# THE IMPLICATIONS OF TRANSFORMATION TO CONTINUOUS COVER FORESTRY SYSTEMS FOR CONIFER TIMBER QUALITY AND LOG SUPPLY IN THE UK

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## FINAL REPORT

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## Background

Forest policy in Great Britain has increasingly moved towards delivery of a range of benefits from the nation's forests in addition to timber. One of the consequences of this shift in policy has been a stated "move to a greater use of continuous cover systems" in Wales ("Woodlands for Wales", Forestry Commission, 2001) and to develop "more mixed forests" in Scotland ("Forests for Scotland", Forestry Commission, 2000). In fact, the Welsh forest strategy states an aspiration to convert at least half of the National Assembly woodlands to continuous cover forestry (CCF) by 2020, where practical. These proposed large-scale changes of silvicultural systems from the current even-aged clearfell system are likely to have impacts on the supply and quality of timber produced. This impact will not only affect areas of broadleaved forest but also the upland conifer forests that are the key sources of material for the major sawmilling industries in Great Britain.

The actual process of transforming stands is likely to take over 50 years before a steady-state CCF system is achieved. The investment time-scale for sawmilling, however, is of the order of 15-20 years. Investments in new sawmilling capacity made now and in the near future will therefore take place before established continuous cover stands are commonly available. Whilst information on timber from established CCF systems can be obtained from Europe, the effects of the process of transformation on timber quality during the conversion period are uncertain, especially for Sitka spruce. The forest industry is therefore in urgent need of information about the impact of transformation of upland conifer crops from clearfell to continuous cover systems on timber quality and supply. This is particularly important in relation to the supply that will become available over the next 15-20 years, because this will have the greatest impact on the existing wood processing sector.

## Objectives

The objectives of this project were:

1. To provide a comprehensive overview of current knowledge about the impacts of transforming even-aged stands to continuous cover forestry (CCF) silvicultural systems on the timber quality and supply of softwoods in the UK (with a particular emphasis on Sitka spruce, Douglas fir and Scots pine).
2. To catalogue existing growth, yield and timber quality models that could be used to predict these impacts.
3. To identify suitable forest stands within Britain that could be used for investigating the effects of transformation to continuous cover forestry on timber quality.
4. To present a problem analysis evaluating the options for further research that would allow forest managers and sawmillers to forecast the impacts of the transformation of stands on timber quality and supply over the relevant short, medium and longer terms.

## Method

In order to meet the objectives set out above the following work has been undertaken:

**1. Literature Review**

A review of published literature relating to the effect of alternative silvicultural systems on timber quality has been undertaken. In the absence of much specific literature relating to the subject, evaluation of the consequences for log quality and wood properties was largely based on an analysis of the ways in which the transformation process affects the stand/tree growing environment, and the consequent impact on timber quality. This review has been written as a journal article which will be submitted for publication in *Forestry*, following internal review within Forest Research. The draft of this paper is presented in Appendix 1 of this report.

## 2. Catalogue of Models

A catalogue of growth, yield and timber quality models that could potentially be used to predict the impact of transformation to continuous cover systems on conifer timber quality and log supply has been compiled. A short description of each model is given together with brief details relating to the model type, the species and type of stand for which it is applicable and an initial assessment of its potential and adaptability for use in UK conditions. This catalogue could form the basis of a critical evaluation of models that the Forestry Commission Forestry Group has indicated that they may commission as a separate study. The catalogue is included in this report as Appendix 2.

## 3. Potential study sites

Site visits were made to a number of forests being managed under continuous cover systems in Scotland, Wales and Northern Ireland. These included some stands where continuous cover management had been in place for a considerable period of time, (more than 20 years) and others where the transformation process has only recently been started. A report of these visits has been produced, including an assessment of their potential usefulness for testing the implications of transformation to continuous cover systems on timber quality. In addition to the forests visited during the study a number Forestry Commission and Forest Research experimental stands that are potentially valuable for future studies of timber quality are included in this report, which is attached as Appendix 3.

## 4. Problem Analysis

In order to synthesise the results of the work carried out in this project a problem analysis setting out the key issues of concern and reviewing the possibilities for moving the work forward has been produced. Options for medium to long term research work are outlined together with time-scales and indicative costs. This is presented below.

## Problem Analysis

This section of the report establishes the key issues relating to the impacts of transformation to Continuous Cover Forestry (CCF) on timber quality and supply, details the questions that require answering and provides a template for moving work forward.

### *Key Issues*

#### Scope

The key question, and one which has yet to be resolved, is the likely extent of forest transformation in Great Britain. It is unclear at the moment exactly which systems are most likely to be used, where CCF is going to be applied, what species are going to be incorporated, when transformation is likely to begin and over what period it will be undertaken.

Although there are many systems available to foresters it is likely that a few will dominate in British coniferous forests. The irregular shelterwood and group selection systems appear to be favoured depending on species and location (Malcolm et al., 2001). It is much more difficult to determine the area of forest within which transformation to CCF management will take place and hence to estimate the proportion of timber production that is likely to be affected. The location, extent and characteristics of forests being converted will be driven by a number of factors including the forest policies of each country (which are likely to vary with time), stand stability, the likelihood of achieving successful natural regeneration and access for harvesting operations. Currently there are firm commitments for conversion to CCF in Wales (Forestry Commission, 2001) and encouragement to use CCF in Scotland (Forestry Commission, 2000) where possible but there was no such undertaking in England (Forestry Commission, 1998).

The choice of species that will be considered for transformation or are likely to be used in CCF is another important consideration. In terms of the species considered for transformation the key species are likely to be Sitka spruce and Scots pine since they represent over 65% of the total conifer forest cover (see Table 1). Of lesser importance are lodgepole pine, Corsican pine, Japanese/hybrid larch and Douglas fir. The choice of species that may be used in new silvicultural systems is larger and will involve all the species above with greater emphasis on Douglas fir plus additionally sycamore, oak, ash, birch and beech. Species, such as Western hemlock, that are currently not sought after for timber (due to, for example, a high incidence of stem fluting) may nevertheless increase in area due to their ability to successfully regenerate in CCF systems because of their shade tolerance.

**Table 1: Area of Woodland in Great Britain by Tree Species**

| **Area of woodland in GB by main tree species** | | | | |
|---|---|---|---|---|
| | | | | **thousands of hectares** |
| **Species** | **GB** | **England** | **Scotland** | **Wales** |
| Scots pine | 227 | 82 | 140 | 5 |
| Corsican pine | 47 | 41 | 2 | 3 |
| Lodgepole pine | 135 | 7 | 122 | 6 |
| Sitka spruce | 692 | 80 | 528 | 84 |
| Norway spruce | 79 | 32 | 35 | 11 |
| European larch | 23 | 14 | 9 | 1 |
| Japanese/hybrid larch | 111 | 33 | 56 | 22 |
| Douglas fir | 45 | 24 | 10 | 11 |
| Other conifer | 30 | 19 | 5 | 6 |
| Mixed conifer | 18 | 9 | 8 | 0 |
| **Total conifers** | **1 406** | **340** | **916** | **149** |
| Oak | 223 | 159 | 21 | 43 |
| Beech | 83 | 64 | 10 | 9 |
| Sycamore | 67 | 49 | 11 | 7 |
| Ash | 129 | 105 | 5 | 19 |
| Birch | 160 | 70 | 78 | 13 |
| Poplar | 12 | 11 | 0 | 1 |
| Sweet chestnut | 12 | 12 | 0 | 1 |
| Elm | 5 | 4 | 1 | 0 |
| Other broadleaves | 120 | 84 | 18 | 18 |
| Mixed broadleaves | 160 | 91 | 62 | 8 |
| **Total broadleaves** | **971** | **648** | **206** | **118** |
| **Total – all species** | **2 377** | **988** | **1 123** | **266** |
| Felled | 47 | 15 | 23 | 9 |
| Coppice[1] | 24 | 22 | 1 | 0 |
| Open space[2] | 217 | 72 | 134 | 11 |
| **Total woodland** | **2 665** | **1 097** | **1 281** | **287** |

Source: 1995–99 National Inventory of Woodland and Trees (not National Statistics).

**Notes**

1 Coppice includes coppice with standards.

2 Areas of integral open space, each less than 1 hectare.

## Implications

There are two areas of concern in terms of the supply of timber from British forests following transformation; changes in available quantity and changes in quality. A thorough literature review of the latter subject is provided in Appendix 1.

*Quantity*

Changes in the available supply of timber may arise from changes in the total volume produced and from the assortment of products (i.e. logs of different dimensions) that can be cut. Studies have already been carried out on the impact of transformation on the log volume from Welsh woodlands (Jaakko Pöyry, 2004). The results of that study suggest a reduction in the volume of timber of approximately 20%. This appears to arise mainly from a change in the species composition, in particular to less productive broadleaved species such as sycamore, oak and ash and also to heavier than normal thinning to allow regeneration of seedlings under the mature canopy. This may reduce the productivity of stands by thinning below the productive capacity of the site and the effect was possibly exacerbated in the model simulations as the new cohorts were not allowed to start growing until the previous crop had been felled. The impact of this lack of realism (normally the new cohort would start growing before the final crop trees were removed) was minimised by restricting the period of final crop tree removal to a maximum of 20 years rather than a more realistic 40 years. Despite these uncertainties there appears to be a high likelihood that transformation will lead to a reduction in the total volume of timber produced from our forests.

In addition to a reduction in the overall standing volume there could potentially be a change in the recovery of sawlogs from this volume. A primary consideration is if there is likely to be any change in the stem form of trees growing under CCF systems. The recovery from trees with higher taper is reduced compared to trees with lower taper. Taper will tend to increase in any silvicultural system which creates gaps, wider spacing or unevenness in tree height. Furthermore, there is a potential for reduced stem straightness in the less uniform forest structures of CCF because trees will bend towards gaps in search of light due to the less uniform surrounding competition.

The sizes of trees being cut will become more varied also. There will tend to be early thinning of larger diameter trees (crown thinning operations), whilst at the same time some trees will be retained well beyond current rotation ages leading to much larger final tree sizes than are normal in British forestry. There will be greater use of "target diameter" thinning in order to ensure the correct distribution of tree sizes within stands (Kerr et al., 2002). The combination of these factors will tend to lead to a greater variability in tree sizes coming onto the market, which will have an influence on the type of sawmills and saw lines most suited to processing the material.

*Quality*

The impact of transformation to CCF systems on timber properties is not straightforward. Both detrimental and beneficial effects can be envisaged, depending on the timing and nature of management interventions. In Table 2 some of the broad changes in silviculture, (compared to clearfell systems), that are likely to occur during and following transformation are set out. An evaluation of the likely effect of these changes on factors that influence timber quality has been made and the assessment of whether this is likely to be positive, negative or neutral is indicated by the colours green (+), red (-) and yellow (=) respectively. This table displays only broad tendencies and there is no measure of relative importance of different impacts. Furthermore, there will be interaction between the factors. For example, in an Irregular Shelterwood system greater variability in stand structure and age class could be expected, as well as an increase in early and later thinnings and longer rotations. Some of these changes in silviculture would be beneficial in terms of timber properties, whereas others could be detrimental. Overall it becomes difficult to evaluate the relative importance of each factor without the aid of a timber quality model that is able to simulate the growing conditions and management operations associated with CCF systems. At this stage, therefore, our understanding of the influence of all these factors on the final sawn timber performance is somewhat speculative and the discussion below is based on the application of existing knowledge of how individual factors influence timber quality.

**Table 2: Impact of CCF on timber quality**

| | Longer rotations | Gap creation | Increased thinning | | Variability | Restricted genetic change |
|---|---|---|---|---|---|---|
| | | | Early thinnings | Later thinnings | | |
| Diameter | + | +/= | + | + | = | - |
| Stem straightness | + | -/= | + | + | - | - |
| Branching/knots | + | - | +/=/- | + | - | - |
| Grain angle | =/+ | - | +/= | + | - | -/= |
| Wood density* | + | SS -<br>SP L DF = | - | SS -<br>SP L DF = | SS -/=<br>SP L DF = | SS +/=<br>SP L DF = |
| Tracheid length | + | +/=/- | - | + | +/=/- | = |
| Microfibril angle | + | +/=/- | - | + | +/=/- | = |
| Juvenile wood | + | +/=/- | - | + | +/=/- | = |
| Compression Wood | = | - - | =/- | =/+ | - | = |

* SS = Sitka spruce, DF = Douglas fir, SP = Scots pine, L = larch

<u>Thinning</u>

The increased use of thinning throughout the life of the crop will generally have a beneficial effect on timber quality by removing trees of poorer form and concentrating growth on better trees. Whilst thinning can have a negative influence on the density of some species such as the spruces and Douglas fir,  this can be more than compensated for by producing more even annual growth. A more serious concern is the necessity to ensure a continuity of management so that the original objectives of the management system put in place are not lost. Also some types of thinning such as “target diameter thinning” can be detrimental because they remove systematically trees above a certain size regardless of the “quality” of the trees left behind.

It is likely that there will be earlier thinning of bigger trees (crown or target-diameter thinning) than in even-aged forestry. This will lead to the felling and processing of trees with a larger percentage of juvenile cores than normal, which may lead to increased problems of distortion and lack of stiffness in stress grading. Heavier early thinnings, that may be used to improve stand stability, could limit crown suppression between trees and result in the retention of deeper living crowns. This will allow lower branches to keep growing producing larger knots in the valuable lower portion of the stem. For self pruning species such as Scots pine and larches this should not be such a problem as it will be in the spruces and Douglas fir. In future forest stands the increased use of regeneration will tend to lead to more trees per hectare, which if properly managed and thinned can help to suppress crown development leading to smaller branches and a reduced juvenile core. Conversely if deer browsing is not controlled or the regeneration is not uniform and dense enough then large branches and juvenile core will again be an issue.

An increase in the frequency of thinning interventions has the potential to cause damage to regenerating seedlings, young trees and damage to the remaining crop trees during extraction. This can only be minimised by ensuring there are properly designated extraction routes, proper operator training and use of specialised thinning harvesters.

Restricted Genetic Change

The predominance of natural regeneration in CCF systems will restrict the opportunity to make improvements through the use of genetically improved plants. In species such as Sitka spruce, where there has been an extensive breeding programme, this will give poorer form, heavier branching and reduced green log volume recovery in comparison to the use of improved material. For other species, where there is less opportunity to use genetically improved material, the impact may be less important. However, if the form and quality of the trees in a stand are poor, then the regenerating crop will also tend to be similarly poor. In these circumstances only replanting with better material can improve the situation.

Variability

Inevitably increased use of CCF systems is going to lead to greater variability in the crop. This variability will manifest itself in a greater range of species, heights, canopy depth, branch size and growing conditions for individual trees. In general this will have effects on the stem shape and branching patterns of the trees leading to, on average, poorer form, larger branches and knots and increased grain angle (due to increased wind exposure). The influence on the internal wood properties is more difficult to assess although it is likely there will be an increased presence of compression wood.

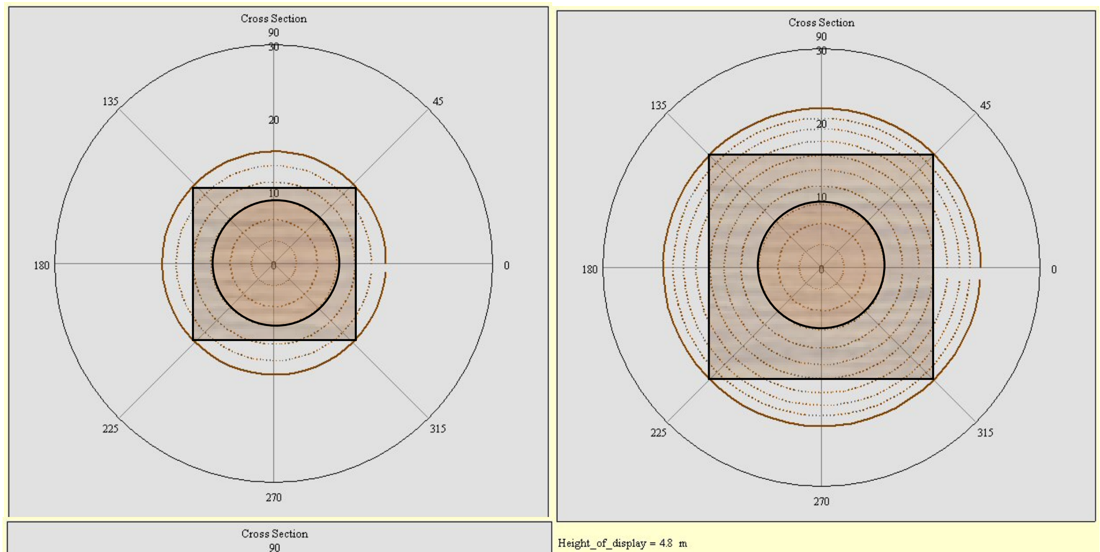
The variability in log sizes being produced from CCF forests has an important influence on the sawmilling sector which is predominately geared up to dealing with a limited diameter range (typically 25cm top diameter). The solution will be an increase in the capacity of mills able to deal with bigger trees (up to +50cm top diameter) and also by pre-sorting in the forest or at roadside to direct logs to the best sawmills. The issue of the additional costs of such operations is not covered here.

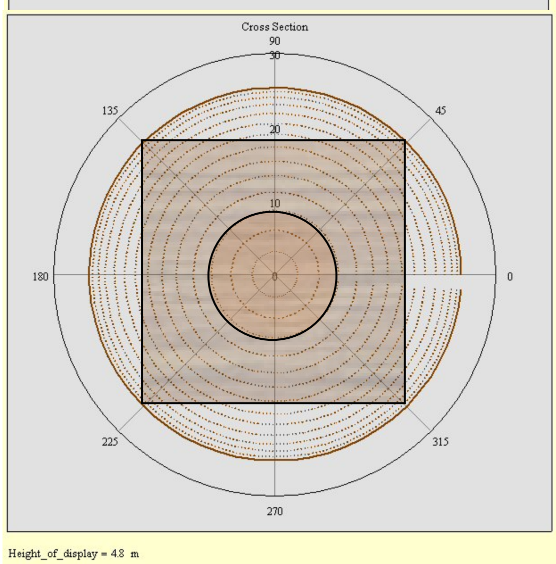
Gap Creation

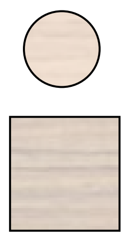
In any CCF system there will tend to be the creation of more gaps within the forest than in conventional clearfell-restock systems. Gap creation can vary from relatively small, of the order of a few trees, to quite substantial (up to 0.25 ha) such as in Group Selection. The impact of gaps will be very similar to that of variability discussed above with a tendency to increase stems of poorer form and branch size. Much of this is due to the biological requirement for each tree to capture as much light as possible in order to compete with neighbours. Gaps encourage the tips of trees and branches to extend into the spaces where more light is available. If the branches become big enough timber can be downgraded. In one sense CCF can be seen as having a tendency to produce a lot more edges than conventional British forestry and consequently creating larger areas with all the problems associated with edge trees.

Longer Rotations

A major benefit of CCF systems is the encouragement of longer rotations. This will provide larger trees, which have a greater percentage of mature wood and a greater percentage of sawn timber recovery.



Juvenile wood area (15 growth rings)

Nominal sawn timber section

| Rotation length | Juvenile wood proportion in relation to log cross-section | Juvenile wood proportion in relation to sawn timber section |
|---|---|---|
| 40 years | 32% | 50% |
| 60 years | 16% | 25% |
| 80 years | 12% | 19% |

**Figure 1: Growth ring pattern in cross section at 4.8 metres (top of butt log) showing juvenile wood area of Sitka spruce, YC 24, 1.7 m spacing at 40, 60 and 80 years**

In Figure 1 an impact of growing trees for longer rotations is illustrated. The percentage of the juvenile core as a function of the sawn timber production drops dramatically. The majority of the timber will be from the more mature timber on the outside of the tree, which generally has higher density, lower grain angle and lower microfibril angle. Currently the majority of timber sawn in British sawmills is cut from the juvenile core (approximately first 12-15 growth rings), which has a tendency to distort in drying more than mature wood and to have reduced stiffness. This is due to the higher microfibril angles found in juvenile spruce wood.

<u>Summary</u>

The overall impact of these changes on the final sawn timber performance is very difficult to determine because there has been little research work carried out in this area. The factors described above cannot be treated in isolation and there are multiple interactions. Integrated growth, timber property and sawn timber performance models offer a possible method of dealing with the complexity of the problem.

**Knowledge**

There is a critical lack of knowledge of the impact of CCF on timber quality, particularly in Great Britain. Large schemes are being put in place with little or no knowledge of the consequences. The literature on the subject is extremely limited (see Appendix 1) although there is now an increase of interest in the subject particularly in Central Europe. In particular this can be seen in a number of papers beginning to appear in the literature on the wood properties and timber quality of open grown trees, which simulate many of the growth conditions of trees in CCF stands. However, there is an almost complete lack of knowledge of tree growth in CCF systems in Britain. We presently do not know how our trees will grow under such systems and we do not yet have the models to predict their growth and subsequent timber performance.

There is also a distinct lack of experience of managing CCF systems in Britain. This means that foresters are in general unfamiliar with CCF systems and how they respond to management. Furthermore, most machine operators are not familiar with working in such systems. The potential to make serious mistakes is large and there is an urgent need for training in how to manage such systems and how to thin and extract timber from them.

**Tools**

Many of the tools we rely on for managing conventional forestry are absent in Britain for CCF systems. There are no published models for the growth of these systems and, therefore, it will be difficult to accurately predict future outputs. Attempts have been made to do this for Wales (Jaakko Pöyry, 2004) but it has meant adapting existing yield models in a less than ideal manner and, furthermore, none of these adapted models have yet been tested against permanent sample plots. The result is an increased lack of certainty in production forecasts, which form the basis for future forest policy and for investment in the processing industry.

In parallel to the lack of growth models is a lack of timber quality models. There are models for predicting the stem form of Sitka spruce in Britain (Stirling et al., 2000; Mochan et al., 2001; Mochan et al., 2002) and Sitka spruce timber properties (Gardiner et al., 2004) but these were only designed for conventional silviculture. The applicability of such models to more complex systems is unproven. There are possibilities of using models developed in other countries for British forests but the likelihood is that most of these would require extensive work to parameterise and validate. A list of models of potential value for answering these questions is provided in Appendix 2.

There is some guidance for managing CCF systems both within the general literature and specifically for Britain (Mason et al., 1999; Kerr at al., 2002; Mason and Kerr, 2004). However, these need to continue to be tested against actual operational systems to see how well they work and such operational systems are rare.

A key requirement is for the diameter distribution to eventually approach a reverse J curve (Kerr et al., 2002). This seems to be the dominating factor in determining whether a stand is approaching or is being managed as a CCF system. The reliability of such a methodology as a basis for thinning decisions requires further testing.

**Perception**

There are many preconceptions in the area of CCF. Often these appear to be accepted beliefs with little clear basis in fact. Many claims are made for CCF such as increased stability, improved timber quality, improved biodiversity etc. with little scientific basis on which to make those claims. Often they appear to be more down to people's beliefs. For example, the claim that CCF forests are more stable is not borne out in any detailed studies (Gardiner et al., 2005). Much more research is required to clarify these issues.

## *Possibilities for Further Research*

### Short Term (1-5 years)

*Systematic Inventory*

There is a need to carry out a systematic inventory of the area and type of silvicultural system planned in each region of the UK. This would be similar to what has already been carried out in Wales but more systematically. In this way it would be possible to build up a picture of the production forecast from our forests over the next 20 years as transformation takes place.

- Timescale: 1- 2 years
- Who: Forestry Commission, Private Sector (CONFOR), Forest Research Biometrics Division.
- Method: The methodology has been developed for a study in Wales (Jaakko Pöyry, 2004) but is appropriate for expansion to the whole of Great Britain. The initial part is to identify those areas identified for transformation, the type of transformation to be carried out and the stage of the transformation. This will tend to be easier in Forestry Commission forests than in the private forest estate where assumptions will need to be made. The next stage is to run production forecasts for both the private sector and for Forest Enterprise with modified yield models that account for the changes in management. Currently this involves modification to the existing yield models to account for the changed silviculture. The modifications have already been carried out and although not ideal, offer an initial assessment of the likely consequences of transformation on timber supplies.

*Sawmilling Studies*

At present there is a lot of speculation of the likely consequences of transformation. The proposed work would compare the performance in terms of volume recovery and stress-grading performance of timber cut from conventional and CCF systems. This would allow the effects of early thinning, gaps and large trees to be formally evaluated. The results for Sitka spruce grown under CCF systems could be tested against the Sitka spruce timber quality model to determine whether the model stills works in these circumstances.

- Timescale: 2-3 years
- Who: Forest Enterprise/Private estates, sawmill operator, Napier University, Bangor University, Forest Research.
- Method: Identify a number of pairs of stands of equal age growing in close proximity (<25 km apart) managed conventionally and under a CCF system. Identify approximately 12 trees from a range of diameter classes from each stand. Following this the measurements would comprise a number of stages:
    - Measure the properties of standing trees including dbh, height, crown characteristics, grain angle, and stem lean.
    - Fell trees and measure volume recovery in terms of green logs, branch size and characteristics, canopy depth and canopy width.
    - Cut trees into 3m logs for sawmill studies. In addition at the bottom and top of each log cut discs to allow measurements of wood density, grain angle, growth rate and microfibril angle for validation of existing Sitka spruce timber quality model or the development of new models for other species.
    - Transport logs to sawmill. Measure potential recovery from logs and then cut all logs into 100 x 50mm battens for comparison of batten performance.
    - Determine strength and distortion of battens cut from trees grown under different silvicultural systems.

## Medium Term (5-10 years)

*Improved Growth and Timber Quality Models*

There is a critical need to adapt and improve our growth and timber quality models to deal with these more complex silvicultural systems. This includes developing models for all the key species including those for which we currently have no timber quality models. This would include Scots pine, Douglas fir and larch. The data collected in the sawmill trials above would act as validation for the models.

- Timescale: 5-10 years
- Who: Forest Research, Bangor University, INRA (Nancy), Boku University (?), British Columbia Ministry of Forests (?).
- Methodology: Continue the development of the M series models (M3-M6) in Forest Research and the Tyfiant Coed model at Bangor University. Continue to collect data in order to develop timber quality models for Scots pine, Douglas fir and larch following the methodology already developed for Sitka spruce and couple these with growth models. Validate against data obtained in previous sawmill study.

## Long-term (10-50 years)

*Long Term Experiments*

There is a need to establish long-term experiments to thoroughly test the assumptions and statements made above and to provide research material for the future.

- Timescale: 40 years
- Who: Forestry Commission, Forest Research, Edinburgh University, Bangor University, Aberdeen University.
- Methodology: Establish trials in Sitka spruce and Scots pine plantations of different ages (20-60 years) and conduct a selected range of treatments to convert into CCF systems. Establish trials in forests in a range of climatic conditions.

A number of sites that might be of potential use for the experiments proposed above have been provided in Appendix 3.

## Conclusions and Recommendations

The use of alternative silvicultural systems to clearfell in conifer forests in Great Britain is increasing. There is a widespread move to transform even-aged plantations to continuous cover management under shelterwood or selection systems, where site and stand conditions are suitable. However, there is limited experience of implementing these systems on a large scale, and it will take time to build up expertise and knowledge in this area. In recent years most of the research and development in this subject has been focused on stand manipulation to achieve successful natural regeneration, with little emphasis on the quality of timber that will be produced from these stands.

From the available information it can be concluded that continuous cover forestry systems do have the potential to produce high quality timber, providing the quality of the original stand is of a sufficient standard. A key factor is likely to be continuity of management, as the transformation process may take 15-30 years and subsequent continuous cover management will require an ongoing commitment to monitoring and control. Careful silviculture with particular attention to the timing of interventions in relation to crown development and to selection during thinning is required. There is likely to be greater variation in the characteristics of future timber supplies in terms of size and wood properties. Wider use of crown thinning will result in an increased quantity of young sawlog-size material being processed in sawmills, which is likely to have inferior mechanical properties and dimensional stability than older material of the same dimensions. The practical impact of these changes in terms of timber performance and value has yet to be evaluated.

The impact of these changes in stand management on timber quality and supply at a national level is hard to judge without a realistic estimate of the location, extent and characteristics of the forests being transformed. Mason (2003) states that a preliminary site evaluation suggests that perhaps 50% of sites in Wales and 30% of sites in Scotland might be suitable for transformation. In order to better gauge the effects of increased use of continuous cover systems a systematic inventory of the area and type of silvicultural system planned for forests in Great Britain will be required.

Research studies are needed to test some of the inferences drawn from the available literature, to determine if they are valid for British conditions. In particular sawmill studies to evaluate the quality characteristics and utilisation potential of logs and sawn timber produced both from young trees during crown thinning and from large old trees retained beyond normal rotations in uneven-aged stands.

Our ability to predict the impact of alternative silvicultural strategies using currently available growth and timber quality models is limited, as these have been largely developed for use in even-aged single species stands. There is a need to adapt and improve models for the main commercial conifer species in Great Britain (Sitka spruce, Scots pine, Douglas fir and larch) so that they can deal with the more complex silvicultural systems that are increasingly being used. The establishment of long term experiments to test these models and provide research material for the future would also be a useful step forwards.

On the basis of information that is currently available the following recommendations can be made, with the aim of ensuring that the quality of timber produced from stands undergoing transformation is as good as possible:

1. As far as possible opening up of the canopy beyond the extent of a conventional intermediate thinning should be avoided until the live crown has receded to a height that is above the most valuable sawlog producing part of the stem.

2. In all thinnings trees with straight stems, superior branching habit (small branch diameters, few branches per whorl, level branch insertion angle) and low taper should be favoured.

3. Use crown thinning carefully to favour the best form co-dominants in order to produce final crop trees with a low proportion of juvenile wood.

4. Where the canopy has to be opened up more radically to promote natural regeneration and stabilise seed trees, and where the seed trees selected are highly tapered with vigorous crowns, consider the use of pruning to improve the quality of the final crop trees. On trees that are to be retained to an age of 60-100 years this will produce an appreciable amount of knot-free timber and may also improve taper. Marking and recording of final crop trees is necessary to ensure that the pruned individuals can be appropriately marketed when they are harvested.

5. If the existing crop has inferior stem straightness and branching, or is not well suited to the site, planting to introduce improved genotypes or provenances, or preferred species, rather than natural regeneration should be used. An irregular structure can still be achieved if underplanting or group planting is used, although costs will be higher than in a clearfelled coupe. Alternatively, clearfelling and restocking with the preferred species or genotype can be used with the conversion to continuous cover management deferred until the next rotation.

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# A review of the effects of transformation of even-aged stands to continuous cover silvicultural systems on conifer log quality and wood properties in the UK

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**Summary**

There is an increasing move in the UK to transform even-aged, single species conifer plantations to more diverse and irregular stand structures, using continuous cover forestry systems. However, there is limited experience of implementing these systems on a large scale in the UK, and research to date has not addressed the possible consequences of this change in management practice on subsequent timber quality. This paper reviews the available information, with reference to the main commercial conifer species growing in the UK.

Recent research has recommended that the silvicultural systems suitable for delivering continuous cover forest management in the UK are uniform or group shelterwood or group selection. The key aspects of transformation to these systems that are likely to affect log quality and wood properties are their longer rotations, the increased use of thinning, the creation of gaps, an increase in variability and restricted genetic change as a result of the use of natural regeneration. It is concluded that continuous cover forestry systems have the potential to produce high quality timber, providing the quality of the original stand is of a sufficient standard. The timing of thinnings and careful selection of the best stems to form the final crop will be critical. However, wider use of crown thinning will result in an increased quantity of young sawlog-size material being processed in sawmills, which is likely to have inferior mechanical properties and dimensional stability than older material of the same dimensions. In addition there is likely to be greater variation in the characteristics of future timber supplies in terms of size and wood properties.

## Introduction

This review aims to provide a comprehensive overview of current knowledge about the effects on timber quality and wood properties of transforming even-aged conifer stands to continuous cover forestry (CCF) systems, with particular reference to commercial conifer species growing in the UK. The background to increased use of continuous cover systems in UK forests is presented, followed by an outline of the systems involved. Aspects of the transformation process that are likely to affect log quality and wood properties are highlighted and a brief explanation of the key log quality characteristics and wood properties is given.

The impact of transformation on timber quality is then evaluated on the basis of information available in the published literature. In conclusion, suggestions for research and development to better inform continuous cover management in Britain are made, together with some simple recommendations for management strategies to optimise timber quality from stands undergoing transformation.

## Background

The forest cover of Great Britain currently extends to about 2.6 million hectares, representing almost 12% of the total land area (Forestry Commission, 2003a). This contrasts with the situation one hundred years ago, when the forest cover was only 5% of the total land area. This significant increase in forest area was the result of an extensive programme of afforestation that took place during the 20th century, particularly between 1950 and 1990 (Figure 1).

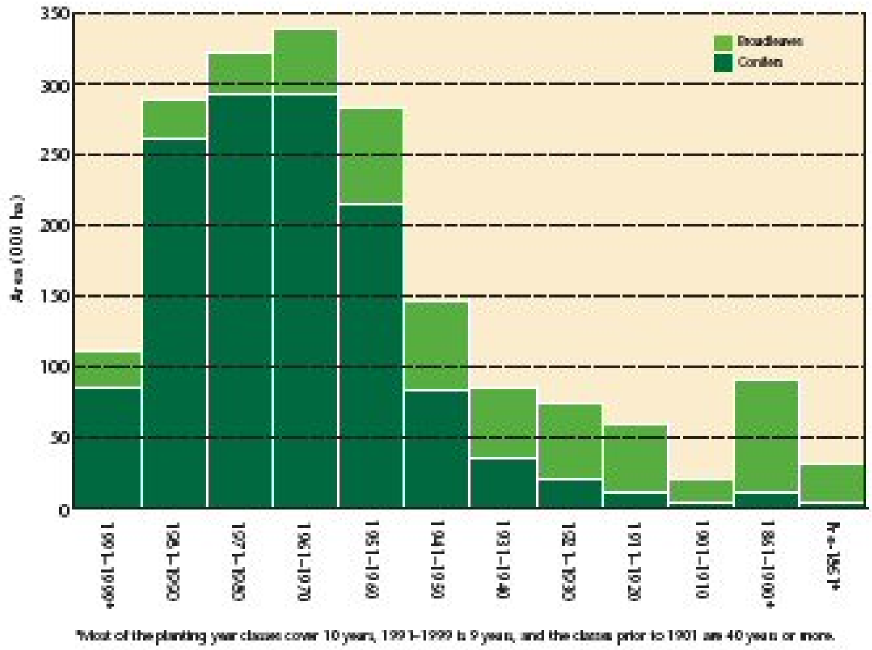


**Figure 1: Area of high forest in Great Britain by planting year class (Forestry Commission, 2003a)**

The major expansion of forestry in Britain was principally the result of the successful establishment of extensive plantations of conifers, generally in upland areas on land that was marginal for agriculture. These plantations are largely composed of stands of single species (predominantly Sitka spruce (*Picea sitchensis* (Bong.) Carr.), Scots pine (*Pinus sylvestris* L.)

or lodgepole pine (*Pinus contorta* Dougl. Ex. Loud.)) planted over a short time period resulting in uniform, even-aged forests. The use of mixed species tends to be limited to nursing mixtures to establish Sitka spruce on nitrogen deficient sites.

The majority of plantations are managed using a system of clear-felling coupes of 5-20 hectares and replanting with bare rooted nursery transplants. Thinning of these stands is carried out where risk of windblow and site conditions allow, and is also influenced by the availability of markets for small roundwood and transport costs. Rotation lengths are generally in the range of 40 – 60 years, with the result that there has been a steady increase in timber production from British forests over the last 10 years, as the stands planted in the second half of the 20th century mature and are harvested (Forestry Commission, 2003b, Figure 2). The availability of softwood from GB forests is forecast to continue to increase over the next 15 – 20 years (Smith *et al.*, 2001, Figure 3), although the actual level of harvesting, particularly in the private sector, will be influenced by factors such as market conditions and incidence of windblow.

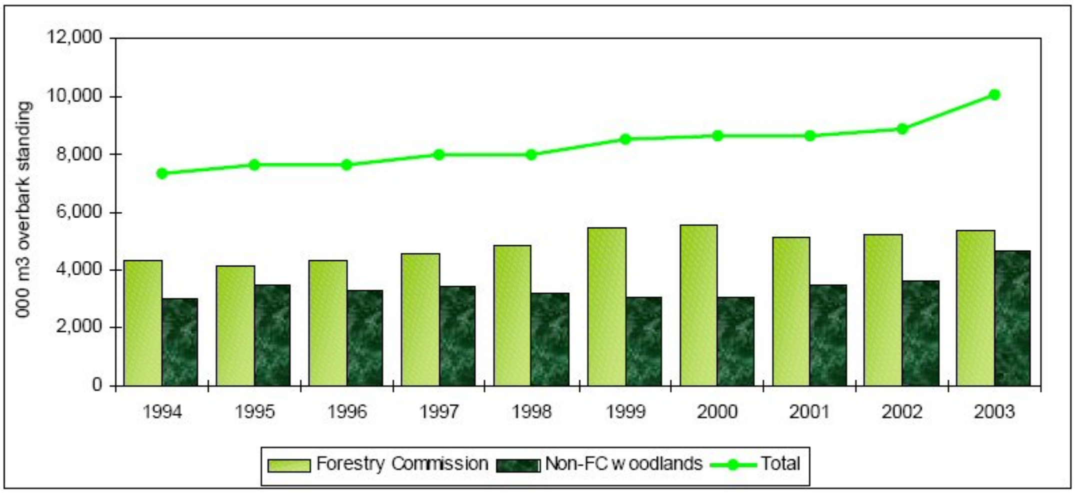


**Figure 2: Total softwood removals: Forestry Commission and non-FC woodlands (Forestry Commission, 2003b)**

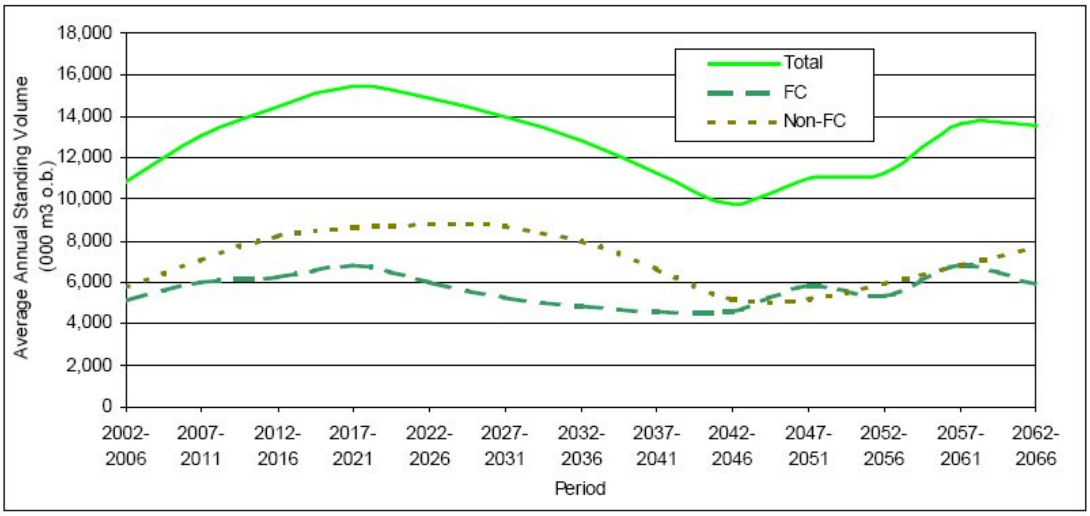


**Figure 3: Forecast of softwood availability from GB forests (Smith *et al*., 2001)**

The conifer plantations established from the 1950s onwards provided a supply of timber that has enabled the development of a major wood processing sector in Britain. Softwood logs are processed in sawmills primarily for the construction, pallet, packaging and fencing markets, while small roundwood is used in the wood based panel industry or for the production of pulp and paper. The even-aged clear-fell and replant systems widely used have made the forecasting of timber yields relatively straightforward. Investment in new technology and increased processing capacity by the wood using industry has been informed by the forecasts of softwood availability produced by the Forestry Commission, in collaboration with private growers. Over the last 15 years more than £1.6 billion has been invested in the British wood processing industry and a further £2 billion is expected to be invested over the next fifteen years, based on a number of estimates of recent and future investment rates (Forestry Commission, 2005).

Forest policy and public expectations have evolved since these conifer plantations were established and forests are now required to deliver an increasingly diverse range of benefits. There is a growing emphasis from governments, policy-makers and the public on the non-economic benefits that forests can provide, with forest owners and managers being encouraged to maximise additional benefits such as wildlife habitats, opportunities for recreation, health promotion, landscape enhancement and carbon sequestration.

During the 1980s increased efforts were made to minimise the visual impact of clear-felling on the landscape and introduce greater diversity through the development of forest design plans and restructuring of large even-aged plantations (e.g. McIntosh, 1995). Felling coupes were designed to fit in with the underlying landform and restocking introduced more open space and a greater diversity of species. In terms of timber production, this type of restructuring does not change the growing conditions of the main commercial conifer species, which continue to be managed in even-aged stands, albeit smaller ones. The forecasting of timber production for industrial processing is still a relatively straightforward process, and the quality characteristics of timber produced are unlikely to differ markedly from that produced in larger plantations, with the exception that there will be a greater proportion of "edge" trees, which tend to be more tapered and have heavier branches (Gardiner, 1996). In some cases the quality and volume of timber produced from these second rotation stands could be expected to be enhanced compared to the first rotation, where improved plants from breeding programmes are used for restocking (Lee, 1999; Lee, 2004).

Whilst restructuring of large plantations has created greater diversity **between** the individual stands in plantations, (in terms of species, age and size class differences), greater habitat diversity and amenity value are likely to be achieved by increasing irregularity **within** the stands (Malcolm *et al*., 2001). The transformation of even-aged stands to continuous cover forestry systems (CCF) or alternatives to clearfell (ATC) is being increasingly used to develop more varied structures within even-aged stands. This change in the approach to managing conifer forests in Great Britain is endorsed in policy documents such as the UK Forestry Standard (Forestry Commission, 2004a) and the audit protocol for the UK Woodland Assurance Scheme (UKWAS, 2000) which expects managers to increasingly adopt "lower impact silvicultural systems". Different CCF systems are described more fully below but in general terms they can be said to be characterised by "the use of natural processes such as natural regeneration, the creation of varied stands with a range of species, working with site limitations, managing the ecosystem rather than the trees and a presumption against clear-felling" (Mason 2003).

The increasing interest in CCF systems at a national and international level has coincided with timber prices paid to forest owners in Great Britain falling to their lowest in more than 20 years (Figure 4). As a consequence, expenditure on replanting operations after felling is hard to justify in economic terms. The use of CCF systems, relying largely on natural regeneration to establish a successor crop, is an attractive alternative to the expensive process of ground preparation, planting and tending that is required when clear-felling and subsequent restocking is undertaken. There is therefore an increased willingness to adopt CCF systems, where practicable, than might otherwise have been the case. In addition some private growers see CCF systems as way of maintaining the capital value of their estate, whilst still obtaining income from thinning operations.

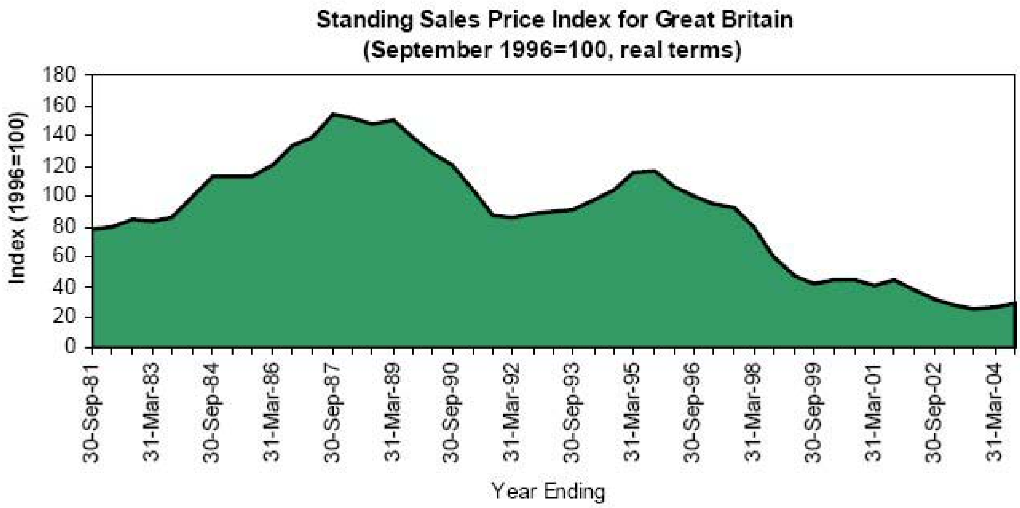


**Figure 4: Coniferous standing sales price index for Great Britain to September 2004 (Forestry Commission, 2004b)**

Whilst these more varied approaches to forest management are being widely adopted there is limited detailed knowledge and experience of putting them into practice or quantifying the likely outcomes in terms of the impact on timber supply and quality. Existing yield and timber quality models for the main commercial conifer species grown in GB cannot easily be used to predict the effect of these changes on the volume and quality of timber produced. The impact on the supply and quality of timber available to industry for processing is therefore uncertain at this stage. The consequences of these changes in management are likely to be more diverse forests than those that have been harvested in the past, with a greater range of tree sizes, crown structure and gap sizes.

**Silvicultural systems for continuous cover forestry**

The concept of continuous cover forestry, and the silvicultural systems that can be used to implement this type of management in UK forests, have been the subject of numerous publications during the last 15-20 years, (E.g. Matthews, 1989; Garfitt, 1995; Hart, 1995; Yorke, 1998; Kerr, 1999; Mason *et al*., 1999; Kerr and O'Hara , 2000; Malcolm *et al*., 2001; Kerr, 2002; Mason, 2002; Kerr *et al*., 2003; Mason, 2003; Ní Dhubháin, 2003; Mason and Kerr, 2004; Pommerening and Murphy, 2004). In addition the recently published "Managing the Pinewoods of Scotland" (Mason *et al*., 2004) describes the application of silvicultural systems suitable for the continuous cover management of Scots pine forests.

In this section we draw upon this published information to provide a review of the silvicultural systems that may be employed to transform even-aged stands to continuous cover forest management. We also highlight the elements of the transformation process and continuous cover management that differ from even-aged clearfell and restock systems in ways that can be expected to have an impact on log quality and timber properties.

***Definitions of continuous cover forestry***

Mason and Kerr, (2004) describe continuous cover forestry as "an approach to management that helps increase species and structural diversity in forests and so contributes to multi-purpose objectives". Pommerening and Murphy (2004) consider the definitions of continuous cover forestry in some detail. They cite more than twenty-five sources for alternative descriptions grouped into six broad categories according to the aspect of management that is emphasised: "i.e. continuity of woodland conditions, ecosystem management, structural diversity, retention, thinning/harvesting methods and philosophy". For the purposes of this paper we will concentrate on the definitions that have been put forward during the past 10 years as being applicable to UK forestry.

Hart (1995) defines continuous forest cover as "a general term covering several silvicultural systems which conserve the local forest canopy/environment during the regeneration phase. Coupe size is normally below 0.25 ha (50 x 50 m) in group systems; and in shelterwood – where used – is retained for longer than 10 years. The general aim of all systems within the concept is the encouragement of diversity of structure and uneven age/size on an intimate scale." Yorke (1998) refers to the early and widely quoted translation of the German term *"Dauerwald"* put forward by Troup (1927) "continuous forest – that is forest so treated that the (canopy) cover is continuously maintained, and the soil is never exposed". Mason *et al*., (1999) refer to the UK forestry standard (Forestry Commission, 1998) for a definition of continuous cover forestry which is given as "silvicultural systems whereby the forest canopy is maintained at one or more levels without clearfelling", where clearfelling is defined as the cutting down of all trees on an area of more than 0.25 ha. They further state that there are four guiding principles that underpin continuous cover forest management, i.e. "managing the forest ecosystem rather than just the trees; using natural processes as the basis for stand management; working within site limitations and creation of a diverse stand structure with a range of species". Ní Dhubháin (2003) suggests that continuous cover forestry systems are generally associated with natural regeneration, although this can be supplemented by planting. Hasenhauer (2004) defines continuous cover forestry as "a forest management system without clear-cutting including shelter wood cuttings and group or single tree selections, as well as target diameter cuts".

The key elements of the continuous cover forestry approach being applied to transform conifer plantations in the UK can be summarised as:

- Management of stands with the objective of increasing species and structural diversity
- An avoidance of clearfelling of areas greater than 0.25 ha (~ two tree heights wide) without the retention of some mature trees
- Using natural regeneration rather than planting in most instances

***Silvicultural systems to achieve continuous cover forestry***

Matthews (1989) defines silvicultural systems as "the processes by which the crops constituting a forest are tended, removed, and replaced by new crops, resulting in the production of stands of distinctive form". The United Kingdom Woodland Assurance Standard (UKWAS, 2000) suggests that appropriate silvicultural systems to meet the requirement for increasing use of low impact silvicultural systems in windfirm conifer plantations are "group selection, shelterwood or under-planting, small coupe felling systems, minimum intervention and single tree selection systems". Kerr (1999) presents an illustration of the broad differences between silvicultural systems (Figure 5).

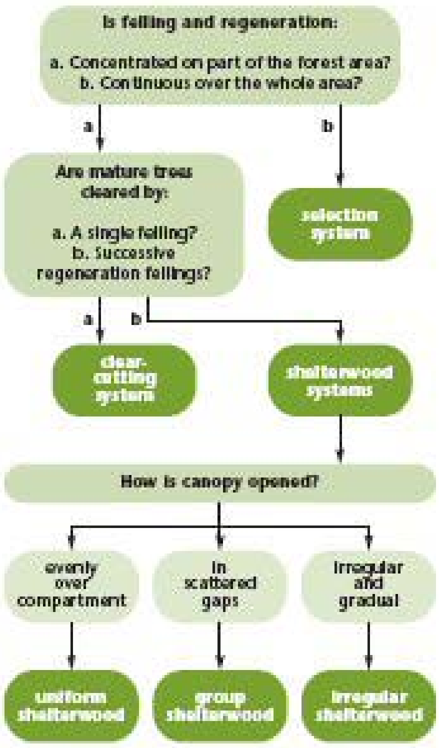


**Figure 5: A decision tree for classifying the main silvicultural systems, from Mason and Kerr (2004) (adapted from Kerr (1999)). Note that selection systems can be further subdivided into group or single-tree selection depending upon the shade-tolerance of the species involved**

The main silvicultural systems that might be used in continuous cover systems are described briefly below, based largely on the classification put forward by Matthews (1989) in "Silvicultural Systems", to which readers should refer for a more detailed explanation and illustrations.

*Shelterwood systems*

Shelterwood systems are those in which the young trees are established under the overhead or side shelter of the older crop, which is retained for some time to provide seed or protection from climatic extremes. Felling and regeneration operations are concentrated on part of the forest area. The older stand is removed in a series of fellings, starting with a "regeneration felling" which is followed by a varying number of "secondary fellings". Once the young stand has been fully established the remaining seed trees are removed in a "final felling", although in some instances a small number of the older trees may be retained indefinitely as reserves for biodiversity or aesthetic reasons. Natural regeneration is generally the preferred method for establishing the successor crop, although planting may be used to introduce more favoured species or genotypes, or where natural regeneration is not successful. The speed with which the canopy is opened up and the length of the regeneration period over which the older crop is removed will depend on a number of factors including choice of species (shade bearing characteristics, frequency of good seed years, seed characteristics), local climate, competing vegetation (depends on site fertility) and browsing pressure on the young regeneration.

The distinctions between the different shelterwood systems lie in the way in which regeneration fellings are carried out and their distribution in time and space:

- *Uniform shelterwood system*

  This system involves the uniform opening up of the canopy over a large area for regeneration purposes, leaving a target number of "seed bearers", depending on the shade tolerance of the species in question, to provide seed from which the successor crop will establish (e.g. Mason, 2004, recommends 100 -150 seed trees per ha for Scots pine). The seed bearers should ideally be well rooted trees of good form with vigorous crowns likely to produce large quantities of seed. Thinning prior to the regeneration felling should have favoured the development of the seed trees. The older stand is removed gradually in successive fellings, depending on the speed of establishment of the young crop and its shade tolerance. The successor crop produced is essentially even-aged and uniform in character, with the exception of any trees from the older stand that are retained. The *seed tree system* is a variant of the uniform shelterwood suited to light demanding species, where a smaller number of scattered trees (20-50 trees per ha) are left on site as seed trees, then removed in one operation once regeneration is established.

- *Group shelterwood*

  In the group shelterwood system, gaps are opened up in the canopy, usually around existing advance regeneration, in a series of ever widening circles. Eventually the regenerating groups coalesce and the final seed trees can be removed, leaving a stand that is initially somewhat irregular in structure, although by the time pole stage is reached the crop is usually more uniform as a result of cleaning and thinning (Matthews, 2004).

- *Strip shelterwood*

  The strip shelterwood system is designed to minimise damage to the standing crop from wind or snow. Trees are felled in a narrow strip, usually around 1-2 tree heights in width, running at right angles to the prevailing wind direction. Further strips are felled in a sequential fashion, in the prevailing wind direction, until the young crop is successfully established. Group or seed tree felling can be used within the regeneration areas (Mason, 2004). This system results in a very regular structure within the forest composed of repeated bands within which there is a gradient in age-class and size.

- *Irregular shelterwood*

  The irregular shelterwood involves a system of successive regeneration fellings with a long and indefinite regeneration period, resulting in a successor crop that is diverse with a range of age and size classes present throughout the stand. Given the extended regeneration period and complex nature of the fellings, careful planning of extraction routes is required to prevent damage to the regenerating crop.

*Selection systems*

Selection systems are characterised by felling and regeneration operations taking place throughout the forest area simultaneously, involving the removal of scattered single trees or small groups of trees. These systems result in “an uneven-aged or irregular type of forest in which all the age or size classes are mixed together over every part of the area” (Matthews, 1989).

- *Single tree selection*

  The basis of this system is the selective removal of scattered single trees across the entire forest area, leaving a continuous series of age classes and allowing continual recruitment to the growing stock through natural regeneration. The result as described by Hart (1995) is a diverse stand where "the canopy is complete and very deep, extending right down to ground level; there are usually three canopy layers which approximate to small sized, middle-sized and large trees". This system is characteristic of central European forests composed of mixtures of shade-tolerant species. The gaps created by the removal of single trees do not allow sufficient light penetration for the successful regeneration of light demanding species, which need to be managed using the group selection system. Since the main commercial conifer species grown in Britain can either be classed as light demanding (pines and larches) or only intermediate in their shade tolerance (Douglas fir, Sitka and Norway spruce) (Mason et al. 1999), there is limited scope for use of the single tree selection system in the transformation of conifer plantations in the UK (e.g. Malcolm et al., 2001).

- *Group selection*

  When the selection system is applied to light demanding species small groups of trees are felled to create areas large enough to allow sufficient light for successful regeneration. The size of the groups opened up will depend on the species being regenerated and can be varied to create diversity. Malcolm *et al*. (2001) give guidance on minimum gap sizes for British conifers, taking into account the northerly latitude and the oceanicity of the climate (resulting in increased levels of cloud cover), which both affect the amount of light reaching the forest floor. Recommended gap sizes range from 0.05 ha for silver fir and western hemlock, through 0.1-0.2 ha for Douglas fir and Sitka spruce and up to greater than 0.2 ha for larch and pine species. The aim is to create a mosaic of age classes within a small area (Mason, 2004).

***Application of silvicultural systems to transform even-aged stands***

As stated previously there is an increasing interest in, and incentives for, the transformation of even-aged stands from clearfell systems to continuous cover forest management. It is widely recognised, however, that transformation will not be appropriate in all circumstances and that the high risk of windblow inherent to many upland forest sites in Britain will restrict the opportunities for intervention in large even-aged plantations. In addition, forest management under continuous cover systems will not be desirable in all circumstances, and in some instances clearfelling may be preferable to provide habitat for particular species of wildlife. For example, recent work has shown the importance of clearfell areas as a habitat for small mammals, such as field voles, which are an important food source for predatory birds like tawny owls and short-eared owls (Petty and Lambin, 2004). Similarly, in the pine forests of

East Anglia, the open areas resulting from clearfelling provide an important habitat for woodlarks and nightjars (Green and Bowden, 1996).

Recent guidance on the choice of silvicultural system appropriate for the transformation of even aged conifer stands in different circumstances is provided by Mason and Kerr (2004). They suggest that the decision to transform an even-aged stand to continuous cover management should be based on a detailed site and stand appraisal which will establish the feasibility of the proposed operation, taking into account factors such as stand stability (ideally using the wind risk software Forest GALES (Gardiner *et al*. 2004)), likelihood of achieving successful natural regeneration and access for harvesting operations. Regarding the choice of system to be used Mason and Kerr (2004) propose that managers should consider the type of stand structure that will best achieve their objectives, differentiating between:

- Simple structure, with 1 or 2 canopy layers – achieved by the uniform or group shelterwood systems
- Complex structure, with 3 or more canopy layers – achieved by an irregular shelterwood or a selection system

The application of continuous cover forestry systems for conifers in Britain is still at a relatively early stage of development and the available guidance is subject to ongoing review and updating. As a result the systems in use are not always strictly defined but are guided by broad principles, with managers trying out different techniques to meet their objectives and adapting their management according to the experience gained. It is possible, however, to identify key aspects of CCF management, common to all systems, that differ from even-aged clearfell-restock systems in ways that affect tree and stand growth. The following elements can be expected to have an impact on log quality and timber properties:

- Longer rotations
- Increased thinning
- Creation of gaps
- Increased variability
- Restricted genetic change

**Aspects of transformation likely to affect log quality and timber properties**

***Longer rotations***

The average age of felling for commercial conifer stands managed under clearfell systems is currently in the order of 40-50 years (e.g. Forestry Commission, 2004c). A key feature of the continuous cover forestry systems described above is that some trees in the stand will be retained well beyond these standard rotation ages to provide seed and shelter for the regenerating younger crop, as well as for landscape and biodiversity reasons. Malcolm *et al.* (2001) suggest that while some species start to produce cones as early as 20 years, for most conifer species the abundance and quality of seed is unlikely to be sufficient for successful natural regeneration before 30 – 40 years after planting. In addition, the frequency of mast years (when heavy cone crops are produced) will affect the age at which natural regeneration can be successfully established in shelterwood or group selection systems. It can therefore be seen that extending current rotations by at least 20 years is likely to be necessary to achieve successful establishment of the successor crop. Where a complex structure stand structure is an objective of management, using irregular shelterwood or group selection systems, retention of older trees may be for significantly longer periods.

The result of delaying the felling of the older element of the stand will be taller trees, with larger diameters composed of wood laid down over a longer period, in comparison to those felled at an earlier age. All of these factors can have an influence on log characteristics and wood properties. In addition it should be noted that trees selected as seed bearers in shelterwood and selection systems are likely to have deep crowns and to be relatively highly tapered – characteristics sought after to promote seed production and stability.

***Increased thinning***

Thinning can be defined as “the removal of a proportion of trees in a crop, ….. usually practised in order to provide more growing space for the remaining trees, to increase the total yield of usable timber over the life of the stand, and to provide an intermediate yield of timber” (Rollinson, 1999). In even aged conifer plantations in Britain, standard thinning practice generally involves the systematic removal of entire rows of trees to allow access for harvesting machinery, often combined with a selective thinning in the matrix between these racks. The selective element of the thinning is normally of the “intermediate” type, involving the removal of most suppressed and sub-dominant trees together with trees of inferior stem form, and also opening up of the canopy by breaking up groups of competing dominant and co-dominant trees. The aim is to achieve an improvement in the quality of the crop and leave a fairly uniform stand where further increment is concentrated on the best trees that will form the final crop and reach sawlog dimensions earlier than would have been the case in an unthinned stand. The rate at which volume is removed is known as the thinning intensity

(Rollinson, 1999). This is normally calculated to enable the maximum volume of timber to be harvested without any loss in cumulative volume production from the site, i.e. marginal thinning intensity. In upland conifer stands thinning practice is strongly influence by the risk of wind damage and some stands may be designated as “no-thin” owing to their extreme vulnerability to windblow. In addition thinning of even aged plantations may not take place owing to operational constraints (lack of access roads, lack of suitable equipment available) or financial considerations (poor market for small diameter material, distance from markets, excessively high operational costs).

In continuous cover forest management, and during the process of transforming even aged stands to CCF systems, thinning is the key tool used by managers to manipulate the stand structure, the canopies of potential seed bearing trees and the light environment for the establishment of a successor crop. Some of the objectives of thinning practice, and the way in which it is applied, will differ from the intermediate type thinning practised in even-aged stands. In common with even aged stands, improvement of the quality of the crop by removing trees of poor stem form or those with excessive branching (“wolf” trees), will still normally be an objective. Additionally, however, thinning will be aimed at developing the crowns of the trees expected to remain on site to provide seed for the successor crop, developing the stability of these trees and manipulating the light environment of the forest floor to develop the type of vegetation cover that will promote advance regeneration or allow seeds to germinate once gaps have been opened up in the canopy (Mason and Kerr, 2004).

To achieve these aims it is likely that there will be greater use of crown thinning (Mason and Kerr, 2004). In a crown thinning trees are removed primarily from the upper canopy, i.e. some dominants and co-dominants. The aim of a crown thinning is to give selected dominants or co-dominants freedom to grow rapidly by gradual removal of competing trees. In a shelterwood system these trees will be those selected as seed bearing trees to form the overstorey beneath which the successor crop will regenerate. In a group selection system these trees are likely to form the matrix within which gaps will be opened up around advance regeneration.

Mason and Kerr (2004) provide guidance on thinning strategies that can be adopted to implement different silvicultural systems to achieve simple or complex continuous cover stands. Several key elements of thinning practice as it is likely to implemented in the transformation of even aged stands can be identified:

- Thinning is likely to be more regular and to continue later in the life of the stand, which is being managed on a longer “rotation” than even aged stands have generally been in recent years
- Thinning will normally aim to remove trees of poor form and branching habit
- Thinning will favour trees with well developed crowns and high taper, as these are expected to be most stable and have the greatest capacity to produce heavy cone crops and large quantities of seed
- In order to try and improve the stability of stands and develop the crowns of seed trees, thinning is likely to be slightly heavier than previously practised in even aged stands (Mason and Kerr, 2004). Depending on the timing of first thinning this could prolong the retention of deep living crowns within the stand
- The use of crown thinning will mean that sawlog diameter material will be produced from stands at a younger age than was previously the case. Whereas most dominants in an intermediate thinning would be left to form the final crop, a proportion of these will be removed during crown thinning.

***Creation of gaps***

In even-aged clearfell management systems trees are generally planted in either a square or rectangular pattern that achieves uniform spacing across the stand, giving each individual an equal amount of growing space. Subsequent thinning is normally designed to maintain this evenness of stocking density and will avoid opening up any large gaps in the canopy which may result in windblow or cause uneven crown or stem development. Transformation of even-aged stands to continuous cover systems, however, will generally involve the creation of gaps in the canopy that will affect the remaining trees which have been left in the stand to provide seed or shelter.

In the uniform shelterwood system the canopy is opened up evenly across the stand, so each tree will be affected in a more or less similar way, receiving an increased amount of light and wind loading. In group, strip and irregular shelterwood systems, and in the group selection system, gaps are created either around advance regeneration or to allow sufficient light in to promote regeneration. In these circumstances the trees around the edge of the gap will be growing in a different environment to the matrix of the stand, with an uneven light environment affecting crown development and an increased wind loading. The regenerating young trees in the gap will also have a range of growing conditions, with those at the edge of the group, more influenced by the older trees, receiving less direct light than those in the middle of the group.

***Increased variability***

Given that a common objective of continuous cover forest management is to increase the species and structural diversity of conifer plantations in Britain, it is evident that there will be an increase in the variation between trees within the forest and consequently the timber harvested from them. Whereas one objective of management in an even-aged stand is often to **enhance** uniformity by thinning operations, in continuous cover systems the aim will be to **reduce** uniformity. This increased variability during the transformation phase is likely to be in terms of spacing between trees, tree heights and diameters and crown characteristics. As the successor crop begins to regenerate there will also be an increase in the variability of species and age class. This increase in variability is likely to be greatest in irregular shelterwood or group selection systems, and least in uniform shelterwood systems.

***Restricted genetic change***

As described previously natural regeneration is generally the preferred method of establishing a successor crop in continuous cover forestry systems. Using natural regeneration avoids some of the costs associated with artificial planting, normally higher in CCF systems than in a clearfell-restock system, owing to the dispersed nature of the planting site. However, when natural regeneration is used the species and genetic make-up of the successor crop will be consequent on the stand from which it is being regenerated. The only opportunity for improvement in terms of vigour, stem form or other characteristics will be through the use of selective thinning to favour better trees. The characteristics of the regenerating stand will depend on the characteristics of the previous stand and those of surrounding stands from which seed may be blown, unless enrichment planting of preferred species or improved genotypes is used.

**Timber quality criteria**

The widely used term “timber quality” can be defined in many ways. One useful definition is “all the wood characteristics and properties that affect the value recovery chain and the serviceability of end-products”. For the purposes of this paper we will consider some of the key log characteristics and wood properties that affect the “fitness for purpose” of timber for two main end-uses, namely construction and joinery. At the moment only a very small amount of British grown softwood is marketed into joinery end-uses, but this is a higher value end-use that many growers would like to gain access to for marketing of better quality material.

In construction the key characteristics of sawn timber are dimensions, mechanical properties and dimensional stability in drying. The mechanical properties of bending stiffness (MOE) and bending strength (MOR) are critical for the performance and safety of timber used in building. Mechanical properties of sawn softwood in Britain are normally determined using machine stress grading that bends each piece of timber to assess its MOE, or more recently using newly developed x-ray grading technology (Holland and Reynolds, 2005). The changes in dimensions that occur as moisture content varies can result in severe distortion of sawn timber. Differential shrinkage of sawn timber during kiln drying can result in significant defects that can lead to rejection of the material.

For joinery end-uses the mechanical properties of timber are not usually critical, but the appearance of the wood and its woodworking characteristics (ease of planing, nailing, gluing, ability to take coatings) are important. Appearance grading for joinery takes into account the number and size of knots, whether knots are tight or loose, and the presence of splits, checks cracks and discolouration, (BSI, 1996). Dimensional stability is also an important performance criterion for joinery applications, where distortion in service must be avoided.

The wood properties and log characteristics that have a significant impact on softwood timber quality have been described in detail by Macdonald and Hubert (2002). These are summarised below.

***Key wood properties and log quality characteristics***

*Branching/knots*

The number and size of knots in sawn timber is determined by branch diameter, the number of branches in a branch whorl, the frequency of whorls and the insertion angle of branches. This last is important as branches with a steep insertion angle result in a greater knot area in the sawn board than those of equal diameter that have a more level insertion in the stem. The grading of softwood sawlogs in Britain recognises the importance of knots to timber quality. In order to be graded into the higher value “green” category, 80% of knots on any individual log must not exceed 5cm in diameter (Forestry Commission, 1993).

Knots have a significant impact on the mechanical properties of timber. The localised grain deviation around knots causes a reduction in the stiffness and strength of sawn timber (Brazier, 1986; Josza and Middleton 1994; Zhang, 1997). Maun (1992) found that a 10% increase in knot surface area in battens resulted in a 3% reduction in the out-turn of SC4 (~C24) grade timber. Whilst Cown *et al.* (1996) found that branch size had a minimal effect on drying distortion in radiata pine, Perstorper *et al.* (2001) reported that increased knot area resulted in greater longitudinal shrinkage in Norway spruce as a result of grain deviation. As described above knots are a critical factor when grading timber for joinery end-uses, with grading rules specifying allowable number and size of knots, as well as their condition, i.e. sound or loose.

*Grain angle*

Grain angle is measured relative to the longitudinal axis of the stem of the tree. The grain angle relative to the longitudinal axis of a sawn batten is determined not only by the inherent grain angle of the tree but also by the taper and straightness of the stem and the sawing pattern used in the sawmill.

Variations in grain angle can have a significant impact on the utilisation of sawn timber. Brazier (1986), Zobel and Jett (1995) and Desch and Dinwoodie (1996) all report that high grain angles significantly reduce the strength and stiffness of timber. Results of work carried out by Maun (1998) are in agreement, showing that grain angle had a significant effect on the machine grade stiffness of Sitka spruce, with increasing grain angle resulting in lower MOE.

It has been widely shown that increased grain angle in sawn timber results in significantly greater drying distortion, particularly twist (Harris, 1989; Maun, 1992; Walker, 1993; Danborg, 1994; Cown *et al.,* 1996; Perstorper *et al.,* 1995; Johansson and Kliger, 2002; Warensjö and Rune, 2004). This is of importance both for construction and joinery applications where dimensional stability is a key requirement.

*Wood density*

Wood density is a widely used indicator of timber quality. Density has been shown to be positively correlated with the strength and stiffness of small clear samples of wood, (e.g. Panshin *et al.,* 1964; CW final report) and consequently high density timber is generally associated with superior mechanical performance. In structural size samples, however, the presence of other strength reducing factors such as knots, variable growth rate, differing proportions of juvenile wood and variations in grain angle, mean that density alone is not always a good indicator of mechanical properties.

Zhang (1995) found that variations in wood density only explained part of the variations in mechanical properties observed in trees of differing growth rates and that this was particularly evident for *Abies* and *Picea* species. Kliger *et al.* (1995) reported that in Norway spruce density could be used with ring width and knot area to explain variations in batten stiffness and strength. Maun (1992; 1998) reported that although density was not the most important influence on Sitka spruce batten stiffness, it did have a highly significant effect. In conclusion then it can be said that density has an important influence on timber strength and stiffness, but that its impact on utilisation varies depending on the effects of other factors such as knots, grain angle and juvenile wood.

It has generally been found that lower density wood (characteristic of fast grown plantations) exhibits higher longitudinal shrinkage, but lower radial and tangential shrinkage (Bengtsson 2001; Perstorper et al. 2001). In terms of practical application, Perstorper *et al.* (1995) found that density had a minimal influence on the variation in drying defects found in construction size sawn Norway spruce samples.

*Juvenile wood*

Kucera (1994) notes that, as the name suggests, the term juvenile wood is widely used to describe the wood produced by cambium that is in the juvenile stage and is therefore located in the rings near the pith and is present as a central core (cone) within the stem of a tree (Figure 6). The properties of juvenile wood exhibit a pattern of change outward from the pith and differ markedly from those of mature wood. Juvenile wood is generally characterised by low density, high grain angle, short tracheids and high microfibril angle, with the result that it has low strength and stiffness and poor dimensional stability compared to mature wood (e.g. Zobel and Sprague, 1998).

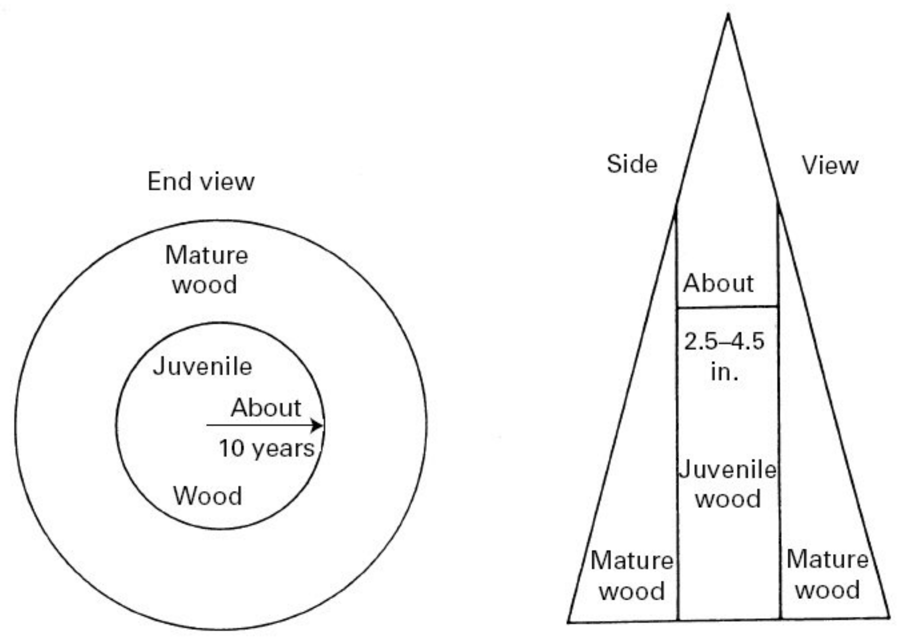


**Figure 6: The concept of juvenile wood shown schematically for loblolly pine (*Pinus taeda*) for a cross section and vertical distribution within the tree (after Zobel and Sprague, 1998).**

Some recent studies (Amarasekara and Denne, 2002; Gartner *et al.*, 2002; Burdon *et al.*, 2004) have revisited the categorisation of juvenile and mature wood, and evaluated the influence of the living crown on variations in wood properties. The concept that the extent of the living crown may determine the timing of the transition from juvenile wood formation to mature wood formation is an important one for continuous cover forestry, where crown manipulation is a key tool used to encourage seed production and promote a microclimate suitable for natural regeneration.

Amarasekara and Denne (2002) note that in addition to juvenile wood other terms have also been applied to this central zone within the tree, including “core wood” and “crown-formed wood” (i.e. wood formed under the influence of the living crown) (e.g. Larson 1969). They found that in Corsican pine the influence of the crown was not the principle determinant of fluctuations in wood properties, but was superimposed on the inherent pattern of change from juvenile to mature wood. Gartner *et al.* (2002) studied the effects of live crown on patterns of wood density and growth in Douglas fir. They found that crown position had no effect on the transition from juvenile to mature wood, when considering wood density, suggesting that cambial age was the most important factor. Most recently Burdon *et al.* (2004), considering *Pinus radiata* and *P. taeda,* presented a detailed examination of both the radial and the axial variation of wood properties in these species. They suggest that within-stem variation should be interpreted in terms of two distinct progressions: firstly from the pith outwards (corewood to outerwood) and secondly from the ground upwards (from juvenility to maturity, where it is the maturation of the apical meristem that is considered to influence wood properties). Importantly, they note that some characteristics of importance to the performance of solid wood products, such as microfibril angle (which influences stiffness and dimensional stability), show an improvement further up the stem, when the same growth ring is considered.

The study of patterns of variations of wood properties within trees and the categorisation of different wood types are clearly the subject of ongoing studies. For ease of reference within this paper we will retain the definition of juvenile wood as the wood found within the first 12 rings from the pith.

*Compression wood*

Compression wood is present in all conifer trees, forming in branches and in the stem wood beneath branches, on the underside of leaning stems, on the leeward side of trees exposed to strong winds, in crooked stems and in the lower part of trees growing on a slope (Walker, 1993; Desch and Dinwoodie, 1996; Nicholls, 1982; Rune and Warensjö 2002). Vigorous growth in conifers has also been observed to result in the formation of mild compression wood all round the stem (Walker, 1993). Although the exact mechanism for compression wood formation is not fully understood its function can be described as to "act to correct the lean of the stem" (Walker, 1993) or to "oppose forces deforming the tree and to restore or maintain a specific pattern among tree parts" (Low, 1964).

The structure and chemical composition of compression wood differs from that of normal wood. The tracheids are shorter with thicker cell walls and are more rounded in cross section, resulting in the formation of intercellular spaces. The $S_3$ layer is often absent and the $S_2$ layer is highly lignified with internal helical checks corresponding to the microfibril angle, which is abnormally high and between 30 and 50° (Walker, 1993).

The presence of compression wood can have a significant effect on timber utilisation. The excessive longitudinal shrinkage which occurs in compression wood results in increased incidence of drying distortion in sawn timber, specifically bow and spring (Perstorper et al. 2001; Kliger *et al.*, 2002; Warensjö, 2003; Warensjö and Rune, 2004). There is deterioration in the mechanical properties of sawn timber, characterised by breakage in a brittle manner. Ni Dhubhain et al. (1988) examined the effects of different levels of compression wood development on the mechanical properties of structural size Sitka spruce battens. They found that while the Modulus of Elasticity (i.e. stiffness) decreased with increasing compression wood content, the ultimate bending strength (Modulus of Rupture) was not affected. They noted, however, that 70% of the battens which had more than 10% compression wood ruptured in a brash manner during MOR testing which indicates that such timber might fail under impact without warning. These findings are in agreement with those reported for other softwood species (Timell, 1986; Walker, 1993; Gardiner and Macdonald, 2005). Compression wood is very hard, making it difficult to nail or work with ordinary tools and reducing its suitability for use in joinery applications.

*Growth rate*

Growth rate, which is reflected in the width of annual growth rings, can have a significant effect on timber utilisation. Fast growth during the period of juvenile wood formation results in a large juvenile core and therefore a higher proportion of undesirable juvenile wood being present for a given log diameter (Macdonald and Hubert, 2002).

The relationship between growth rate and wood density is complex and varies between species. The previously widespread belief that fast diameter growth in conifers always results in the production of low density wood with inferior mechanical properties was challenged by authors in the 1940s and 1950s (e.g. Turnbull and du Plessis, 1946; Turnbull, 1948; Rendle, 1958; Rendle, 1959). Turnbull (1948) advanced the theory that in pine stems the specific gravity of wood formed in a particular year is not determined by rate of growth but is proportionate to a function of age as measured in number of rings from the pith.

Rendle and Philips (1958) compared the density of wood formed early in life with the density of wood of similar ring width formed later in Corsican pine and Douglas fir. In Douglas fir they found that there was no significant relationship between ring width and density, and that there was a trend of increasing density outward from the pith for the same ring width. With the Corsican pine samples they again found that wood from the outer rings was significantly denser than that from the inner rings for the same ring width. There was some evidence of a relation between ring width and density for rings that were the same age from the pith, with density tending to increase with diminishing ring width. Rendle and Philips concluded that the importance of growth rate in determining density had been over-rated for these species. Henderson and Petty (1972) examined the relationship between ring width and density in two provenances of Lodgepole pine (central Interior BC and southern Coastal), considering rings 16-20 from the pith. They concluded that ring width accounted for a relatively small part of the variance in density. In spruce, however, increased growth rate at any age has been shown to be associated with the formation of lower density wood, (Brazier, 1970a; Zhang, 1995). Brazier showed that in Sitka spruce this was due to an increase in earlywood width, together with a reduction in its average density, without a corresponding increase in latewood width.

These results are in agreement with the conclusions reached by Zobel and van Buijtenen (1989) who reviewed much of the literature relating to the effect of growth rate on wood density. They state that "...it seems safe to generalise that increased growth rate in conifers generally lowers specific gravity with the exception of the hard pines, *Pseudotsuga* and *Larix*" and "within the hard pines there is generally little or no relationship between wood specific gravity and growth rate of the individual tree". The pine species grown commercially in Britain, (Scots pine, lodgepole pine and Corsican pine) all fall within the Subgenus Diploxylon (the "hard" or "yellow" pines).

Visual grading rules for joinery have limits for ring widths which must not be exceeded if the timber is to be acceptable.  In addition, unevenness of growth rate resulting in widely varying growth ring widths can cause problems for drying, planing and gluing timber.

*Diameter*

The diameter of logs determines the sizes of sawn timber that can be cut and affects value recovery as unit costs during harvesting, transport and processing are lower for large diameter logs. There are restrictions, however, on the diameter of sawlogs that most modern British sawmills are designed to process, with the majority currently unable to accept logs with a butt diameter greater than 55 cm. Large trees yielding large diameter sawlogs can also pose operational difficulties in the forest, as the widely-used mechanised harvesting and extraction equipment is not designed to handle the dimensions and weight of bigger trees and logs.

*Taper*

The term taper refers to the rate of decrease in diameter with increasing height up the stem of a tree (Newnham, 1992). Increased taper results in reduced recovery of sawn timber and is also associated with higher grain angles and thus reduced strength, stiffness and dimensional stability (Zhang, 1997).

*Stem straightness*

Poor stem straightness has a negative impact on value recovery at all stages of the wood production chain and crooked trees are therefore of lower quality than straight trees for all end uses. The proportion of high quality sawlogs that can be cut, and their length, is reduced while the cost of extraction and transport may be increased due to the greater space occupied by bent logs.

In the case of sawn timber, volume recovery is reduced compared to logs that are straight. The deviations in grain angle and increased compression wood formation that accompany bent stems (Harris, 1989; Nicholls, 1982; Sinnott 1952) also result in poorer mechanical performance and increased drying distortion.

## Evaluation of the effects of transformation on log quality and wood properties

### *Longer "rotations"*

As described previously, transformation of even aged stands to continuous cover management will involve extending rotations by perhaps 20- 50 years, when compared to the average felling ages currently applied for commercial conifer crops in Great Britain. Two aspects of retaining trees to older ages need to be considered: firstly, the impacts on timber quality and secondly the operational and marketing implications of harvesting older, bigger trees.

*Timber quality*

Growing trees on a longer rotation gives managers greater opportunity to produce high quality timber. Regular selective thinning, which can be expected to be practised in stands being transformed to continuous cover management, should concentrate increment on final crop trees of good form and maintain an even growth rate. Logs produced from larger diameter, older trees will have a lower proportion of juvenile wood, resulting in a greater volume of mature wood with more desirable wood properties in terms of mechanical performance and drying stability – higher density, lower microfibril angle, lower grain angle. Figure 7 and Table 1 illustrate the predicted impact on juvenile wood proportion of extending a Sitka spruce rotation from 40 to 60 or 80, where an intermediate thinning model has been applied. Guldin and Fitzpatrick (1991) compared log quality in a natural uneven aged stand of Loblolly pine with that found in two even aged stands, one planted and one natural. They found that the uneven stands produced logs of a better grade than the even-aged plantations, and attributed this difference in part to the fact that trees of a given size were older in the uneven aged stand.

With longer rotations there is the potential to produce a significant amount of knot-free timber in the valuable sawlog part of the stem, once branches have self-pruned, particularly in Scots pine and larch, which lose branches readily. However, there is also the potential to produce extremely large coarse trees with big branches, especially in the case of relatively open-grown Douglas fir or Sitka spruce. The selection of seed trees with deep vigorous crowns, desirable for stability and seed production, will tend to favour final crop trees with large branches, at least in the upper part of the stem. Similarly, whilst stem taper is generally lower in older trees, this effect is likely to be mitigated in stands undergoing transformation by the selection of seed trees with high taper. Recent work by Kladtke (2005), has investigated the possibility of maintaining acceptable wood quality in Norway spruce stands by controlling stem taper. He notes that thinning focused on final crop trees will tend to favour more highly tapered trees with low height/diameter ratios to minimise the risk of wind or snow damage, but that these trees will also have large branch diameters and wider growth rings. He suggests that maintaining stem diameter at a height/diameter ratio of greater than 60 will result in branch diameters that do not exceed 4cm, considered the maximum acceptable for good timber quality in his study.

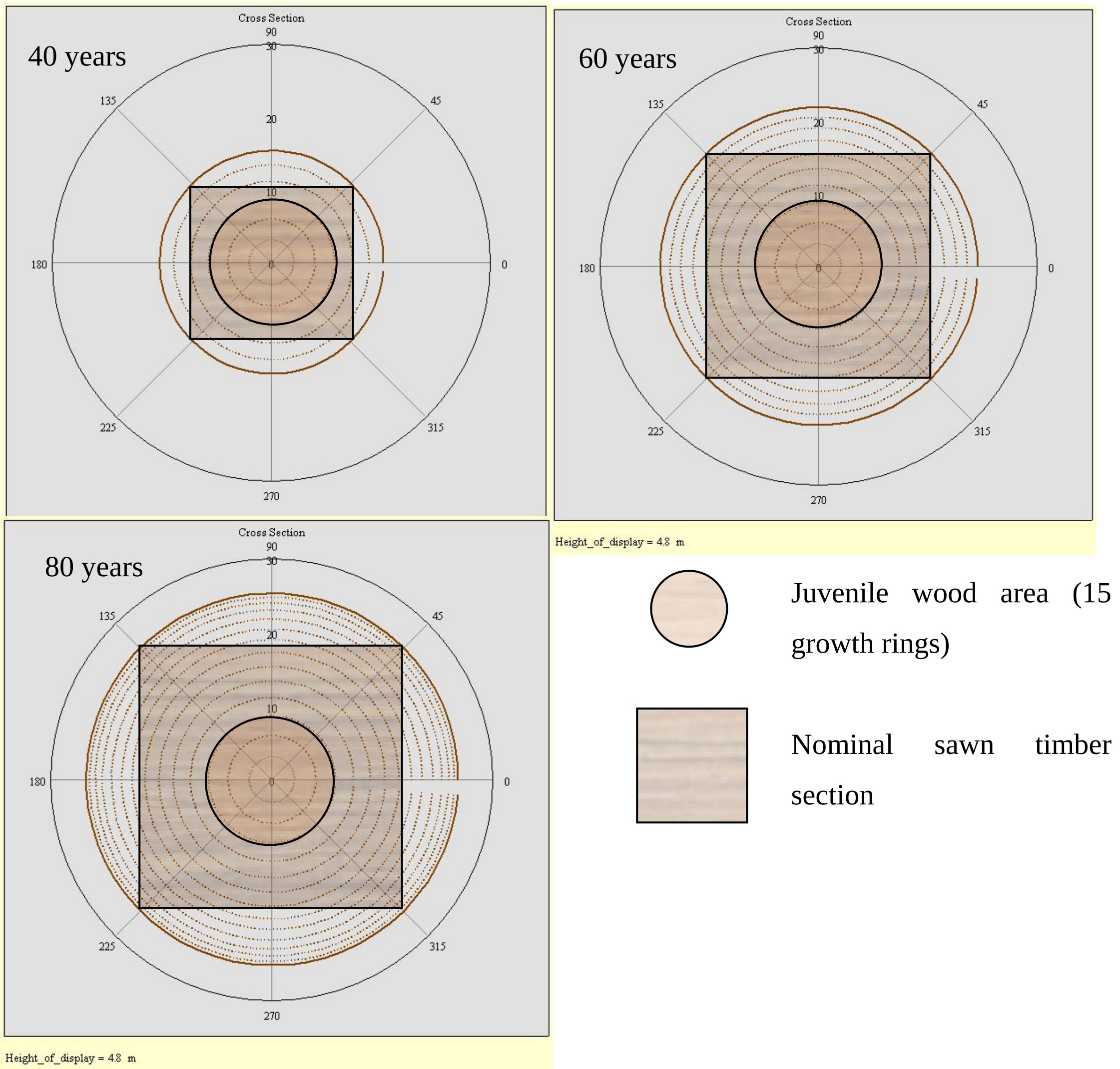


**Figure 7: Predicted wood properties of Sitka spruce, YC 24, 1.7 m spacing with intermediate at 40, 60 and 80 years. Growth ring pattern in cross section at 4.8 metres (top of butt log) showing juvenile wood area**

| Rotation length | Juvenile wood proportion in relation to log cross-section | Juvenile wood proportion in relation to sawn timber section |
|---|---|---|
| 40 years | 32% | 50% |
| 60 years | 16% | 25% |
| 80 years | 12% | 19% |

**Table 1: Predicted wood properties of Sitka spruce, YC 24, 1.7 m spacing at 40, 60 and 80 years. Juvenile wood proportion in relation to log cross-section and sawn timber section**

*Operational and marketing implications of larger trees*

Modern mechanised harvesting systems are optimised for the felling and extraction of trees with an average diameter at breast height of 25-35 cm. The limited availability of suitable machinery and trained labour to harvest large conifers may increase the operational costs associated with longer rotations.

Most modern sawmills are currently unable to process logs with a butt diameter greater than 50-55 cm, so if significant quantities of large diameter logs become available from continuous cover forests, investment in new processing technology will be required. Large trees have the potential to supply specific market demands for long lengths and large sections. However there is a limited established market for these larger dimension sawn products and many end-uses are now supplied by engineered wood products (e.g. I-beams), so at present there is little or no premium on large size logs.

Poncelet (2004) considers the issue of the quality and marketability of large conifers (Norway spruce, silver fir and Douglas fir) from the forests of Belgium, eastern France, the Black Forest in Germany and Switzerland. He notes that the concept of large conifers has changed with time. Whereas 150 years ago the French National Forest Inventory defined a large conifer as having a DBH of 46 cm or greater, this has now been reduced to 37.5 cm. The processing capacity of sawmills has developed accordingly. He suggests that there is a danger of large conifers decaying while standing, unless there is an incentive for owners to harvest and sell them into profitable markets. He concludes that poor quality large trees with big knots and wide growth rings are unlikely to be accepted in high value markets, but that good quality stems from stands that have been carefully managed have the potential to find good outlets. In order to produce better quality large trees he recommends either even-aged management with pruning and regular selective thinning up to an age of at least 70 years, or management in an uneven-aged, irregular stand where the final crop trees are identified early, favoured in thinnings and retained until at least 80 years of age.

***Increased thinning***

Stands that are selected for transformation to continuous cover systems will be those where it is judged that risk of windblow is sufficiently low to allow regular thinning to be carried out without an unduly high risk of damage occurring. It is therefore expected that these stands will be subject to programmes of regular selective thinning. These can be expected to have a generally positive effect on the log quality and wood properties of the crop, removing trees with poor stem form and excessively coarse branching to concentrate increment on the best stems in the stand. Compared to trees in an unthinned stand, those in a thinned stand will have a lower proportion of juvenile wood in the valuable sawlog part of the stem as their growth continues at a faster rate once the period of juvenile wood formation has ended (12-20 years). In British conditions this has been shown to result in an increase in the total volume of sawlog sized material that is produced and an increase in the proportion of higher value green logs (Methley, 1995). In Sitka spruce and Douglas fir the increased growth rate brought about by thinning will result in a reduction in wood density compared to the same growth rings in a no-thin regime. The greater uniformity of annual growth rings and the reduction in proportion of juvenile wood can be expected to compensate for this reduction.

As noted earlier it has been suggested that thinning in stands undergoing transformation to continuous cover systems is likely to slightly heavier than current standard practice (Mason and Kerr, 2004). Heavier thinning will favour retention of a deeper living crown with vigour branches. Depending on the time at which a heavy thinning is carried this could have a significant impact on log quality resulting in larger knots in the sawlog part of the stem. Heavy thinning is also known to increase stem taper (Brazier, 1977) due to wider spacing. It will also result in increased wind loading on the remaining trees, which tends to lead to increased amounts of compression wood, increased taper (to provide stability) and poor stem form (Jacobs, 1936; Low, 1964; Malcolm and Studholme, 1972).

One measure that might be considered to reduce these negative impacts in stands where the crop quality is generally high is to prune selected final crop trees. Pruning limits the extent and size of knots, producing a small knotty core and maximising the amount of clear timber formed. Pruning also has the effect of advancing crown recession, with the wood in the pruned part of the stem being less under the influence of the live crown (Megraw, 1986). It has been suggested that this accelerates the transition from juvenile to mature wood formation (Briggs and Smith, 1986) and thus reduces the volume of juvenile wood produced. There is also some evidence to suggest that pruning reduces taper (Henman, 1963). In stands where replanting costs are being saved through the use of natural regeneration, some growers may consider investing in pruning of selected trees in order to produce a final crop of high quality stems. In Sitka spruce, however, pruning may not result in the production of clear timber. Studies have shown that both heavy thinning and pruning in Sitka spruce can lead to the development of numerous epicormic sprouts (Deal *et al.*, 2003). Whilst these would not affect the suitability of timber for structural purposes (as there would be unlikely to be any appreciable loss in mechanical properties caused by the small knots arising from epicormics), the wood produced would not be suitable for joinery applications, owing to the frequency of the small knots.

The greater use of crown thinning will affect the quality of timber being produced from the thinning operation and the quality of timber in the remaining crop trees. Crown thinning will involve the removal of larger trees at a younger age than has been the case during the more commonly practised intermediate thinnings. For the grower this will be likely to be beneficial in financial terms as there will be an increase in the average tree size during thinnings, resulting in lower unit costs for the operation, and a higher proportion of sawlogs produced. These sawlogs will be younger for their diameter than logs produced at the end of a rotation from no thin stands or where intermediate thinning has been used. They will tend to have wider growth rings, lower density and a higher proportion of juvenile wood. They can therefore be expected to produce sawn timber with inferior mechanical properties and dimensional stability. The trees that remain in the stand after crown thinning will tend to be co-dominants of better form on which, depending on the timing of the thinning, branches on the most valuable part of the stem have already been suppressed. Since they have grown more slowly than the larger trees removed in the thinning they will have a smaller core of juvenile wood, higher wood density and narrower growth rings. Following the thinning, increment will be added to these trees and they have the potential to grow on to form final crop trees of good form, uniform growth and a small proportion of juvenile wood. Presenting the results of a study on the impact of spacing on timber quality, Brazier (1970b) suggests that for Sitka spruce grown at “wider spacing” (i.e. 1.8m and 2.4m), crown thinning offers an opportunity to produce better quality timber. Its use in the transformation of even-aged plantations to continuous cover systems could be expected, with careful attention to selection of trees and timing of thinning, to significantly improve the timber quality of the final crop. In addition, removal of some of the largest trees during thinning to concentrate growth on slower grown individuals could go some way to alleviate the operational and marketing difficulties associated with the production of large trees on longer rotations. Target diameter thinning, a technique where all trees above a certain diameter are removed, is likely to have a similar impact to crown thinning provided it is combined with an element of selection to remove poor quality trees (Sterba and Zingg, 2001).

Several studies have investigated the impact of different thinning strategies on timber quality. Seeling (2001) examined log quality, wood properties and sawn timber performance in Norway spruce from a thinning trial that included heavy thinning treatments that were similar to those that might be applied during transformation of an even-aged stand. The trees were aged 27 when the first thinning treatments were applied, and examination of the timber took place 23 years after that. Table 2 shows the number of trees per hectare for each treatment.

**Table 2: *From Seeling (2001)* Number of trees per hectare in different sampling plots for different years**

| | Number of trees per hectare | | | | |
|---|---|---|---|---|---|
| | **1973[a]** | **1974[b]** | **1980** | **1988** | **1995** |
| **Plot I** | 5410 | 3770 | 2049 | 1584 | 645 |
| **Plot II** | 4920 | 2680 | 1223 | 896 | 437 |
| **Plot III** | 5200 | 3900 | 800 | 800 | 400 |
| **Plot IV** | 5110 | 3240 | 431 | 417 | 236 |

[a] Before establishing the thinning trials [b] After establishing the thinning trials

When roundwood quality was assessed it was found that the widest spacing after thinning was associated with increased mean ring width, higher taper, bigger branch stubs, increased spiral grain, more compression wood and greater pith eccentricity in log ends. These differences represented a reduction in the quality of timber from the plots that had been most heavily thinned, which was reflected when logs were graded according to European Standard EN 1927-1 (Figure 8).

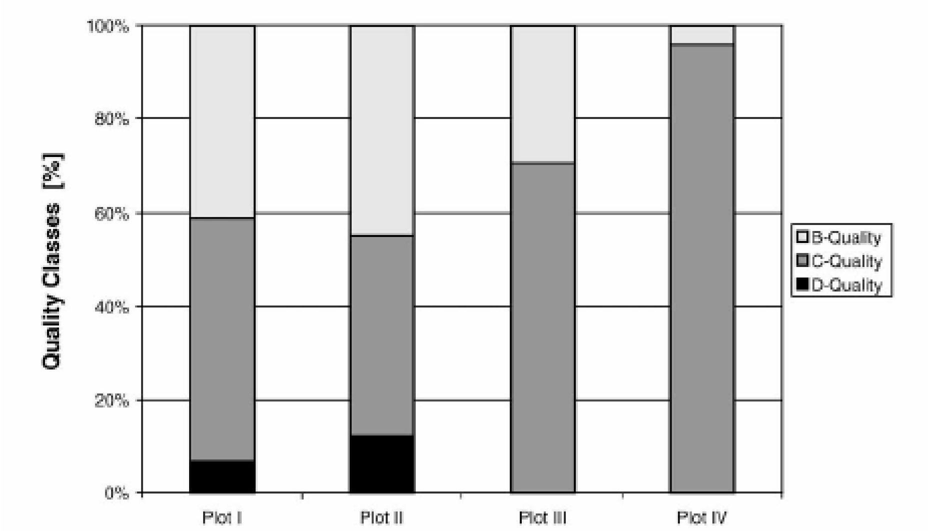


**Figure 8: *From Seeling (2001)* Roundwood quality (volume weighted) according to EN 1927-1 (A: best quality; D: worst quality)**

There were no Category A logs in any of the plots. Less than 5% of logs from the most heavily thinned plot were graded as Category B, with the remainder falling into Category C. In both of the least heavily thinned plot more than 40% of logs were graded into category B, with around 50% as Category C and a small number in category D.

Examination of the sawn timber showed increases in maximum knot diameters and amount of compression wood from material from the widest spaced plots, but these were not statistically significant. After kiln drying increased twist was found in timber from the widest spaced plots: This was thought to be associated with the increased amounts of compression wood. Both bending stiffness and bending strength showed a reduction with increasing spacing after thinning, but these were not statistically significant.

Jähagen and Lageson (1996) compared the effects of thinning from above (i.e. crown thinning) and thinning from below on the timber quality of the residual stand after a first thinning in Scots pine. They assessed the diameter of the thickest branch, stem taper, ring width, stem straightness and stem lean. The only significant differences that they found were for stem lean and stem straightness, where thinning from above resulted in fewer leaning or crooked stems. They suggested that the lack of differences in other characteristics may be due to the fact that in a first thinning all the trees in access racks for extraction have to be felled, reducing the element of selection in the thinning.

Pape (1999a, 1999b) reported the results of two comprehensive studies of the impact of different thinning treatments on the growth, wood properties and stem quality of Norway spruce growing on highly productive sites in southern Sweden. Different intensities of thinning from below (removing 20% of basal area in each of 6 thinnings, 40% of basal area in each of 3 thinnings or 70% of basal area in 1 thinning respectively) were compared with a no-thin (or “natural thinning” regime) and thinning from above (20% of basal area removed in each of 6 thinnings). Thinning from above was characterised by removal of the largest trees in the stand. Thus the thinning quotient (dbh of thinned stems divided by dbh of the remaining stems) ranged from 1.18-1.38 for the thinning from above treatment and 0.71-0.86 for the thinning from below treatments.

One aim of the study was to try to determine whether any differences were due to changes in growth after thinning or to differences between the residual trees selected during thinning. The residual trees in the stands that were thinned from above had a higher average density than the unthinned stand and the two heaviest thinning from below treatments. Detailed analysis of the data showed that this was due to selection of slower growing trees to form the final crop, rather than to production of lower density wood after thinning. The two heaviest thinning from below treatments resulted in a reduction in wood density compared to the unthinned stand that was attributable to faster growth after thinning treatments were applied. All thinning treatments reduced the juvenile wood proportion (assessed as percentage of basal area, based on juvenile wood being designated the first 12 growth rings from the pith) compared to the unthinned treatment. This reduction was not any greater for the thinning from above treatment, but the author notes that if trees that have been thinned from above were left to grow on to the same diameter as those thinned from below then a greater reduction in juvenile wood content could be expected. Crown characteristics were also studied. The only difference in branch diameter (assessed as the diameter of the thickest branch between 1m and 2m above the ground) was between thinning from above and the heaviest thinning from below treatment. This difference was attributed to selection as the live crown had already receded above 2m before thinning was carried out. As would be expected the height to the first live branch was greatest for the unthinned stand (showing greatest crown recession) and lowest for the most heavily thinned from below stands. Stem taper between 1.3m and 4m up the stem was lowest for the unthinned stand and highest following the heaviest thinning from below. The author concludes that thinning from above can have a positive impact on timber quality, but notes that the risk of wind or snow damage could be increased. He also suggests that heavy thinning from below on a reduced number of occasions, removing up to 40% of basal area, will not substantially affect wood properties.

From this consideration of the impact of increased thinning on log quality and wood properties the following key points can be highlighted:

- Compared to no-thin regimes, selective thinnings in even-aged plantations undergoing transformation to continuous cover systems will have a beneficial effect on timber quality, concentrating increment on trees of better stem form and producing a greater volume of better quality sawlogs
- The use of heavier thinnings may result in the retention of deep living crowns that will increase knot size and taper in the sawlog part of the stem. Timing of thinning will be important if this is to be avoided, preferably avoiding opening up the canopy too markedly until branches in the lower part of the stem have been suppressed. This need will have to be balanced with stability considerations and the requirement to favour trees with vigorous crowns for future seed production
- Greater use of crown thinning and target diameter thinning could have a positive effect on the timber quality of the residual crop, providing an opportunity to produce high quality stems with a small juvenile core. However, the removal of sawlog size material at a younger age than is currently the norm will mean that logs with a high proportion of juvenile wood, with inferior mechanical properties and dimensional stability, will be processed in sawmills. Testing of sample material will be required to determine whether this will have a practical impact on the out-turn of construction grade timber.

***Gap creation***

Some of the effects of gap creation will be similar to those described above for heavier thinning, i.e. retention of deep living crown, increased growth rate. The particular aspects of gap creation that may have a different impact on timber quality are creation of an uneven light environment and an increase in wind loading.

Watson and Cameron (1995) studied the effects of growing Sitka spruce in a nursing mixture with Japanese larch or lodgepole pine. They found that after 25-30 years the incompatible growth rates, where the spruce had outgrown the nurse species, had produced spruce with large uneven crowns, resulting in greater knot areas and increased compression wood formation. It is probable that the creation of gaps in group shelterwood or group selection systems will produce similarly imbalanced crowns on the trees on the edge of the gap. Depending on the age at which the canopy is opened to form the gaps extremely large knots could form in the sawlog producing part of the stem as branch growth into the gap increases in response to the additional light.

Creation of gaps will result in the production of a greater number of “edge” trees than is normally the case in even-aged plantations. There will be increased wind loading on these trees (Gardiner *et al.* 1997). The effects of increased wind loading can include the development of leaning stems with elliptical cross-section, compression wood formation, increased taper, increased grain angle and poor stem straightness (Jacobs, 1936; Low, 1964; Malcolm and Studholme, 1972; Nicholls, 1982). All of these effects are likely to have a negative impact on timber quality compared to stands where a uniform canopy density is maintained and only opened up gradually.

Quine (2004) studied the development of epicormic sprouts on Sitka spruce stems following the formation of windthrown gaps. He found that the production of epicormic sprouts was widespread in Sitka spruce, and that larger gaps and roadline felling resulted in longer, thicker epicormic branches that survived for longer than those on trees in smaller gaps. These results suggest that the opening up of gaps during the transformation of Sitka spruce stands is likely to promote the development of abundant epicormic sprouts on the stems of trees around the edge of the gap (e.g. Figure 9). As described above, in relation to heavy thinning and pruning, the practical impact of epicormic sprouting is unlikely to be significant unless a joinery market is sought.

**Figure 9: Production of epicormic sprouts in Sitka spruce following strip felling, Cefn Llwyd, Wales (managed by Tilhill Forestry)**

***Increased variability***

As described earlier the promotion of irregularity and diversity in continuous cover forestry systems will inevitably lead to increased variability in tree growth characteristics and consequent timber quality.  During transformation the variable spacing and creation of gaps will have some of the impacts described in the previous sections relating to longer rotations, thinning and gap creation. The move away from more uniform growing conditions will result in some trees having increased taper, less even crown development and greater compression wood development. At the same time careful selective thinning and longer rotations could also produce some high quality stems with superior wood properties. In addition, in many instances there will be a greater range of tree sizes in stands at any one time. This variability in the characteristics and size of timber being produced will necessitate a greater degree of pre-sorting in the forest and development of innovative techniques for assessing timber quality prior to or during harvest. This could ensure that timber is targeted to the end-use for which it is best suited and optimise value recovery for both growers and processors.

Diversity of species is likely to be increased in successor crops, either by manipulation of microclimate to favour particular species, enrichment planting or selection during cleaning and thinning. As these more varied stands start to produce merchantable timber there may be a need for development of new markets, particularly in areas where greater volumes are produced from broadleaved species.

***Restricted genetic change***

The use of natural regeneration in transformation to continuous cover systems removes the opportunity to make improvements in terms of growth and wood properties through the use of genetically improved plants. The extensive Sitka spruce breeding programme in Great Britain has produced significant genetic gains in terms of growth, stem form and wood density when compared to unimproved material (Lee, 1999; Lee, 2004). Seeds are commercially available from different improved production populations, allowing growers to choose, for example, between improved growth and stem form without a reduction in wood density or improved density with a smaller increase in growth and similar stem form improvement. For Scots pine seed orchard material can also provide improvements in diameter growth and straightness. For other species where there is less opportunity to use improved material the impact of using natural regeneration may be less direct. However, if the form and quality of the existing crop trees are poor then the regenerating trees will also tend to be poor, and replanting or enrichment with better material will be the only way to improve the situation.

In stands that are of good quality in terms of stem form, branching characteristics and growth, the use of natural regeneration may have some advantages compared to planting. Successful natural regeneration tends to result in much more densely stocked stands than planting, which are normally respaced at around 3 metres in height. The increased stand density results in early suppression of branches in the lower stem, improved stem straightness and allows a greater element of selectivity in thinnings as there are a larger number of trees to choose from.

There is also some evidence that young trees in stands grown from direct seeding develop better root systems than planted ones (Pfeifer, 1982; Watson and Tombleson, 2002). This reduces the incidence of toppling as a result of wind or snow damage in the young trees and may also have an impact on stem form and longer term stand stability. Naturally regenerated trees could be expected to exhibit similar characteristics to those grown from direct seeding.

**Conclusions and Recommendations**

The use of alternative silvicultural systems to clearfell in conifer forests in Great Britain is increasing. There is a widespread move to transform even-aged plantations to continuous cover management under shelterwood or selection systems, where site and stand conditions are suitable. However, there is limited experience of implementing these systems on a large scale, and it will take time to build up expertise and knowledge in this area. In recent years most of the research and development in this subject has been focused on stand manipulation to achieve successful natural regeneration, with little emphasis on the quality of timber that will be produced from these stands.

From the available information it can be concluded that continuous cover forestry systems do have the potential to produce high quality timber, providing the quality of the original stand is of a sufficient standard. A key factor is likely to be continuity of management, as the transformation process may take 15-30 years and subsequent continuous cover management will require an ongoing commitment to monitoring and control. Careful silviculture with particular attention to the timing of interventions in relation to crown development and to selection during thinning is required. There is likely to be greater variation in the characteristics of future timber supplies in terms of size and wood properties. Wider use of crown thinning will result in an increased quantity of young sawlog-size material being processed in sawmills, which is likely to have inferior mechanical properties and dimensional stability than older material of the same dimensions. The practical impact of these changes in terms of timber performance and value has yet to be evaluated.

The impact of these changes in stand management on timber quality and supply at a national level is hard to judge without a realistic estimate of the location, extent and characteristics of the forests being transformed. Mason (2003) states that a preliminary site evaluation suggests that perhaps 50% of sites in Wales and 30% of sites in Scotland might be suitable for transformation. In order to better gauge the effects of increased use of continuous cover systems a systematic inventory of the area and type of silvicultural system planned for forests in Great Britain will be required.

Research studies are needed to test some of the inferences drawn from the available literature, to determine if they are valid for British conditions. In particular sawmill studies to evaluate the quality characteristics and utilisation potential of logs and sawn timber produced both from young trees during crown thinning and from large old trees retained beyond normal rotations in uneven-aged stands.

Our ability to predict the impact of alternative silvicultural strategies using currently available growth and timber quality models is limited, as these have been largely developed for use in even-aged single species stands. There is a need to adapt and improve models for the main commercial conifer species in Great Britain (Sitka spruce, Scots pine, Douglas fir and larch) so that they can deal with the more complex silvicultural systems that are increasingly being used. The establishment of long term experiments to test these models and provide research material for the future would also be a useful step forwards.

On the basis of information that is currently available the following recommendations can be made, with the aim of ensuring that the quality of timber produced from stands undergoing transformation is as good as possible:

1. As far as possible opening up of the canopy beyond the extent of a conventional intermediate thinning should be avoided until the live crown has receded to a height that is above the most valuable sawlog producing part of the stem.

2. In all thinnings trees with straight stems, superior branching habit (small branch diameters, few branches per whorl, level branch insertion angle) and low taper should be favoured.

3. Use crown thinning carefully to favour the best form co-dominants in order to produce final crop trees with a low proportion of juvenile wood.

4. Where the canopy has to be opened up more radically to promote natural regeneration and stabilise seed trees, and where the seed trees selected are highly tapered with vigorous crowns, consider the use of pruning to improve the quality of the final crop trees. On trees that are to be retained to an age of 60-100 years this will produce an appreciable amount of knot-free timber and may also improve taper. Marking and recording of final crop trees is necessary to ensure that the pruned individuals can be appropriately marketed when they are harvested.

5. If the existing crop has inferior stem straightness and branching, or is not well suited to the site, planting to introduce improved genotypes or provenances, or preferred species, rather than natural regeneration should be used. An irregular structure can still be achieved if underplanting or group planting is used, although costs will be higher than in a clearfelled coupe. Alternatively, clearfelling and restocking with the preferred species or genotype can be used with the conversion to continuous cover management deferred until the next rotation.

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# Modelling Catalogue

In this appendix we have listed forest and tree growth models (Table 1) that are felt to be potentially of value in helping to answer questions about future timber supply and wood quality from forests being transformed to CCF. We have made substantial use of the excellent modelling review of Porté and Bartelink, (2002). We have also listed models that are of additional value because they provide information on product assortments, tree size distributions or wood properties of British grown trees Table 2 and would be required as add-ons to the growth or yield models.

## *Model Selection*

In order to select the models in a systematic way we judged all the models we were able to list (Table 3) against the following two criteria:

Criteria 1. Any models that had been specifically developed for British conditions were accepted

Criteria 2. Any models that were not developed for British conditions but met all of the following sub-criteria were also accepted

A. Developed for species relevant to UK forestry
B. Describe stand structure (tree size class distribution)
C. Developed to inform CCF management
D. Track record of application to forestry practice

Any models developed for tropical forestry were excluded as were any derivative models.

## *Discussion*

We have attempted in Table 1 to give a range of information to inform potential users of such models. These include the type of model (M1-M5), the species and stands to which the model is applicable, the outputs the model produces, the applications for which it is appropriate and the current status of the model.

There has also been an attempt to identify for all models in Table 1 the t**ransferability** of the model to British conditions as follows:

1. Easy: These models have been built to deal with growth or timber quality for British conditions and, therefore, are already able or with little effort (1-2 years) can be used.

2. Moderate: Probably not designed for use in Britain and would need calibration for British conditions. Time scale to implement in Britain 2-5 years.
3. Difficult: The models have potential but will require substantial (> 5 years) of effort to make use of under British conditions.

In addition we have made an assessment of the **extendibility** of the model. In other words is it possible to use the models in situations or for species for which they were not originally developed. Again we have broken the models down into 3 categories:

1. Easy. The models have a very flexible structure that would allow them to easily be extended to deal with a range of forest conditions and species. Such models are likely to be process based.
2. Moderate. Will be extendable with some effort but not entirely straightforward.
3. Difficult. The models are either complex or have built in limitations that will make them very difficult to extend. This may be due to the software structure or inherent assumptions made in the model.

Although there are a large number of models listed in Table 1 this does not mean that there are this number of approaches to modelling. Generally the models fall into a number of distinct categories and these categories also tend to reflect the time period over which they are most appropriate for modelling transformation to CCF.

1. Short Term (1-10 years): Dynamic yield models that can be used with relatively little effort to model initial impact of transformation.
2. Medium Term (10-40 years or approximately 1 rotation): Distance dependent tree growth models. These models explicitly deal with the influence of competition from neighbours and so can potentially model growth of the final crop trees to the point at which the stand has reached a CCF structure. Recruitment is not normally included so that the models can only deal with a single rotation.
3. Long Term (> 40 years or more than 1 rotation): Successional models/gap models. These models specifically deal with recruitment and mortality and are, therefore, applicable to longer time scales.

**Table 1: List of growth and yield models of potential use in evaluating timber quality in forest undergoing transformation to CCF**

| **Name** | | No name | BWIN-PRO | PROGN-AUS/OSIS | EFM |
|---|---|---|---|---|---|
| **Model type M-System** | 1 | | | | |
| | 2 | | | | |
| | 3 | | X | X | |
| | 4 | X | | | |
| | 5 | | | | X |
| **Key species** | | Scots Pine, Norway Spruce | Norway Spruce, Scots Pine, Beech | Norway Spruce, White Fir, European Larch, Scots Pine, Beech, Oak | All major forest types |
| **Key stand types** | Even aged | X | | X | |
| | Multi aged | | X | X | X |
| | One species | | | X | |
| | Multi species | X | X | X | |
| **Output variables** | Stand variables | X | X | X | X |
| | Size distribution | X | X | X | X |
| | Spatial structure | X | | | |
| | Assortments | | | | |
| | Stem quality | | | | |
| **Applications** | Policy/scenario | X | X | X | X |
| | Estate forecasting/planning | | X | X | X |
| | Management/quality interactions | | X | | |
| | Economic analysis at stand level / Management option evaluation | X | X | X | |
| | Stand management DSS | X | X | X | |
| | Education | X | X | X | X |
| | Environmental change impact | | | | X |
| **Status** | Under development | | | | |
| | Research tool | X | | | X |
| | Public domain | | X | | |
| | Commercial product | | | X | |
| **Transferability** | Easy | | | | |
| | Moderate | | | X | |
| | Difficult | X | X | | X |
| **Extendibility** | Easy | X | | X | |
| | Moderate | | | | X |
| | Difficult | | X | | |
| **Key references** | | Pukkala et al. (1994, 1998) | Döbbeler et al. (2001) | Monserud & Sterba (1999) | Thornley and Cannell (1992) |

| Name | | DynamicYield | D-FIR | ForestYIELD | M1 |
|---|---|---|---|---|---|
| **Model type M-System** | 1 | | | X | X |
| | 2 | X | X | | |
| | 3 | | | | |
| | 4 | | | | |
| | 5 | | | | |
| **Key species** | | Sitka spruce | Douglas fir | All major forest types | All major forest types |
| **Key stand types** | Even aged | X | X | X | X |
| | Multi aged | | | | |
| | One species | X | X | X | X |
| | Multi species | | | | |
| **Output variables** | Stand variables | X | X | X | X |
| | Size distribution | | | | |
| | Spatial structure | | | | |
| | Assortments | | | | |
| | Stem quality | | | | |
| **Applications** | Policy/scenario | X | X | X | X |
| | Estate forecasting/planning | X | X | X | X |
| | Management/quality interactions | X | X | X | X |
| | Economic analysis at stand level / Management option evaluation | X | X | X | X |
| | Stand management DSS | X | X | X | X |
| | Education | X | X | X | X |
| | Environmental change impact | | | | |
| **Status** | Under development | | | | |
| | Research tool | | | | X |
| | Public domain | | | | |
| | Commercial product | X | X | X | |
| **Transferability** | Easy | X | X | X | X |
| | Moderate | | | | |
| | Difficult | | | | |
| **Extendibility** | Easy | | | | |
| | Moderate | X | X | X | X |
| | Difficult | | | | |
| **Key references** | | COFORD (2005) | Knowles (pers comm.) | Matthews et al. (2005) | Arcangeli & Matthews (pers comm) |

| Name | | M3 | TYFIANT COED | TIPSY/SYLVER/TASS |
|---|---|---|---|---|
| Model type M-System | 1 | | | |
| | 2 | | | |
| | 3 | X | | |
| | 4 | | X | |
| | 5 | | | |
| Key species | | Sitka spruce | Sitka spruce and birch | Douglas Fir, Lodgepole Pine, Western Hemlock, Western Red Cedar, White Spruce, Sitka Spruce |
| Key stand types | Even aged | X | X | X |
| | Multi aged | | X | |
| | One species | X | X | |
| | Multi species | | X | X |
| Output variables | Stand variables | X | X | X |
| | Size distribution | X | X | X |
| | Spatial structure | | X | X |
| | Assortments | X | X | |
| | Stem quality | | | |
| Applications | Policy/scenario | X | | |
| | Estate forecasting/planning | X | X | |
| | Management/quality interactions | X | X | |
| | Economic analysis at stand level / Management option evaluation | X | X | X |
| | Stand management DSS | X | X | X |
| | Education | X | X | X |
| | Environmental change impact | | | |
| Status | Under development | | X | |
| | Research tool | | | |
| | Public domain | | | |
| | Commercial product | X | | |
| Transferability | Easy | X | | |
| | Moderate | | X | X |
| | Difficult | | | |
| Extendibility | Easy | X | X | X |
| | Moderate | | | |
| | Difficult | | | |
| Key references | | Matthews et al. (2005) | Pommerening and Wenk (2002) | Di Lucca (1999) |

| **Name** | | SILVA2 | 3PG | CACTOS | MOTTI |
|---|---|---|---|---|---|
| **Model type** | 1 | | | | |
| | 2 | | | | |
| | 3 | | | X | X |
| | 4 | X | | | |
| | 5 | | X | | |
| **Key species** | | Norway Spruce, Silver Fir, Scots Pine, Beech, Oak, Black Alder | All major forest types | All major forest types from Western US | Norway Spruce Scots Pine, Aspen, Birch Grey Alder |
| **Key stand types** | Even aged | | X | | X |
| | Multi aged | X | | X | X |
| | One species | | X | | |
| | Multi species | X | | X | X |
| **Output variables** | Stand variables | X | X | X | X |
| | Size distribution | X | | X | X |
| | Spatial structure | X | | X | |
| | Assortments | | | | X |
| | Stem quality | | | | |
| **Applications** | Policy/scenario | X | X | X | X |
| | Estate forecasting/planning | | X | X | X |
| | Management/quality interactions | X | | X | X |
| | Economic analysis at stand level / Management option evaluation | X | | | X |
| | Stand management DSS | X | | | X |
| | Education | X | X | X | |
| | Environmental change impact | | X | X | |
| **Status** | Under development | | | | |
| | Research tool | X | X | | |
| | Public domain | | | | |
| | Commercial product | | | X | X |
| **Transferability** | Easy | | X | | |
| | Moderate | | | X | X |
| | Difficult | X | | | |
| **Extendibility** | Easy | X | | | |
| | Moderate | | | | |
| | Difficult | | X | X | X |
| **Key references** | | Pretzsch et al. (2002) | Landsberg et al. (2003) | Ritchie (1999) | Hynynen et al. (2005) |

| Name | | M3 | TYFIANT COED | TIPSY/SYLVER/TASS |
|---|---|---|---|---|
| **Model type M-System** | 1 | | | |
| | 2 | | | |
| | 3 | X | | |
| | 4 | | X | |
| | 5 | | | |
| **Key species** | | Sitka spruce | Sitka spruce and birch | Douglas Fir, Lodgepole Pine, Western Hemlock, Western Red Cedar, White Spruce, Sitka Spruce |
| **Key stand types** | Even aged | X | X | X |
| | Multi aged | | X | |
| | One species | X | X | |
| | Multi species | | X | X |
| **Output variables** | Stand variables | X | X | X |
| | Size distribution | X | X | X |
| | Spatial structure | | X | X |
| | Assortments | X | X | |
| | Stem quality | | | |
| **Applications** | Policy/scenario | X | | |
| | Estate forecasting/planning | X | X | |
| | Management/quality interactions | X | X | |
| | Economic analysis at stand level / Management option evaluation | X | X | X |
| | Stand management DSS | X | X | X |
| | Education | X | X | X |
| | Environmental change impact | | | |
| **Status** | Under development | | X | |
| | Research tool | | | |
| | Public domain | | | |
| | Commercial product | X | | |
| **Transferability** | Easy | X | | |
| | Moderate | | X | X |
| | Difficult | | | |
| **Extendibility** | Easy | X | X | X |
| | Moderate | | | |
| | Difficult | | | |
| **Key references** | | Matthews et al. (2005) | Pommerening and Wenk (2002) | Di Lucca (1999) |

| Name | | No name | | | |
|---|---|---|---|---|---|
| **Model type** | 1 | | | | |
| | 2 | | | | |
| | 3 | X | | | |
| | 4 | | | | |
| | 5 | | | | |
| **Key species** | | Norway Spruce, White Fir, Beech | | | |
| **Key stand types** | Even aged | | | | |
| | Multi aged | X | | | |
| | One species | | | | |
| | Multi species | X | | | |
| **Output variables** | Stand variables | X | | | |
| | Size distribution | X | | | |
| | Spatial structure | | | | |
| | Assortments | X | | | |
| | Stem quality | | | | |
| **Applications** | Policy/scenario | X | | | |
| | Estate forecasting/planning | X | | | |
| | Management/quality interactions | | | | |
| | Economic analysis at stand level / Management option evaluation | X | | | |
| | Stand management DSS | | | | |
| | Education | X | | | |
| | Environmental change impact | X | | | |
| **Status** | Under development | | | | |
| | Research tool | X | | | |
| | Public domain | | | | |
| | Commercial product | | | | |
| **Transferability** | Easy | | | | |
| | Moderate | X | | | |
| | Difficult | | | | |
| **Extendibility** | Easy | | | | |
| | Moderate | X | | | |
| | Difficult | | | | |
| **Key references** | | Buongiorno et al. (1995) | | | |

**Table 2: List of additional non growth/yield models of potential value**

| **Name** | | BSORT | ASORT | ForestWOOD |
|---|---|---|---|---|
| **Model type** | | Diameter Distribution Model | Product Assortment | Wood Properties (Density, branching, grain angle) |
| **Key species** | | All major forest types | All major forest types | Sitka Spruce |
| **Key stand types** | Even aged | X | X | X |
| | Multi aged | | | |
| | One species | | | |
| | Multi species | | | |
| **Output variables** | Stand variables | | | |
| | Size distribution | X | | |
| | Spatial structure | | | |
| | Assortments | | X | |
| | Stem quality/Wood Properties | | | X |
| **Applications** | Policy/scenario | | | X |
| | Estate forecasting/planning | X | X | |
| | Management/quality interactions | X | X | X |
| | Economic analysis at stand level / Management option evaluation | | X | |
| | Stand management DSS | | | |
| | Education | | | X |
| | Environmental change impact | X | | X |
| **Status** | Under development | | | |
| | Research tool | X | X | X |
| | Public domain | | | |
| | Commercial product | | | |
| **Transferability** | Easy | X | X | X |
| | Moderate | | | |
| | Difficult | | | |
| **Extendibility** | Easy | X | X | |
| | Moderate | | | X |
| | Difficult | | | |
| **Key references** | | Matthews& Duckworth (2005) | Rollinson & Gay (1983) | Gardiner et al. (2002) |

**Table 3: Selection criteria for models**

| Name | Reference | Criterion 1 | A | B | C | D | Criterion 2 | Final score |
|---|---|---|---|---|---|---|---|---|
| COMMIX | Bartelink | X | V | V | V | X | X | X |
| JABOWA – FORET | Botkin | X | V | X | X | X | X | X |
| SORTIE | Pacala | X | X | V | X | X | X | X |
| - | Kolstrom | X | V | V | V | X | X | X |
| SHOOT | Kellomaki | X | V | V | X | X | X | X |
| FINNFOR | Vaisanen | X | V | V | X | X | X | X |
| CROBUS | Makela | X | V | V | V | X | X | X |
| BWIN PRO | Döbbeler | X | V | V | V | V | V | V |
| TIPSY/TASS | Di Lucca | X | V | V | V | V | V | V |
| - | Courbaud | X | V | V | V | X | X | X |
| FORECAST | Kimmins | X | V | X | X | V | X | X |
| | Garcia | X | X | X | X | V | X | X |
| FIBER 3.0 | Solomon | X | X | V | V | V | X | X |
| G-HAT | Amateis | X | X | V | V | V | X | X |
| - | Siekierski | X | V | V | V | X | X | X |
| LIGNUM | Sievanen | X | V | V | V | X | X | X |
| ZELIG | Urban | X | V | X | X | X | X | X |
| - | Pukkala | X | V | V | V | V | V | V |
| DynamicYield | COFORD | V | V | X | X | X | X | V |
| DFIR | Knowles | V | V | X | X | X | X | V |
| Forest Yield | Matthews | V | V | X | X | V | X | V |
| M1 | Arcangeli | V | V | X | V | V | X | V |
| M3 | Matthews | V | V | V | V | X | X | V |
| TYFIANT COED | Pommerening | V | V | V | V | X | X | V |
| PROGN-AUS/OSIS | Monserud | X | V | V | V | V | V | V |
| CACTOS | Ritchie | X | V | V | V | V | V | V |
| FPS | Arrey | X | V | X | X | V | X | X |
| ORGANON | Hann | X | V | X | V | X | X | X |
| SPS | Maron | X | V | X | X | V | X | X |
| - | Buongiorno | X | V | V | V | V | V | V |
| SILVA2 | Pretzsch | X | V | V | V | V | V | V |
| 3PG | Landsberg | V | V | X | X | X | X | V |
| MOTTI | Hynynen | X | V | V | V | V | V | V |
| PTAEDA3.1 | Amateis | X | X | V | V | V | V | X |
| EFM | Thornley | V | V | V | X | X | X | V |

V ≡ valid
X ≡ doesn't meet criteria

Criteria for accepting models
Criteria 2. Developed for British Isles conditions
Criteria 3. Satisfies all the following sub-criteria

A. Developed for species relevant to UK forestry
B. Describes stand structure (tree size class distribution)
C. Developed to inform CCF management
D. Track record of application to forestry practice

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**Examples of continuous cover forestry systems in conifer stands in the UK including their potential for use in future research on timber quality**

## Introduction

This report forms part of the Scottish Forestry funded study “Reviewing the Implications of Continuous Cover Forestry Systems for Conifer Log Supply and Timber Quality. One objective of this project is to identify forest stands within the UK that could potentially be used for testing the implications of transformation of even-aged stands to continuous cover management on log quality and wood properties. Site visits were made to a number of forests being managed under continuous cover systems in Scotland, Wales and Northern Ireland. These included stands where some form of continuous cover management had been in place for a considerable period of time, (more than 20 years) and others where the transformation process has only recently been started. The sites visited were mainly privately owned, although some Forestry Commission sites were also included. In addition to the forests visited during the study, a summary of a number of additional Forestry Commission and Forest Research experimental stands that are potentially valuable for future studies of timber quality are included in this report. A further source of information regarding forests where continuous cover management is practised is “Alternatives to Silvicultural Systems to Clear Cutting in Britain: A Review” by Cyril Hart, (Hart, 1995).

## Site Visits

This section of the report contains a description of the site visits made to stands being managed under CCF systems or undergoing a process of transformation to CCF management. The forests described are examples of the current practice of CCF management in the UK, but do not represent an exhaustive catalogue.

### *Scotland*

*Novar Estate (NGR: NH 600 700)*

Novar Estate is located near the village of Evanton in Easter Ross, about 18 miles north of Inverness. The estate has been owned by the Munro Ferguson family since the late 18$^{th}$ century and has a forestry tradition dating from that time. The Head Forester at Novar is Cameron Ross, who has worked on the estate since 1988.

The estate extends to a total of 9000 hectares, of which 3500 hectares are woodland, with the remainder comprised of a mixture of agricultural and sporting ground. Novar has a diverse range of interests in addition to forestry and agriculture. These include salmon & trout fishing, pheasant, partridge and red grouse, deer stalking, long term and holiday property lets, a sawmill, a windfirm and a micro hydro scheme. The estate is well used for recreation by both the local population and visitors. Approximately 10,000 people walk up Cnoc Fyrish each year to view the landmark Fyrish monument, commissioned by Sir Hector Munro of Novar in 1792 to provide work for unemployed workers. Public access and landscape impact are therefore important considerations in the management of Novar.

The forest area at Novar can be split into two broad categories. The older woods, lower down the hill and closest to the estate house, were established around 1900 and cover an area of about 1000 hectares. Much of this area has been managed using a shelterwood system that has resulted in the forest developing a diverse structure with a range of species and age classes. In the 1960s large areas of hill ground and marginal farmland were planted in the, amounting to a further 2500 hectares of forest. These even-aged plantations are currently in the process of undergoing restructuring, with thinning, clearfelling and restocking being carried out in accordance with forest design plans. It is the older area of woodland that is of particular interest for this study and which is considered in more detail below.

The predominant species in the old woods at Novar are larch, Scots pine and Douglas fir, approximately in the proportions 40:40:20. In addition there is a range of other conifer species present including Sitka and Norway spruce, western red cedar, western hemlock and a variety of broadleaved species. The management of much of this area using shelterwood systems was largely initiated in the 1950s by the owner at the time, after he had completed a forestry degree. Much of the natural regeneration that became established was western hemlock, for which a ready market was available during the 1970s in the form of poles for the aluminium smelter at Invergordon. By the late 1980s, after closure of the smelter, the preponderance of western hemlock became a problem for the estate, as marketing of this species to sawmills became difficult. During the 1990s a decision was taken to try and move away from western hemlock natural regeneration to try to encourage establishment of more valuable species such as Douglas fir, Scots pine and larch.

The past management at Novar, where stands were thinned continually and individual trees retained well beyond conventional commercial rotations, has produced some extremely high quality and valuable timber, mainly larch, Douglas fir and western red cedar. The estate has an annual harvesting programme of 15000 $m^3$, of which more than 90% is sold standing to large sawmills under long term contracts. The balance is made up of the higher quality sawlogs from older, large trees that are harvested in response to specific demand. These are sold to a few local processors who operate in specialist markets such as external cladding and beams for house construction and boat building. It is the continuing production of this type of high quality material that the estate hopes to achieve through the use of continuous cover systems in the old woods.

In order to promote regeneration of preferred species the silvicultural system used at Novar has evolved over the last 10 years, and is still undergoing a period of development as different techniques are tested and refined. There has been a move from what seemed to be broadly an irregular shelterwood system, characterised by a continual programme of thinning, where the relatively low light levels resulted in abundant western hemlock regeneration, to a system more akin to group shelterwood or group selection. Existing gaps have been expanded, particularly around advance regeneration and new gaps have been created. Ground preparation to encourage regeneration has been undertaken in some places and underplanting used to establish desirable species where regeneration has not been successful or where bracken will prevent its establishment. (Figures 1 - 3) Wherever possible the opportunity is taken to increase the area of Douglas fir. The greatest constraint on achieving successful natural regeneration has been deer browsing pressure, with both Scots pine and Douglas fir extremely vulnerable to damage. In areas of high public access, where dog walking keeps the deer numbers at a lower level, natural regeneration has been more successful. In some places small coupes have been clearfelled and planting undertaken to introduce desirable species.

Where natural regeneration has been successfully achieved stocking densities of more than 10000 stems per hectare are common. A respacing operation to achieve uniform five foot (1.5m) spacing is undertaken when the regeneration is around 2 – 2.5m high, at which time preferred species are favoured. This dense stocking will result in early suppression of branches on the lower part of the stem and restrict the size of the juvenile core.

The motivation for using continuous cover systems of management for the old woods at Novar is to produce high quality timber whilst retaining the diverse structure and character of the woodland, particularly on the prominent south facing slopes of the estate which are highly visible from the A9 and surrounding villages and towns. In the Scots pine areas there is an additional objective of management to provide habitat for Capercaillie. Of the 1000 hectares of the old woods at Novar it is planned that 300-500 hectares will be managed using continuous cover systems. Small clearfell coupes will be used in the remaining area, with continuous cover and clearfell areas managed in an intimate mosaic. The management of this forest does not follow a strict system, but is the result of a process of testing a range of techniques to achieve management objectives and subsequently modifying practice in response to the results achieved.

**Figure 1: Novar Estate: Sitka spruce and western hemlock regeneration under larch and Douglas fir**

**Figure 2: Novar Estate – larch underplanted with Douglas fir in bracken areas, aiming for natural regeneration in heather areas.**

**Figure 3: Novar Estate – planted Sitka spruce with western hemlock regeneration**

*Cawdor Estate (NGR: NH 810 560)*

Cawdor Estate, which lies about 14 miles east of Inverness, has been owned by the Cawdor family for over 700 years and has a long history of forest management. The Head Forester is Steve Connolly, who also runs Cawdor Forestry, a forest management company offering long term forest planning and management, landscape design and visualisation services to the forest industry.

The total land area of Cawdor Estate is 22500 hectares, of which 5500 hectares are woodland. In addition to forestry and farming the Estate has a wide range of other commercial interests including Cawdor Castle and grounds (open to visitors from May to October), a golf course, holiday lettings, fishing and shooting. 75% of the forest area is classified as "commercial forestry", including areas under continuous cover management. The remainder is managed for other specific objectives including native pinewood schemes, riparian zone management on the River Findhorn and various amenity and conservation projects. Within the commercial forestry area approximately 50% is Scots pine, with in the region of 10% Sitka spruce, 10% lodgepole pine, 4% Douglas fir and 4% larch. The remaining area is composed of broadleaves and other conifer species.

Continuous cover management at Cawdor is focused on the use of a group selection system in Scots pine stands. The selection of sites for continuous cover management is mainly based on silvicultural considerations, the aim being to identify sites well suited to Scots pine growth (dry, relatively poor soil) in order to improve the success of natural regeneration. Additional considerations when selecting suitable sites are public access, (as continuous cover management is considered a means of preserving the amenity of value of Scots pine stands), landscape and conservation issues. Information regarding the total area being managed under continuous cover systems was not available from the Estate.

In areas managed under a continuous cover system the production of quality timber is a key objective, and management operations are designed to promote this. Stands are thinned using an intermediate thinning pattern in accordance with standard management table intensities, up until an age of about 50 years. After this some areas are opened up more heavily, to manage the light environment to try and develop a ground cover largely composed of moss, which is a favourable seed bed for natural regeneration. The aim is to achieve some advance regeneration in these more heavily thinned areas, around which gaps are subsequently opened up to allow the young trees to grow on. The regeneration is not normally respaced, and the first intervention in the regenerated areas will be a first commercial thinning. The key consideration for the Estate in managing Scots pine using this group selection system is achieving successful natural regeneration, with deer browsing a significant constraint.

A good example of the group selection system practised at Cawdor is Delnies Wood near Nairn (Figures 4 - ). This stand of Scots pine was planted in 1910 and has been managed under a group selection system for over 30 years. The wood is well used for informal recreation, particularly dog-walking, which, as at Novar Estate, has probably contributed to the success of natural regeneration on this site. The stand is predominantly Scots pine with some larch, Douglas fir, Sitka spruce, birch, holly and other broadleaves. The groups of regeneration are about 15-20 metres in diameter, with the oldest groups containing trees of around 30 years of age.

**Figure 4: Cawdor Estate, Delnies Wood – young natural regeneration in Scots pine group selection system**

**Figure 5: Cawdor Estate, Delnies Wood – Scots pine natural regeneration in group selection, showing density of stocking achieved**

**Figure 6: Cawdor Estate, Delnies Wood – the forest has a network of paths and is well used by the public for dog-walking, a factor which probably keeps deer numbers low and contributes to the success of natural regeneration**

**Figure 7; Cawdor Estate – some of the oldest regeneration in Delnies Wood. It can be seen that trees on the edge of the group are developing some large branches**

*Buccleuch Estates – Drumlanrig and Bowhill (NGR: NX 850990 and NT 427279)*

Two of the Buccleuch Estates properties, owned by the Duke of Buccleuch, were visited as part of this project – Drumlanrig in Dumfriesshire and Bowhill near Selkirk. Both estates combine a range of land uses including agriculture, forestry, sporting and tourism. Buccleuch Woodlands is a company within the Buccleuch group that manages the forests at Drumlanrig, Bowhill, Langholm and Dalkeith Estates in Scotland and Boughton Estate in Northamptonshire. The total woodland area covered by the estates extends to 10000 hectares. The Woodland Business Manager is Graham Booth.

Within the Buccleuch family there has been enthusiasm for forestry over many generations. The estates have a history of some form of continuous cover forest management with involvement in forest management planning from some significant individuals over the last

100 years, including Sir William Schlich, Professor M.L. Anderson and Professor J.D. Matthews. A prime motivation for avoiding clearfelling has been to maintain the structure, diversity and amenity value of the woods around the main houses in each of the estates. In the past, planting was often used rather than natural regeneration to establish a successor crop in continuous cover systems.

During the last decade there has been renewed interest in the environmental, amenity and economic potential of developing continuous cover forestry systems in the Buccleuch woodlands. Around 10% of the forest area has been designated as continuous cover in forest plans, and this area is expected to increase over time. At present a mixture of shelterwood and group selection techniques are being tested out, using a responsive approach to management that can be adapted to suit the developing situation. Where gaps arise due to windblow these are monitored to see if natural regeneration occurs, and in some instances ground preparation will be undertaken if this is felt necessary. Planting is used where regeneration is unsuccessful or where there is a wish to introduce different species. Deer browsing has been a significant constraint on achieving natural regeneration for decades and renewed efforts are being made to control deer numbers within the woodland with crop damage rather than deer population being the key indicator. This objective has to be balanced with the sporting requirements of the Estate, where deer stalking has historically represented a substantial source of income. It is now accepted short term stalking income will be minimal in the transformation stage whilst aiming at longer term financial benefits within the woodlands.

The Estate wish to maintain the diverse mixtures of species found in the woodlands, particularly around the main houses where a wide variety of broadleaves and conifers are found (Figure 8). At the same time there is an aim of increasing the area of Douglas fir which is considered a valuable timber species. At Bowhill a particularly successful example of Douglas fir regeneration with some beech in a Douglas fir group shelterwood was seen (Figure 9).

**Figure 8: Buccleuch Estates, Drumlanrig – mixed woodland with regeneration in a gap**

**Figure 9: Buccleuch Estates, Bowhill – Douglas fir natural regeneration in a group shelterwood**

*Tay Forest District – Craigvinean and Faskally (NGR: NN 980450 and NN 920590)*

The Forestry Commission's Tay Forest District includes the forests managed by Forest Enterprise Scotland in the northern part of Fife, Perthshire and Angus. The total land holding in the district is 38000 hectares, of which 31000 hectares are classed as Productive High Forest. 17% of the productive high forest area has been designated as being managed under continuous cover systems in Forest Plans. Whilst management using continuous cover systems delivers a range of benefits in terms of amenity, landscape and biodiversity, it is also now being implemented as a means of reducing restocking costs at a time of restricted cash flow. The Forest District Manager is Charlie Taylor. Two stands being managed under continuous cover systems were visited – Craigvinean and Faskally.

Craigvinean is one of Scotland's oldest managed forests, created in the 18th century with larch seed brought from the Alps. It is located above the village of Dunkeld and is a prominent feature in the landscape seen from the A9 trunk road between Perth and Pitlochry. The forest is adjacent to the National Trust's Hermitage woodland and is well-used for walking, mountain biking and horse-riding. The forest contains a mixture of mainly coniferous species; including Sitka and Norway spruce, larch and Douglas fir. This forest (approximately 500 ha) is being managed by Forest Enterprise as a demonstration area for continuous cover management, mainly using a group shelterwood approach. (Figures10-11).

**Figure 10: Tay Forest District, Craigvinean – mixed age stand**

**Figure 11: Tay Forest District, Craigvinean – regenerating group of Sitka spruce**

Faskally wood lies about 1 mile north-west of Pitlochry on the north shore of the Loch Faskally reservoir. Hart (1995) notes that the forest was originally planted as policy woods for a Victorian mansion, now Faskally House and describes their development. During the 1950s and 1960s Faskally House was run as a Foresters' Training School and the woods were managed according to a plan drawn up by Professor M. L. Anderson of Edinburgh University. The aim was to use a group selection system ("Anderson groups") to convert the even aged stands of larch, Scots pine, Douglas fir and Norway spruce to an irregular structure with a greater range of species. Where natural regeneration was unsuccessful after 3 years planting was to be used.

Today the woods contain about 23 different species of trees, have an attractive irregular structure and are well used for recreation (Figures 12 - 14). The Forest District now manage Faskally using an approach that is close to single tree selection across much of its area, with larger gaps opened up in some parts to encourage more light demanding species.

**Figure 12: Tay Forest District, Faskally – mixed species stands with an irregular structure produced by management using a group selection approach**

**Figure 13: Tay Forest District, Faskally – mixed age class Douglas fir**

**Figure 14: Tay Forest District, Faskally – view of mixed woodland**

***Wales***

*Clocaenog (NGR: ST043540)*

Clocaenog is a Forestry Commission forest that lies on the southern edge of the Denbigh Moors in north Wales. The stand visited contains permanent 1 hectare sample plots that are part of the Tyfiant Coed growth model project being undertaken by Bangor University and the Forestry Commission (http://tycoed.bangor.ac.uk/Research_Plots.htm). The stand is composed of Sitka spruce that was planted in 1948 and 1951 in mixture with lodgepole pine which has now largely been removed. The stand has been well thinned and there is now abundant natural regeneration beneath the main canopy, particularly in gaps opened up by windblow (Figure 15 and 16). The stand at Clocaenog is being managed using an approach that is close to a uniform or group shelterwood system. Bangor University and Forest Research are monitoring natural regeneration and wind climate in the stand.

**Figure 16: Clocaenog forest – Sitka spruce natural regeneration beneath shelterwood**

**Figure 17: Clocaenog – permanent sample plot for monitoring of growth and natural regeneration**

*Cefn Llwyd (SJ 010354)*

Cefn Llwyd forest is located near Llandrillo, south-east of Bala in north Wales and extends to over 400 hectares. It was originally owned by Shotton Paper and managed by Talis Kalnars. It is now managed by Tilhill Forestry Ltd. The stand visited was planted in the late 1950s and is composed predominantly of Sitka spruce, with some Douglas fir, larch, Scots pine and occasional broadleaves. Since the late 1980s the stand has been managed with the aim of transforming it from an even-aged uniform plantation to an uneven-aged mixed species forest, whilst at the same time producing high quality timber. A system of variable density thinning was used to encourage regeneration and introduce irregularity by gradually opening up the canopy. This approach has largely been successful and much of the stand now has an irregular structure with abundant natural regeneration of different ages (Figures 18-19). In windblown gaps some older areas of regeneration are present (Figure 20). Growth and regeneration were monitored along transects through the stand.

Along the windward edge of the forest a system of strip felling has been used to open up the stand, by felling strips approximately two tree heights in width. Different methods of obtaining a successor crop have been tried with some strips receiving no treatment, others having ground preparation and others being planted (Figure 21). Cefn Llwyd forest is a finalist in the 2005 Woods for Wales Awards.

**Figure 18: Cefn Llwyd – uneven-aged structure developing**

**Figure 19: Cefn Llwyd – range of ages and diameter classes**

**Figure 20: Cefn Llwyd – natural regeneration following windblow**

**Figure 21: Cefn Llwyd – natural regeneration in strip felling**

*Coed Trallwm (SN 878541)*

Coed Trallwm consists of approximately 160 hectares of conifer plantations, established in 1967. The forest is owned and managed by Mr George Johnson and is located about 12 miles west of Builth Wells in mid Wales. The owners have constructed mountain bike trails within the woods, own a number of holiday cottages and have just completed construction of a visitor centre with cafeteria facilities and shop. The stand visited within Coed Trallwm is a study site for a project investigating the operational aspects of transformation to continuous cover forestry systems. The work is being conducted jointly between Bangor University (Colin Price and Martin Price) and Forest Research (Technical Development). Eight 0.5 ha buffered sample plots have been established in uniform areas of Sitka spruce consisting of the following treatments:

- Low thinning (2 plots) – the marking of trees to be thinned was based on the owner's normal thinning practice for the Forest
- Frame tree/shelter building tree (2 plots) – thinning to favour selected trees chosen as future seed bearers on the basis of form, stability, crown vigour
- Group system (2 plots) – opening up of a gap in the canopy and thinning the surrounding area
- Economic target diameter harvesting (1 plot) – removal of dominants to maximise income
- Clearfelling (1 plot) – all trees in the sample plots felled

Harvesting outputs and costs were studied in detail. Regeneration within the sample plots will be monitored.

**Figure 22: Coed Trallwm – thinning from below plot**

**Figure 23: Coed Trallwm – group felling plot**

***Northern Ireland***

*Baronscourt Estate (H 364 817 on Irish Grid)*

Baronscourt Estate, owned by the Duke of Abercorn, is located near Newtownstewart in County Tyrone, Northern Ireland. Activities on the estate include farming, forestry, fishing, shooting, holiday accommodation, a golf course, a cookery school and a wind farm.

The woodland area at Baronscourt extends to around 1500 hectares, around half of which is managed under a system of long term leases to the Northern Ireland Forest Service. As the leases expire the land is being taken back in hand by the estate. The predominant species is Sitka spruce, with Douglas fir, larch and other conifers also present. The woods around the main house also contain a mixture of broadleaved species including some fine stands of southern beech (*Nothofagus spp).* Approximately 350 hectares of forest at Baronscourt has been designated for management under continuous cover forestry systems, and the transformation of plantations is in the early stages. Techniques to achieve successful natural regeneration are being developed and tested (Figure 24). The aim is to progressively thin stands using an intermediate thinning pattern initially then moving towards a target diameter or crown thinning to open up stands to initiate natural regeneration. Deer browsing pressure is a significant limitation on establishing natural regeneration.

**Figure 24: Baronscourt Estate – natural regeneration in windblown gap**

One site visited was a clearfell area that had been planted with improved "Super Sitka" following a lack of success in restocking the site using natural regeneration. Following the planting operation dense natural regeneration of Sitka spruce from surrounding stands had become established, perhaps due to the change in microclimate brought about by the planting (Figure 25). The improved progeny were clearly ahead of the natural regeneration in height growth, and it seemed likely that they would retain this growth advantage. The naturally regenerated trees would help ensure early suppression of lower branches on the improved progeny.

**Figure 25: Baronscourt Estate – Planted improved Sitka spruce progeny with subsequent natural regeneration**

In addition to stands undergoing transformation to continuous cover forestry systems, a visit was also made to a respacing experiment managed by the Northern Ireland Forest Service. The Baronscourt trial was established in an 11 year old stand of Sitka spruce in 1960, prior to canopy closure, to investigate the effects of spacing on the growth and wood quality of Sitka spruce. Five spacing experiments equivalent to square spacing of approximately 1.9m, 2.6m, 3.7m, 4.6m and 5.6m were allocated to plots of 0.15 ha in a 5x5 Latin Square design. Some results from the experiment were published by Kilpatrick *et al.* (1981) and Savill and Sandels (1983). The trees are now 56 years old and although there has been some windblow in a few plots the majority of the experiment is still intact. Although not directly related to continuous cover forestry this experiment has the potential to provide extremely valuable information about the influence of spacing on growth, wood properties and timber utilisation. In particular the data could be used in the further development of a timber quality model for Sitka spruce (Gardiner *et al., 2004*) and help inform future assessments of the quality of timber from trees grown at wider spacing. It is hoped that Forest Research will be able to collaborate with the Northern Ireland Forest Service and Balcas Ltd in a joint project to assess the experiment, fell trees and evaluate the wood properties and timber performance in relation to spacing.

**Figure 26: Baronscourt spacing experiment**

***Summary of sites visited***

| Forest | Main species | Brief description |
|---|---|---|
| Novar Estate,<br>Easter Ross<br>Scotland | Larch, Scots pine, Douglas fir (also Sitka and Norway spruce, western red cedar) | • Around 14% of woodland designated as CCF<br>• History of shelterwood management since 1950s<br>• Diverse mixed species stands with irregular structure<br>• Good examples of old, large trees retained well beyond normal rotation<br>• Continued use of group shelterwood, some planting where regeneration not successful |
| Cawdor Estate<br>Inverness-shire,<br>Scotland | Scots pine (c. 50%), also Sitka spruce, lodgepole pine, Douglas fir, larch | • CCF management focused on Scots pine sites using group selection<br>• Some examples of mixed age stands with regeneration more than 30 years old |
| Buccleuch Estates:<br>*Drumlanrig*<br>*Bowhill*<br>Dumfriesshire and Selkirkshire, Scotland | Sitka spruce, Norway spruce, Douglas fir, larch (also mixed broadleaves) | • Around 10% of woodland designated as CCF<br>• Long history of CCF management, particularly around main houses on each estate – mixed stands of conifers and broadleaves<br>• Renewed interest in use of CCF over last 3-5 years<br>• Underplanting used where required<br>• Different systems being tried depending on circumstances |
| Tay Forest District<br>*Craigvinean*<br>*Faskally*<br>Perthshire, Scotland | Sitka and Norway spruce, Douglas fir, larch (also wide range of conifer and broadleaved species at Faskally) | • Around 17% of Forest District designated as CCF<br>• Craigvinean designated as demonstration area for CCF management. Management seems to be mainly using group shelterwood. Some stands developing irregular structure<br>• Faskally managed since 1950s under CCF, initially using group selection, now closer to single tree selection. Very diverse age class and species composition |
| Clocaenog forest,<br>North Wales | Sitka spruce | • Sitka spruce planted in 1948-1951<br>• Progressively thinned, uniform/group shelterwood.<br>• Abundant regeneration now established and being monitored<br>• Permanent sample plots for Bangor University/FC Tyfiant Coed growth model project |
| Cefn Llwyd,<br>North Wales | Sitka spruce (also Douglas fir, larch, Scots pine and some broadleaves) | • Planted in late 1950s, managed since 1980s to developed mixed species, uneven aged stand structure<br>• Variable density thinning used – irregular structure now established in much of stand<br>• Strip felling also used on windward edge, with planting and natural regeneration |
| Coed Trallwm<br>Mid Wales | Sitka spruce | • Planted in 1967<br>• Study site for Bangor University/FR project on operational aspects of transformation to CCF<br>• Sample plots comparing low thinning, "frame tree" thinning, group felling, target diameter thinning and clearfell<br>• Growth and regeneration will be monitored |
| Baronscourt Estate<br>Co. Tyrone,<br>Northern Ireland | Sitka spruce, Douglas fir, larch (also other conifers and mixed broadleaves) | • Plan to transform 25% of Estate woodlands to CCF management<br>• Early stage in development of techniques, shelterwood approach being used<br>• Regeneration becoming established on some sites<br>• May use target diameter thinning to avoid production of oversize material (very fast growth rates for Sitka spruce)<br>• Respacing experiment managed by NIFS, planted in 1949. Examples of large trees grown at wide spacing |

**Forest Research Experimental Sites**

Table 2, from Mason *et al.* (2004), lists the main experimental sites being used by Forest Research and collaborating organisations to investigate aspects of continuous cover forest management in Britain. These experiments could potentially be useful for future studies of the impact of continuous cover systems on timber quality.

| Forest | Main species | Approximate age (years) | Main aspects under investigation |
|---|---|---|---|
| Aberfoyle[a] | European larch | 70 | Thinning, seed fall, light regime |
| Glasfynydd | Sitka spruce | 50 | Thinning, light regime, *Hylobius* damage |
| Wykeham[a] | Scots pine/others | 70/50 | Thinning, stand development |
| Gwydyr | Douglas fir/others | 80 | Thinning, stand development |
| Gwydyr | Scots pine/others | 80/70 | Natural succession, mycorrhizal ecology |
| Clocaenog[a] | Sitka spruce | 50 | Thinning, natural regeneration, stand stability |
| Clocaenog[a] | Japanese larch and Norway spruce/others | 75 | Natural succession |
| Mortimer | Douglas fir | 35 | Thinning |
| Glen More | Scots pine | 75 | Thinning, light regime, seed fall |
| Coed y Brenin | Sitka spruce/birch | 30/20 | Stand development |
| Cardrona[a] | Scots pine | 65 | Natural regeneration, cultivation |
| Trawllm[a] | Sitka spruce | 40 | Thinning, operational aspects |

[a] Denotes that the experiment is located within a national CCF demonstration site.

**Table 2: Main experimental sites, species and aspects for the investigation of CCF in Great Britain (Mason *et al.* 2004).**

**Forestry Commission Demonstration Sites**

To help improve knowledge and understanding of continuous cover forestry, the Forestry Commission is establishing a number of large-scale (> 500ha) commercial trials within FC forests. Table 3 gives details of these trial areas, as set out in Forestry Commission Operational Guidance Booklet No. 7, (Forestry Commission, 2005).

| Trial Sites | | Status |
|---|---|---|
| **England** | | |
| Wykeham | North York Moors FD | Established 2000 |
| Whinlatter | North West England FD | |
| Dartmoor | Peninsula FD | |
| **Wales** | | |
| Clocaenog | Coed y Gororau FD | Established 2001 |
| Trallwm | Privately owned | |
| Cym Berwyn | Llanymyddfri FD | |
| **South Scotland** | | |
| Glentress/Cardrona | Scottish Borders FD | Established 2002 |
| Lochard / Strathyre | Cowal & Trossachs FD | |
| Loch Eck | Cowal & Trossachs FD | |
| **North Scotland** | | |
| Inshriach | Inverness FD | Established 2002 |
| Craigvinean | Tay FD | |
| Morangie | Dornoch FD | |

**Table 3: Proposed Forestry Commission CCF demonstration sites**

**Conclusions**

The site visits made during this project have shown that there is a wide variation in the degree of development of continuous cover forest management systems in the UK. Some stands (e.g. Novar Estate, FC forest at Faskally) have a well developed irregular structure resulting from around 50 years of continuous cover management. Others (e.g. Clocaenog, Baronscourt) are in the earlier stages of transformation from even-aged management to alternative silvicultural systems. What is clear is that there is a commitment throughout the forest industry to manage a proportion of UK forests using continuous cover systems, and that there is generally a willingness amongst forest owners and managers to participate in research that will inform this change in management (e.g. George Johnson at Coed Trallwm).

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