Forest Research

Forest Development Types: Diversification of existing forests

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About this guide

This guide aims to provide general principles of how to transform even-aged stands dominated by a single species into more diverse Forest Development Types (FDTs). It is intended as a technical document, supplementing the FDT Flashcards [1] and Guide [2].

1 The rationale for diversification

It is widely accepted that the consequences of climate change present an unprecedented challenge to British forestry. Whilst rising temperatures and changing precipitation patterns will affect the climatic suitability of many tree species, the anticipated rise in severity and frequency of forest pest and disease outbreaks is likely to render the reliance on large scale even-aged monocultures unsustainable. Diversification is therefore an essential step to improve the resistance and resilience of our forests to withstand these challenges.

Forest diversification can occur at different scales. An even-aged, single species sub-compartment may lack diversity, yet a forest block composed of a multitude of sub-compartments of different species and age classes can show considerable diversity (Figures 1 and 2). In many cases diversification may be achieved by more than one pathway, and some of the area may retain its initial structure of even-aged, single species stands.

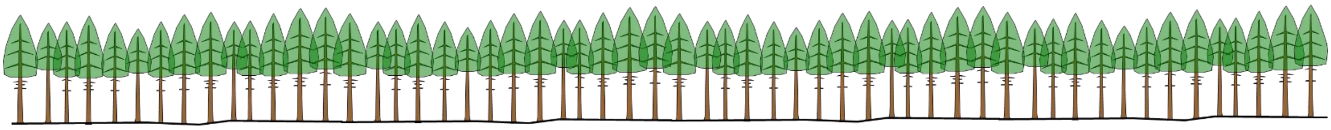


Figure 1: Unstructured, even-aged forest block composed of a single tree species

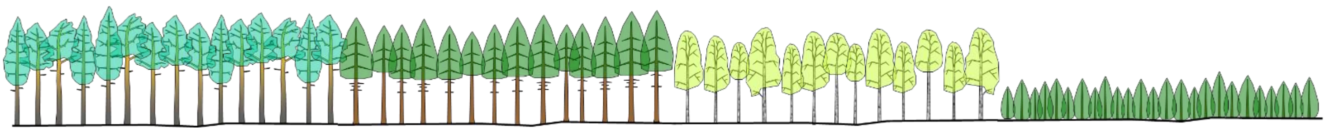


Figure 2: Diversification at landscape level can be achieved by breaking forest blocks into stands of different species and age classes, whilst retaining a single species and age in each stand.

Diversification at landscape level will not be considered in any detail here. Instead, this guide focusses on diversification at stand level as illustrated in Figure 3. The principles and methods outlined in this guide can of course be applied at any scale but FDTs as the main silvicultural tool have been primarily designed for use at forest stand level.

The diversity of a forest stand has two main components: species diversity and structural diversity. Whilst the former applies to the species composition of a stand, the latter describes the age structure of the stand. Thus, diversification may imply a change in tree species or age structure, or both (Figure 3).

Operational and management aspects need to be taken into account, as different approaches are not equally easy to achieve in terms of expertise, labour skills, cost and use of technology. As a general rule, the more complex the target forest structure is in terms of tree species composition and age structure, the more effort will be required to achieve it and probably over a longer period of time. The FDT concept has been designed to facilitate the planning and decision-making process of stand level diversification. A Forest Development Type is a long-term vision of how the species composition and structure of a forest stand is intended to develop. Current guidance on FDTs [1, 2] describe the concept of FDTs and a suite of mixture options suitable for use in Britain.

This guide describes how to make the change from even-aged, single species stands to a target FDT that has greater diversity in terms of species and stand structure. The following terms are used consistently throughout the guide:

- **Pathway**: Term used to describe generic categories of diversification (Section 2)
- **Approach**: Used to distinguish between the main ways of harvesting and restocking, *i.e.* clearfell-and-restock, Lower Intensity Management Approaches (LIMA), and Continuous Cover Forestry (CCF)
- **Method**: Term used to describe the approach in detail, *e.g.* shelterwood method
- **Scenario**: Application of an approach to a certain combination of tree species

2 Pathways for stand diversification

There are three main pathways to achieve diversification of an even-aged, single species stand (Figure 3). Pathway A makes the change to an even-aged stand with more than one species. Pathway B involves maintaining a (predominantly) single species stand but changing it to a simple (2 canopy strata) or complex (3 or more canopy strata) structure. Pathway C seeks to increase species diversity and also achieve a change of structure; the time horizon for doing this will be much longer than for pathways A or B and hence it will usually require an intermediate step of creating a two-aged stand. Examples of the use of pathways are given in section 6.

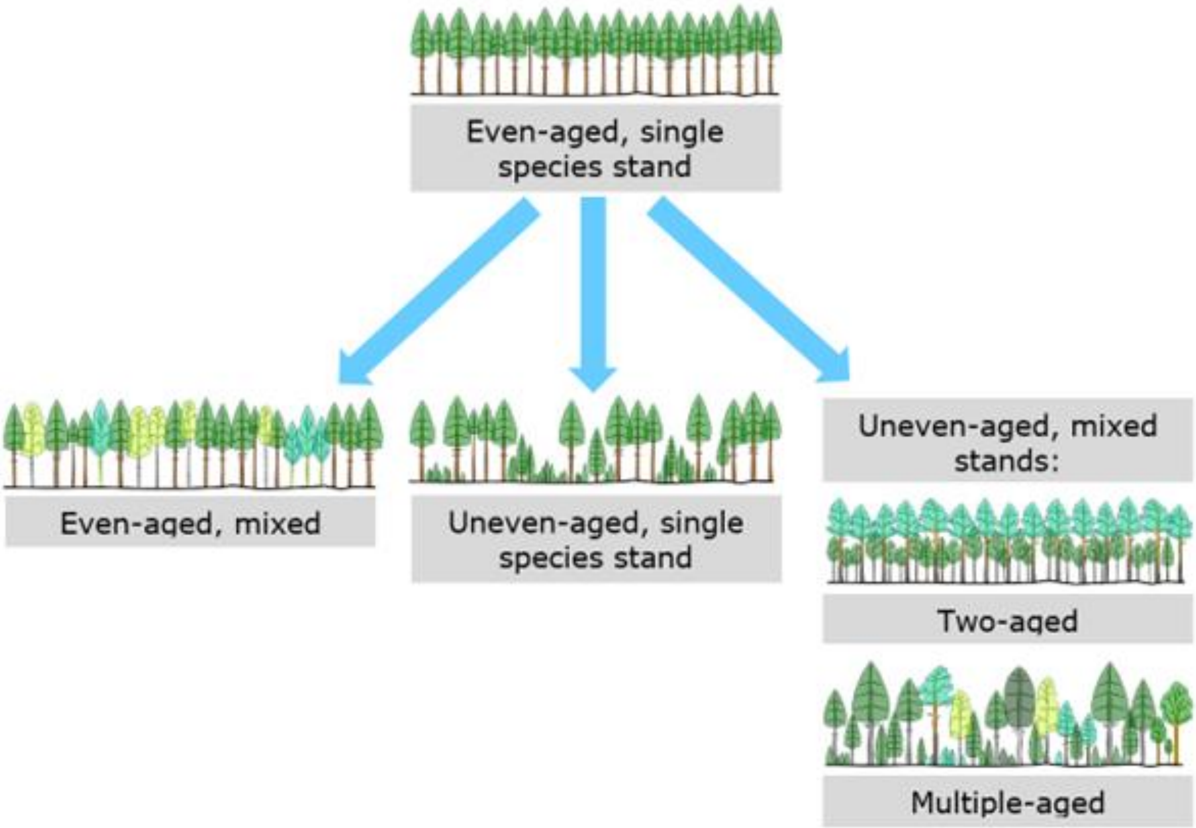
3 Selecting the target FDT and stand structure

When attempting to diversify a forest stand it is important to be clear about the desired future species composition and structure. This requires careful consideration and should be informed by management objectives, the site constraints and how these may change in the future.

The first step is to select a suitable FDT composed of tree species suitable for the site conditions. This means considering the current and projected climatic conditions as well as the inherent soil properties.

Shade tolerance and the compatibility of the species in the FDT determine the likely horizontal and vertical structure of the future stand, and thus also the method of diversifying the stand. For most FDTs several stand structure options are available. The most suitable stand structure should be chosen in a second step, considering the management objectives for the site, and any operational or management constraints.

More guidance on how to select a suitable FDT and stand structure is available in [2].



Pathway A	Pathway B	Pathway C
Increased species diversity and similar structural diversity compared to initial stand	Increased structural diversity and similar species diversity compared to initial stand	Increased species and structural diversity compared to initial stand
Can be straightforward to achieve via clearfelling; other methods can be more challenging	Requires successful implementation of LIMA or CCF	Requires successful implementation of LIMA or CCF
Achievable in 10 years (clearfelling) or 25-30 years (LIMA / CCF)	Achievable in 25-30 years	Achievable in 30-100 years; may require intermediate step of two-storey forest

Figure 3: Diversification pathways at forest stand level

4 Diversification approaches to achieve the selected FDT and stand structure

Diversification approaches and methods describe how the pathway will be achieved. In other words, how the stand structure and / or species composition of an existing forest stand will be changed into a different FDT. The terminology used in relation to silvicultural systems can sometimes be confusing, so to avoid this in the following sections we therefore only distinguish between three main approaches:

1. Clearfell-and-restock,
2. Lower Intensity Management Approaches (LIMA), and
3. Continuous Cover Forestry (CCF).

These approaches mainly differ in how the canopy of the original stand is removed or opened, and are linked to the FDT target stand structure as shown in Figure 4.

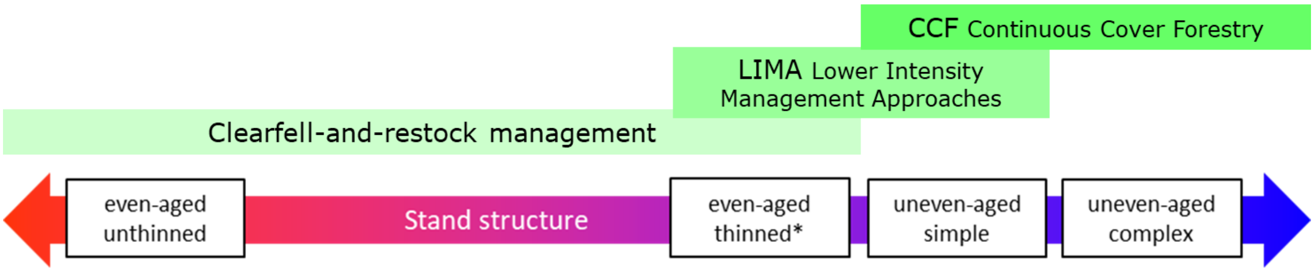


Figure 4: Diversification approaches and likely stand structure of the FDT

Note that both clearfell-and-restock and LIMA always result in stands with a simple structure (*i.e.* with one or two canopy strata), whereas CCF may result in simple or complex structures. More information on how to implement these diversification approaches is given in Appendix 1.

In all three approaches establishment of the successor stand may be by planting (including underplanting), natural regeneration, direct seeding, or a combination of these. Details on establishment techniques can be found in Appendix 2.

5 Diversification scenarios

Diversification aims to introduce an understorey and / or at least one additional species to the stand. The main driver for choosing an appropriate method is species ecology, in particular the shade tolerance of the tree species involved. Growth rate, growth pattern and apical dominance of the species must also be considered when choosing and designing a suitable diversification method. Table 1 combines the general suitability of diversification methods with the light demand of the tree species involved. Details on how to implement the diversification scenarios are given in the numbered footnotes.

Tree species involved		**Diversification approach**			
Existing species (current stand)	*Introduced species (target FDT)*	*Clearfell-and-restock*	*LIMA*	*CCF (simple structure)*	*CCF (complex structure)*
light demanding	light demanding	**1**	**2**	**4**	**7**
light demanding	shade tolerant	**1**	**2**	**5***	**5***
shade tolerant	light demanding	**1**	**3**	**6**	**7**
shade tolerant	shade tolerant	**1**	**2**	**5**	**8**

Table 1: Suitability of diversification methods in different scenarios of shade tolerance

Legend:

(green)	Very suitable diversification scenario which is likely to succeed.
(yellow)	Diversification scenario requires some attention to detail.
(red)	Diversification scenario is unlikely to succeed.
1	This is a straightforward way to introduce a new species, also suitable for very exposed sites. The result will be another even-aged stand. Infill with natural regeneration of desirable species is possible if seed source is present nearby.
2	A fairly straightforward way to introduce a new species, which also achieves age diversification at coarser resolution. The Strip shelterwood method is best suited for more exposed sites, otherwise this option carries a higher risk of wind damage than 1. Due to the shorter distance to seed sources, infill with natural regeneration is more likely than in scenario 1.
3	Similar to option 2 but attention to shade tolerance of the species involved is required when implementing LIMA, particularly to ensure that groups are large enough to encourage good early growth of the light demanding species.
4	This is a fast diversification scenario which requires frequent interventions to keep stand basal area low. The two-storey stand structure which will be produced initially is likely to diversify further over time. Good individual tree stability is essential. Attention to shade tolerance of species involved is required when designing a CCF method to be applied. Infill by natural regeneration is likely.
5	This scenario offers a good opportunity to introduce sensitive species which do not establish well under open ground conditions; often natural regeneration of shade tolerant species may already be present on site. Good individual tree

	stability is essential. The scenario requires less frequent interventions than scenario 4 and the transformation period can be longer, potentially even allowing the introduced shade tolerant species to grow into the main canopy.
*****	These scenarios imply an irreversible change from light demanding to intermediate or shade tolerant species.
6	Due to the light demand of the species involved this scenario is not recommended. The desired stand structure is better achieved using LIMA (scenario 3).
7	This scenario may require considerable adaptation of standard methods to accommodate the light demand of the introduced species. High individual tree stability is essential. Infill with natural regeneration of intermediate and shade tolerant species is likely.
8	This scenario offers a good opportunity to establish and maintain high structural diversity, usually via a simpler CCF structure as an intermediate stage. Transformation period is likely to be long and high individual tree stability is required. Natural regeneration may already be present at the beginning of the transformation stage and is highly likely at later stages.

6 Examples

6.1 Pathway A – achieving an even-aged mixed stand

Situation:	An 80-year-old stand of BE (FDT 6.1.1) planted on ex-agricultural land is to be diversified. From ESC [3] analysis and local management objectives FDT 5.2.1 (SOK and BI) is identified as the desirable target stand. It is expected that the target FDT will be even-aged initially but will become uneven-aged over time due to the different felling ages of SOK and BI.
Diversification approach:	The diversification scenario (Table 1) is that of converting a stand dominated by a single shade tolerant species into a stand of two light demanding to intermediate species. Clearfell-and-restock (scenario 1) is chosen as the most appropriate diversification approach, particularly because the current stand has reached maturity.
Plan of interventions:	The current stand of BE is clearfelled and the site is re-planted with clusters of SOK at high density embedded in a matrix of BI at low density. Infill from natural regeneration of BI and other broadleaved species is expected. Early interventions (respacing) must focus on mixture control and the survival and integrity of the

	SOK clusters. Further management according to guidance on FDT 5.2.1 flashcard [1].
Comments:	Depending on the design and scale of operations (keeping the size of clearfell areas < 2 ha), the approach could also be classified as LIMA instead of Clearfell-and-restocking.

6.2 Pathway B – achieving an uneven-aged single species stand

Situation:	An unthinned 20-year-old stand of SS (FDT 1.1.1) is to be diversified into an uneven-aged stand (FDT 1.1.2) with a complex structure.
Diversification approach:	Diversification scenario 8 (Table 1) applies here – an intermediate to shade tolerant species is to be diversified structurally only, with no change in primary species. CCF therefore appears to be the most appropriate diversification method, and natural regeneration the best way of establishing the next stand.
Plan of interventions:	The stand is thinned immediately (rack + matrix), after that Final Crop trees (FC trees) are identified. The next thinning follows within 3 – 5 years and is carried out as a heavy crown thinning, aiming to release the FC trees from competition. Further thinning according to flashcard guidance for FDT 1.1.2. The thinning stage ends when FC trees reach target dbh <u>and</u> natural regeneration starts to appear. At this point final harvesting / regeneration felling may commence, aiming to open the canopy in an irregular fashion to promote growth and self-differentiation in the next generation of trees and achieve the target complex structure.
Comments:	Although the stand structure will be very different within 25 – 30 years, achieving the structural diversity of a complex structure will require more time.

6.3 Pathway C – achieving an uneven-aged mixed stand

Situation:	Due to the risk of *Dothistroma sp.* Infection, a 30-year-old stand of CP is to be diversified. From ESC analysis and local management objectives FDT 3.1.3 (DF and XCST) with a complex structure is identified as the desirable target stand.

Diversification approach:	The diversification scenario (Table 1) is that of turning a stand dominated by a single light demanding species into a stand of several shade tolerant species (scenario 5*). Because of the age of the current stand and the complexity of the target stand in terms of both tree species and structure diversification can be seen as a 2-step approach. Achieving FDT 2.2.1 (CP and XCST) is identified as the intermediate objective, which is eventually developed into the final target FDT 3.1.3. Both FDTs are best achieved by CCF as the diversification approach.
Plan of interventions:	The current stand of CP is thinned and underplanted with DF and other XCST species. Further management according to guidance given for FDT 2.2.1. Final harvesting of CP when target dbh is reached or XCST start growing into CP crown area. The remaining stand of DF and XCST is managed towards FDT 3.1.3 thereafter.
Comments:	FDTs 2.2 have been deliberately designed as transitional FDTs to facilitate the diversification of CP stands.

7 Factors to consider when choosing diversification method

Which diversification approach and method is the most appropriate in each case depends on a number of factors, and all have certain advantages and disadvantages. The following section aims to provide an overview of the most important factors to consider. The numbering does not necessarily reflect any ranking or priority.

7.1 Suitability of tree species to site conditions

Choosing tree species suitable for site conditions should be a guiding principle for any attempt to diversify forests. Site conditions can be divided into:

- Climatic conditions (temperature, wetness, exposure, continentality);
- Soil conditions (moisture, fertility, texture, depth *etc.*) and
- Silvicultural conditions (*e.g.* light availability, competition *etc.*).

The better the current species is suited to soil conditions, the lower the risk of wind damage and the higher the chance of the species regenerating naturally. Whereas the former is generally beneficial for the choice of diversification method, the latter may actually pose some problems, depending on the intended target species composition (see also Appendix 2 on techniques for tree establishment).

The role of new species being introduced on the site in natural succession cycles should be considered; light demanding pioneer species are more likely to establish well under open ground conditions or in large canopy gaps, whereas shade tolerant climax species may require canopy shelter and protection.

7.2 Compatibility of tree species

Two different aspects of tree species compatibility need to be considered. Firstly, if a new (additional) tree species is to be introduced into a stand dominated by another species, the shade tolerance of both species dictates which diversification methods are suitable. Establishing an intermediate or shade tolerant species into a stand of a light demanding one can often be done under canopy, whereas light demanding species establish better in canopy gaps, along canopy edges and in open ground conditions.

Secondly, scenarios where several species are being established together need to consider the light demand and growth rate of each species in order to design mixtures which are robust enough to survive to first thinning without additional respacing interventions. A "Compatibility Score" [4] facilitates decision making about suitable mixture patterns. The lower the score, the more suitable are species for intimate mixtures; high-scoring species combinations should be mixed in larger groups or small areas. If multiple species are being established under canopy then the shading effect of the overstorey on the performance of all understorey species will also have to be considered.

7.3 Site exposure and wind stability of the current stand

Site exposure defines the risk of the stand suffering catastrophic wind damage. It is expressed by the DAMS scale (see Table 2). The risk is generally greater for evergreen conifers than for deciduous tree species. The level of exposure and the general risk of wind damage can be assessed for specific site / species combinations by use of the decision support tool ForestGALES [5].

DAMS score	Description
DAMS < 12	sheltered
12 ≤ DAMS < 16	moderately exposed
16 ≤ DAMS < 19	highly exposed
19 ≤ DAMS < 22	severely exposed
22 ≤ DAMS	too exposed for commercial forestry

Table 2: DAMS scale categories

The resistance of the forest against wind damage can be divided into stand stability and individual tree stability. Whilst stand stability relies largely on a closed canopy and mutual support between the trees, individual tree stability is dependent on stem taper and height to diameter (h/d) ratio. High individual tree stability is generally achieved by early and regular thinning. Soil characteristics such as rooting depth affect stability in general, but it should be noted that the size of a tree's root system corresponds to the size of its crown and is therefore related to individual tree stability. Individual tree stability is much more important for diversification scenarios than stand stability because most methods require that the forest canopy is opened during the process.

Thus, the higher the site exposure and the lower the individual tree stability, the more limited the choice of diversification methods. For the most vulnerable stands diversification via Clearfell-and-restock is the safest, and sometimes the only option. The Strip shelterwood method offers the best possible alternative on exposed sites, provided it is designed with consideration of the prevailing wind direction (see Appendix 1).

7.4 Stand age

The age of the stand to be transformed is primarily relevant for stability considerations and seed production. Younger stands have a lower mean and top height and are therefore less vulnerable to wind damage, even after relatively heavy interventions in the main canopy. Stand age should therefore be included in stability considerations as outlined in Appendix 1.

The production of sufficient viable seed is the first pre-requisite for natural regeneration. Stands which have reached seed-bearing age are therefore more likely to regenerate naturally. The choice of a suitable diversification method can further facilitate the establishment of natural regeneration.

7.5 Browsing level and other risks during establishment phase

Browsing damage poses a risk to tree growth and survival for as long as the leader shoots of trees are within reach of grazing animals. Diversification methods which boost fast early height growth are therefore likely to shorten the period during which trees are at risk, although the gain may be insignificant and the young stand may still require specific protection measures. Protection against browsing may also be necessary if locally new, palatable tree species are introduced in the diversification process.

For some insect pests such as *Hylobius abietis*, which rely on the availability of fresh tree stumps for breeding, there is a clear connection between diversification method and risk level. Whilst on clearfell sites of pine and spruce considerable damage often occurs, damage in CCF approaches is likely to be negligible or non-existent, provided sufficient canopy cover is retained and the number of fresh stumps is limited.

7.6 Operational and economic constraints

Not all diversification methods are equally easy to implement; some require considerably more operational skill, planning, continuity, and management effort and thus carry higher overhead costs than others.

The Clearfell-and-restock approach is usually perceived as carrying the lowest costs. However, it is also the one which often delivers the least environmental and social benefits, and costs for missing out on these are usually not included in economic calculations. There is no doubt though that clearfelling and subsequent restocking is operationally straightforward and, as it has been conventional practice in the UK for quite some time, presents few challenges to forest managers and operators.

LIMA methods offer much of the operational simplicity of Clearfell-and-restocking, however at a more complex management level as they are applied simultaneously on multiple sites at limited scale (maximum fell area 2 ha). Some methods (*e.g.* Strip shelterwood) combine ecological benefits similar to CCF techniques with the operational simplicity of (small scale) clearfell operations.

CCF methods are characterised by an overlap of harvesting and regeneration phase, *i.e.* the next generation of trees is already establishing or established when final harvesting of the predecessor crop takes place. This may require some additional efforts and skill (*e.g.* careful tree selection, manual and directional felling, planning of stacking areas *etc.*). The low cutting intensity (Shelterwood method) or local nature of felling (Group method) is sometimes perceived as an economic disadvantage to the use of modern mechanised harvesting technology.

Note that the list of factors affecting the choice of diversification methods is not necessarily exhaustive. Of the factors listed, the compatibility of tree species and their suitability to current and future site conditions must take priority over other factors. Decision-making is often complex and may require compromises in some cases, however the strict adherence to the principles outlined in sections 7.1 and 7.2 is essential for the success of the diversification attempt.

Appendix 1: Overview of diversification methods

Clearfell-and-restock

This management approach is based on patch clearfelling and subsequent restocking of areas larger than 2 ha in size. It is characterised by relatively straightforward forest operations but carries several disadvantages due to the temporary loss of canopy cover (loss of forest climate, alteration of ground water table, disturbance of soil ecosystem *etc.*). It may also provide ideal breeding conditions for insect pests such as weevils.

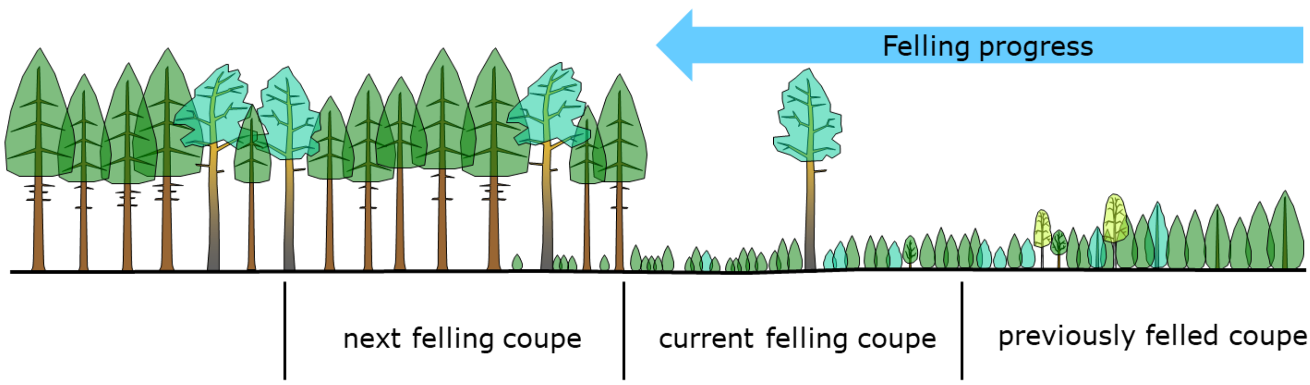
Clearfell-and-restock as a diversification method is most appropriate where the species of the target FDT are easy to establish (light demanding pioneer species) and where the low individual tree stability of the current stand means alternative options carry a high risk of severe wind damage. It may also be the best option when very rapid diversification is required, *e.g.* after wind damage has occurred or in the case of catastrophic pest or disease attack.

Lower Intensity Management Approaches (LIMA)

Lower Intensity Management Approaches cover silvicultural methods which do not necessarily maintain continuous canopy cover but where the canopy is opened at a limited scale, and therefore doesn't carry the same disadvantages as clearfelling. They include patch clearfelling of areas up to 2 ha in size as well as techniques which border on CCF management such as Seed tree method and Strip shelterwood.

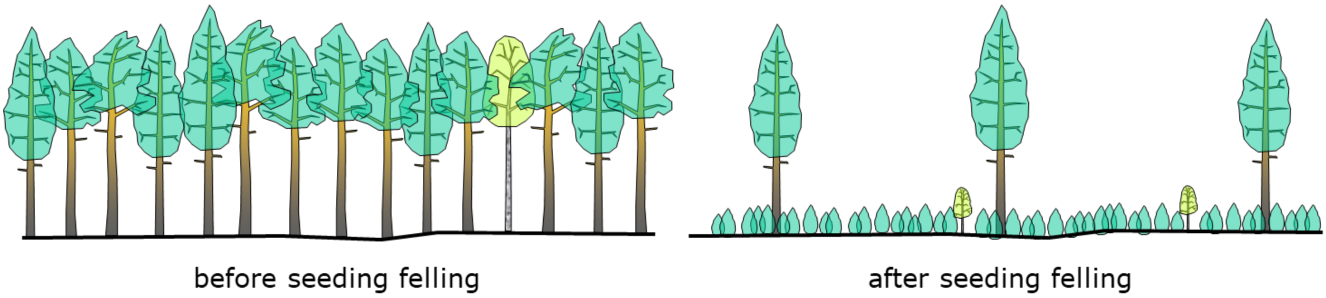
Examples of LIMA:

Strip shelterwood



Strip shelterwood is defined by a succession of adjacent narrow felling coupes (usually up to two tree lengths wide). The woodland climate is maintained by lateral shelter provided by the adjacent old stand. Depending on their length, felling coupes often exceed the permissible size of 0.25 ha for CCF and have therefore been included under LIMA here.

Seed tree method



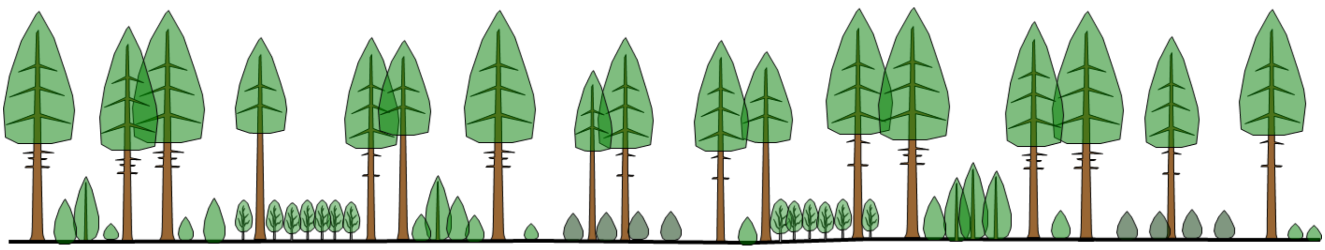
The Seed tree method involves a radical opening of the canopy in one cut, retaining no more than 30 – 50 seed trees per hectare. It is appropriate for light demanding pioneer species such as pines, larches and birches on suitable relatively sheltered sites.

Continuous Cover Forestry (CCF) methods

CCF aims to retain canopy cover, and thereby forest climate conditions, at all times. CCF methods are therefore most suitable for establishing intermediate and shade tolerant tree species, although some methods and modifications also work for light demanding species. The definition of CCF limits the interruption of the forest canopy to a maximum size of 0.25 ha. CCF methods may result in simple or complex stand structures.

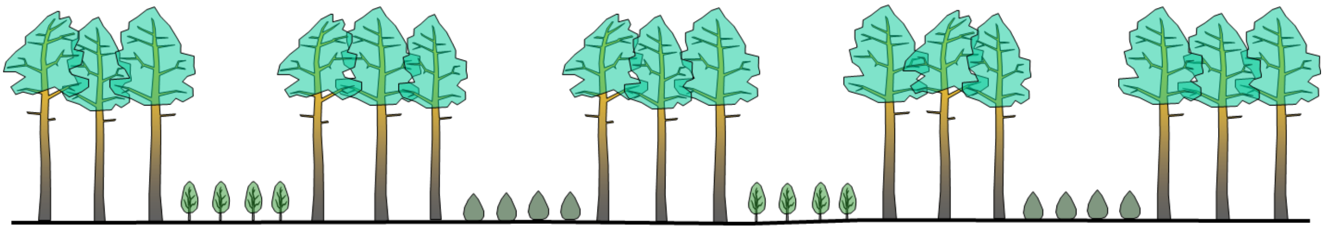
Simple stand structures are those which are composed of no more than two canopy layers or age classes. Two-storey stand structures are usually created by a Shelterwood method, where the canopy is opened gradually to facilitate the growth of a new established understorey. If the canopy is opened evenly the method is sometimes termed Uniform shelterwood, whereas a less-even opening is referred to as Irregular shelterwood.

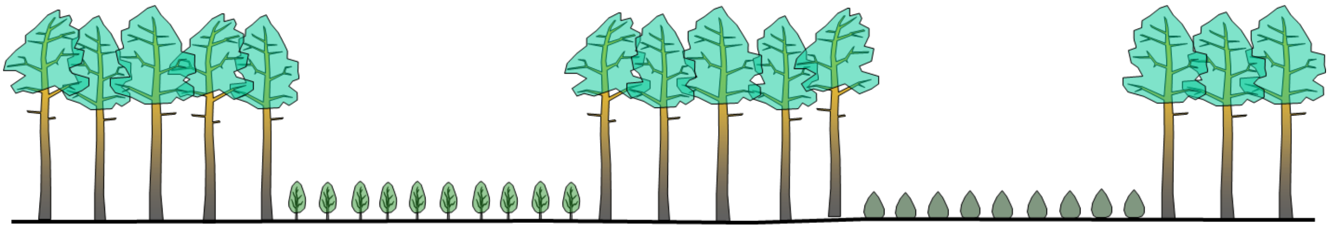
Uniform shelterwood



Following *Dothistroma sp.* infection in Corsican pine stands, a number of methods have been designed recently to rapidly convert pine stands by underplanting, whereby the canopy is opened by removing one or several rows of trees. Although often referred to as “strip fellings”, these techniques should not be confused with Strip shelterwoods as described above, as both the sequence of operations and the ecological principles are rather different. They are better included in the Shelterwood category, unless the scale of canopy removal exceeds the limit for CCF.

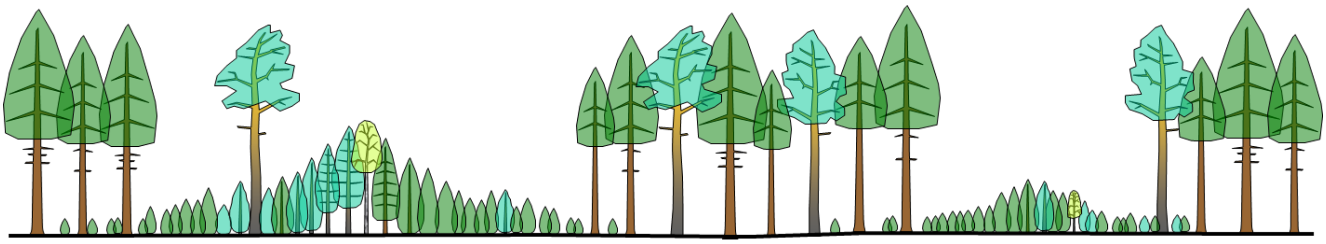
Examples of regular Shelterwood approaches, where a defined number of rows is removed to facilitate underplanting and minimize future harvesting damage:





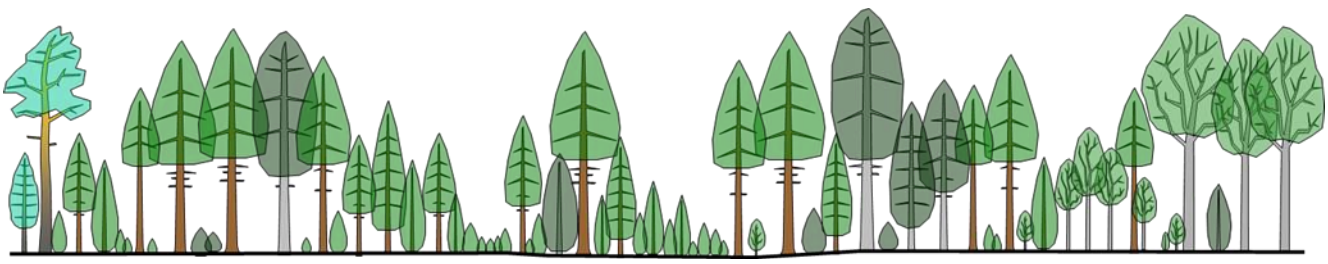
Complex stand structures are characterized by more than two canopy layers or age classes. They are often also more diverse in terms of tree species composition than simple structures and thus provide a higher degree of resistance and resilience to pests and diseases. Complex stand structures usually require forest operations to be carried out at lower intensity and / or limited scale.

Group method



The Group method is based on opening the canopy in small patches, usually not exceeding one tree length in diameter initially. These canopy gaps may be enlarged later as the next generation of trees develops, leading to a multiple-aged stand structure.

Selection system



The high structural diversity of a Selection system is usually achieved over longer periods of time. Unlike the other CCF methods, this represents a genuine silvicultural system where regeneration, tending, thinning and final harvesting occur continuously over the entire area.

Appendix 2: Silvicultural techniques for tree establishment

Introducing an understorey or additional species can be done in various ways. The main points to consider about these options are covered in this section. In stands where the objective is to achieve an intimate mixture of conifer and broadleaved trees the broadleaved species are best established in single-species clusters for the benefit of timber quality.

Restocking after clearfelling

This option is applicable to Clearfell-and-restock and LIMA as diversification methods. Species, provenance and other genetic characteristics (*e.g.* improved stock) can be chosen freely, and timing and planting design (spacing and mixture pattern) are, in principle, controlled by the forest manager. Stand establishment by planting on clearfelled sites is a well-established method of forest regeneration in the UK which under most conditions presents few challenges. Ground preparation measures can be built into the process, and the operation itself can be carried out at any scale, possibly even making use of mechanised planting techniques.

Potential disadvantages include weed problems and nutrient leaching due to fallow period, insect pests (*e.g. Hylobius abietis*), planting shock and root deformation, browsing damage and other issues which are inextricably linked to clearfelling as a forest management approach (see Appendix 1). From an ecological viewpoint, restocking after clearfelling is generally less suitable for shade tolerant climax species which are ill adapted to open ground growth conditions. The trend towards drier and warmer spring seasons is likely to exacerbate this problem. It should also be noted that undesirable natural regeneration may occur on restock sites, particularly if ground cultivation is carried out.

Underplanting

This option is limited to CCF as a diversification method. It aims to combine the benefits of planting as an establishment method whilst avoiding the disadvantages of clearfelling. Underplanting is particularly suitable for establishing shade tolerant climax species, and less suitable for light demanding pioneers [6]. Options for ground cultivation are limited (although still possible) but are also less likely to be required. Some establishment risks such as weed growth and insect pests can be significantly reduced, although not always completely avoided, compared to restocking of clearfelled sites.

Other planting issues like browsing, planting shock and root deformation remain relevant, as does the possibility of undesirable natural regeneration. Initial growth rate of the transplants may be somewhat slower than on open ground, however this is not necessarily a disadvantage. Ongoing harvesting operations in the main canopy can cause substantial damage in the establishing understorey and require careful planning and operational skill. Flexibility and creativity may be required when applying conventional protection measures such as fencing.

Natural regeneration

Natural regeneration may occur in all diversification methods, although it is least likely on larger clearfell sites. It is a rather unpredictable process by nature and its use therefore requires silvicultural experience and continuous monitoring of the site. If successful, it can result in a high density of seedlings and saplings which allows the forest manager to select the best individuals for further management. One of the main advantages of naturally regenerated trees is their undisturbed root development which is highly beneficial for individual tree stability. Natural regeneration is usually also an indicator of good suitability of the species or individuals to current site conditions.

The success of natural regeneration depends on several factors (*e.g.* seed production, seedbed conditions, seed predation / browsing level *etc.*) and can be difficult to predict. Specific measures may be required to address issues which have been identified as preventing the establishment of regeneration (*e.g.* ground scarification). Supplementary planting may be required if parts of the site do not regenerate adequately. Also, the genetic features of the seedlings are entirely dependent on the parent trees; the introduction of new species, provenances or improved material is therefore not possible. Finally, the high seedling density may require extensive and costly respacing operations which must be carried out within a specific time frame. If natural regeneration occurs under canopy, harvesting operations will have to be carried out to the same high standards as in underplanting scenarios to prevent damage to the establishing trees.

Direct seeding

Direct seeding can be applied in all diversification methods. Like natural regeneration, it carries the advantages of undisturbed root development but gives forest managers more control over seed source, location and amount of seedlings. Seed sowing itself is generally easy and fast, and new application methods are being developed [7]. However, overall direct seeding requires more exacting silviculture to be put in place than with planting, and outcomes are less predictable.

The main barriers to a more widespread application include the relatively high seed costs and the potential for high losses amongst seeds and seedlings – it is often perceived as a “wasteful” method of forest establishment. The current experience with this technique is generally limited but growing.

References

[1] Haufe, J., Kerr, G., Stokes, V. and Bathgate, S. (2021a) *Forest Development Types: FDT Flashcards. Version 1.1.* Forest Research, 126p.

[2] Haufe, J., Kerr, G., Stokes, V. and Bathgate, S. (2021b) *Forest Development Types: A guide to the design and management of diverse forests in Britain. Version 1.1.* Forest Research, 64p.

[3] Forest Research (2024) ESC www.forestresearch.gov.uk/tools-and-resources/fthr/ecological-site-classification/

[4] Kerr, G., Haufe, J., Stokes, V. and Mason, B. (2020) Establishing robust species mixtures. Technical Paper, *Quarterly Journal of Forestry*, 114 (3), p.164-170

[5] Forest Research (2024) ForestGALES www.forestresearch.gov.uk/tools-and-resources/fthr/forestgales/

[6] Kerr, G. and Haufe, J. (2016) *Successful underplanting.* Silvicultural Guide, Forestry Commission, 42p.

[7] Willoughby, I., Jinks, R., Gosling, P. and Kerr, G. (2004) Creating New Broadleaved Woodland by Direct Seeding. *Forestry Commission Practice Guide 16*, Forestry Commission, Edinburgh

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