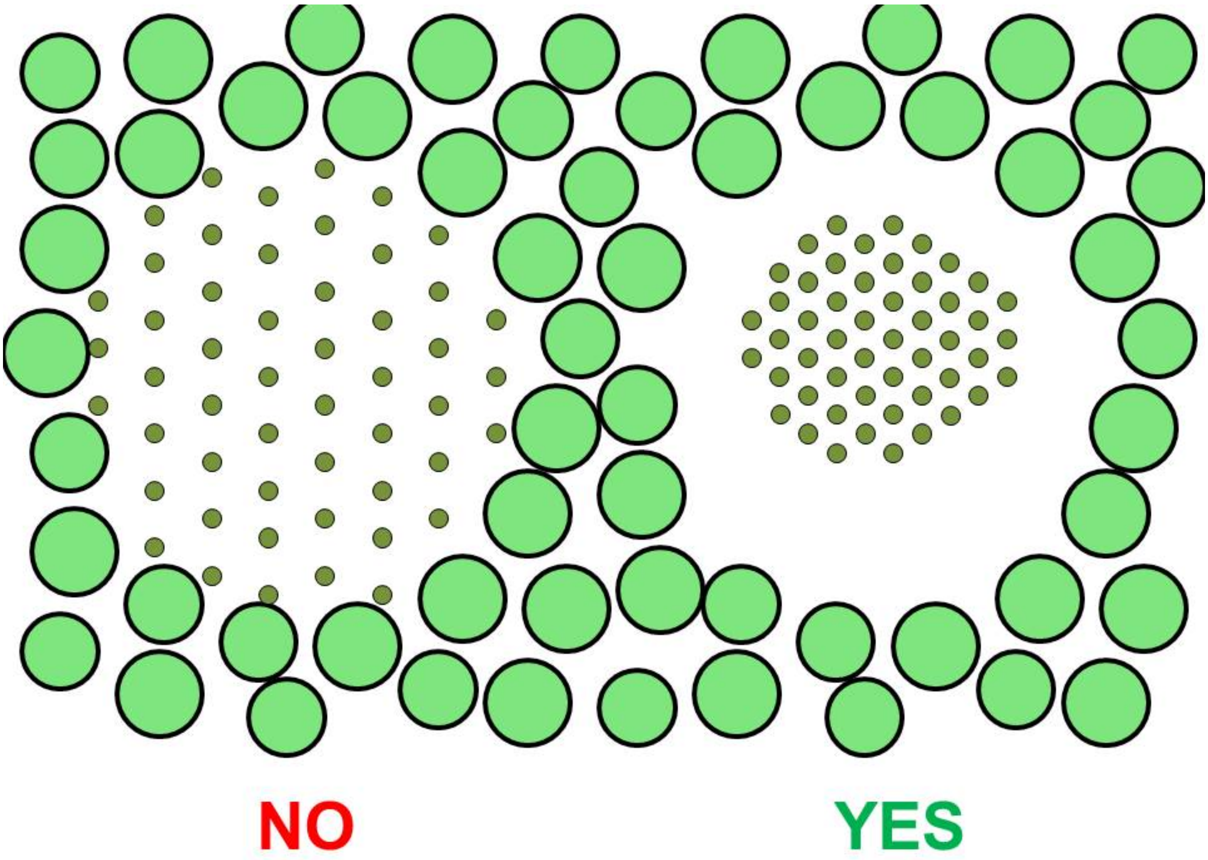
4.4 Group planting

Group planting is a common method of regenerating forests and minimizes the problems described above about ensuring compatibility between overstorey trees and those being planted. Group planting is not strictly ‘underplanting’ but since many of the ecological and operational factors are the same it is covered here for completeness. Group planting:

- is mainly used for regeneration underplanting;
- is well suited for planting light demanding species;
- can be used to create a simple stand structure if the regeneration period is short;
- can be used to create a complex stand structure with longer regeneration periods; but
- can compromise the stability of a stand and must be used with care in exposed locations.

When planting in a canopy gap, whether it is naturally occurring or formed by thinning, the characteristics of the area will be different to the rest of the stand but should provide improved conditions for plant growth, that is trees, shrubs and weeds. Conditions will vary within the gap depending on factors such as distance to the remaining trees, position within the gap (e.g. north or south side) and aspect (e.g. east or west-facing slope). Consequently young trees planted in the centre of a large gap on flat ground will experience very different conditions to those close to mature trees on the southern side of a small gap situated on a north-facing slope.

Figure 2 Diagrammatic representation of where to plant trees in a group



Creating a gap of suitable size is an important consideration and will depend on many factors including the site, the shade tolerance of the planted trees and the height of the surrounding trees. General experience of using group planting indicates that gaps are often too small and the surrounding trees close canopy quickly and have a negative effect on planted trees. The only way to recover this situation is to enlarge the group and hence good operational planning is required. However, you should try to avoid this problem by specifying a robust size from the start. The following steps have been designed to help you do this.

1. Estimate the height of trees in the stand and round up to the nearest 5 m.
2. Determine the species with the least shade tolerance in the mixture being planted; is it shade tolerant/intermediate/light demanding?
3. Select a minimum size for the groups based on (1) and (2) from Table 4.
4. Consider if all groups should be the same size or should they vary?
5. When planning the groups remember that sizes must be measured from crown edge to crown edge.

Table 4 Minimum group areas for underplanting trees of differing shade tolerances

Height of surrounding trees (m)	Minimum area for groups (ha)	Minimum 'crown edge to crown edge' diameter (m)
Shade tolerant species to be planted		
15	0.02	15
20	0.03	20
25	0.05	25
30	0.07	30
Intermediate species to be planted		
15	0.07	30
20	0.13	40
25	0.20	50
30	0.28	60
Light demanding species to be planted		
15	0.16	45
20	0.28	60
25	0.44	75
30	0.64	90

A method for successful underplanting of trees in a group is to plant only 50% of the area with the number of trees that would be planted on the whole area at 2500 trees per hectare (Figure 2). For example, if a circular group of 0.30 ha is used the diameter (canopy edge to canopy edge) would be approximately 62 m (3019 m^2) but a patch of only 44 m (1520 m^2) diameter in the centre would be planted. The number of trees planted would be 750 (0.3 x 2500).

The practice of planting in the centre of groups at relatively close spacing has a number of advantages:

- it prevents planting too close to the edge of the group;
- the planted group will require less maintenance as it will close canopy quickly;
- it provides an opportunity for natural regeneration to develop;
- it can facilitate operational access to the group for further enlargement; and
- it can reduce costs.

The position of the planted group within the canopy gaps should be where growth conditions will be best. For the range of latitudes in Britain this will generally be between the centre of the group and the northern edge. However, local factors such as aspect, soil variation and the pattern of existing vegetation may alter this.

If you plant a mixture of species, take advantage of the fact that growing conditions differ within the gap; for example, consider the location of species with different growth rates and shade tolerances – plant those that are fast-growing and not shade tolerant in the centre of gaps.

Case study – Group planting at Kyloe forest and Yair forest

A group has been created in a stand of mature mixed conifers and planted with Scots pine at Kyloe. The trees are planted at conventional spacing and are distributed evenly up to and including under the canopy trees at the edge of the group, which is not an optimal design.

A successful group planting of Sitka spruce in a mature Sitka spruce stand at Yair Forest. However, in some of the newly formed groups, trees had been planted very close to the existing stand.

Case study – Group planting at Stowell Park Estate, Gloucestershire

A robust group planting in a stand of mature mixed broadleaves. Trees are planted in treeshelters to protect from browsing; they are planted at relatively close spacing and well away from the canopy edge.

4.5 Operational planning

When designing any type of underplanting a fundamental factor that you must consider is the future requirement for operational working, i.e. access for harvesters and/or forwarders. Experience in Britain has generally shown that the operational requirements for underplanting can be achieved with small alterations to the usual practices when thinning equivalent stands. These are the main things to consider:

- Split the entire area into 'planting zones' and 'felling zones' as illustrated in Figure 3. Felling zones include the extraction racks plus a buffer of 2 to 3 m on each side; this is the area where machines can operate, where the crowns of felled trees should land and where most of the harvesting residue is left. Planting zones should be kept as free as possible from harvesting impacts.
- Do not plant trees in areas that will form part of the extraction rack network used to move wood from out of the stand to the road. Access racks are often designated as permanent features, which gives good scope for underplanting to be planned around the rack layout. However, this requires racks to be used carefully and not damaged during extraction. Rack reinstatement costs can be high if soil disturbance occurs.
- When planning the rack network ensure that sufficient space is made for operational working and for operators to maintain a clear view during operations for safety. One tip from our work at Clocaenog has been to incorporate stacking areas into the design and leave these clear of planted trees.
- On wet or sensitive sites take particular care in the choice of appropriate harvesting technology to ensure that ground disturbance is minimized. The number of extraction racks should be kept to a minimum on such sites; this will make more brash available for the racks and therefore reduce soil compaction.
- Even with an appropriate machine the thinning operations may not create enough brash for robust extraction racks. There are a number of options to alleviate this: use of 'corduroy racks' (small roundwood placed in wetter areas to prevent machines getting bogged down (see Ireland *et al*., 2006); movement of brash from neighbouring areas (e.g. prolific regeneration from the roadside); use of stoning to facilitate linking of extraction racks to the permanent extraction system/roads.
- As the stand develops some extraction racks may have to be decommissioned, effectively reducing the number of live racks over time as illustrated in Figure 4. For example, a common practice in Germany is to start with a rack spacing of 20 m in first and second thinning, and later extending the rack distance to 40 m, on sensitive soils even to 60 m. This requires more diverse harvesting methods and technology including the use of manual tree felling and skidders or winches. It also ensures that even in later thinnings enough brash material is available to create robust extraction racks (see above).

Figure 3 Defining planting and felling zones for successful underplanting

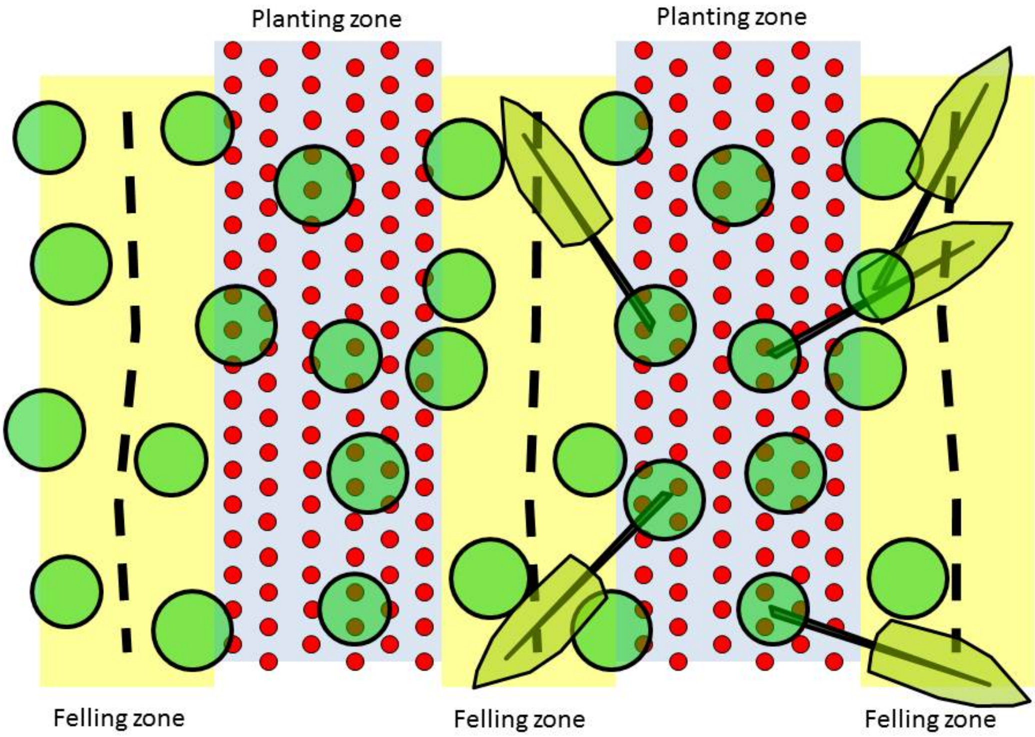
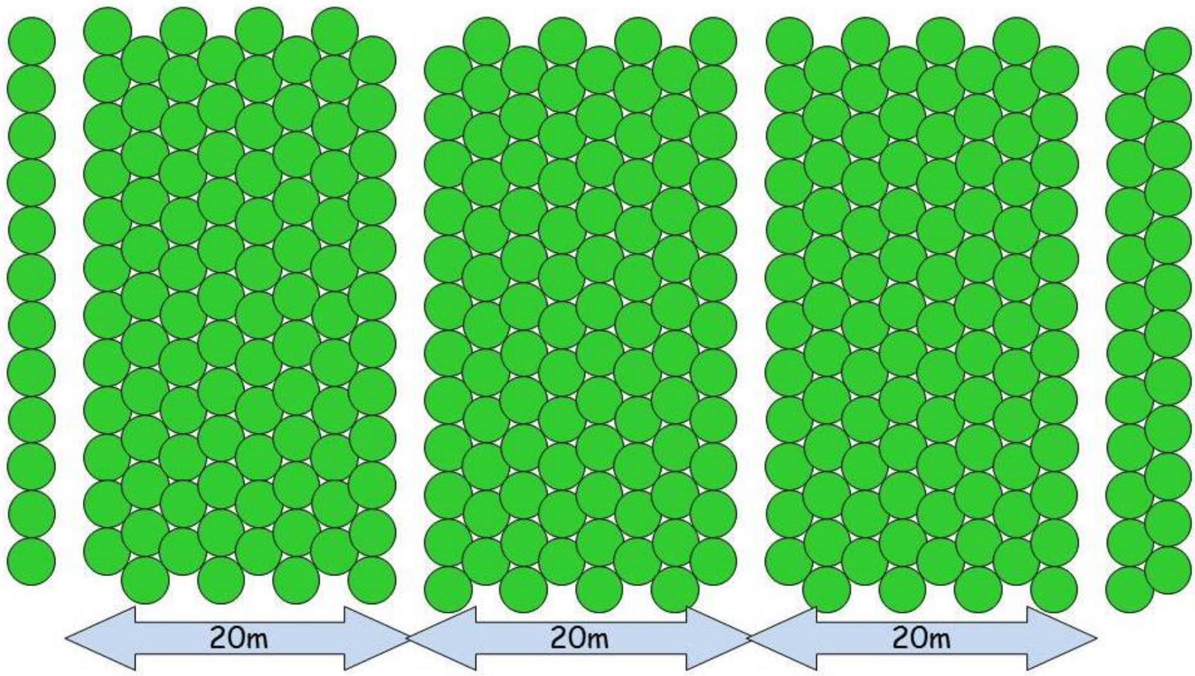
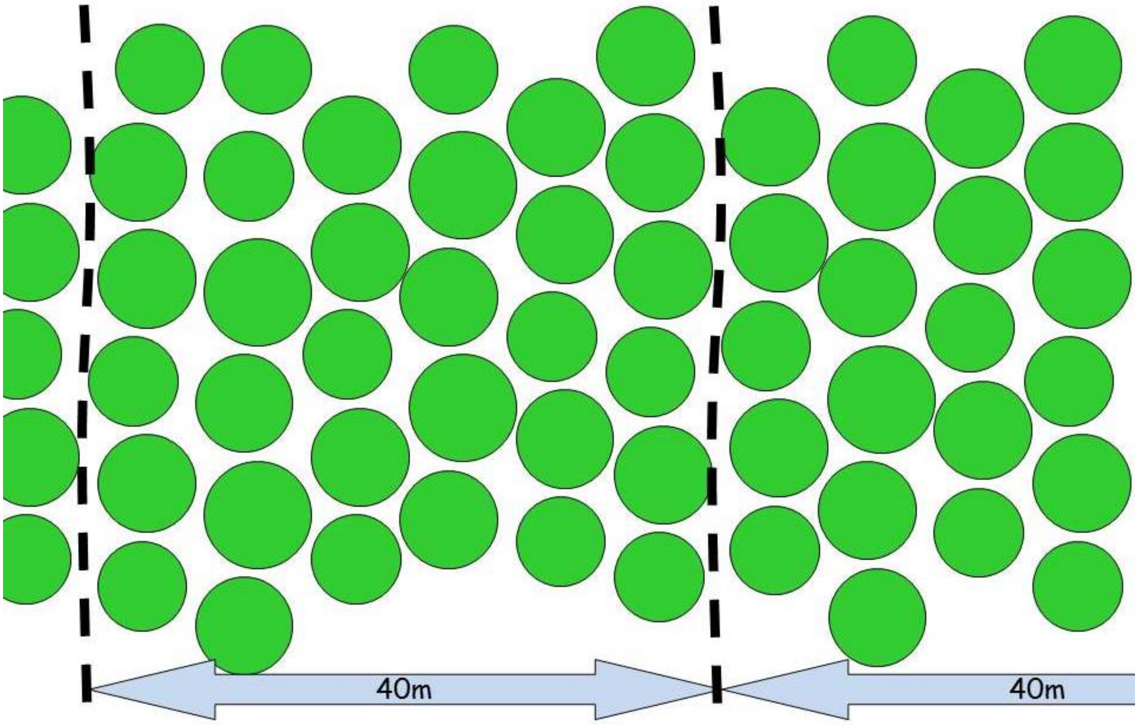


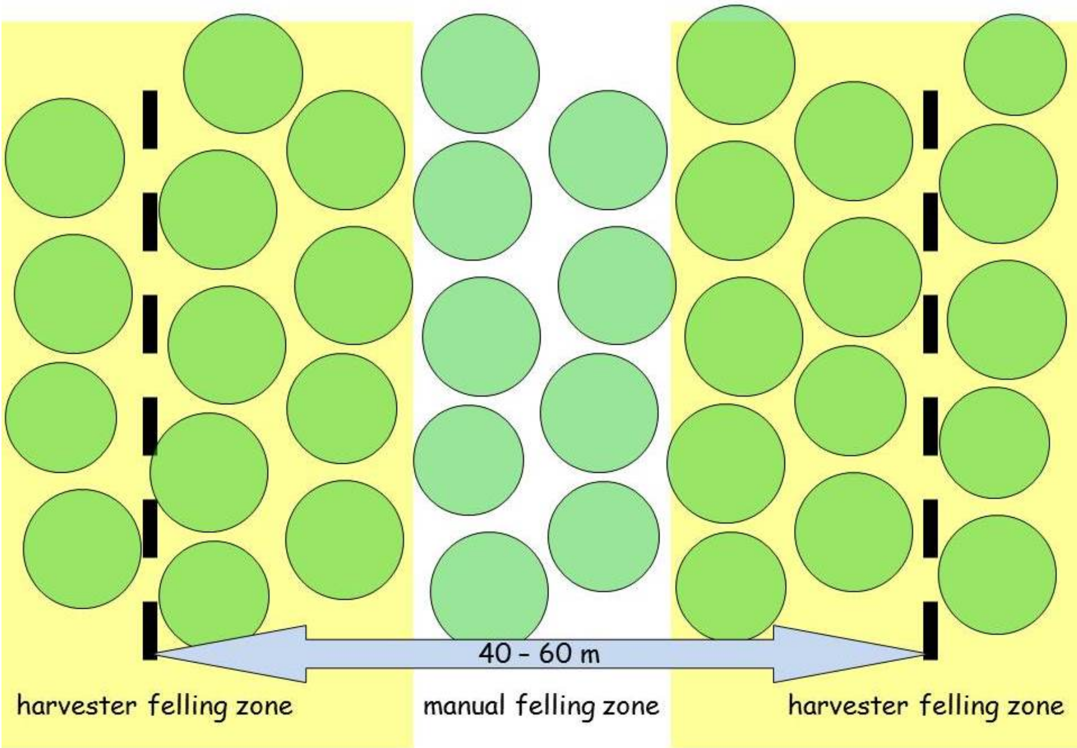
Figure 4 Extraction racks at spacing of 20 m ensure efficient operations in first and second thinning



As some extraction racks are decommissioned in later interventions more brash becomes available per rack, thus soil damage is reduced



On sensitive sites and where underplanting is used, rack distance may be further increased towards the end of rotation. This will require more complex operations including manual felling and the use of skidding and winching techniques



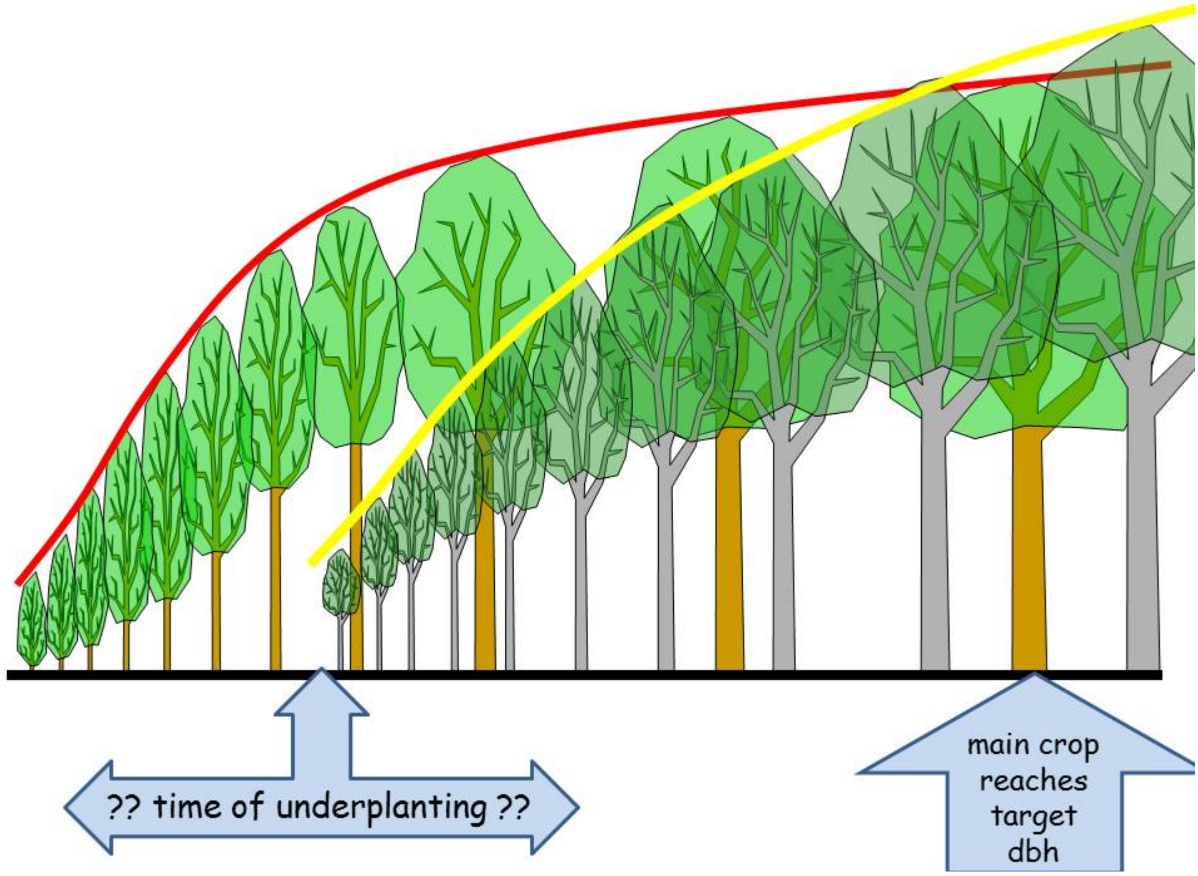
Case Study – Underplanting in Clocaenog Forest

The picture shows an underplanting experiment in the CCF Research Area in Clocaenog Forest in northeast Wales. Five species have been planted in replicated plots under a Sitka spruce canopy where the basal area has ranged between 25 and 30 m^2 ha^{-1} since the experiment was planted in 2007. During this time the stand has been thinned three times and little damage has been recorded on any of the planted trees. This has been due to good site organisation (marked racks; operational zones for working and stacking; stoning to join racks to road network), excellent machine operation and clear on-site management by the forester, Dave Williams. Despite being an experiment the area was not treated very differently to other surrounding areas receiving the same treatment.

4.6 Timing

The question of when to establish an understorey is different for regeneration and stand improvement underplanting. In regeneration underplanting the young trees will grow and develop and eventually become the overstorey. The timing of the planting is therefore quite flexible; for example, in Figure 5 the timing is towards the end of the 'rotation' of the overstorey trees and the overlap period is quite short. However, in stands affected by DNB (Page 9) the underplanting is much earlier and the length of the overlap period, whilst expected to be quite short, is mainly governed by the development of the fungus.

Figure 5 Effects of height growth rates and target dbh on the timing of stand improvement underplanting



For stand improvement underplanting timing is more important and needs to take account of the expected growth rate of the understorey (Figure 5). You must establish the understorey early enough to maximise the beneficial effects it is supposed to provide (e.g. suppression of epicormics and ground vegetation, additional produce etc.), but not so early that it might grow into the canopy of the overstorey and compete with the main crop trees. Determining the right time for underplanting needs to take account of a number of factors and we suggest the following steps to help you achieve the right balance:

1. Estimate the rotation length of the main crop (A) based on yield class, thinning history and target diameter.
2. Estimate the expected final top height of the overstorey (B).

3. Estimate the expected crown depth of the overstorey when target diameter is achieved (C) (for conifers this may result from tree stability indicators, for broadleaves from the length of clean bole specified in the management objectives).
4. Estimate a realistic yield class for the understorey based on site observations and/or ESC analysis. To take account of the overstorey we suggest reducing any estimate by one yield class, i.e. use GYC 10 instead of 12.
5. Calculate a permissible final top height for the understorey (D = B – [C/2]; final top height minus half the crown depth).
6. Estimate the rotation length of the understorey (E) from final top height (D) and expected yield class of the understorey trees.
7. Calculate the time for underplanting (F) as the difference between the rotation length of over- and understorey (i.e. F=A-E).

Here is a worked example for a stand of oak (GYC 8) that is to be underplanted with beech (see Section 9 – Example 2).

1. The management objective is to produce quality logs, and target dbh for the final crop trees is 65 cm. This requires a rotation of 130 years: A = 130.
2. At an age of 130 years the expected top height is 32 m: B = 32.
3. The management objective states that a clean bole of at least 12m is to be achieved. This means the expected crown depth of the final crop oaks could be up to 21 m: C = B – clean bole, C= 32m – 12m, C = 20 m.
4. Beech is expected to achieve a GYC of 6 to 8.
5. In order not to pose any undue competition, the beech is only supposed to grow half way into the oak canopy: D = B – C/2, D = 32 – 20/2, D = 32 – 10, D = 22, thus the top height for beech at the end of the rotation is 22 m.
6. At GYC 6 the top height of beech is achieved at an age of 75 years; E = 75.
7. According to: F = A – E, F = 130 – 75, F = 55; this means the time for underplanting is therefore when the oak is 55 years old. However, note that this is sensitive to the GYC of the understorey; for example, if GYC8, then F = 70 years.

As this example shows the process implies several assumptions and uncertainties and therefore the result should be treated as indicative. Many different types of stand improvement underplanting have been used in British forestry in the past, particularly in oak stands, and so it might be possible to obtain reliable guidance from field observations. The timing of underplanting should also take into account the intended thinning regime for the understorey. For example, in the scenario above it is very likely that the beech understorey would be treated under a rigorous crown thinning regime (i.e. repeated removal of the most dominant trees), which would delay its height growth considerably. The option to modify the thinning type can be used to a certain degree to compensate for the uncertainties in yield class.

4.6 Maintain stability

A key consideration in any underplanting is that you take account of the risks of wind damage when thinning the canopy or creating gaps. The subject of thinning and stability is fully covered in *Thinning Practice: A Silvicultural Guide* (Kerr and Haufe, 2011), which you should refer to in addition to the guidance here.

When underplanting the emphasis should be on maintaining individual tree stability and this can be assessed using height:diameter ratios and relative crown length. Trees from thinned stands which can be considered to be stable will have values in the range shown in Table 5. However, group planting is quite different because the creation of larger canopy gaps can lead to a much greater risk of wind damage. For this reason only use group planting on sites with low exposure (DAMS score <13) and then enlarged towards the prevailing wind direction. If the stability of a stand is a concern then consider using the strip system.

Table 5 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.

** Length of crown divided by height of tree.

5. Implementation

Once you have designed the underplanting and you have prepared the stand to create a conducive environment, the next stage is to implement the plan and plant the trees. The main difference here is that compared to restocking the developing roots of the underplanted trees will have to compete against the roots of the overstorey trees for water and nutrients. Where there are different tree species in the overstorey and understorey, they can have different rooting patterns and competition may be less intense. In addition, the deeper root systems of the overstorey provide additional benefits. For example, they can actively remove water from the soil, mainly by evapotranspiration, and thus can reduce any waterlogging, making drainage and ground cultivation operations redundant, in contrast to many restocking sites. On dry soils the overstorey will maintain a more humid micro-climate compared with a restock site. Overall the positive effects are likely to outweigh the disadvantages caused by competition.

5.1 Spacing and planting pattern

When underplanting there may be a temptation to use the spacing and arrangement of trees commonly used when restocking after clearfelling, e.g. about 2500 trees per hectare on a regular grid pattern. However, the required planting density in underplanting scenarios may be different depending on the purpose or type of underplanting. Regeneration underplanting aims to establish the next generation crop, and planting density will mainly depend on tree species and management objectives, such as timber quality. In stand improvement underplanting the understorey will have to fulfil very different functions, such as controlling ground vegetation and adding diversity, which may require a greater or lower density than for timber production. In both scenarios the net area available is reduced because of the canopy trees and their root systems, and it is worth considering both the density of trees and their arrangement when designing the underplanting.

In general for stands where timber production is an important objective, we suggest the following.

1. It is better to plant at higher densities compared with restocking. Future felling operations in the overstorey are likely to cause some losses, and closer spacing of the transplants (>2500 trees ha^{-1}) will facilitate rapid establishment. Recent experience from some forest managers has shown that the use of close spacing (5000-10000 trees ha^{-1}) in areas to be underplanted can be very successful and the increased cost of planting more trees has been balanced by the reduced need for weed control and maintenance.
2. Consider future harvesting operations in the overstorey, and adjust the planting design accordingly by leaving some areas unplanted (Figure 3).
3. Planting positions should be governed by the position of overstorey trees and their roots rather than using a strict planting pattern. This may lead to the use of a large number of small clumps rather than planting every tree at approximately even spacing. In any case a rectangular spacing is preferable over a square pattern because it facilitates future operations.

Case study – Using close spacing in underplanting

Underplanting in groups of closely spaced trees has been successfully used in a range of forests in the western Lake District by Gareth Browning. This picture shows a group of Douglas-fir that were planted at 1 m x 1 m in Parkgate Forest as a regeneration underplanting in a mature stand of Japanese larch.

In stands where the understorey will have a stand improvement function only we suggest the following.

1. Lower densities compared to restocking may suffice for the intended purpose. However, you will need to anticipate losses through further harvesting operations.
2. The planting design should facilitate future operations and serve the intended purpose of the underplanting. For example, if the understorey is supposed to suppress epicormics and prevent sun scorch on the stems of valuable timber, the underplanted trees may be primarily positioned around the final crop trees.

Once the site has been planted, natural regeneration may develop, but the chance of this **should not** influence the decision on how many trees to plant.

5.2 Establishment operations

Consider the following points.

- Ground preparation is seldom required for underplanting and in any case the options are limited compared with restock sites. This does not mean that identified problems which could be addressed by ground preparation should be ignored. Because of the live root system of the overstorey trees, ground cultivation can only improve conditions on the surface by removing weeds or raw humus layers, usually by screefing or shallow scarification. This may be best achieved by manual methods that are combined with the planting operation. If you use mechanised techniques, consider the machine size to avoid undue damage to the existing overstorey trees.

- Consider the density of the underplanted trees and anticipate some losses due to harvesting. This has been discussed above and generally the more trees the better. Where timber quality is an important management objective the minimum density of trees in underplanting should be similar to those recommended for restocking for broadleaves and conifers.
- Planting design should take into account future harvesting operations. This is best achieved by dividing the area into 'planting zones' and 'felling zones', the latter usually including extraction racks plus some additional work space (Figure 3).
- The plant material must be well adapted to the site to ensure it will grow vigorously if protected and weeded. For example, you may want to improve the productivity of a stand by planting improved Sitka spruce. In these cases you should know and protect the positions of the initial plantings in case there is subsequent regeneration from unimproved spruce.
- Select the best type of tree for planting. Research and experience has shown that transplants, undercuts and cell-grown stock can all be successful if they meet specified size and quality criteria. When ordering the plants, specify that they must meet the minimum size and quality recommendations in British Standard 3936: Part 4: 2007. Underplanting guidance from Germany recommends using larger transplants in order to aid quick establishment and to compensate for extra competition from overstorey trees. The most important size parameter is the root collar diameter, which is the diameter of the stem where it meets the roots. Trees with a sturdy stem generally have lots of roots which, if the tree is handled well, will regenerate quickly when planted and supply the tree with the required water and nutrients. The physiological condition of the plants is also important and this can be inferred by the appearance of the roots, shoots and buds; evidence of fungal growth or insect pests and scarred bark all indicate poor quality and possible ill-health.
- Both transplants and cell-grown stock can be successfully used if handled carefully and planted properly during the dormant season. The main differences between the two are that bare-rooted stock is usually cheaper but cell-grown stock offers greater flexibility and resistance to damage.
- All trees are best planted while still dormant; usually the safe period is November to March, into frost-free ground. The sheltered environment provided by the overstorey can offer protection from frosts to planted trees.
- The quality of planting is important to ensure high survival rates and facilitate quick establishment. Avoid root deformation and damage as they will negatively affect growth and tree stability. The planting technique and tools should be selected according to the type and size of the transplants, and site characteristics, such as soil texture, stoniness, rooting and weed cover. Single notch planting is acceptable for transplants with small or narrow root systems. For larger and wider roots L-notch or T-notch techniques are preferable, and for large transplants pit planting will deliver the best results (Figure 6).
- A general rule-of-thumb is that planted trees in regeneration underplanting should not be closer than 2-3 m to the stem of overstorey trees, even if the species is shade tolerant.

Figure 6 Planting the tree is critical to the success of underplanting

The following pictures show that a range of techniques are available in addition to simple notch planting with a spade.

A range of tools has been developed for tree planting. The choice should depend on transplant type, root size and shape, and soil conditions.

The blade of the planting tool should exceed root length by 2'' – using shorter blades will result in root deformation. This spade is **unsuitable** for the root size shown.

Spade with long enough blade.

Planting mattocks are an efficient tool for angle-notch planting without previous ground preparation.

Planting mattocks are an efficient tool for manual screefing.

Pit planting is particularly suitable for large bare-rooted transplants.

5.3 Protection and maintenance

5.3.1 Weed control

Ideally weed growth is suppressed by the reduced light level underneath the main canopy and, if used, by higher planting densities. However, you may still need some direct weed control to ensure high survival on underplanting sites, particularly when canopy cover is reduced and/or the site is fertile. Direct weed control is required if the weed growth severely reduces the transplants' growth rate and therefore delays or endangers the full establishment of the understorey. Chemical methods of weed control are currently prevalent but always consider mechanical alternatives (Willoughby *et al*., 2004).

5.3.2 Protection against animals

Planted trees must be adequately protected from browsing, fraying or other mechanical damage caused by mammals. Several options are available; the decision about which one to use will depend on cost implications and local circumstances:

- reduce the population level by culling or trapping: this is usually the preferable option for deer and other mammals that cause damage;
- individual tree protection: only use open mesh or light coloured plastic designs because treeshelters will reduce the amount of light reaching the plants; or
- fence protection: consider the specification and design – fences may have to be removable and re-erectable in order to facilitate felling operations (see Case Study on Page 20).

5.3.3 Protection against pests and diseases

Weevils that breed in stumps and roots, such as the large pine weevil (*Hylobius abietis*) and black pine beetles (*Hylastes*) are unlikely to constitute a major problem in underplanting scenarios. On the other hand, other pests, such as the green spruce aphid (*Elatobium abietinum*) can significantly affect the growth and development of newly planted spruce trees (Figure 7). You will have to address other insect pests according to species-specific guidance.

Compared with restock sites, fungal diseases may be more common in underplanting scenarios due to the moister and more balanced climatic conditions. To ensure healthy growth conditions for the underplanted trees it is important to maintain high enough light levels and good air circulation throughout the site.

5.3.4 Respacing

Natural regeneration occurring on an underplanted site may provide many benefits, such as added diversity, better control of ground vegetation, improved timber quality and others. However, excessive infill by natural regeneration, particularly if it is an unwanted or aggressive species, may require respacing to ensure the survival and continuous growth of the underplanted trees. Regularly monitor your sites to pick up this problem early enough. Interventions will become necessary if regeneration outgrows and suppresses the underplanted trees. In the early stages you can tackle natural regeneration using chemical weed control; once selective removal is required you will have to use manual or motor-manual methods.

6. Monitoring and review

Effective monitoring is an important part of any successful underplanting and it is important to collect useful information and use this to inform any adjustments to management if things are not going to plan, i.e. practise 'adaptive management'. Dave Williams, who has extensive experience of underplanting in Clocaenog forest in northeast Wales, is keen to emphasize this and comments, "what I am keen to stress is that the adaptive management and flexibility are key to the success of underplanting; regular site visits are critical". As Dave has found, walking the site regularly and making observations are a key part of monitoring. If you require data to support your observations we recommend the method described in Forestry Commission Information Note 45 (Kerr *et al*., 2002) as the best way to collect information on the success of underplanting. A good combination for monitoring underplanting is to assess it objectively using FCIN45 one and five years after planting, with more informal methods used in-between. A simple spreadsheet that calculates useful stand data from FCIN45 assessments can be downloaded from http://www.forestry.gov.uk/fr/INFD-9KTJAL.

There are some important differences between trees growing under a canopy and those in the open under restocking conditions. In general, underplanted trees are affected to a much greater extent by competition for light and this can affect the growth and the form of the tree. However, forest managers should not assume that light is the only factor if a problem develops with underplanted trees. Other reasons include: moisture stress on dry sites, nutrient problems on unsuitable sites (i.e. poor species choice), pests and diseases (Figure 7) and, perhaps of greatest importance, browsing by mammals.

Figure 7 Elatobium damage to a young Sitka spruce that has been underplanted

If there is enough light, i.e. because the stand has been well prepared, then there will be only small effects on growth and form compared with restocking. However, when light and other factors start to become a constraint the tree will change its growth to compensate for this. In general when light is the constraining factor the tree will adjust by trying to compensate and alter its growth to capture more light. For conifers this can be observed as changes in the ratio of the leader to the upper lateral branches. When seedlings and saplings are growing well under a canopy this ratio is ≥1, as shown in Figure 8; however, when constrained it will be <1. For broadleaves the same sorts of changes occur but because of their different growth habit there is not an equivalent measurable ratio. However, height growth will be reduced and more lateral growth will occur and this can include changes to the shape of the main stem (Figure 9).

Figure 8 Leader:lateral ratio of young conifer (SS)

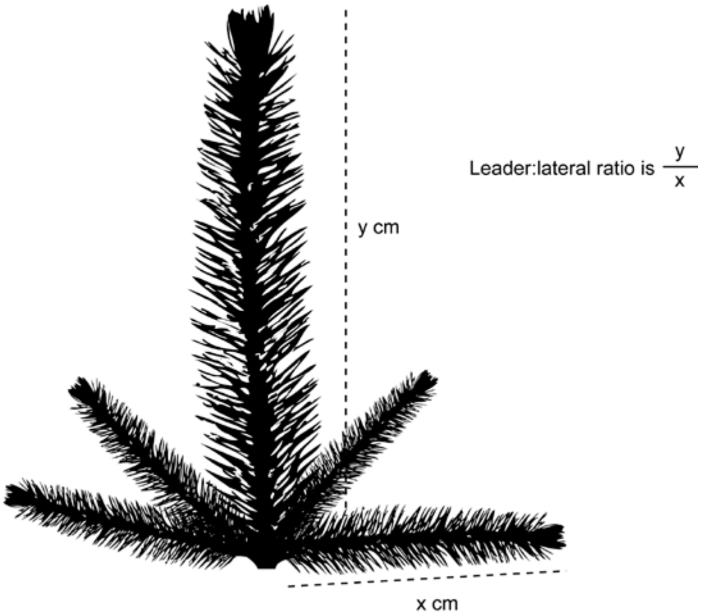


Figure 9 Light constrained beech regeneration at Vernditch Forest

Photo: Mike Abraham

7. Acknowledgements

During the preparation of this guide we have benefitted from discussions and input from a wide range of people and we are very grateful for their help. In particular we would like to thank Bill Mason for reviewing early copies and making some excellent suggestions for improvement. In addition, Mark Malins, Mike Abraham, Gareth Browning, Tim Medlock, Andy Powers and Nigel Connor have allowed us to use their images to support points made in the text. We are also grateful to Jon Bates, Andy Powers, Charlie Taylor, John Tewson, Sophie Hale, Dave Williams and Helen McKay for reviewing the guide to make sure it meets the needs of forest managers. Finally, we are grateful to Oliver Williams who produced the final version of the publication. During the preparation of the Guide John Tewson, Head of Land Management for Forest Enterprise England, pointed out that in future 35-50% of their planting programme is likely to be underplanting; a timely reminder of the changes being made to forestry practice to build resilience in planted forests.

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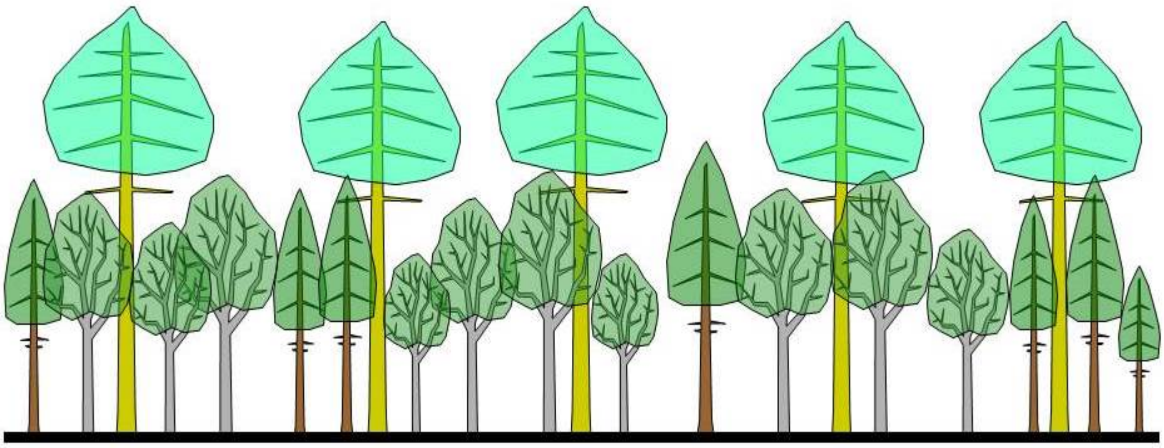
9. Appendix: Setting a long-term vision

As mentioned earlier in the Guide developing a long-term vision of what the stand should look like to achieve management objectives is an important step for successful underplanting. Management objectives and a visualised stand structure should be recorded in the Management plan/Forest Design Plan to leave a legacy for future forest managers. Two examples of how to set this out are shown below.

Example 1 – Long term vision

Figure 10 Two-storied stand with European larch (EL) in the overstorey and beech (BE) and Norway spruce (NS) in middle- and understorey. EL is even-aged and regularly distributed over the area. BE and NS are underplanted after 60 – 80 years; BE in clusters of at least 30 trees, NS individually or in small groups. The middle- and understorey is interspersed with minor species from natural regeneration including birch, rowan, oak and willow. The plan should leave open the option to develop the stand into continuous cover management.



The following links the vision and structure with the management objectives.

Management objectives:

- economic:
  - EL (GYC12) – quality sawlogs target dbh 60 cm+ in 120 years
  - EL (GYC12) – sawlogs target dbh 50 cm+ in 75 years
  - NS (GYC14) – sawlogs target dbh 35 cm+ in 60 years
  - BE (GYC8) – biomass target dbh 25 cm+ in 50 years
- environmental:
  - Minor species provide elements of NVC types W11/W17.
  - Diverse structure ensures stability and resilience with regard to risk factors such as wind, pests and diseases, climate change.
  - Control of ground vegetation by understorey facilitates use of natural regeneration if using continuous cover management.
- social:
  - Mix of species is attractive to forest visitors (e.g. autumn colours).
  - Diverse structure provides additional interest.

Species proportions: (by basal area)

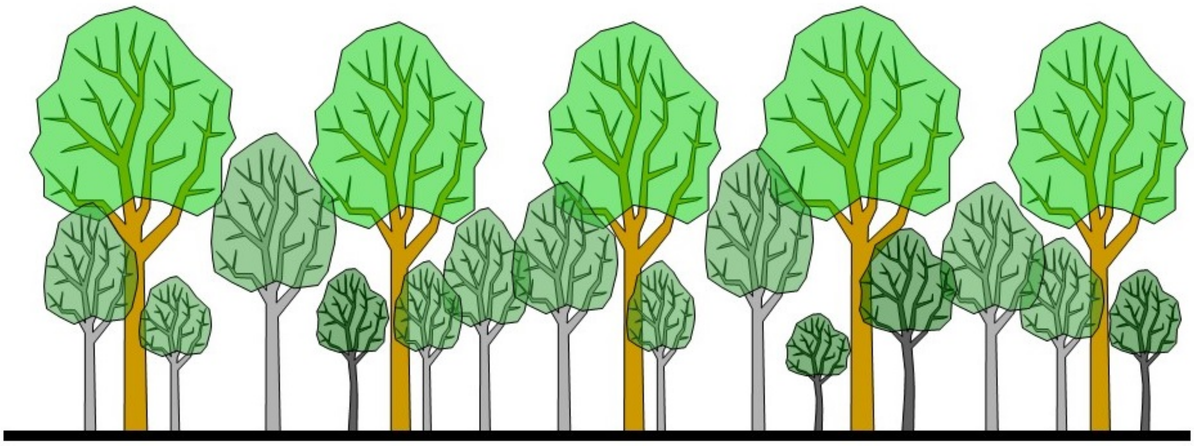
- EL (main species) 50 – 80%
- BE/NS (secondary species) 20 – 40%
- minor species < 20%

Mixture pattern:

- EL – evenly spread across entire area
- BE – small to medium sized groups
- NS – individual trees to small groups
- minor species – individual trees to small groups.

Example 2 – Long term vision

Figure 11 Multi-storied stand with sessile oak (SOK) in the overstorey and beech (BE) and hornbeam (HBM) in middle- and understorey. SOK is even-aged and regularly distributed over the area. BE and NS are underplanted after 70 – 95 years; because of its less aggressive height growth HBM could be introduced earlier, or even established together with SOK. The middle- and understorey is interspersed with minor species from natural regeneration including lime, birch, rowan, sycamore, aspen and willow. The management plan includes the use of natural regeneration to establish the next generation of SOK.



The following links the vision and structure with the management objectives.

Management objectives:

- economic:
  - SOK (GYC8) – quality sawlogs/veneer target dbh 65cm+ in 130 years
  - BE/HBM (GYC6) – sawlogs target dbh 35cm+ in 85 years
  - BE/HBM (GYC6) – biomass target dbh 25cm+ in 65 years
- environmental:
  - Suitable for NVC types W8/W10, or W12/W14 at a succession stage where oak is still dominant.
  - Diverse structure ensures stability and resilience with regard to risk factors such as wind, pests and diseases, climate change.
  - Long rotation provides opportunities for development of large trees, deadwood and species diversity.
  - Control of ground vegetation and development of suitable seedbed conditions by understorey facilitate the use of natural regeneration of oak.
- social:
  - Mix of species is attractive to forest visitors (e.g. autumn colours).
  - Diverse structure and large trees provide additional interest.

Species proportions: (by basal area)

- SOK (main species) 70 – 80%

- BE/HBM (secondary species) 10 – 20%
- minor species < 10%

Mixture type:

- SOK – evenly spread across entire area
- BE – single trees to medium sized groups in understorey, individual trees in middle storey
- HBM – individual trees to small groups in under and middle storey
- minor species – individual trees.